

17424
633.4 (213)
x
3-5-85

**COUNCIL OF THE
INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS 1973-76**

President:

D.G. Coursey (U.K.)

Vice Presidents:

E. Alvarez-Luna (Colombia)
(4th Symposium)

P.H. Haynes (Nigeria)
(Regional Affairs)

D.L. Plucknett (Hawaii)
(Fund Raising)

Secretary:

T.U. Ferguson (Trinidad)

Treasurer:

L.B. Rankine (Jamaica)

Councillors:

J.H. Cock (Colombia)

L.M. Degras
(Co-opted)

F.W. Martin (Puerto Rico)
(Editor: Newsletter)

B.N. Okigbo (Nigeria)

L.A. Wilson (Trinidad)
(Ex-officio)

**Participants at the 3rd Symposium of the International Society for Tropical Root Crops
held at IITA, Ibadan, Nigeria, 2-9 Dec. 1973**

- Abraham, Abraham, *FAO Regional Office, Box 1628, Accra, Ghana.*
- Adesuyi, Samuel Adeniran, *Nigerian Stored Products Research Institute, Federal Ministry of Trade, Ibadan, Nigeria.*
- Adetunji, S.A. *Agricultural Research Council of Nigeria, Moor Plantation, Ibadan, Nigeria.*
- Adeosun, David Ola Olu, *Commonwealth Development Corporation (Nigeria) Ltd., 47, Marina, Box 2012, Lagos, Nigeria.*
- Agbo, Fabian M.O., *Federal Agricultural Research & Training Station, Umudike, Umuahia, Nigeria.*
- Agboola, Akinola A., *Department of Agronomy, University of Ibadan, Ibadan, Nigeria.*
- Alvarez-Luna, Eduardo, *Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.*
- Amon, B.O.E., *Agricultural Research Council of Nigeria, PMB 5382, Ibadan, Nigeria.*
- Anersen, Per Pinstруп, *Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.*
- Ange Alphonse Joseph, *Centre ORSTOM, B.P. 193, Yaounde, Cameroun.*
- April, Jay, *University of Colorado, Boulder, Colorado, U.S.A.*
- Arinze, Anthony, *Department of Botany, University of Lagos, Nigeria.*
- Atanda, Oluremi Ademola, *Agricultural Research Council of Nigeria, PMB 5382, Moor Plantation, Ibadan, Nigeria.*
- Awani, Napoleon, *Cadbury Nigeria Ltd., Iseri Road, Ikeja, Lagos, Nigeria.*
- Ayanaba, A. *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*
- Ayensu, Edward S. *Department of Botany, Smithsonian Institute, Washington D.C. 20560, U.S.A.*
- Azih, Victor, *Federal Department of Agricultural Research, Moor Plantation, Ibadan, Nigeria.*
- Ballaux, Jean-Claude, *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*
- Ballestrem, Conrad C. *P.O. Box 220, National Horticultural Research Station, Thika, Kenya.*
- Black, William, *National Agricultural Laboratories, P.O. Box 30028, Nairobi, Kenya.*
- Blom, Marijke van, *NEDECO, P.O. Box 973, Kano, Nigeria.*
- Blom, Peter van, *NEDECO, P.O. Box 973, Kano, Nigeria.*
- Booth, Robert, *Tropical Products Institute, 56-62 Gray's Inn Road, London WC1X 8LU.*
- Bourke, Richard M. *DASF Keravat, ENB, Papua New Guinea.*
- Bot, Markus G. *M.N.R. Riyom, P.O. Box Vom, B/P State, Nigeria.*
- Bruno, Fassi, *FAO, Rome.*
- Caesar, Knud, *Technical University of Berlin, Berlin, Germany.*
- Chan, Seak Khen, *MARDI, Serdang Sg. Besi, West Malaysia.*
- Clarke, W. *Department of Human Geography, Australian National University, Canberra, Australia.*
- Cock, James H., *Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.*
- Correa, Heliv, *IPEACO, Caixa Postal 151, 35700 Setehagoas, MG Brazil.*
- Coursey, Donald G. *Tropical Products Institute, 56/62 Grays Inn Road, London WC1X 8LU.*
- DeVries, Cornelius A. *Royal Tropical Institute, Amsterdam, Netherlands.*
- Doku, Emmanuel V. *Crop Science Department, University of Ghana, Ghana.*
- Doll, Jerry, *Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.*
- Dumont, Roland, *IRAT, 110 Rue de l'Université, Paris, France.*
- Ekanem, Moses J. *Federal Department of Agricultural Research, PMB 1032, Uyo, ECS, Nigeria.*
- El-Fouly, Mohamed M., *National Research Centre, Cairo-Dokki, Egypt.*
- Ene, Leonard S. *National Root Crops Research Institute, Umudike, Umuahia (Imo State) PMB 1006 Umudike, Nigeria.*
- Enyi, B.A.C. *Faculty of Agriculture, University of Papua and New Guinea, P.O. Box 4820, Port Moresby, Papua New Guinea.*

Enyinnaya, Anosike M. *Federal Agricultural Research & Training Station, Umuahia (Imo State) PMB 1006 Umudike, Nigeria.*

Evenson, John, *Agricultural Department, Queensland University, Australia.*

Ezumah, H.C. *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Favier, Jean C. *Center ORSTOM, B.P. 193, Yaounde, Cameroun.*

Ferguson, Theodore, *Caribbean Development Bank, P.O. Box 408, Wildey, St. Michael, Barbados.*

Flach, Michel, *Department of Tropical Crop Science, Ritzema Bosweg 32, Wageningen, Netherlands.*

Getahum, Amare, *P.O. Box 138, Dire-Dawa, Ethiopia.*

Godfrey-Sam-Aggrey, Wilhelm G. *Njala University, Freetown, Sierra Leone.*

Gramacho, Ivan da Costa P. *CEPLAC-Cx Postal 7, Itabuna, Bahia, Brazil.*

Guzman, Adrina G. *Ministecio de Agricultura, Managua, Nicaragua.*

Hahn, Sang Ki, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Haynes, Patrick H. *Koronivia Research Station, Nausori, Fiji.*

Hernandez, Teme, *L.S.U., Baton Rouge, U.S.A.*

Hersh, Gilbert van, *University of Colorado, Boulder, Colorado, U.S.A.*

Heys, Gilbert, *Shell-BP, P.O. Box 230, Warri.*

Hojo, Yoshio, *ARI 70, Kitamoto, Saitama International Institute of Agricultural Science, Saitama, Japan.*

Howland, Audrie, *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*

Hozyo, Yosyo, *ARI 70, Kitamoto, Saitama International Institute of Agricultural Science, Saitama, Japan.*

Hussein, Zahed, *Tropical Institute, University of Gotting, W. Germany.*

Hutagalung Rudy I., *Faculty of Agriculture, University of Malaya, Kuala Lumpur, Malaysia.*

Idusogie, E.O., *United Nations Food and Agriculture Organisation, P.O. Box 1628, Accra, Ghana.*

Iruobe, Francis, *Food Specialities (Ltd), PMB 1164, Ikeja, Lagos.*

Javadia, Virendra Singh, *Department of Entomology, University of Udaipur, India.*

Jennings, Derek I., *Scottish Horticultural Research Institute, Invergowrie, Dundee, U.K.*

Jong, Seungkeun, *Crop Experiment Station, Suwon, Korea.*

Kamal, Mohamed Elbereir, *P.O. Box 213, Shambat, Khartoum, Sudan.*

Kande, Beya, *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*

Kang, B.T., *International Institute of Tropical Agriculture, PMB. 5320, Ibadan, Nigeria.*

Kavadia, Virendra, *Insect Toxicologist, Department of Entomology, University of Udaipur, India.*

Kawano, Kazuo, *Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.*

Kinross, Keith J. *Massey Ferguson Division, BEWAC Ltd., P.O. Box 385, Ibadan, Nigeria.*

Kunar, Dhananjay, *University Hill, P.O. Box 35060, Dares-Salaam, Tanzania.*

Lal, Rattan, *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*

Lawson, Theodore L. *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*

Look, Graham F. *PANS Office, College House, Wrights Lane, London W8.*

Lozano, J. Carlos, *Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.*

MacKenzie, Eric, *CB70 Vanga, B.P. 4728, Kinshasa II, Republic of Zaire.*

Mamicpic, Noel G. *Department of Agronomy, College of Agriculture, Laguna, Philippines.*

Marrewijk, Gijsbert van, *IVP, Sawickse Allee 166, Wageningen, Netherlands.*

Nangju, Dimyan, *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*

Nartey, Frederick, *Institute of Plant Physiology, Farimagsgade 2A, 1353, Copenhagen, Denmark.*

Nestel, Barry, *IDRC Apartado Aereo 53016, Bogota, Colombia.*

Njoku, Eni, *University of Nigeria, Nsukka, Nigeria.*

Njuguna, Simon K. P.O. Box 30028, Nairobi, Kenya.

Nwigwe, Chinenye, *Federal Agricultural Research Station, Unuahia, ECS, Nigeria.*

Nwoke, Festus, *Department of Botany, University of Nigeria, Nsukka, Nigeria.*

Nwosu, Nelson A., *Federal Agricultural Research & Training Station, Umudike, Umuahia, Nigeria.*

Ogundana, S.K. *Federal Agricultural Research, Ibadan, Nigeria.*

Oke, Olusegun, *University of Ife, Ife-Ife, Nigeria.*

Okigbo, Bede N. *International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria.*

Okereke, O.U. *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Okoli, C. *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Okoli, Obinani, *F.A.R.T.S., Umudike, Umuahia, Nigeria.*

Okonkwo, George, *Deputy Chief Research Officer, Federal Agricultural Research & Training, Umudike, Umuahia.*

Okonkwo, Samuel, *Department of Botany, University of Nigeria, Nsukka, Nigeria.*

Okusanya, Funso, *Federal Department of Agricultural Research, Ibadan, Nigeria.*

Olorunda, Ayodele O., *University of Ife, PMB 5029, Moor Plantation, Ibadan, Nigeria.*

Oppong, Angelina, *Crops Research Institute, P.O. Box 3785, Kumasi, Ghana.*

Osarollor, Gomba H. *Shell-BP, P.O. Box 263, Port Harcourt, Nigeria.*

Otoo, John A., *Crops Research Institute, P.O. Box 3785, Kumasi, Ghana.*

Oyolu, Dr. & Mrs. C., *University of Newcastle-upon-Tyne, Department of Plant Science, Newcastle NE1 7RU, U.K.*

Phillips, Truman, *School of Agricultural Economics, University of Guelph, Guelph, Ontario, Canada.*

Plarre, Werner F.K., *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Plucknett, Donald L., *Office of Agriculture, Technical Assistance Bureau, Agency for International Development, AID Washington D.C., 20523, U.S.A.*

Posthumus, Adam C., *Centre for Plant Physiological Research, Bornesteeg, Wageningen, Netherlands.*

Rankine, Lloyd B., *Department of Agricultural Economics, University of the W. Indies, St. Augustine, Trinidad.*

Rawal, Kanti, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Roa, Gonzalo, *Agricultural Engineering Department, University Del Valle, Apartado Aereo 21-88, Cali, Colombia.*

Robinson, K.L., *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Robson, Robert, *FAO/IAEA Joint Division for Food and Agriculture, Vienna, Austria.*

Rosanow, Michael, *H.V.A. Amsterdam, P.O. Box 10328, Amsterdam, Netherlands.*

Sadik, Sidki, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Sebasigari, Kabony, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Silvis, Henk, *P.O. Box 913, Khartoum, Sudan.*

Singh, Shiv Raj, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Spora, Ngale L., *IRAT Bambui Station, Bamenda, Cameroun.*

Suchamel, Dale, *M.O.N.R., Riyom, Via Vom, Beune-Plateau State, Nigeria.*

Terry, Eugene R. *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Thompson, Anthony K., *P.O. Box 913, Khartoum, Sudan.*

Thurston, H. David, *Department of Plant Pathology, Cornell University, Ithaca, N.Y., U.S.A.*

Umanah, E.E. *Federal Department of Agricultural Research PMB 5042, Ibadan, Nigeria.*

Wien, H. Chris, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Williams, Robert, *International Institute of Tropical Agriculture, IITA, PMB 5320, Ibadan, Nigeria.*

Wilson, Lawrence, *U.W.I. Department of Biological Science, St. Augustine, Trinidad.*

Wudiri, B.B., *Institute for Agricultural Research, Moor Plantation, PMB 5382, Ibadan, Nigeria.*

FOREWORD

Since the inception of the International Society of Tropical Root Crops and the holding of the First International Symposium on Tropical Root Crops on 2–8 April, 1967 in the University of the West Indies at St. Augustine, Trinidad, a lot of interest has been generated on this usually neglected group of crops which can potentially contribute significantly more, if well managed, efficiently produced and utilized, to the solution of food shortage problems in the humid and sub-humid tropics. This is evidenced by the very large number of papers that has been presented by scientists from almost all parts of the globe in the areas of agronomy, genetics, breeding, improvement, socio-economics, plant protection, storage and processing, etc. during the Third Symposium held at Ibadan in December 1973, the proceedings of which are documented here. It is hoped that these proceedings will constitute reference and information material on root crops as its predecessors have done.

It is regretted that due to a lot of unforeseen developments, it was not possible to publish these proceedings at the time anticipated before the proceedings of the Fourth Symposium which has already been published. As a result of the importance of the data presented during the Third Symposium, it is still necessary that the proceedings are published and made available to the scientific community however late the delay and despite the disappointments and inconveniences that have been suffered by authors of the papers that have been held up.

The Society wishes to express its appreciation to Dr. William K. Gamble, Director General of IITA, for exceptional interest he has shown in the activities of the Society and the necessary actions he took to commit resources of IITA in assisting the Society to ensure that the proceedings of the Third Symposium are published.

Dr. B.N. Okigbo, Deputy Director,
International Institute of Tropical Agriculture.
August 1977.

EDITORIAL

The 3rd Symposium on Tropical Root Crops was announced in March 1973 and held at IITA at Ibadan, Nigeria from 2–9th December 1973. The Symposium received an enormous response reflecting the rapidly accelerating interest in the tropical root crops as a mainstay of food supply in tropical and equatorial countries. No less than 171 papers were submitted, including some which were specially invited.

In the event, in an overcrowded week, 123 participants read and discussed 86 papers in a programme arranged by Professor Lawrence Wilson under the chairmanship of Drs. S. Sadik, B.N. Okigbo, E.T. Terry, A.I. Akinrele and L.B. Rankine.

Clear instructions to authors had been provided in the announcing notice, requesting papers of not more than 3,000 words with a 100 word abstract and completed copy was to be provided to the Society before leaving Ibadan. Nearly all the authors' submissions exceeded these guidelines in length and many scripts were received late. An editorial committee of officers of the Society strove to prepare papers for publication, but the task was a daunting one, and after long delays, the present editor was asked to undertake the role of preparing for publication those papers of which a sufficiently complete typescript was available. Dr. Bede Okigbo (IITA) was responsible for the selection of the papers, and they included all those actually presented at the Symposium of which complete copy had been provided. To any whose papers have been unduly distorted or compressed the editor offers apologies as well as to those whose papers, for one reason or another, have not been published.

The International Society wishes to acknowledge assistance from the International Development Research Center for travel fellowships which made it possible for 18 young scientists from various countries to attend the Symposium.

I would like to thank Professor Donald Plucknett, current President of the International Society for Tropical Root Crops, for encouragement in this task, and Mr. Raymond Woodis of IITA for liaison work. The figures have been prepared for publication at IITA. I would also especially like to thank Mrs. Susan Leakey who has typed the edited versions of the texts.

Colin L.A. Leakey

Cambridge, England.

August 1977.

SECTION A

Genetics, Breeding, Improvement and Classification

- Chapter 1. Conservation and evaluation of tuber crops germplasm in Kerala.
A. Abraham, C.A. Ninan, S. Abraham, P.H. Chandrasekharan Nair, P. Kuriachan and P. Gopalakrishna Pillai.
- Chapter 2. Cassava breeding at I.I.T.A.
S.K. Hahn, A.K. Howland and E.R. Terry.
- Chapter 3. Breeding for protein enhancement in cassava.
N. Hrishii and J.S. Jos.
- Chapter 4. Extending frontiers of genetic improvement in cassava.
M.L. Magoon and R. Krishnan.
- Chapter 5. Physiological variability in the mineral nutrition of four cassava cultivars in flowing solution culture.
D.A. Forno, C.J. Asher, D.G. Edwards and J.P. Evenson.
- Chapter 6. A collection of West African yams.
F.W. Martin.
- Chapter 7. Overcoming cross- and self-incompatibility in *Ipomoea batatas* (L.) Lam and *Ipomoea trichocarpa* Elliot. W.B. Charles, D.G. Hoskin and P.J. Cave.
- Chapter 8. The sterility-incompatibility complex in sweet potato.
G.A.M. van Marrewijk.
- Chapter 9. Sweet potato breeding in India — problems and prospects.
M.L. Magoon and R. Krishnan.
- Chapter 10. Breeding techniques, heritabilities, insect resistance and other factors affecting sweet potato breeding.
S.D. Thibodeaux, T.P. Hernandez and T.P. Hernandez.
- Chapter 11. Edible aroids — new insights into phylogeny.
R. Krishnan and M.L. Magoon.
- Chapter 12. Potato breeding for resistance to bacterial wilt in Kenya.
S.K. Njuguna.

SECTION B

Tubers and Tuberization

- Chapter 13. Environmental factors affecting tuberization.
A.C. Posthumus.
- Chapter 14. Tuber development in yams; physiological and agronomic implications.
T.U. Ferguson.
- Chapter 15. A comparative study of the anatomical changes associated with tuberization in the roots of cassava and sweet potato.
P. Indira and T. Kurian.
- Chapter 16. Changes in soluble amino acids of some tropical starchy roots during chilling.
O.L. Oke.
- Chapter 17. Components of tuber yield in sweet potato.
L.A. Wilson.

SECTION C

Growth, Development and Yield

- Chapter 18. Growth, development and yield of some tropical root crops.
B.A.C. Enyi.
- Chapter 19. Beneficial effects of chlormequat (CCC) on root crops under Egyptian field conditions.
M.M. El-Fouly.
- Chapter 20. Some physiological aspects of yield in cassava (*Manihot esculenta* Crantz).
J.H. Cock.
- Chapter 21. The effect of defoliation on the yield of cocoyams.
S.K. Karikari.
- Chapter 22. "Mericlone" of taro (*Colocasia esculenta*).
M.O. Mapes and W.J. Cable.
- Chapter 23. Screening sweet potatoes for low CO₂ compensation point.
S. Sadik.
- Chapter 24. Potassium requirement of taro in relationship to growth, foliar analysis, yield, and quality as grown in solution culture.
W.J. Cable.
- Chapter 25. Mineral nutrition of taro (*Colocasia esculenta*) with special reference to petiolar phosphorus level and phosphate fertilizers.
R.B. Kagbo, R.S. de la Pena, D.L. Plucknett and R.L. Fox.
- Chapter 26. The biogenesis and metabolism of cyanogenic glucosides in germinating cassava seed and seedlings.
F. Nartey.

SECTION D

Ethnobotany and Economic Botany

- Chapter 27. A change of subsistence staple in prehistoric New Guinea.
W.C. Clarke.
- Chapter 28. The comparative ethnobotany of African and Asian yam cultures.
D.G. Coursey.
- Chapter 29. The sago palm: a potential competitor to root crops.
M. Flach.
- Chapter 30. Role of roots and tubers in Nigerian nutrition and agricultural development.
E.O. Idusogie and S.O. Olayide.
- Chapter 31. Comparative performance: large-scale production vs. small-scale production of yams and sweet potatoes in the Caribbean.
L.B. Rankine.

SECTION E

Information, Development and Perspective

- Chapter 32. The information center at CIAT.
F. Monge.
- Chapter 33. Current trends in cassava research.
B.L. Nestel.
- Chapter 34. Development-oriented integrated cassava projects.
S.J. Nusbaum.
- Chapter 35. Present and potential labour use in cassava production in Colombia.
P. Pinstup-Andersen and R.O. Diaz.
- Chapter 36. Potential supply of and demand for cassava in the '70's and 80's.
T.P. Phillips.

SECTION F

Propagation

- Chapter 37. The use of nursery transplants in taro (*Colocasia esculenta*) culture.
H.C. Ezumah and D.L. Plucknett.
- Chapter 38. A rapid method for the propagation of cassava (*Manihot esculenta* Crantz)
D.W. Wholey and J.H. Cock.
- Chapter 39. A new method of yam propagation.
B.N. Okigbo and D.G. Ibe.

SECTION G

Mechanization

- Chapter 40. Mechanization of yam cultivation in the Ivory Coast.
R. Vandevenne.
- Chapter 41. A mechanical harvester for diosgenin-producing yams.
L.W. Nystrom, J.E. Shrum Jr. and R.F. Dawson.
- Chapter 42. Mechanization of cassava production. A study to determine the suitability of present cassava cultivars for mechanical harvesting.
B.E. Onochie, G.A. Makanjuola and E.E. Schulte.
- Chapter 43. Preliminary studies on the mechanical harvesting of cassava roots in Nigeria.
G.A. Makanjuola, B.E. Onochie and E.E. Schulte.
- Chapter 44. Mechanization of taro (*Colocasia esculenta*) culture in Hawaii.
D.L. Plucknett, H.C. Ezumah and R.S. de la Pena.

SECTION H
Agronomic Research

- Chapter 45. Effects of method of seed bed preparation, mulching and time of planting on yam in Western Nigeria.
R. Lal and S.K. Hahn.
- Chapter 46. Effects of different fertilizers on cassava root yield, root number per plant and average root weight per plant after six years bush fallow in Sierra Leone using cuttings of different age.
S. Godfrey-Sam-Aggrey.
- Chapter 47. Effects of different fertilizers on root yield, root number per plant and top/root weight ratio of cassava in two cropping systems in Sierra Leone.
W. Godfrey-Sam-Aggrey.
- Chapter 48. Effects of plant population and fertilizers on yield and yield components of cassava in the forest zone of Ghana.
A.M. Gurnah.
- Chapter 49. An evaluation of the yield and quality of some Nigerian cassava varieties as affected by age and nitrogen fertilizer application.
G.O. Obigbesan and A.A. Agboola.
- Chapter 50. A field experimental approach to maximizing starch yields from cassava in Indonesia.
M. Rosanow.
- Chapter 51. A cultivar trial with yams in the British Solomon Islands.
D.E. Gollifer.
- Chapter 52. Agronomic studies on edible yam in the grassland plateau region of the United Republic of Cameroon.
S.N. Lyonga, A.A. Fayemi and A.A. Agboola.
- Chapter 53. Effects of cultivations and heights and directions of staking on yield and general performance of eight yam cultivars.
B.N. Okigbo.
- Chapter 54. Effects of different rates of NPK fertilizers on yield and storage properties of white yam.
E.E. Umanah.
- Chapter 55. Response of taro, *Colocasia esculenta* (L) Schott to water management, plot preparation and population.
H.C. Ezumah and D.L. Plucknett.
- Chapter 56. Aspects of taro production on the shallow calcareous soils of Niue.
R.J. Lucas, B. Punu and W.J. Cable.
- Chapter 57. The effects of rainfall and time of planting on yield of taro (*Colocasia esculenta* (L) Schott) in Western Samoa.
S.G. Reynolds and P. Netram.
- Chapter 58. Effects of Spacing in taro (*Colocasia esculenta*).
P. Sivan.

SECTION J

Farming Systems

- Chapter 59. A long term rotation trial in New Britain, Papua New Guinea.
R.M. Bourke.
- Chapter 60. Integration of yam into a continuous farming system in Dahomey.
R. Dumont.
- Chapter 61. Some indigenous cropping systems of Eastern Nigeria.
N.A. Nwosu.

SECTION K

Weeds, Pests and Diseases

- Chapter 62. Effects of time of weeding and plant population on the growth and yield of cassava.
J.D. Doll and W. Piedrahita C.
- Chapter 63. Weed control in cassava.
J.R. Barrios.
- Chapter 64. Insecticide residues in soils and in root crops grown on treated soils.
B.P. Srivastava and V.S. Kavadia.
- Chapter 65. Bioecological studies on the cassava mite *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae).
Z.M. Nyiira.
- Chapter 66. Bacterial blight of cassava in Central and South America: etiology, epidemiology and control.
J.C. Lozano.

SECTION L

Storage and Conversion

- Chapter 67. Advances in yam storage research in Nigeria.
S.A. Adesuyi.
- Chapter 68. The storage of fresh cassava roots.
R.H. Booth.
- Chapter 69. Reduction of wastage in stored yams.
A.K. Thompson, B.O. Jeen and C. Perkins.
- Chapter 70. The utilization of cassava (tapioca) in livestock feeding.
R.I. Hutagalung, Phuah Chui Hing and Hew Voon Fong.
- Chapter 71. Evaluation of two cassava cultivars for starch and chip production.
Seak Khen Chan.
- Chapter 72. History of the development of the first mechanized continuous gari manufacturing plant.
J.G. Purcell and D.H. Williams.
- Chapter 73. Gari project report.
N.D. Wadhwa.
- Chapter 74. The status of tropical root crop processing research at the University of the West Indies, Trinidad.
G.M. Sammy.

CONSERVATION AND EVALUATION OF TUBER CROPS GERMPLASM IN KERALA

*A. Abraham, C.A. Ninan, S. Abraham
P.N. Chandrasekharan Nair, P. Kuriachan and P. Gopalakrishna Pillai

SUMMARY

Germplasm collections of *Manihot*, *Ipomoea*, *Dioscorea*, and various Aroids are maintained at Kerala University. *Manihot* species have been extensively evaluated and hybridized and polyploids produced.

Sweet potato is under improvement. Interspecific hybridization of *Dioscorea* spp. is in progress and good edible cultivars of *D. alata* are being multiplied for release. Various aroids are under evaluation.

RESUME

Les collections de plasm germinatif de *Manihot*, *Ipomoea*, *Dioscorea* diverses aroidées sont entretenues à l'Université de Kerala. Les espèces du *Manihot* ont été l'objet d'une évaluation et d'une hybridation intensives, ce qui a permis la création de polyploïdes.

La patate douce est en voie d'amélioration. L'hybridation d'espèces de *Dioscorea* spp. est en cours et de bons cultivars comestibles de *D. alata* sont en train d'être multipliés en vue de leur popularisation. Diverses aroidées sont en cours d'évaluation.

RESUMEN

En la universidad de Kerala se mantienen *Manihot*, *Ipomoea*, *Dioscorea* y varias Aráceas. Se han evaluado extensivamente e hibridado especies de *Manihot* y se han producido poliploides.

El camote se encuentra bajo mejoramiento. Se está llevando a cabo la hibridación interespecífica de *Dioscorea* spp. y se están multiplicando, para su liberación, cultivares comestibles de *D. alata*. Varias aráceas se encuentran bajo evaluación.

GERMPLASM COLLECTION

As a result of exploration and introduction work conducted during the past three decades, a germplasm collection of 633 accessions of root and tuber crops belonging to 22 species of the genera *Manihot*, *Ipomoea*, *Dioscorea*, *Amorphophallus*, *Coleus*, *Curcuma*, *Zingiber* and *Maranta* including their wild species has been assembled in the experiment station attached to the Department of Botany, University of Kerala, Kariyavattom, Trivandrum.

Extensive evaluation studies of these crops have revealed enormous variability among the genetic stocks which makes it possible to select directly valuable phenotypes for use in breeding programmes intended to develop hybrid clones suited to Indian conditions.

Among these tuber crops, cassava is the most important in South India while sweet potato, yams and aroids are more popular in Northern and Eastern India. It is estimated that the area of cassava is about 0.7 million acres, sweet potato and yams each 0.5 million acres.

CASSAVA PROGRAMME

Cassava is grown in 9 states, Kerala, Tamil Nadu, Andhra Pradesh, Mysore, Assam, Meghalaya, Tripura, Orissa and Maharashtra. The first two of these are the most important. In Kerala alone 10 percent of the cultivable land is under this crop, and this accounts for 90 percent of the total production of cassava in India. Kerala, with its tropical climate and well distributed rainfall, is pre-eminently suited for the cultivation of this crop.

Cassava was introduced into India by the Portuguese during the latter half of the 17th Century. One of the Maharajas of Travancor (now known as Kerala State), Sri Visakom Thirunal Maharaja was personally responsible for popularising this crop in Travancore. Cassava can produce large amounts of food with low inputs on fertile land and has gained a reputation as a useful famine relief crop.

Three hundred and eighty three accessions of cassava are maintained in the experimental station of the Department. Our collection includes interspecific hybrids of *Manihot esculenta* Crantz, x *M. glaziovii* M.

*Department of Botany, Kerala University, Trivandrum

Arg. made in this department and their back crosses to *M. esculenta*; intervarietal hybrids; inbred lines; artificially produced polyploids (triploids and tetraploids) and a rich germ plasm of over 172 cultivars. The genetic variability present is continuously being screened and evaluated to determine which stocks have valuable economic characters for utilization in the breeding programmes. Materials showing disease and drought resistance, high protein content, improved keeping qualities, outstanding cooking qualities, short duration, medium sized and stalked tubers and high recovery of sun-dried products are being selected for further study and propagation.

The greatest threat that the cassava industry faces today in Kerala is mosaic disease. This disease is estimated to reduce tuber yield by up to 35 percent, and most of the local cultivars under cultivation are susceptible to it. However, M_4 , widely cultivated in Kerala, is relatively free from the disease although it often suffers a mild attack. This cultivar is also the most popular in the State on account of its excellent cooking quality.

Most of the local cultivars contain only about 2 percent protein, but some recent introductions from Colombia have been found to contain from 2 to 6.5 percent protein, but the cooking quality of most of the high protein material is not good. However, one of these introductions, namely CMC 9 possesses good cooking quality and 6.5 percent protein. Attempts are being made to incorporate genes for high protein into the best available local strains like M_4 . Many new hybrids have been produced with this objective and are being evaluated.

Sixty percent of produced of cassava in Kerala is used as food, 20 percent as raw material for industrial purposes, including conversion into animal feed, and the balance is sent to neighbouring States like Madras for industrial purposes, including tapioca production. In the marketing of fresh tubers, the keeping quality of the tubers plays an important role as they tend to decay within a day or two after harvest. It is generally considered in Kerala that stalked tubers have better keeping qualities than the non-stalked ones which are found in some new high yielding cultivars. Development of high yield cultivars having stalked tubers and good cooking quality would therefore be considered an advantage. In areas where the tubers are sun-dried and marketed, cultivars having a higher conversion to dried products are important.

Intervarietal hybridization to seek for good combining ability was begun by the senior author in 1944. Many hybrids have already been produced. Preliminary evaluation showed that some hybrids between local cultivars contain about 5 percent protein, and also have good cooking quality. Yield trials are in progress to assess the yields of these.

Though triploid and tetraploid derivatives of the cultivar M_4 were produced and were tested on a large scale in 1950, both yield and cooking quality of the polyploids were poor. The polyploid types have been maintained. With the recent installation of a 1260 curie Co 60 gamma radiation unit in this department, mutation breeding is being attempted to rectify the defects of promising material.

SWEET POTATO PROGRAMME

Sweet potato is used as an important subsidiary food crop in many States in India. Sweet potato ranks third in importance among tuber crops in India, next only to *Solanum* potato and cassava.

As sweet potato can be a short duration crop, it can be conveniently fitted into any multiple cropping programme and can be grown immediately after the harvest of the main crop. It is well adapted to fertile, well drained sandy loam with clayey subsoil.

One hundred and forty clones of *Ipomoea batatas* Poir. have been collected and grown in the experimental station at Kariyavattom, Trivandrum. These are being evaluated for yield and other desirable characters. There is considerable variation for starch and protein content. Both selections within the collection and hybridization are being used to achieve higher tuber yield, high starch content and high sugar content.

YAM PROGRAMME

Over a dozen species of *Dioscorea* are available in Kerala State. The commonest is *D. alata* of which many varieties are under cultivation. Seventy six accessions of *Dioscorea* belonging to 4 cultivated species (*D. alata* L., *D. esculenta* Burkill, *D. spinosa* Boxb., and *D. sativa* Thun.) and 10 wild species (*D. bulbifera* L., *D. pentaphylla* L., *D. tomentosa* Koerig, *D. hispida* Dennst., *D. wallichii* Hook., *D. oppositifolia* L., *D. composita* Hemsl., *D. friedrichsthali* R. Knuth., *D. spiculiflora* Hemsl. and *D. floribunda* Mar. and Gal.) are maintained in our collection. There is considerable variation for size, weight and shape of the tubers and cooking quality. Morphological characters and tuber quality have also been studied. Most plants are males, but a few are females; some have not yet flowered. Botanical data has been collected. Inter-specific hybridization is in progress. Detailed studies on edible cultivars of *D. alata* have shown that some of these possess well shaped tubers, thin skin, white flesh, uniform sized starch grains and good cooking quality. These have been selected and multiplied for distribution. The diosgenin content in different species in our collection is being studied.

AROID PROGRAMME

Aroids comprise *Colocasia*, *Alocasia*, *Xanthosoma* and *Amorphophallus*. Scope for hybridization in these crops is rather limited due to high female sterility. However, in *Colocasia* it has been possible to overcome the sterility block through embryo culture. Many sexually derived plants of *Colocasia* obtained by this method are being evaluated.

Irritability factors are very important in these tubers.

Amorphophallus campanulatus Blume., commonly known as 'elephant foot yam' is also commonly cultivated in this area. Single corms from well cultivated plants weigh as much as 50–60 lbs. *Amorphophallus bulbifer* Blume., *A. dubius* Blume., and *A. sylvaticus* Kunth. are wild species collected from areas in South India.

Coleus parviflorus Benth., *Maranta arundinacea* L., (arrow root) *Zingiber officinale* and *Curcuma aromatica* are minor tuber-bearing plants collected from this area. No improvement work has so far been done on these.

DISCUSSION

This vast germplasm collection of tuber and root crops from South India is a treasure store of genetic variability present in this area. The collection is a resource for current and future plant breeders. Loss of valuable genetic resources can be avoided by this kind of conservation in areas of maximum variability of these species.

Stocks of these crops can be obtained from Professor C.A. Ninan, Head, Department of Botany, Kerala University, Kariyavattom, Trivandrum, India.

CASSAVA BREEDING AT I.I.T.A.*

S.K. Hahn, A.K. Howland and E.R. Terry

SUMMARY

The breeding objectives in the Root and Tuber Improvement Programme of the International Institute of Tropical Agriculture (IITA) were laid down. Basic considerations in cassava breeding were reviewed and discussed. The paper attempts to produce a cassava breeding system applicable on a world-wide basis and describes the present state and the future development of cassava breeding.

RESUME

Exposé des objectifs du Programme de Sélection et d'Amélioration des Plantes à Racine et à Tubercule à l'Institut International d'Agriculture Tropicale (IITA). Examen critique des problèmes fondamentaux de la sélection et de l'amélioration du manioc et tentative de formulation d'un système de sélection et d'amélioration du manioc ayant une application universelle. Présentation de la situation actuelle et des perspectives pour le développement de la sélection du manioc.

RESUMEN

Se establecieron los objetivos de hibridación del Programa de Mejoramiento de Raíces y Tubérculos del Instituto de Agricultura Tropical (IITA). Se discutieron las consideraciones básicas del mejoramiento genético en yuca. El reporte intenta producir un sistema de hibridación que sea aplicable sobre una amplia base mundial y describe el estado presente y el futuro desarrollo del mejoramiento genético de la yuca.

INTRODUCTION

Cassava is widely grown and used as a staple food in many parts of the tropics. World production amounts to about 100 million tons annually from 10 million hectares, of which Africa produces about 40 million tons from about 5 million hectares. In Africa, especially West Africa, cassava is the most popular of the root and tuber crops, and the trend in production shows a steady increase¹⁵.

Cassava is potentially able to produce more food calories per unit area than any other lowland crops grown in Nigeria, owing to its high yielding ability, adaptation to diverse climatic and cultural conditions and ability to survive the four to six month's dry season. It requires less management input than cereal crops. Both root and leaf are valuable as human food and livestock feed, the leaf protein is high in quantity and of good quality in some cultivars, and the root is widely used for industrial production of starch and alcohol.

I.I.T.A. began its Root and Tuber Improvement Programme in 1971, and this includes cassava, sweet potato, yam and cocoyam, all of which are important food crops in many parts of Africa. However, in view of cassava's potential and its economic importance within the lowland humid tropics more generally, priority is being given to this crop. The main aims are to improve yield both in quantity and quality and to breed for resistance to the two major diseases, bacterial blight and cassava mosaic. At present the average yield of cassava in Africa is low, being about 8 tons per hectare per year fresh weight, equivalent to a little less than 3 tons dry weight. The quality criteria are not well defined, but some definite improvements can be made in advance of this knowledge. Cassava mosaic disease is a serious problem in Africa, as it is also in India and Indonesia. Nearly all plants are infected, resulting in an average yield reduction of 50 per cent²³. Bacterial blight caused by *Xanthomonas manihoti* has recently been reported in Africa. In Nigeria³⁸ and Zaïre³⁹ it causes severe tip die-back and defoliation, often resulting in the death of the plant. It is now thought that bacterial blight is potentially a more serious disease than cassava mosaic within the areas affected.

Although cassava is economically important in many other parts of the world, breeding for improvement in this crop has been given very little attention compared with many other crops. There is practically no information on the practical and fundamental approaches in breeding for the solution of many of the problems limiting or inhibiting the use of cassava. The breeding work during the period 1930 to 1950 in East Africa, West Africa, Brazil, Indonesia and Madagascar has for the most part not been sustained.

Our aim is to devise a breeding system that will be applicable on a world-wide basis and this paper describes the present state and future development of I.I.T.A.'s programme. We evaluate the possibility of in-

*International Institute of Tropical Agriculture, Ibadan.

corporating some of the methodologies already successfully used in breeding corn, alfalfa, sorghum and sweet potato.

BREEDING OBJECTIVES

The ultimate goal of cassava breeding is to incorporate into clonal cultivars all the characteristics, not yet fully explored, which appear to be associated with high yield expressed both in terms of quantity and quality per unit of area and time. Stability of the desirable characteristics is required over a wide range of environments and cultural practices.

Bearing in mind the limiting factors affecting cassava production in Africa, we regard the following objectives as realistic and our aim is to produce:

1. High yield in terms of dry matter per unit of land area and time.
2. Multiple resistance to diseases, especially cassava mosaic and bacterial blight and to pest attack.
3. Improved quality in terms of high starch (both quantity and quality), low or zero cyanide and high protein content, especially in the leaf.
4. Adaptation to a wide range of environments.
5. Improved plant types, especially in respect of canopy and root characteristics.

BASIC CONSIDERATIONS IN CASSAVA BREEDING

Breeding materials and evaluation

The acquisition and selection of superior breeding material is a primary necessity in any breeding programme. *M. esculenta* exhibits wide variation in form and there are about 128 other *Manihot* species³⁵, the genetic variation of which has not yet been fully explored or utilized.

Cassava is indigenous to the new world tropics and was probably domesticated in the drier parts of western and southern Mexico, northern Guatemala and also in northeastern Brazil³³. It was introduced to the West African coast via the Gulf of Benin and the Congo river at the end of the 16th century and to Malaya, Indonesia, Ceylon, India, Madagascar and Zanzibar during the 18th century²⁴.

Cassava in Africa shows considerable variation which is readily apparent in many local germplasm collections. This is not surprising as it flowers and sets seed freely, and new cultivars are established from volunteer seedlings which grow readily under optimum temperatures (30–35°C) and rainfall conditions which occur during some periods of the year. Cassava is rarely self-pollinated, since male and female flowers on the same inflorescence mature at different times. Thus, continuing recombination has occurred from outcrosses of genetically heterozygous cultivars. Some level of resistance to cassava mosaic has been established through intelligent selection by local farmers of superior seedlings for vegetative propagation, thereby developing new cultivars. Genetic fixation is not required in a vegetatively propagated crop since clonal cultivars can be produced from selected heterozygotes. Spontaneous mutation may also be a cause of additional genetic variation.

Genetic variability in Africa is not however expected to be as great as in Latin America where cassava originated. Original introductions may represent only a non-representative sample of the total germplasm available so that systematic introduction of new breeding material is important and is specially desirable from areas having similar ecological conditions. Introductions from countries where the crop is indigenous will be particularly valuable.

Manihot esculenta is the only edible cultivated species. Cultivars within this species have become extremely diversified during the process of clonal selection in different environments and their potential as sources of breeding material may be considerable, but is difficult to predict.

The IITA germplasm collection has not yet been thoroughly evaluated. Phytosanitary regulations require that introductions of new breeding material be confined to true seed which has had the appropriate fungicide/insecticide dressing, as the risk of introducing new diseases in vegetative material is considered too great. At IITA the Root and Tuber Improvement Program has adopted this procedure from the beginning, and Martin³⁰ has suggested that the germplasm banks of the future should be in seed form rather than as clonal collections. Cassava mosaic is not seed-borne⁷, nor, so far as is yet known, is bacterial blight. Other pathogens of cassava, *Cercospora* spp., *Botryodiplodia theobromae*, *Colletotrichum* spp. causing stem anthracnose, and a *Phomopsis* sp. causing root rot and *Fusarium* spp. are endemic in Nigeria and therefore need be of no concern as far as phytosanitary regulations are concerned.

The large number of local clonal cultivars and plants grown from seed require evaluation in order to be of practical value. Their potential as breeding parents, as well as their own characteristics need to be screened. Their breeding value can be indexed by studying their general combining ability in test crosses to a low yielding local variety¹¹. The testcross can be made by growing the germplasm collection and the local test variety in isolation, using the tester as a universal pollen parent and removing the male flowers from all

plants of the germplasm collection. The following year evaluation of the testcrosses by growing the seed in replicated trials at several different locations and seasons would give the necessary information and useful agronomic traits should be noted at the same time.

Floral mechanism and cross-pollination

Cassava is diclinous, flowers of different sex being separated on the same inflorescence. Female flowers at the base of the inflorescence open first and apical male flowers normally open about a week later. During the flowering season there is great activity among nectar gathering insects and pollen collecting wild bees.

In India many cultivars rarely or never flower²⁸. The same problem has been observed within the germplasm collection of several thousand entries at CIAT, Colombia. Cassava has a short day flowering response, but the effect of temperature and its interaction with day length on flowering has not yet been studied. At IITA most cassava clones flower during the period August to January with the peak of flowering occurring during the period October to December.

The stigma remains receptive for up to twenty-four hours, and dried pollen remains viable for six days. Eight to nineteen hours are required for fertilization to occur⁶. Structurally and functionally therefore the cassava flower is well adapted to cross-pollination. Both the stigma and pollen are sticky and pollination is effected mainly by insects, although wind and rain may also be agents. Wild bees are probably the principal pollen vectors as cassava nectar is very attractive to them. Some plants have been observed to attract more bees than others, and this has been found to be associated with greater nectar production which is sometimes so prolific that it can be found on the petioles. Wild bees are most active at high temperature, low humidity and high light intensity.

During the first breeding phases, selection was made among accessions of *M. esculenta*, *M. glaziovii* and *M. melanobasis* for early and profuse flowering characteristics that enhance the outcrossing potential. However, it has been observed that these characteristics are not associated with high yield, but depend on branching habit. Non-branching or indeterminate types flower relatively little since inflorescences, when they occur, develop at the point of branching.

Rogers³⁴ reported that *M. esculenta* is generally less fertile than other species, but we have not found, under Nigerian conditions, that this is apparently so. Seed matures in about 75–90 days⁶. The fruit has three locules and three seeds, and on average 100 seed weigh 10g.

Hand pollination

Flowers for crossing of both sexes are at the point of opening. Male flowers are collected early in the day and pollinations made during the remainder of the day. Bagging of female flowers before pollination is not practised, unless the particular population is very small and every flower must be utilized. Satisfactory results are obtained when a white paper bag (17 x 9 cm) is used to cover the pollinated flowers and this has proved much more satisfactory than the waxed narrow type commonly used by cereal breeders. Fruits and seeds set readily in most cultivars and families, but there was a 100 percent failure in hand pollinations to Llanera* which set seed only when naturally pollinated, but this could be used as the male parent in controlled crosses.

Germination of seed

Cassava seed germinates irregularly over a period of 2–4 months at ambient temperatures. The percentage germination is generally about 10–40 percent. In the past 'cracking' the seed coat was recommended and produced between 80–100 percent germination within 15–20 days. However, this method was very laborious and many of the seedlings were poor, due to damage to the embryo during cracking. The Federal Experiment Station of Nigeria has developed a most successful wet-heat treatment giving germination of a large number of seed of uniform stand over a short period of time^{4,13}. However, at IITA we use unscarified seed, dressed with an insecticide/fungicide and planted directly in the nursery in January/March in shallow drills and kept well watered. At this time of the year, the soil temperature is within the required range and an irrigation regime ensures adequate moisture, resulting in an 80 percent germination within three weeks. By this technique about 12,000 seedlings were produced in 1972 and about 100,000 in 1973. The only problem with this technique is the profusion of weeds. To reduce weed competition, an experiment on preplanting treatments was conducted in order to shorten the days from planting in the field to seedling emergence. A presowing treatment, using wooden flats filled with sieved soil kept well watered and held outdoors resulted in a uniform 85 percent germination within 9 days after planting. A convenient and successful (80–90% germination) method for small experiments is to plant untreated seeds in peat pots

*The quoted use of this Colombian clone suggests that this must have been introduced to West Africa other than by seed. This supposedly high protein clone was for some time regarded as having great potential for improved nutrition in cassava eating areas.

held in black plastic or wooden seed trays. These, if kept well watered, grow equally well outside or in the hotter screen houses.

From a series of experiments on seed germination, it has been proved that light and drastic changes of temperature are not required for successful germination, but that a soil temperature between 30–35°C and regular moisture are essential.

Male sterility

Male sterility is common in cassava^{5,8,23,28,31}, and it has been suggested by Martin³⁰ that it could usefully be employed in the hybridization of cassava. We do not however agree, since incorporating this factor would take some time, and technical difficulties might arise. We prefer to produce the required hybrid seed by emasculation of the female plants which is easy because of dicliny. Also, since self pollination is rare, the required hybrids can be produced if a population consisting of a single plant of each clone is planted in several isolated breeding plots. Unlike corn, which requires a large amount of hybrid seed for economic production, cassava relies on vegetative propagation. However, male sterility might be worth considering if true seed was to be used in commercial cassava production on a large scale; but this neither seems feasible nor relevant at present.

Genetics in relation to breeding

There is little published information on cassava genetics. Cassava has the karyotype $2n = 36^{1,9,14,28,32}$, and is probably allopolyploid (i.e. $x = 9$)*. Abraham² produced several 'tetraploids' ($2n = 72$) which gave a poorer yield than the original ($2n = 36$) parents: 'triploids' ($2n = 54$) were superior to the tetraploids.

Doughty¹⁰ and Jennings²³ reported that resistance to cassava mosaic is multigenic. Based on data obtained from about 10,000 segregations in 72 families, it appears that resistance is under quantitative genetic control.¹⁷ From our seven parent diallel cross, it appeared that resistance to cassava mosaic is recessive and has a high heritability of about 60 percent.

Cyanide content appears to be regulated by a complex of minor genes. A cross between two cultivars of low cyanide content produced plants having a much lower content than either of the parents, but the frequency of such transgressive types was very low.

Plot size and replications

Thompson and Wholy³⁷ have concluded by reviewing experimental work that a minimum of 16 and a maximum of 32 sample plants are needed to give a reliable estimate of yield and have suggested four replications as a minimum.

We applied the method employed by Hatheway²⁰ to decide by preliminary experimentation a convenient plot size and number of replications for the experimental determination of yield for subsequent work with this crop. Cassava was planted at 1 x 1 m. spacing. If the true difference among clones expressed as percentage of the mean is 13.7 percent in a trial employing four replicates of 16 m² than, in order to measure the same true difference, eight replicates would be required for a plot size of 8 m², or two to three replicates for a plot size of 32 m². We decided that to conduct yield trials for ten varieties in a convenient way, a plot size of 4 x 12 m will be used, but harvesting only the central 2 x 10 m, and using four replications would be satisfactory.

BREEDING METHODS

Introduction

Several methods have been used before in cassava breeding, but systems which have been recently developed and most successfully used by breeders of other crops have not previously been applied to cassava.

A breeding plan is required which will allow efficient selections from the variability and genetic potential of breeding populations.

Our short term objective is to collect and evaluate local clonal cultivars. This is to be followed by hybridizing amongst those selected ones. We need to find clones that will complement each other and produce good hybrids with each other that can then in turn be cloned. This should be easier than trying to break linkages and obtain all the favourable genes and gene combinations into one seed propagated variety, as is necessary in a non-vegetatively propagated crop.

*Ed.

Conventional breeding systems

The early techniques, which were probably carried out by all the cassava growing countries which had facilities to do so, consisted of:

1. Collection and observation of a many local clones as possible.
2. Selection of the best of these for immediate use and for producing hybrids.
3. Selection of the best plants within hybrid populations.
4. Comparison of yield potential and other important agronomic traits of the cloned hybrids.
5. Evaluation of the best selections in local and district trials, followed by general distribution.

Such an approach would be followed by introducing additional germplasm from various sources and screening and using this in the same way as the local germplasm.

Intervarietal hybridization

When a desirable hybrid (heterozygote x heterozygote) plant is obtained, it can be issued as a clone of variety after testing. Genetic 'fixation' is unnecessary. If, however, a gene or genes which determine a desirable character is recessive, then an F_2 generation will need to be produced to bring such a gene into a homozygous state or further crossings may be made between selected plants to create desirable recombinations. It is necessary to have as large a population of clone x clone seedlings as possible because each plant will be genetically distinct at this stage and thus provide a source population for selection. In a vegetatively propagated crop, provided the first cross can be made, the parental material may come from many diverse sources, including wild species and those having different chromosomes or genomes.

Interspecific hybridization

Incorporation into cultivars of useful genes from related species appears to be of great possible value in a cassava breeding programme.²⁸ Since almost all the related *Manihot* species can be crossed with cassava³⁶ the entire genus *Manihot* can probably be considered as a common pool of germplasm from which desirable genes can be drawn for cassava improvement.³⁰ However only a few *Manihot* species have so far been used. *M. glaziovii*, *M. catingea*, *M. saxicola*, *M. melanobasis* and *M. dichotoma* have been used as sources of resistance to cassava mosaic and insect attack, for high protein content and for drought tolerance. Incorporation of resistance to cassava mosaic by crossing cassava with *M. glaziovii* has been particularly successful. It has recently been observed within our screening that this interspecific cross also produces a high degree of resistance to cassava bacterial blight (*Xanthomonas manihotis*). It is thus anticipated that a useful potential exists for obtaining from other *Manihot* spp economically desirable characteristics not found within *M. esculenta* itself.

However, the methodology of accomplishing the introduction of traits, which are frequently quantitative in inheritance, into cultivated cassava needs investigation. Backcrossing, followed by selection, has been used extensively^{2,3,23,25,29}, to introduce new genic sources from related species. Two or three backcrosses to adapted cultivars were made, in general, in order to incorporate the resistance to cassava mosaic disease of *M. glaziovii*, but except for this resistance, no overall improvement in cassava was achieved.

There is a great need for breeders to develop a methodology to introgress exotic germplasm most efficiently into their breeding populations, recombine simultaneously among genes from more than two germplasm sources but retain desirable gene complexes built up within the crop species during recent evolution and breeding.

The major problem of using exotic germplasm is how to effect the integration of the special features desired from the wild forms in a sufficiently short time to make the effort economically worthwhile.

Mackey²⁷ has proposed a modified convergent crossing that might be worth considering since it provides more opportunity for retaining good gene complexes and combinations already present in the current elite adapted varieties; and for the inclusion of any desired percentage of unadapted germplasm in the breeding population. The adapted germplasm in a given convergent cross may come from one, or many adapted varieties. This approach has been used in our breeding programme to incorporate the resistance of *M. glaziovii* to both cassava mosaic and bacterial blight into adapted local cultivars. Three-way crosses instead of single crosses have been effective for introgressing new germplasm into breeding populations¹⁶. Efron and Everett¹² suggested making a series of hand crosses between adapted and exotic material, and growing out the hybrids as a population, allowing natural random crossing in subsequent generations.

Population improvement

Several cassava breeders have already recognized the importance of improving base populations in order to provide more desirable sources of new genotypes. As cassava is normally cross-pollinated, uncontrolled crossing usually takes place accompanied by a high degree of seed setting. Nevertheless one might

expect a certain degree of self-pollination in the absence of self incompatibility. It should be borne in mind, moreover, since flowering times differ among individuals, complete parental representation might prove difficult and uncontrollable.

As we look ahead to the next decade, we believe that outcrossing will therefore not equate to 'random mating'. Our greatest yield advances in both quantity and quality in cassava are likely to come from the use of improved populations developed through cyclic selection and recombination.

Breeding schemes are needed which can provide continuous genetic upgrading of the breeding populations through new germplasm introgression, with opportunities for the selection of individuals from continuous improved recombinations.

Cassava breeders are fortunate in dealing with a plant with a flowering mechanism which makes it easy to achieve a large number of cross pollinations with minimum effort, and in the case of vegetative propagation which provides quantities of planting material for testing any particular genotype.

PROGRESS IN THE BREEDING PROGRAMME AT IITA

In 1972, about 12,000 seedlings were raised comprising three main groups:

1. Open-pollination among Nigerian local cultivars.
2. Hybrids among the selected Nigerian cultivars.
3. Seed introductions from Latin America and Asia.

The populations were screened for resistance to diseases, especially cassava mosaic and bacterial blight; evaluated for reaction to insect attack, plant conformation, and tuberous root characteristics. From these, about 1,200 promising individuals were selected and planted out as clones in rows for preliminary evaluation of yield potential, dry matter percentage, starch content and quality, and various other agronomic traits. Many clones resistant to cassava mosaic and bacterial blight were obtained from groups 1 and 2 but most of the plants from group 3 were highly susceptible. About 1,000 individuals representative of each selected clone, were planted in isolation to produce the base population for mass selection and comprehensive breeding schemes.

About 100,000 seedlings were raised in February-March of 1973, and screened for resistance to cassava mosaic and for acyanogenesis. A large number of individuals having resistance to the disease and low cyanide content were obtained. In September-October, about 50 promising families from various sources were selected and planted out in isolation to start a half-sib family selection scheme. These were planted in replicated trials interplanted with basal root-cuttings of those plants showing the best root characteristics (short, fat, compact and uniform). A second selection of about 3,000 individuals was made amongst all families, primarily on conformation. However, for certain exotics a considerable number of selections was made of the vigorous plants irrespective of conformation in order to provide as many different sources of genetic diversity as possible (in the population). These were planted in rows for evaluation in the dry season, and a further selection will be made in March-April for wet season evaluation. About 1,000 root stocks selected from the first 3,000 selections (chosen for desirable characteristics) have been planted out in isolation to provide a germplasm reservoir and to apply various selection schemes for population improvement.

It is now known that resistance to cassava mosaic is controlled by quantitative genes, appears to be recessive and has a high heritability of about 60%. Cyanide content appears to be regulated by a recessive minor gene complex, and resistance to cassava mosaic and bacterial blight appears to be associated, the resistance to both coming from *Manihot glaziovii*. It appears that tuberous root characteristics are highly heritable and that selection for them is possible at the seedling stage. Significant variety-season interaction and varietal competition have also been noted.

REFERENCES

1. Abraham, A. (1957) Breeding of tuber crops in India, *J. Gen. and Pl. Breeding* 17, 212-17.
2. — — — — (1970) Breeding work in tapioca (cassava) and a few other tropical tuber crops. *Proc. 2nd Int. Symp. Trop. Root Crops*, 1, 76-8.
3. Beck, B. (1971) The breeding goals in a cassava breeding programme in West Africa. (Unpublished)
4. — — — — (1972) The germination of cassava seeds. The effect of temperature and scarification. (Unpublished)
5. Capinpin, J.M. & Bruce, V.C. (1955) Floral biology and cytology of *Manihot utilissima*. *Phil. Agr.* 39(6), 306-16.
6. Chandraratna, M.R. & Nanayakkara, K.D.S.S. (1948) Studies in cassava. II. The production of hybrids. *Trop. Agr.* 194, 59-74.
7. Chant, S.R. (1958) Studies on the transmission of cassava mosaic virus by *Bemisia* spp. (Aleyrodidae). *Ann. Appl. Biol.* 46, 210-15.

8. Cours, G. (1951) Le manioc a Madagascar. *Memo Inst. Rech. Sci. Madagascar Ser. J. Biol. Veg.* 3(2), 203–400.
9. Cruz, N.D. da (1968) Citologia no genero *Manihot* Adans. 1. Determinacao do numero de cromosomos em algumas especies. *An. Acad. Brazil Cienc.* 40(1): 91–5.
10. Doughty, L.R. (1958) Cassava breeding for resistance to mosaic and brown streak virus. A review of twenty-one years' work. *Record of Res. E. Afr. Agr. and For. Res. Org. Ann. Rep.* 48–55.
11. Eberhart, S.A., Harrison, M.N. & Ogada, F. (1967) A comprehensive breeding system. *Der Zuchter* 37, 169–74.
12. Efron, Y. & Everett, H.L. (1969) Evaluation of exotic germplasm for improving corn hybrids in northern U.S. *Crop Sci.* 9, 44–7.
13. Ekandem, M.J. (1970) Technique for cassava hybridization and production of seedlings. *Fed. Dept. Agr. Res. Nigeria, Memo No. 105.*
14. Ene, L.S.O. (1972) Programme for the production of haploids, diploids, poly-haploids and other types from national polyploids of *Manihot esculenta* by interspecific hybridization. Presented at 1st Nigerian Society Gen. and Breeding.
15. F.A.O. (1971) Production Yearbook. Vol. 25.
16. Hahn, S.K. (1970) Development of modern system of breeding improved small grains. Code No. RES-TF-68-10. MOST/USAID/K.
17. — — — — & Howland, A.K. (1972) Breeding for resistance to cassava mosaic. Proc. cassava mosaic workshop, IDRC/IITA.
18. Harrison, M.N. (1967) Selection of source material and methods of formation of composites for maize breeding. East Afr. Cereals Res. Conf.
19. — — — — (1973) Personal communication. IITA.
20. Hatheway, W.H. (1961) Convenient plot size. *Agron. J.* 53, 279–80.
21. Hendershut, C.H. et al. (1972) A literature review and research recommendations on cassava. AID Cont. No. csd/2497.
22. Hull, F.H. (1945) Recurrent selection for specific combining ability in corn. *J. Am. Soc. Agron.* 37, 134–45.
23. Jennings, D.J. (1970) Cassava in Africa. *Field Crop Abst.* 23, 271–8.
24. Jones, W.O. (1959) *Manihot in Africa*. Standord Univ. Press, Standord.
25. Koshy, T.K. (1947) The tapioca plant and methods for evolving improved strains for cultivation. *Proc. Indian Acad. Sci. Sect. 26*, 32–59.
26. Lonquist, J.H. (1964) A modification of the ear-to-row procedures for the improvement of maize populations. *Crop Sci.* 4, 227–228.
27. Mackey, J. (1963) *Autogamous plant breeding based on already highbred material. Recent plant breeding research. Svalof 1946–1961.* Edited by E. Aherberg et al. John Wiley and Son, N.Y.
28. Magoon, M.L. (1967) Recent trends in cassava breeding in India. Proc. 1st Symp. Trop. Root Crops. 1, 100–17.
29. — — — — (1970) Problems and prospects in the genetic improvement of cassava in India. Proc. 2nd Int. Symp. Trop. Root Crops. 1, 58–61.
30. Martin, F.W. (1970) Cassava in the world of tomorrow. Proc. 2nd Int. Symp. Trop. Root Crops. 1, 51–58.
31. Moh, C.C. (1966) Preliminary observations of meiotic chromosome pairing in *Manihot esculenta*. The applic. Nuclear Energy to Agr. Turrialba, Inst. Interamericano de Ciencias Agricolas, Ann. Rep.
32. Perry, B.A. (1943) Chromosome number and phytogenetic relationships in the Euphorpiaceae. *Amer. J. Bot.* 30(7), 243–57.
33. Rogers, D.J. (1963) Studies of *Manihot esculenta* Crantz and related species. *Bull. Torrey Bot. Club.* 90, 43.
34. — — — — (1965) Some botanical ethnological considerations of *Manihot esculenta*. *Econ. Bot.* 19, 369–77.
35. Rogers, D.J. & Appan, S.G. (1970) Untapped genetic resources for cassava improvement. Proc. 2nd Int. Symp. Trop. Root Crops. 1, 72–5.
36. Rogers, D.J. (1973) Personal communication.
37. Thompson, R.C. & Wholey, O.W. (1972) *A guide for cassava field trials*. CIAT, Cali, Colombia.
38. Williams, R.J. et al. (1973) Bacterial wilt of cassava in Nigeria. *Plant Res. Rep.* October.
39. Williams, R.J. & Hahn, S.K. (1973) Investigations on cassava in the Republic of Zaire. (Unpublished)

BREEDING FOR PROTEIN ENHANCEMENT IN CASSAVA

N. Hrish and J.S. Jos*

SUMMARY

An intraspecific cross in *Manihot esculenta* between a Madagascar clone and a clone from Malaysia has a protein content of 7.9% but a low yield potential. In interspecific crosses between *M. saxicola* and *M. esculenta* there was a higher protein content in the roots of seedlings than in the parents, but the protein content reverted to normal levels in the clonal offspring of the hybrid seedlings. Tetraploids were produced from Malayan 4 and the protein content of these was increased by 42% over the level in the diploid and this was stable under vegetative propagation. Mutation breeding is also being undertaken.

RESUME

Un croisement intraspécifique dans *Manihot esculenta* entre un clone malgache et un clone de Malaisie a une teneur en protéine de 7.9%, mais le potentiel de rendement est bas. Dans des croisements interspécifiques entre *M. saxicola* et *M. esculenta*, la teneur en protéine est plus élevée dans les racines et les plantules que dans les parents, mais la teneur en protéine redevient normale dans les descendants des plantules hybrides. Des tétraploïdes ont été créés à partir du Malayan 4 avec un accroissement de 42% de leur teneur en protéine au dessus du niveau observé dans le diploïde; l'enrichissement acquis s'est maintenu lors de la multiplication végétative. La sélection de mutations est également en cours.

RESUMEN

El contenido de proteína de una cruce intraespecífica en *Manihot esculenta* es de 7.9%, pero su rendimiento potencial es bajo. En cruces interespecíficas entre *M. saxicola* y *M. esculenta*, hubo un contenido más alto de proteína en las raíces de la progenie que en los padres; revirtiéndose, sin embargo, a niveles normales en la progenie clonal de los híbridos. Se produjeron tetraploides a partir de Malayan 4, con un contenido de proteína incrementado en un 42% sobre el nivel encontrado en los diploides y estable bajo propagación vegetativa. Se intenta también la hibridación por mutaciones.

INTRODUCTION

The diet in the developing regions in the world is deficient in protein. It is desirable to develop strains of food crops having higher protein content, as one means of combating malnutrition. Cassava (*Manihot esculenta*) is biologically a highly efficient producer of calories, and if it could be made a more efficient producer of protein, it could make a greater contribution to nutrition in the tropics.

Protein malnutrition is prevalent particularly among low-income families where cassava is an important food. In cultivars presently grown the tubers generally contain about 1.8% protein (Coursey and Haynes⁴), and the protein is also poor in essential amino-acids, and especially in the sulphur-containing amino-acids (Jones⁷).

We have attempted to improve the protein content of cassava through conventional breeding methods involving selection and hybridization at both intra- and inter-specific level. Breeding by induced polyploidy and mutation have also been found to hold promise. We present the results obtained so far and discuss the future approach to the enhancement of protein in cassava.

RESULTS AND DISCUSSION

Germplasm evaluation

The total germplasm collection of clones comprises about 1,400 entries, of which 250 are exotics. Screening for quality characteristics did not reveal any significant variability in protein content of the tubers. This supports the findings of Bolhuis². However, a clone recently received from Colombia has been claimed to contain about 8% protein and this is being multiplied.

Intervarietal hybridization

Though a break-through has been achieved in yield (Magoon *et al.*¹⁰) by hybridization, quality im-

*Central Tuber Crops Research Institute, Trivandrum, India.

provement has received little attention. Superior genotypes have been crossed and desirable recombinants have been selected and maintained clonally. In a population of 54 segregants derived from a cross between a Madagascar and a Malayan stock, there appeared to be continuous variation from 2.08 to 7.99% protein content on a dry weight basis. Selections 1579(1), 1586(3) and 602(3) had 6.2%, 6.3% and 7.99% respectively. However, these had very poor yields and indicate a negative correlation between protein and yield.

'Interspecific' hybridization

Manihot saxicola is a wild species reported to contain 11% protein. However, Bolhuis² questioned the validity of classifying *M. saxicola* as a separate species since seed set in the 'interspecific' cross with *M. esculenta* often exceeded the seed set in cassava x cassava crosses. Crosses made between *M. esculenta* and *M. saxicola* yielded a few seedlings with comparatively high protein in the tubers but when these selections were propagated clonally the protein content fell back to typical levels (Jones⁷). A new attempt seemed worthwhile to transfer the protein productivity of *M. saxicola* to cassava, avoiding the breakdown of this character associated with clonal propagation. It is also important to collect other species to intensify the breeding programme in this direction.

Polyploidy

Polyploidy has been successfully used for improvement in rye, turnips, clover, berseem etc. (Mehta & Swaminathan¹¹, Allard¹). Recently, polyploidy has been found effective in improving quality in root crops (Gaul⁶).

Cultivated cultivars of cassava are diploids with $2n = 36$ chromosomes. Auto-tetraploidy was induced in Malayan-4 by treating the sprouts of stem cuttings with 0.5% colchicine solution (Magoon *et al.*⁹). Clones raised from treated shoots showed the usual gigas characters associated with polyploidy, but no significant difference in yield potential or in dry matter content was found between 'tetraploid' and the parental clones.

The average crude protein content in the diploid was found to be 2.79% while tetraploid has as high as 3.97% on a dry weight basis, representing an increase of 42.3%. Tubers of diploid parents showed a range of 2.26 to 3.30% crude protein, while in the corresponding tetraploids, the range was found to be 3.30% to 4.86%. The increase in protein content was consistent in tubers of different individual tetraploid plants of a particular clone (Jos, *et al.*⁸).

Tubers of tetraploid and diploid plants did not differ significantly in shape or size, so that the variation in protein content is not merely a characteristic related to the overall size of the tubers. Rather, it seems that protein *per se* had increased in the tubers. This is in contrast to the situation in crops like rye, where increase in protein at the tetraploid level is attributable to the small seed size and lower seed setting in the tetraploid plants (Frost & Ellerstrom⁵). Tetraploidy in cassava appears to persist and be stable through vegetative propagation.

Mutation

Developing crop cultivars having either higher protein content or enhancing the content of certain essential amino-acids in their protein through mutation, has opened new vistas in breeding for quality, particularly in cereals. Using a wide variety of mutagens, a mutation breeding programme in cassava has been initiated for protein enhancement. Though significant improvement could be achieved for the increase in starch content and decrease in rind thickness (Vasudevan *et al.*¹²), further detailed analysis is underway to screen the irradiated population for protein characteristics. Also, mutation breeding may be of further help in breaking undesirable linkages.

REFERENCES

1. Allard, R.W. (1960) *Principles of plant breeding*. John Wiley, New York.
2. Bolhuis, G.G. (1953) A survey of some attempts to breed cassava varieties with a high content of protein in roots. *Euphytica* 2, 107-112.
3. — — — (1967) Intra- and Inter-specific crosses in the genus *Manihot*. *Proc. of the Inter. Symp. on Tropical Root Crops* 1, 81-8.
4. Coursey, D.G. & Haynes, P.H. (1970) Root crops and their potential as food in the tropics. *World Crops* 22, 261-5.
5. Frost, S. & Ellerstrom, S. (1965) Protein content and fertility in tetraploid rye. *Hereditas* 54, 119-22.
6. Gaul, H. (1970) Plant protein sources. Their improvement by the application of nuclear techniques. *FAO/IAEA Symposium, Vienna*.

7. Jones, W.O. (1959) *Manioc in Africa*. Stanford Univ. Press, Stanford, California.
8. Jos, J.S., Nair, R.G. & Maini, S.B. (1972) Quality improvement in cassava through autotetraploidy. *SABRAO Newsletter* 4, 117-8.
9. Magoon, M.L., Jos, J.S., Vasudevan, K.N. & Mair, S.G. (1969) Cytomorphological studies on induced polyploids of cassava. *Genet. Iberica* 21, 27-47.
10. Magoon, M.L., Appan, S.G., Krishnan, R. & Mandal, R.C. (1970) Some promising high yielding hybrids and selections of cassava. *SABRAO Newsletter* 2, 19-26.
11. Mehta, R.K. & Swaminathan, M.S. (1957) Studies on induced polyploids in forage crops. *Indian J. Genet.* 17, 27-57.
12. Vasudevan, K.N., Nair, S.G., Jos, J.S. & Magoon, M.L. (1967) Radiation-induced mutations in cassava. *Indian Journ. Horti.* 24, 95-98.

EXTENDING FRONTIERS OF GENETIC IMPROVEMENT IN CASSAVA

M.L. Magoon and R. Krishnan*

SUMMARY

Special problems retarding genetic improvement are discussed and methods for overcoming barriers for gene flow are evaluated. The principles discussed have been applied in the cassava breeding programme at Trivandrum and proved valuable. Pachytene analyses for studying the karyotype and chromosomal homology at interspecific level is described and has revealed the very close relationship of cassava and *Manihot glaziovii*. Three clones from variety x variety crosses have been selected after careful testing. These are H-165, H-97 and H-226. They have 2–3 times the yield potential of local 'control' cultivars in regional trials. For future work a return to the diploid level for more intense selection before reforming polyploids from selected diploids is suggested as a promising technique.

RESUME

Les facteurs particuliers liés à l'arriération de l'amélioration génétique ont été abordés et des méthodes pour progresser évaluées. Les principes avancés ont été mis en application par le programme de sélection du manioc à Trivandrum et ils se sont révélés dignes d'intérêt. Des analyses pachytènes pour l'étude de caryotype et d'homologie chromosomique ont révélé la relation très étroite qui existe entre le manioc et *Manihot glaziovii*. Trois clones H-165, H-97 et H-226 issus de croisements variété x variété ont été sélectionnés après un essai minutieux. Ils ont 2–3 fois le potentiel de rendement des cultivars "témoins" locaux en essais régionaux. L'intensification de la sélection au niveau des diploïdes avant de réformer les polyploïdes à partir des diploïdes sélectionnés a été proposée comme une technique pleine d'espoir dans la poursuite des travaux de recherche.

RESUMEN

Se discuten problemas especiales que retardan el mejoramiento genético y se evalúan métodos para superar barreras al flujo de genes. Los principios discutidos han sido aplicados en el Programa de Hibridación de Yuca en Trivandrum y han probado ser valiosos. El análisis en fase de paquiteno, para el estudio del kariotipo y la homología cromosómica — que se describe — han revelado una relación muy cercana entre yuca y *Manihot glaziovii*. Tres clones de cruza variedad x variedad se seleccionaron después de cuidadosas pruebas, ellos son: H-165, H-97 y H-226. Estos clones alcanzan 2–3 veces el rendimiento potencial de los cultivares "testigo" locales, en los ensayos regionales.

Se sugiere, como técnica prometedora para futuros trabajos, el regresar al nivel diploide para hacer una selección más intensa, antes de reformar los poliploides a partir de los diploides seleccionados.

INTRODUCTION

Cassava is a multi-purpose crop. Its acknowledged superiority in calorie production and its adaptability to a wide variety of conditions is offset only by its longer crop duration and relatively high labour requirement for cultivation^{7,25,26,27}. These facts have ensured its continued cultivation in the face of competition from several other crops (which have been the subjects of comprehensive studies by plant scientists). Much remains to be accomplished in adapting cassava to its various roles and in raising its current status in several parts of the world from a subsistence crop to that of an industrial crop¹⁷. Understanding the genetic architecture of its important agronomical, biochemical and physiological characters can assist in recombining these characters, employing modern breeding techniques¹⁹. Recent genetic research opens up new possibilities.

SOME AIMS FOR THE IMPROVEMENT OF CASSAVA

Present day cassava cultivars can be improved upon to meet the growing demands on them, as food, feed and/or industrial crop^{5,6,19}. Of primary importance among the needs are:

1. Production of high-yielding cultivars of improved plant types, wider adaptability and responsiveness to modern agronomic practices, particularly the use of fertilizers.

*Indian Grassland and Fodder Research Institute, Jhansi (U.P.) India.

2. Incorporation of resistance against important diseases e.g. 'cassava mosaic' and pests (*Bemisia* spp., scale insects, red spider mites etc.)
3. Upgrading tuber quality including lowering of cyanide content.
4. Prolonging storage life and enhancing suitability for processing.
5. Reducing maturity.
6. Improving cold and drought tolerance.

SPECIAL FACTORS AFFECTING THE GENETIC IMPROVEMENT OF CASSAVA

A high degree of heterozygosity can be presumed, since monoecy promotes outbreeding and vegetative propagation stabilises this. Non-flowering cultivars (clones) occur frequently, and among those that flower, varying degrees of gametic and zygotic sterility are common^{3,14,15}. This imposes a restriction on the exploitation of naturally occurring genetic variability since many clones cannot be used as parents. Many seeds are also inviable.

The possibility of securing a significant level of homozygosity is hampered by severe inbreeding depression⁷ which may be explained by a high genetic load of deleterious recessive mutations which are not exposed in heterozygotes.

While fixation of desirable genotypes can be achieved immediately by clonal propagation, quick multiplication of promising clones for practical utilization needs to be worked out.

GENETIC STUDIES

Information on the genetics of the important agronomical, biochemical and physiological aspects is almost totally lacking. In acquiring this information, the possibility of polyploid origin¹⁸ is important because of the gene buffering and interaction to be expected especially in polyploids.

An F_1 population arising from hybridization of heterozygous parents is in the genetical sense more equivalent to an F_2 generation with respect to heterozygous loci common to the parents. Hybridization, therefore, will promote the segregation of parental genes in addition to reshuffling of paternal and maternal chromosomal complements and production of new recombinations arising from crossing over within linkage groups. For maximum efficiency and reliability of hybridization programmes, parents should be genetically diverse and highly fertile to facilitate raising of a sizable F_1 population.

Based on phenotypic diversity and geographical origin, intervarietal crosses were made using a common maternal parent of Madagascar origin and three pollen parents originating from Malaysia, Madagascar and a hybrid between Brazilian and Indian cultivars. The F_1 populations were scored for several contrasting qualitative and quantitative traits and for various biochemical constituents^{23,24}. The F_1 populations of all these three crosses consisted of branched and unbranched plant types even though all the parents exhibited branching. The three populations differed in the frequency of narrow and broad-leaved plants. In crosses involving narrow and broad, the proportion of both the types were nearly equal while narrow x narrow crosses produced narrow leaved plants only. The colour of stipules in F_1 plants of deep purple x deep purple crosses included both green and purple types in some crosses and all purple stipuled seedlings in one cross. In deep purple x green petiole hybrids, almost equal numbers of plants of each petiole colour were produced. All the contrasting parental traits were expressed in the F_1 populations as well as new traits confirming the heterozygosity of the parental genotypes.

The important plant characteristics which affect tuber yield in cassava^{1,23} are the number and size of tuber, the size and efficiency of the leaf canopy, the ratio of top to roots and the duration of the period before tuberization. Character association studies for several of these characters in F_1 populations are revealing of their relationships to the yield. Tuber length, tuber circumference and tuber number per plant were all positively correlated with tuber yield, but tuber number per plant was negatively correlated with tuber length and circumference. Hence, simultaneous improvement for all the three yield components is likely to be difficult and a compromise will be essential. The breeder can profitably select for moderate numbers of medium sized tubers of moderate numbers with the expectation of securing a high proportion of marketable tubers and ease of harvesting and handling.

For plant type the breeder was a choice between branched and unbranched types, both of which can be selected from hybrid populations. Unbranched types would probably be preferred when mechanized cultivation is under consideration. Under rainfed conditions it seems that hybrids between cultivars with widely divergent leaf number can be selected that have a high leaf number and associated high yield potential.

SCOPE FOR GENETIC MANIPULATION OF BIOCHEMICAL CONSTITUENTS

Starch, dry matter crude protein and cyanide contents show wider variation in the hybrid populations than exists among the parents²⁴. Crude protein values in many hybrids were appreciably higher than found in parents. Character association studies for the above four traits indicated their independent inheritance. The breeder, therefore, can expect to be able to achieve simultaneous improvement for each.

INTENSIFICATION OF CYTOGENETICAL STUDIES

There are other *Manihot* species²⁹, several of which carry desirable genes for disease resistance (e.g. *M. glaziovii*) and relatively high protein content (e.g. *M. melanobasis*, *M. saxicola*) which can be crossed readily with cassava^{1,7}. There have been cytogenetical studies by the use of pachytene analyses and related cytogenetical studies in both species and species hybrids in order to explore the possibilities for successful inter-specific gene transfer.

Pachytene analysis has proved suitable for studies of chromosome homologies in karyotype analysis^{4,13,20,21}. In cassava and *M. glaziovii*, all the eighteen pachytene bivalents, which are morphologically distinguishable were identified. In both species several duplicated chromosomal types were found. In the light of the lower chromosome number reported for other Euphorbeacean genera and the behaviour accompanying polyploidization, the presence of three nucleolar-associated bivalent types and duplicated chromosomal types in both cassava and *M. glaziovii* suggested a polyploid origin for the *Manihot* species with $n = 18$ ¹⁸.

Some chromosomal differentiation between cassava and *M. glaziovii* was apparent from the comparative study of their pachytene karyotypes, and was in agreement with observations on chromosomal homology made at pachytene stage in their interspecific hybrid^{20,22}. The major chromosomal differentiation in the two species seemed to involve three chromosomes of the haploid complement.

Pachytene analyses in back cross plants showed no departure from random assortment of parental chromosomes and confirmed the close relationship between the two species (evident in the intimate synapsis of the parental chromosomes at pachytene stage in the F_1 hybrid) and absence of barriers for gene exchange.²⁰

Cytogenetical studies on similar lines might profitably be carried out in other *Manihot* species in order to resolve the impasse in the taxonomic treatment of the genus.

Studies on chromosome morphology in artificially induced triploids ($3n = 54$) and induced tetraploids ($4n = 72$) have thrown light on the nature of chromosome pairing as related to factors affecting fertility and meiotic irregularities^{2,10,11}. Efforts are now underway to obtain aneuploids by making triploid-diploid crosses. This should be possible because the triploid produces viable aneuploid gametes that may unite with euploid gametes from the diploid parent.

Comparative developmental studies of several male fertile and male sterile lines of cassava have been conducted^{3,14}. Cytological data suggest that meiotic abnormality is not the cause of pollen degeneration in the material studied. In some male sterile lines, degeneration of individual microspores may be due to the failure of the separation of microspores from tetrads, but in other male sterile lines pollen abortion has been attributed to abnormality of the structure and function of the tapetum. Attempts to study the genetics and breeding behaviour of various male sterile lines are underway.

CHOICE OF BREEDING STRATEGY

The approaches described have been followed and their results are apparent in the success of the cassava breeding programme at Central Tuber Research Institute, Trivandrum. By stringent selection and evaluation procedures in the germplasm collection several superior seedling selections were identified. A large scale hybridization programme among diverse genotypes was followed by rigorous selection in the hybrid populations and led to the recovery of promising F_1 hybrid plants as clones. Among those in the advanced stages of evaluation are selections S-1309, S-1310, S-1315, S-2380, S-2331 and S-2480 and hybrids H-165, H-97, H-226, H-86, H-43, H-2057 and H-57. Several selections have proved outstanding in local and multilocation yield trials conducted over three years, recording two or three fold higher tuber yield (ranging from 23.5 to 87.7 t/ha) than the respective regional or local controls (yield range 10.0 to 31.0 t/ha). Evaluation used a block design with four replications, NPK at the rate of 100 kg/ha in two split doses, and spacing of 90 cm x 90 cm. Three hybrids H-165, H-97 and H-226 have been released, backed by a package of recommended agronomic practices for general and commercial cultivation in the states of Kerala, Tamil Nadu and Mysore. These three hybrids all possess good responses to fertilization, a high degree of field resistance to Cassava Mosaic virus disease, scale insects, red mites and mealy bugs and good tuber qualities, namely, desirable tuber size, high starch and low cyanide contents, good cooking quality etc. They are relatively early maturing and are well adapted to a wide range of agro-climatic conditions¹².

Mutation breeding in cassava improvement might be useful when rectification of specific defects in commercial varieties, such as high toxicity, late maturity or disease susceptibility is required. Already, by using a dose range of 4000 r and 7500 r, a mutant of var 300 has shown an increase in starch content to 31.3% (on fresh weight basis) and decrease in cyanide content to 0.01 percent³¹.

In view of the polyploid origin of cassava, notwithstanding the practical difficulties^{9,16,30}, 'analytical breeding' or a 'genome approach' is being pursued for efficiently tackling the problems of intergenomic and intragenomic repatterning⁷. The main aim of this method is to reverse the evolutionary course and re-

generate diploids from polyploids with a view to being able to intensify selection before returning to the polyploid level. This approach may also provide promising materials for basic genetic, cytogenetic and evolutionary studies which would be of great value in further improvement of the crop²⁸.

REFERENCES

1. Jennings, D.L. (1970) Cassava in Africa. *Field Crop Abstracts*. 23, 271-8.
2. Jos, J.S., Magoon, M.L. and Nair, S.G. (1970) A cytological and morphological analysis of triploid cassava. *Genet. Iber.* 22, 27-39.
3. — — — — —, Sadasivaiah, R.S. and Appan, S.G. (1966) Studies on sterility in cassava 1. Mechanism of pollen abortion in some male sterile lines. *Indian Jour. Hort.* 23, 177-84.
4. Krishnan, R., Magoon, M.L. and Vijaya Bai, K. (1970) The pachytene karyology of *Manihot glaziovii*. *Genet. Iber.* 22, 177-91.
5. Magoon, M.L. (1967) Role of root and tuber crops in human nutrition. *Proc. Int. Symp. Sub-trop. and Trop. Horticulture*, New Delhi. 1, 46-61.
6. — — — — — (1967) Recent trends in cassava breeding in India. *Proc. Int. Symp. Trop. Root and Tuber Crops* (Trinidad). 1, 100-116.
7. — — — — — (1968) Some immediate problems, possibilities and experimental approaches in relation to genetic improvement of cassava. *Indian Jour. Genet.* 28A, 109-26.
8. — — — — — (1970) Problems and prospects in the genetic improvement of cassava in India. *Proc. 2nd Int. Symp. Trop. Root and Tuber Crops*, Honolulu, Hawaii, U.S.A. 1, 58-61.
9. — — — — —, Cooper, D.C. and Ramanujam, S. (1962) Cytogenetical studies in relation to the origin and differentiation of species in the genus *Solanum*. *Caryologia* 15, 151-2.
10. — — — — — et al. (1969) Cytomorphological studies in induced polyploids of cassava. *Genet. Iber.* 21, 27-48.
11. — — — — — (1970) Cytogenetics of induced polyploids of cassava. *Tropical Root and Tuber Crops Newsletter* 3, 18-20.
12. Magoon, M.L., Appan, S.G., Krishnan, R. and Mandal, R.C. (1970) Some promising high yielding hybrids and selections of cassava. *S.A.B.R.A.O. Newsletter* (Japan) 2, 19-26.
13. — — — — —, Jos, J.S. and Appan, S.G. (1966) Cytomorphology of the interspecific hybrids between cassava and ceara rubber. *Chromosome Information Service* (Japan). 7, 7-10.
14. — — — — —, Jos, J.S. and Nair, S.G. (1969) A morphological, embryological and cytological study of male sterility in *Manihot esculenta*. *Tropical Root and Tuber Crops Newsletter*, 2, 10-11.
15. — — — — — and Vasudevan, K.N. (1968) Male sterile cassava. *Nucleus*. 11, 1-6
16. — — — — —, and Khenna, K.R. (1963) Haploids. *Caryologia*, 16, 191-235.
17. — — — — — and Krishnan (1971) Genetic improvement of tuber crops (other than potatoes) in India. *Proc. 2nd Int. Symp. Sub-trop. and Trop. Horticulture*. 2, 1-20.
18. — — — — — (1971) Problems on the elucidation of genomic evolution in some important tropical tuber crops. *Proc. Symp. Genome Concept in Eukaryota*, Indian Sci. Congr. Calcutta.
19. — — — — — (1972) Plan and prospects for the improvement of tuber crops (other than potatoes) *Proc. All India Symp. Adv. in Cytogenetics*. 1, 1-19.
20. — — — — — and Vijaya Bai, K. (1969) Cytogenetics of F_1 hybrids between cassava and ceara rubber and its back cross. *Genetica*, 41, 425-36.
21. — — — — — (1970) Morphology of the pachytene chromosomes and meiosis in *Manihot esculenta* Crantz. *Cytologia*. 34, 612-26.
22. — — — — — (1971) Chromosomal differentiation between cassava and ceara rubber. *Tropical Root and Tuber Crops Newsletter*. 4, 23-5.
23. Magoon, M.L., Krishnan, R. and Lakshmi, K. (1972) Association of plant tuber characters with yield in cassava. *Tropical Root and Tuber Crops Newsletter*. 5.
24. Magoon, M.L., Maini, S.B. and Krishnan, R. (1972) Breeding for tuber quality in cassava. *Tropical Root and Tuber Crops Newsletter*. 5.

25. — — — — and Appan, S.G. (1966) Cassava — a food for the millions. *Indian Farming* 16, 12-13.
26. — — — — (1966) Industrial utility of cassava. *Industrial and Labour Review* 4, 1-8.
27. Magoon, M.L. and Sinha, S.K. (1967) Non-conventional foods — importance of subsidiary root and tuber crops in India. Proc. Joint Symp. Science and India's Food Problem Natl. Inst. Sci. and I.C.A.R., New Delhi. 1, 318-31.
28. Magoon, M.L. and Ramanujam. S. (1960) Nature of chromosome pairing in the genus *Solanum* section *Tuberarium*. *Indian J. Genet.* 20, 22-41.
29. Rogers, D.J. (1965) Some botanical and ethnological considerations of *Manihot esculenta*. *Econ. Bot.* 19, 369-77.
30. Swaminathan, M.S. and Magoon, M.L. (1961) The origin and cytogenetics of commercial potato. *Advances in Genetics (U.S.A.)* 10, 217-56.
31. Vasudevan, K.N., Jos, J.S., Magoon, M.L. and Nair, S.S. (1967) Radiation-induced mutations in cassava. *Ind. Jour. Hort.* 24, 95-8.

PHYSIOLOGICAL VARIABILITY IN THE MINERAL NUTRITION OF FOUR CASSAVA CULTIVARS IN FLOWING SOLUTION CULTURE

D.A. Forno, C.J. Asher, D.G. Edwards and J.P. Evenson*

SUMMARY

Results obtained since 1972 at the University of Queensland indicate substantial differences between cultivars Ceiba, UQ2, UQ5 and Nina in the rates of root development from stem tip cuttings in response to changes in substrate calcium concentrations and temperature in liquid culture. When rooted cuttings were grown in flowing solution culture, large differences were observed between cultivars in their response to calcium and to ammonium and nitrate nitrogen concentrations in the culture solution. Our data provide evidence of differences between genotypes in responses to nutrients and there may be some relationship, as yet undetermined, that would allow such methods to be of use in breeding cassava cultivars adapted to specific nutritional environments.

RESUME

Les résultats obtenus depuis 1972 à l'Université de Queensland révèlent qu'il existe des différences non négligeables entre les cultivars Ceiba, UQ2, UQ5 et Nina dans le taux de développement des racines à partir des boutures d'extrémité de tige en réponse aux changements dans les concentrations du substrat de calcium et aux changements de température dans une culture liquide. Lorsqu'on a cultivé des boutures de racine dans une solution de culture flottante, on a noté de grandes différences entre les cultivars dans leur réponse aux concentrations de calcium, d'ammonium et d'azote dans la solution de culture. Les données disponibles prouvent qu'il existe des différences entre génotypes en réponse aux éléments nutritifs et il doit y avoir une relation encore indéterminée permettant d'utiliser de telles méthodes pour la sélection et l'amélioration des cultivars de manioc adaptés à des milieux de nutrition spécifiques.

RESUMEN

Los resultados obtenidos desde 1972 en la Universidad de Queensland indican diferencias substanciales entre los cultivares Ceiba, UQ2, UQ5 y Nina en el grado de desarrollo de raíces, a partir de estacas terminales, como respuesta a cambios en la concentración de calcio y temperatura en el sustrato líquido. Cuando se hicieron crecer estacas ya enraizadas en soluciones nutritivas recicladas se observaron amplias diferencias, entre cultivares, en cuanto a su respuesta a las concentraciones de calcio, amonio y nitratos presentes en la solución nutritiva. Nuestros datos proveen evidencias sobre diferencias entre genotipos, en respuesta a nutrientes y puede haber alguna interrelación, si bien no determinada todavía, que pudiera permitir que tales métodos fuesen usados en la adaptación de cultivares de yuca a ambientes nutricionales específicos a través de mejoramiento genético.

INTRODUCTION

The importance of cassava (*Manihot esculenta* Crantz) for food as a potentially cheap source of carbohydrate for livestock and for industrial purposes is now widely recognized. However, although considerable attention has been given to improving the overall agronomy of the crop and to the breeding of superior lines, relatively little attention has been paid to the physiology of cassava. Morphological differences between cassava cultivars are well known² and provide outward evidence of the genetic diversity among cultivars. Less is known about physiological variation, although limited evidence available suggests that this too may be substantial³. Large differences between cassava cultivars in their response to fertilizers, observed in Ghana (S.H. Evelyn, personal communication), provide further evidence for physiological differences in cassava.

MATERIALS AND METHODS

In order to investigate physiological differences between cultivars in nutrient response, studies were commenced at the University of Queensland in early 1972. We have mostly used culture techniques

*Department of Agriculture, University of Queensland, Brisbane, Australia.

employing flowing solution since this permits precise control to be maintained over nutrient ion concentrations, pH and root temperature¹. We have used small stem tip cuttings for assaying responses since these have lower nutrient reserves than large stem cuttings, and so might be expected to be more sensitive to changes in the medium.

We have also readily propagated stem tip cuttings, lateral buds, and even detached leaves in mist culture, and we have constructed mist propagators in which both root temperature and nutrient supply can be varied.

RESULTS AND DISCUSSION

Effect of substrate calcium concentrations on root development

Root development by stem tip cuttings grown in mist propagation chambers was markedly affected by the concentration of calcium in the root medium (Fig. 1). When no calcium was supplied root development of the three cultivars in the trial was greatly retarded and the roots were stunted and had brownish-black tips.

In Ceiba, root growth appeared to be healthy at 15 μ M calcium, but in Nina and UQ2, the roots still showed obvious symptoms of calcium deficiency. Marked differences in response to calcium supply were noted at higher concentrations. Thus Ceiba was relatively insensitive to substrate calcium concentrations over the range 15 to 1500 μ M, root yields increasing gradually throughout this range while in Nina and UQ2, substantial increases in root yield occurred when the calcium concentration was increased from 15 to 150 μ M, and yields tended to decrease at higher calcium concentrations.

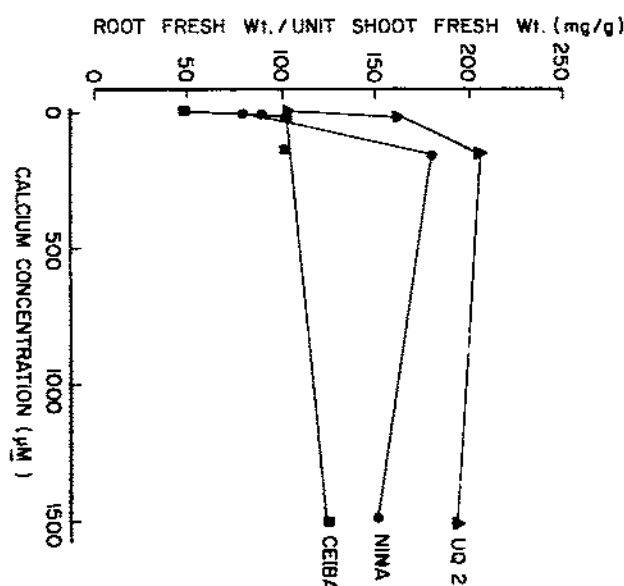


Figure 1. Effect of substrate calcium concentrations on root development by tip cuttings of three cassava cultivars at a mean root temperature of 25°C. Root yield data represent means of four replications; calcium concentrations are means of analyses on alternate days for the 14 day experimental period.

Effect of substrate temperature on root development

When stem tip cuttings were supplied with 155 μ M calcium, large effects of temperature on root development were obtained in the root propagation chambers and there were again substantial differences between responses of individual cultivars (Fig. 2). At 20°C, root growth was severely retarded in all three cultivars, and increasing the temperature to 25°C caused a four-to-nine-fold increase in root yields.

At 25°C, Nina produced its greatest root growth, whereas with UQ2, greatest growth was obtained at 30°C. For Ceiba however, root growth was greatest at the highest temperature of 35°C. At this latter temperature, the root growth of Nina and UQ2 was retarded in comparison with that at 30°C.

The data obtained in this experiment relate to optimum root temperatures for root initiation and development, rather than to optimum root temperature for prolonged growth. Nevertheless, substantial differences may exist between cultivars in root temperatures required for optimum growth. For the following studies, the root temperatures of all cultivars were maintained at 25°C to avoid possible heat injury.

Effect of calcium concentration on growth of rooted cuttings

In a flowing culture experiment conducted at a range of controlled calcium concentrations, large differences were found in the responses of individual cultivars. Figure 3 shows the results for two cultivars studied. In the three lowest treatments (0.3, 3 and 10 μM Ca), the growth of both Nina and UQ5 was severely retarded and root growth was particularly stunted. However, above 100 μM , there was little effect of calcium concentration on the growth of Nina, but for UQ2, yields continued to increase up to 1000 μM . Beyond this, further increases in calcium concentration caused substantial yield reduction of UQ5. However, since calcium was supplied as calcium chloride, the yield depression in UQ5 may have been due to a greater sensitivity in this cultivar to high chloride concentrations.

Effect of nitrate and ammonium nitrogen concentrations on the growth of rooted cuttings

Quite large differences were observed between cultivars in response to nitrogen, but the response to various nitrogen concentrations depended upon whether nitrogen was supplied as nitrate or ammonium. Much higher concentrations of nitrate than ammonium nitrogen were needed for maximum growth (Figs. 4, 5).

When nitrogen was supplied solely as the ammonium ion, the growth of Ceiba was best at 29 μM , and was depressed at higher concentrations. In contrast to this, UQ2 responded to ammonium concentrations up to 490 μM (Fig. 4).

The response to nitrate however was somewhat different. Although the growth of both Ceiba and UQ2 was severely retarded at low nitrate concentrations (0.5 to 5 μM), Ceiba was much more responsive to intermediate concentrations of nitrate than UQ2. Thus an increase in nitrate concentration from 16 to 52 μM resulted in a 30 percent increase in the growth of Ceiba but only a 2 percent increase in the growth of UQ2. By contrast, at high concentrations the situation was reversed, thus there was a 47 percent increase in the growth of UQ2 between the 560 and 5050 μM nitrate treatments, compared with only a 15 percent increase in the growth of Ceiba.

CONCLUSIONS

The existence of major differences in the response of small stem tip cuttings of different cassava cultivars to nutrient elements in liquid culture may indicate that fertilizer recommendations for one cultivar may not necessarily be suitable for other cultivars. Also, that, with further knowledge of physiological variation in cassava, it may be possible to select for specific nutrient responses in cassava breeding programmes.

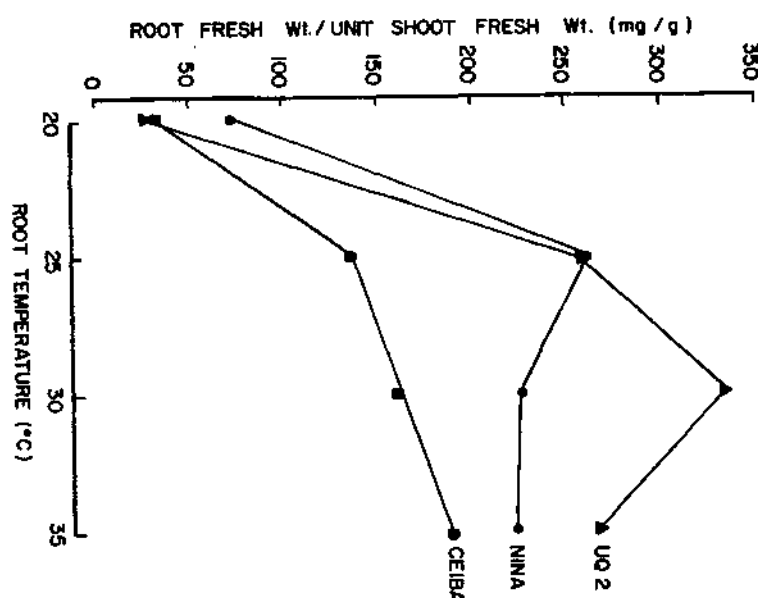


Figure 2. Effect of temperature of the rooting medium on root growth by tip cuttings of three cassava cultivars at a mean substrate calcium concentration of 155 μM . Root yield data represent means of four replications; root temperatures are means of hourly recordings at five locations in the rooting medium for the 14 day experimental period.

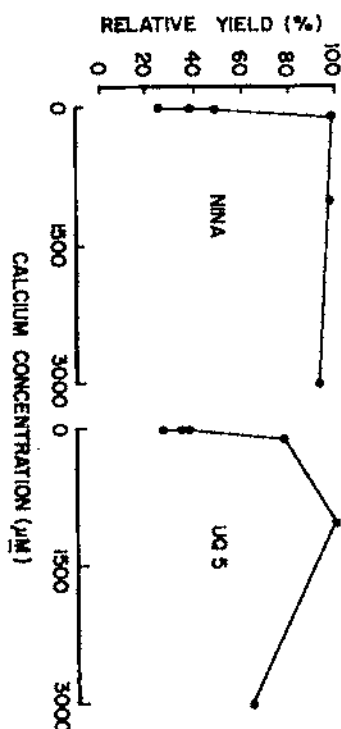


FIGURE 3.

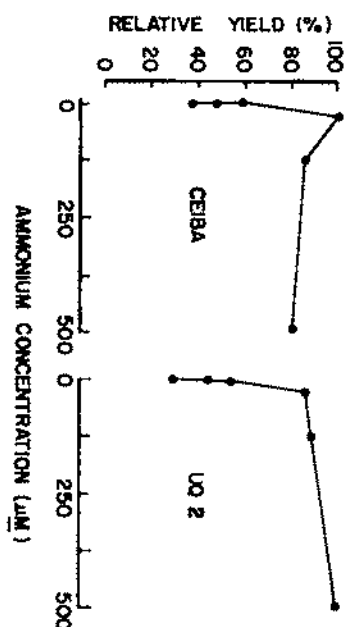


FIGURE 4.

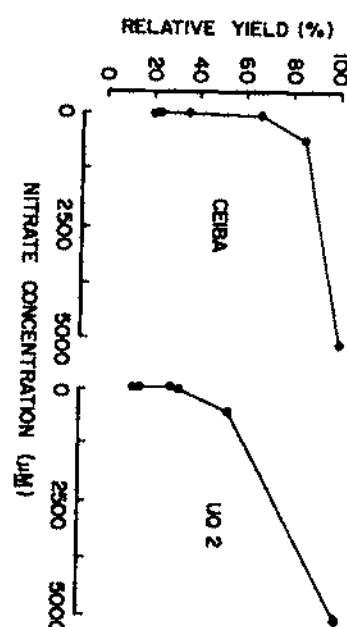


FIGURE 5.

- Figure 3. Effect of calcium in flowing solution culture on the growth of two cassava cultivars at a solution temperature of 25°C and pH 5.8. Whole plant yield data represent means of three replications; calcium concentrations are means of daily analyses for the 30 day experimental period.
- Figure 4. Effect of ammonium-nitrogen in flowing solution culture on the growth of two cassava cultivars at a solution temperature of 25°C and pH 5.8. Whole plant yield data represent means of three replications; ammonium concentrations are means of analyses made twice daily for the 20 day experimental period.
- Figure 5. Effect of nitrate-nitrogen in flowing solution culture on the growth of cassava cultivars at a solution temperature of 25°C and pH 5.8. Whole plant yield data represent means of three replications; nitrate concentrations are means of daily analyses for the 20 day experimental period.

REFERENCES

1. Asher, C.J., Ozanne, P.G. and Loneragan, J.F. (1965) A method for controlling the ionic environment of plant roots. *Soil Sci.* 100, 149-56.
2. Fleming, H.S. and Rogers, D.J. A classification of *Manihot esculenta* Crantz using the information carrying content of a character as a measure of its classificatory rank. In *Tropical Root and Tuber Crops Tomorrow*. Vol. I. Proc. Second International Symp. Trop. Root and Tuber Crops. 1970. pp. 66-71.
3. Williams, C.N. (1971) Growth and productivity of tapioca (*Manihot utilissima*). II. Stomatal functioning and yield. *Experimental Agric.* 1, 49-62.

A COLLECTION OF WEST AFRICAN YAMS

F.W. Martin*

SUMMARY

Yams collected in West Africa in 1971 are being intensively evaluated, and multiplied for distribution. Two seasons of observations have revealed important differences in disease resistance, seasonal responses, and yield potential. Preliminary selections have been made of cultivars suitable for distinct purposes, including mechanization. A comparison of accessions of the *rotundata-cayenensis* complex using methods of numerical taxonomy is expected to clarify the interrelationship between the two species. Virus diseases constitute the most serious problem found in the collection. Selected, disease-free cultivars will eventually be available for pantropical distribution.

RESUME

Des ignames collectionnées en Afrique Occidentale en 1971 sont en cours d'évaluation intensive et sont multipliées pour être popularisées. Deux saisons d'observation ont révélé d'importantes différences de résistances aux maladies, de réponses saisonnières et de potentiel de rendement. Des sélections préliminaires de cultivars adaptés à des buts spécifiques, dont la mécanisation, ont été entreprises. On escompte que la comparaison de variétés du complexe de *rotundata-cayenensis* permettra, en utilisant la méthode de taxonomie numérique, de clarifier l'interrelation entre les deux espèces. Les viroses constituent le problème majeur que comporte la collection. On finira par obtenir des cultivars sélectionnés et indemnes de maladie qui seront distribués à travers les tropiques.

RESUMEN

Ñames colectados en Africa Occidental en 1971 están siendo evaluados intensivamente y multiplicados para su distribución. Las observaciones de dos temporadas han revelado importantes diferencias en cuanto a resistencia a enfermedades, respuesta a la época de siembra y rendimiento potencial. Se han hecho selecciones preliminares de cultivares para distintos propósitos, incluyendo mecanización. Se espera que usando métodos de taxonomía numérica se puedan comparar introducciones de un complejo *rotundata-cayenensis* y se clasifique la interrelación entre las dos especies. Las enfermedades virales constituyen el más serio problema encontrado en la colección. Eventualmente, se podrán tener cultivares libres de enfermedades virales para su distribución en el trópico.

INTRODUCTION

Although yams are now grown throughout the wet tropics, the most important region of the world where they have become a staple crop, and where they continue to hold an important, if tenuous, role is in West Africa. The species *Dioscorea rotundata* and *D. cayenensis* were domesticated in this area. Although their cultivation is very old, they are sexually fertile which suggests that they are not ancient clonal species, and that evolution is continuing. This is very important for plant breeding. In addition to the commonly cultivated species, others, such as *D. dumetorum* exist as both wild and cultivated forms, and are used in times of special need. Entirely wild species that can be used for food are also found.

In West Africa, yam, the staple food crop is now being replaced in most regions by the easier-to-grow cassava. Rice is usurping it in the river valleys. The culture of the yam will change, and may disappear completely from some regions. Concern for the germ plasm of the African yams, and its potential for contributing to feeding the hungry people of the world led therefore to the sponsorship of an expedition in 1971 to collect West African yams in their regions of origin. The Food and Agriculture Organization of the United Nations, and the Department of Agriculture of the United States collaborated in this expedition.

Because time and money were limiting, the area could not be collected exhaustively, and some noteworthy gaps in the collection occur. Most of the collection was made through existing institutions which had themselves made collections for many years. Introduced as well as native cultivars were obtained. Tubers were sent to Puerto Rico where they have been extensively studied for two years. It is our intention to evaluate these West African yams, to select cultivars for special purposes, and to distribute selections throughout the tropics to places where they can best be utilized.

*Federal Experiment Station, Mayaguez, Puerto Rico.

ACCESSIONS

The yam belt of West Africa extends from Cameroun to the Ivory Coast. The species and numbers of accessions of yams collected from this region are given in Table 1.

Accessions from the eastern Camerouns were highly desired, but were not obtained, since they might be expected to be extreme forms. Neither were collections received from the small country of Togoland. Nigeria was fairly well sampled although the northernmost areas were neglected. Sierra Leone proved to be a rich source of introduced species but the more common species of African yams are not apparently very important there. We feel that we have collected many, but not all, of the best cultivars and a broad range of germplasm.

MANAGEMENT OF THE COLLECTIONS

When tubers were received in Mayaguez, Puerto Rico, they were cut into setts and planted in the greenhouse in plastic bags. There the soil was treated with systemic insecticides to eliminate the possibility of beetle infestation, and the initial plants were observed for disease symptoms. Initial symptoms of virus disease in the greenhouse did not appear more severe than, nor distinct from, symptoms previously observed in yams of African origin grown in Puerto Rico. Subsequently in the field, severe virus symptoms occurred in many accessions. The affected plants were dug from the field and re-established in the greenhouse. During the second year, strongly virus-infected accessions were grown in an isolated area for observations. Plants propagated from tubers of plants with severe virus symptoms were often relatively free of symptoms.

During both years extensive notes were taken on the foliage, disease, reproduction, tuber and culinary characteristics of all accessions which are proving useful in sub-specific classification.

OBSERVATIONS ON NON-AFRICAN SPECIES

Dioscorea esculenta accessions received from five different countries of Africa all rather closely resembled one another and appear to have originated from one common source. Nevertheless, subtle differences among them suggest that some evolutionary divergence may have occurred. In comparison with accessions of this species from the Caribbean region, the African accessions performed very well. The African forms represent only a tiny fraction of the genetic potential of this species as already represented in available germplasm.

Since we had already studied over 150 accessions of *D. alata* from other regions we did not expect to find from Africa any superior clones of this species. However, of the 55 accessions received 10 were selected as possible superior types. The selections included clones giving superior yields, some with tuber forms adaptable to mechanization, and some that resisted leaf spot diseases for two seasons. Some of the best of these, and their characteristics, are given in Table 2.

OBSERVATIONS ON THE AFRICAN SPECIES OF THE *rotundata-cayensis* COMPLEX

A typical cultivar of *D. rotundata* can easily be distinguished from a typical cultivar of *D. cayensis*. Whereas the former has thin ovate leaves, few spines, long, narrow and white-fleshed tubers, the latter has thick, almost orbicular leaves, many spines, and compact yellow-fleshed tubers. However, both species can develop a second or seed tuber after the first harvest. Taxonomic problems arise because many cultivars show neither the typical traits of *D. rotundata* nor *D. cayensis*, but a mixture of the two. We thus prefer to call all these yams the *D. rotundata-D. cayensis* complex. Others have noted these discrepancies, but have regarded the atypical forms as the products of hybridization.

We shall attempt to illuminate this problem by the use of numerical taxonomy in which all the differences among accessions can be handled simultaneously. The principal components method will be our chief tool. In this method the similarities among accessions are determined on the basis of differences in mutual distance apart in a multi-dimensional space. Our hope is to identify the distinct (species) and their characteristics.

The descriptors we shall evaluate in this complex in order to help to standardize description include 6 stem characters, 6 petiole characters, 17 lamina characters, 13 culinary characters and 5 'laboratory' characters, as well as several 'characters' represented by ratios between metrics included in these main categories. The total number of descriptors being used is 83.

In the present analysis equal weight will be given to each characteristic, but we may need to find ways of weighing the characteristics, and perhaps of deriving a selection index.

There are a few characteristics that have not yet been evaluated. One is the suitability of the tuber for preparing fufu, a product prepared by pounding cooked yam. A second is the ability of the plant to grow a second tuber after the first harvest. Others are the ability of the plant to grow independently off season and the relationship between the ability of the tuber to germinate and the storability of the tuber. We also have not yet evaluated the suitability of the accessions for different climatic situations. Satisfactory systems of evaluating these characteristics cannot be worked out until more is known of their physiological basis.

On the information at present available, we have been able to make some judgments and to begin to reduce the collection to a more workable level. Table 3 presents some of the best accessions selected on the basis of yield, tuber and culinary characteristics.

DISEASE AND INSECT PESTS OF YAMS IN THE GERMPLASM COLLECTION

The yam collection was introduced mostly as small tubers. Since smallness may be associated with factors that inhibit growth, and in Puerto Rico small yams are often those that come from virused plants, by selecting small tubers we may have introduced many virused accessions to Puerto Rico that could have been avoided.

In one survey of the collection, every plant was found to show some virus-like symptoms. It would appear that all plants may already be infected with virus, but the type and severity of symptoms is variable. This could indicate either a virus complex or suggest that environmental factors influence symptom expression. In working with the sapogenin-bearing yams we have seen similar symptoms. Such yams can be grown from seed and we have been able to transmit the virus mechanically from old plants to new seedlings.

Viruses from species of edible yam, when transmitted to supposedly healthy seedlings of the sapogenin-bearing yam, have induced symptoms similar to those seen in the sapogenin-bearing yam, including mild mottling, severe mottling, green banding, little-leaf symptoms and Christmas tree effect.

To avoid introducing new viruses into yams already in Puerto Rico we have isolated virused plants into one area and the African yam collection is also isolated from other collections. As mentioned, plants from small tubers often appear to be virused and conversely, selection of large yams as seed material seems to be a useful method of reducing the incidence of virus expression. However, we cannot be sure that any apparently healthy plant is not a symptomless carrier of virus.

In 1972 we selected yam varieties that had the most severe virus symptoms. Storing these at somewhat higher than normal temperatures and until all were sprouting we obtained field plots that were free of virus-like symptoms. Judging from these results it should be possible to rid yams of virus-like symptoms at least, — and perhaps of viruses.

POTENTIAL FOR AFRICAN DIOSCOREA SPECIES

What is the place of the African yams, particularly *D. rotundata* and *D. cayenensis*, in the tropical world? As yet it is uncertain. In contrast with *Dioscorea alata*, the African yams have not yet been well tested throughout the tropics. As staple food crops that have formed the basis of a civilization, the African yams merit a wider trial.

TABLE 1

Accessions of West African yams by country and species

	<i>D.</i> <i>rotundata</i>	<i>D.</i> <i>cayenensis</i>	<i>D.</i> <i>dumetorum</i>	<i>D.</i> <i>alata</i>	<i>D.</i> <i>esculenta</i>	Other species
Cameroun	0	0	0	0	0	0
Nigeria	70	16	12	28	2	5
Dahomey	14	22	2	0	1	0
Togoland	0	0	0	0	0	0
Ghana	29	1	1	2	0	0
Ivory Coast	29	8	1	13	2	4
Sierra Leone	2	9	0	10	1	10
Other sources	7	0	0	2	0	1
Total:	151	56	16	55	6	20
Grand total:	304					

TABLE 2

Accessions of *D. alata* selected for superior characteristics, their names, origins, and special features

Our number	Local name	Name assigned	Country of origin	Special notes
15477	Pacala	-	Ivory Coast	Large, spindle shaped tubers
15478	V 7/1	Veeven	Ivory Coast	Large tapering cylinders
15539	Suidie	-	Ivory Coast	Spindle shape, best flavour
15545	Puka	-	Ghana	Compact tubers, strong bark
15547	Alowinrin	-	Nigeria	Medium cylinders with strong bark, excellent flavour
15555	Nae Onwula	-	Nigeria	Short, stout cylinders
15561	-	Nsukka	Eastern Nigeria	Short cylinders, thick bark
15571	Ewura Oya	-	Nigeria	Large, compact cylinders
15573	-	Leone Globe	Sierra Leone	Heart shaped single tubers
15575	-	Suave	Sierra Leone	Club-like

TABLE 3

Selected varieties of the *d. rotundata*-*D. cayenensis* complex

Number	Name	Source	Tuber notes
15085	Guinea Blanco	Puerto Rico	Smooth cylinders
15326	Guinea Blanco	Puerto Rico	Smooth cylinders
15484	Grosse Gaille Corrosol	Guadeloupe	Large cylinders
15487	Saint Prix	Martinique	Large cylinders
15489	Vedos	West Africa	Several tubers
15493	Negro	Jamaica	High yields
15605	-	Ivory Coast	Stout cylinders
15607	-	Ivory Coast	Very smooth short cylinders
15610	Besu	Ghana	Compact tubers
15618	Diaje	Ghana	Large cylinders
15625	Borofoo	Ghana	Early, large tubers
15629	Bombetinga	Ghana	Long cylinders
15633	Punakonna	Ghana	Elongated heart shapes
15637	Ekepe	Dahomey	Long, smooth cylinders
15643	Soussou	Dahomey	Uniform cylinders
15646	Douba Yeserou	Dahomey	Large, well-shaped cylinders
15647	-	Dahomey	Very large, branched
15654	Pape	Nigeria	Large, irregular shape
15655	Dagi	Nigeria	
15656	Zaria	Nigeria	Very large, irregular shape
15657	Awure	Nigeria	Elongated globe
15658	Gbare	Nigeria	Smooth tapering cylinders
15660	Etentu	Nigeria	Heavy tapering cylinder
15662	Iyawoolorun	Nigeria	Heavy tapering cylinder
15665	Fele	Nigeria	Large cylinders
15666	Efon	Nigeria	Elongated heart shape
15667	Boki	Nigeria	Smooth cylinders
15668	Lakoko-Ayin	Nigeria	Smooth, compact cylinders
15669	Iro	Nigeria	
15672	Jocha	Nigeria	Smooth cylinders
15673	Inowe	Nigeria	Stout cylinders
16774	Alafulu	Nigeria	Long, smooth cylinders
15677	Awudo	Nigeria	Large, conical
15682	Ejiji	Nigeria	Large globes
15686	Unegba	Nigeria	Large, somewhat irregular
15691	Aga	Nigeria	Long, smooth cylinders
15693	Ukom	Nigeria	Smooth, stout cylinders
15702	Obiatorogu	Nigeria	Pointed globes
15705	-	Nigeria	Early germination and maturity
15707	-	Nigeria	Irregular cylinders
15708	-	Nigeria	Long, conical
15709	-	Nigeria	Many tubered
15710	-	Nigeria	Many tubered
15714	-	Nigeria	Long, smooth cylinders
15718	Abani	Sierra Leone	Top shaped
15719	Abana	Sierra Leone	Large smooth globes
15720	-	Ghana	Long cylinders
15724	Dodo	Dahomey	Compact cylinders
15729	Beterou	Dahomey	Long, club shaped
15731	Foucou	Dahomey	Short, stout cylinders
15736	Yassou Sika	Dahomey	Several cylinders per plant
15740	Baniowre Bagarow	Dahomey	Irregular cylinders
15744	Igangan	Nigeria	Large cylinders
15769	Akandou	Ivory Coast	Smooth cylinders

OVERCOMING CROSS- AND SELF-INCOMPATIBILITY IN *IPOMOEA BATATAS* (L) LAM AND *IPOMOEA TRICHOCARPA* ELLIOT

W.B. Charles*, D.G. Hoskint and P.J. Cave†

SUMMARY

Pollen germination in the wild species *I. trichocarpa* is inhibited on the stigma of incompatible genotypes. Removal of the stigmatic lobes allowed successful germination. No similar inhibition mechanism was found on the stigma of *I. batatas* in which however short flower life, coupled with slow rate of pollen tube penetration, limited fertilization in incompatible pollinations. Suppression of abscission by the application of 2,4-D (conc. 100 ppm) to the pedicels provided adequate time for pollen tube penetration to occur in incompatible styles of sweet potato and resulted in fertilization and seed-set. Seedling development could be accomplished by embryo culture before fruits matured. The practical techniques developed allow a measure of sifting to be introduced into the breeding programme and for crosses to be made between pairs of desirable but normally incompatible parental genotypes.

RESUME

La germination pollinique dans les espèces *I. trichocarpa* sauvages est contrariée sur le stigmate des génotypes incompatibles. La germination se produit normalement quand on retire les lobes stigmatiques. On ne rencontre pas un phénomène d'inhibition semblable sur le stigmate de *I. batatas* dans lequel, toutefois, la courte durée de floraison et le taux lent de pénétration du tube pollinique limitent la fertilisation dans les pollinisations incompatibles. La suppression de l'abscission lorsqu'on applique 2,4-D (con. 100 ppm) aux pédicelles assure le temps nécessaire pour que la pénétration du tube pollinique se réalise dans les styles incompatibles de la patate douce et aboutit à la fertilisation et à la formation des graines. On peut obtenir le développement des plantules par la culture d'embryon avant la maturité des fruits. Les méthodes pratiques mises au point permettent une mesure de vannage à introduire dans le programme de sélection et des croisements à opérer entre des paires de génotypes parentaux aux caractéristiques désirables mais normalement incompatibles.

RESUMEN

La germinación de polen en las especies silvestres de *I. trichocarpa* se inhibe en el estigma de genotipos incompatibles. La remoción de los lóbulos estigmáticos permitió una germinación exitosa. No se encontró un mecanismo inhibitor similar en el estigma de *I. batatas* en el cual, sin embargo, la reducida vida de la flor, apareada con el bajo grado de penetración de los tubos polínicos, limitó la fertilización en las polinizaciones incompatibles. La supresión de la abscisión con la aplicación de 2,4-D (conc. 100 ppm) a los pedicelos, proveyó de un tiempo adecuado para que la penetración de los tubos polínicos ocurriera, obteniéndose como resultado fertilización, y producción de similla. El desarrollo de las plantas se logró mediante cultivo de embriones antes de que los frutos estuviesen maduros. Las técnicas prácticas que se desarrollaron permiten introducir una forma de selección en los programas de mejoramiento genético y en las cruas que se hagan entre pares de tipos deseables, con genotipos parentales normalmente incompatibles.

*Department of Crop Science, University of the West Indies, St. Augustine Trinidad. †Plant breeder, ‡ research assistants.

INTRODUCTION

Cross- and self- incompatibility in West Indian cultivars of sweet potato has been a problem in breeding, since many of desirable parents are in the same incompatible group.

Self-incompatibility in the sweet potato was first reported by Mendiola in 1921 (in 16). Cultivar variation in self-incompatibility occurs⁹.

Several methods have been employed to overcome the fertilization barriers. Togari and Kawahara¹⁵ and Fujisie³ were unsuccessful when they tried to self-fertilize sweet potato cultivars by bud pollination. Van Schreven¹⁶ however reported an increase in pollen tube development after bud pollination with self pollen. Mangelsdorf and Reeves⁷ obtained hybrid seed from a cross between the two genera *Zea* and *Trip-sacum* by cutting off part of the style and Davies² used the same method successfully or crossing two species of *Lathyrus*. Chaudhuri¹ lengthened the life of flowers in arrowroot by applying p-chlorophenoxy acetic acid (conc. 100 ppm) to pedicels and was able to attain successful seed-set in crosses. Laibach^{5,6} was the first to demonstrate the possibility of using embryo culture technique to attain seedling development from inter-specific crosses in *Linum* where normal seed production fails on account of premature abscission of young fruits.

The purpose of this study was to investigate the nature of the barriers to self-fertilization in *I. trichocarpa* and in *I. batatas* cultivars of West Indian sweet potato, and attempt to overcome it.

MATERIALS AND METHODS

Eight cultivars of *Ipomoea batatas* (L.) Lam., and two strains of a wild species, *Ipomoea trichocarpa* Elliot were studied (Table 1). Experiments were conducted in an insect proof greenhouse and an additional set of plants was grown in the open for comparison.

Flowers were emasculated between 1.00 and 3.00 p.m. the day prior to anthesis and paper clips were placed over the end of the corolla to keep the flower closed until the crosses of selfs were made. The corollas of flowers to be used as pollen sources were also clipped. Pollinations were made on the day following emasculation between 8.00 — 10.00 a.m. when stigmatic surface of pistils appeared to be most receptive. Where capsules developed they were harvested within a month of pollination. Pollen germination and tuber penetration in self- and cross-pollinated flowers were examined *in vivo* using excised styles, stained with aniline blue and fluorescent pollen bands examined under UV light of 365 *mu* wavelength according to the method of Martin⁸.

Experiment 1. The cause of the incompatible reaction of pollen in *I. trichocarps* was investigated in styles following self- and cross-pollinations. Eight styles of each treatment were examined after 2,4,6 and 12 hrs. (Table 2).

Experiment 2. The following techniques were employed to investigate the inhibition to pollen germination after self-pollination in *I. trichocarpa*: 1. the stigma lobes were scraped superficially, 2. the lobes were excised, 3. the style was trimmed to half its length and 4. the style was severed at the style-ovary junction. Sixteen flowers of strain 3 were used for each treatment and styles were examined after 6 and 24 hours (Table 3).

Experiment 3. The self-incompatibility reaction of pollen was investigated in styles of *I. batatas* with stigma lobes removed and retained. Eight flowers of each of five cultivars were examined for pollen germination and depth of tube development at 3,6,24 and 30 hrs. An ocular micrometer was used to measure tube length and depth of penetration was expressed as a percentage of the entire length of the style (Table 4).

Experiment 4. Observations were made on floral life following anthesis in both species in the open. In an attempt to induce seed set, flowers were self-pollinated, 1. after excision of stigma lobes and, 2. with lobes retained. Eight flowers of each treatment were used in each species.

Experiment 5. Investigations of an exploratory nature were done to prolong floral life by using growth substances to suppress the formation of the abscission layer in pedicels. Indole acetic acid, naphthalene acetic acid, 2,4-Dichlorophenoxy acetic acid and 2,4,5-trichlorophenoxy acetic acid were dissolved separately in an anhydrous lanolin base to give concentrations of 50 and 100 ppm. The pedicel and ovary base of eight flowers of the cultivar 30/57 of *I. batatas* and strain 3 of *I. trichocarpa* were treated with each level of four growth substances immediately after self-pollination. The stigma lobes were removed only in *I. trichocarpa* (Table 5).

Experiment 6. The frequency of 2,4-D (100 ppm) application was increased to determine its effect on

further ovary development. Two applications were applied to eight flowers of each species at a 16-day interval; three applications at an 8-day interval and five applications at a 4-day interval (Table 6).

Experiment 7. Embryos were cultured from immature seeds of *I. batatas* resulting from compatible and incompatible pollinations. Seeds were surface sterilized with 0.1% mercuric chloride for 1 minute and washed with distilled water. Embryos were then excised using a needle and forceps sterilized in 80% ethanol and flamed. They were then cultured inside screw cap bottles with a mineral nutrient medium containing 0.8% agar and 2.0% dextrose⁴. Fungal and bacterial contaminations were reduced by flaming the mouth of bottles before making transfers in an isolation chamber. Cultures were developed at room temperature under ordinary daylight.

Thirty five flowers of A26/74 were pollinated with compatible pollen from R223. Sixty three flowers of A26/74 were pollinated with incompatible pollen from 30/57. A total of ninety-six flowers were self-pollinated in R223. Seed-set was induced artificially by the application of 2,4-D (100 ppm) after pollination (Table 7).

RESULTS

Pollen retention and germination on the stigma differed between self- and cross-pollinations in *I. trichocarpa* (Table 2). Pollen failed to germinate on stigmas following self-pollination; the mean number of grains retained on the stigma was considerably less than those found in the cross-compatible pollinations. Tube penetration into the styles of compatible pollinations was central and completed within two hours.

No germination was visible on any of the carpels in *I. trichocarpa* when the stigma lobes were superficially scraped nor when styles were severed at their bases before self-pollination (Table 3).

Successful germination was observed on all carpels with stigma lobes removed and on 25-50 percent of the styles trimmed to half their lengths. Further examination in treatment 2 showed that pollen development was peripheral to the central core of the style and the depth of penetration was $\frac{1}{4}$ the total length of the style at 6 hours. Complete penetration into the style and ovaries was accomplished after 24 hours.

Pollen germination on stigmatic surfaces was visible in all five cultivars of *I. batatas* irrespective of whether the stigma lobes were removed or retained. The mean percentage depth of tube extension in the styles differed in the early stages of development among cultivars (Table 4). With stigma retained, no tube penetration was observed in 12/56, 22/56 and 30/57 after 3 hours and after 6 hours tube penetration was inhibited only in 12/56. When the stigma was excised no delay in tube penetration was observed at 3 and 6 hours in any cultivar. However, considerable variation in tube depth was observed among cultivars at 3 hours. The tube depths in styles of 12/56 and 22/56 were very much shorter than in any of the other cultivars. These differences were not apparent after 6 hours of pollination. After 24 and 30 hours no difference in tube depth was observed in ovules of carpels examined when stigmas were either excised or retained.

It was observed that flowers in both species opened in the morning and closed during the hotter periods of the day (Experiment 4). Within 3 hours of flower opening, anthers showed signs of withering; by evening styles began to shrivel up and flowers showed signs of wilting. Complete floral abscission occurred within 1-3 days after anthesis. Abscission was earlier by one day in *I. trichocarpa* than in *I. batatas*. There were signs of ovary enlargement in incompatible crosses of *I. batatas* only when stigmas were excised but nevertheless no seed-set was accomplished.

The application 2,4-D at a concentration of 100 ppm prolonged floral life more in both species than any of the other treatment combinations (Table 5). In *I. trichocarpa* and *I. batatas* flower life was extended by 15 and 10 days respectively beyond that of the controls. Although ovary enlargement was observed, ovary abortion however took place.

When the frequency of 2,4-D (100 ppm) application was increased, ovary development resulted in seed-set in both species (Table 6). In *I. trichocarpa* no differences were found between the three frequencies of application in the percentages of flowers which set seed. However, in *I. batatas* the percentage of flowers that set seed increased from 0 to 75 percent with increasing frequency of application and optimum response was obtained with 5 applications at 4-day intervals. No germination was obtained from seeds collected from dried capsules in either species. Further examination revealed that the embryos had completely aborted and disintegrated in mature seeds.

The highest percentage of capsules was obtained in the compatible cross A 26/74 x R 223 (Table 7). The percentage capsules developed in the incompatible cross A 26/74 x 30/57 was considerably greater than that resulting from self-pollination in R 223. No embryo abortion was found in immature seeds in the compatible cross. Embryo abortion was 30.4 percent in the incompatible cross and 61.2 percent in the selfing of R 223. Despite precaution taken to prevent contamination, approximately 20 percent of the embryos excised in treatment 1 failed to develop on account of fungal and bacterial infections. Contamination accounted for 53.1 percent embryo loss in culture in treatment 2 and 66.6 percent in treatment 3. Excised

embryos from the compatible cross germinated and developed relatively faster than those from the incompatible pollination. The rate of embryo development from R 223 after self-pollination was very much slower than in embryos from the incompatible cross. Over sixty-six percent of the immature seeds from selfing R223 failed to germinate. From the compatible cross, 79.3 percent of the embryos excised developed and produced 23 seedlings. From the incompatible cross 46.8 percent of the excised embryos germinated in culture and 15 seedlings were developed. Only four seedlings developed representing 33.3 percent of the number of embryos excised from the self pollination of R 223.

DISCUSSION

The self-incompatibility reaction was stronger in the wild species, *I. trichocarpa* than in the cultivated forms of *I. batatas* studied.

The primary site of the self-incompatibility mechanism in *I. trichocarpa* was the stigmatic surface which inhibited wrong pollen germination. This is similar to the mechanism reported for *I. batatas*^{10,12,15,16} Fujisie³ attributed the failure of pollen germination to lack of stylar growth substances necessary to stimulate germination of incompatible pollen. Complete pollen germination failure was ascribed by Martin and Cabanillas¹⁰ to a strong incompatible reaction resulting from the interaction of substances diffusing from pollen or stigma or both. Martin¹⁴ reported disorientation of pollen tube development in incompatible styles in *I. batatas* and confirmed similar observations made in *I. trichocarpa* when the stigma lobes were removed before self-pollination. The peripheral pathway taken by pollen tubes allowed the evasion of substances inhibitory to tube development present in the central core of the style. Mechanical retardation in tube growth could have resulted from the nature and arrangement of cells in the region of tube penetration as reported by Martin and Ortiz¹³.

Williams and Cope¹⁹ found that fewer pollen grains were retained on incompatible stigmas than on compatible ones in *I. trichocarpa* and explained this as due to lack of mechanical anchorage by pollen tubes penetrating the stigma of compatible styles. Similar observations have been made in this study. The technique used by Mangelsdorf and Reeves⁷ and Davies² of truncating the styles before pollination gave greater reduction in germination than when only stigma lobes were removed. This suggests that the physiological reaction for pollen incompatibility may increase with nearness to the ovary. Complete failure of pollen germination for pollen placed at the style-ovary junction confirmed results obtained by Martin and Cabanillas¹⁰. The rate of pollen tube extension in incompatible styles when the stigma lobes were removed was slower by 22 hours than in compatible styles.

No instance of complete germination failure on an incompatible stigma occurred in cultivars of *I. batatas*. The principal self-incompatibility mechanism appeared to involve failure of the pollen tubes to grow normally after germination. The mechanism for this is not yet understood. The relative levels of self-incompatibility between cultivars could be assessed during the initial phase of tube penetration within 3–6 hours after germination. Under field conditions a temporary arrest in the early phase of tube penetration by incompatible pollen may effectively prevent fertilization by wrong-pollen since styles tend to shrivel shortly after flowers are opened on the same day. The possibility of further delay occurring at the style-ovary junction as suggested by Martin and Cabanillas¹¹ cannot be ruled out, although no evidence of this was visible after 24 hours of tube penetration in our materials.

Wang¹⁷ reported that in addition to the incompatibility factor, temperature, pollen viability and meiotic abnormalities are important factors influencing seed-setting ability of different cultivars. Warmke and Cruzado¹⁸ suggested that non-disjunction and other irregularities are common and can account for a high percentage of poorly formed pollen grains in commercial varieties of sweet potato. Martin¹⁴ suggested that seedset failure may not only be due to the incompatibility reaction of pollen but to certain sterility factors associated with gametic imbalance. We have not investigated these other factors in our material but our findings suggest a physiological rather than a genetic mechanism.

The production of non-viable seed from self- and cross-incompatible pollinations but the successful development of seedlings from such crosses by embryo culture are similar to the results obtained for *Linum* by Laibach^{5,6}. It seems that there may be an incompatible reaction between tissue of the maternal parent and the developing embryo as the seed matures.

Current practical results have made it possible to establish an improvement programme employing selfing as a step in a breeding method. At least partially homozygous forms can be tested for combining ability for certain desirable characters. Also benefit can now be derived from hybridization among cross-incompatible groups having good commercial characteristics. The fact that the sweet potato is an asexually reproduced crop allows improved genotypes to be perpetuated.

ACKNOWLEDGEMENTS

The authors wish to thank Professor E.A. Tai for his support and invaluable advice during the course of the investigation and Dr. D.B. Williams for making the plant material available.

REFERENCES

1. Chaudhuri, S.K. (1965) Report on arrowroot research in St. Vincent. Dept. Crop Sci., University of the West Indies, St. Augustine, Trinidad.
2. Davies, A.J.S. (1957) Successful crossing in the genus *Lathyrus* through styler amputation. *Nature* 180, 612.
3. Fujisue, K. (1964) Studies on flowering, seed-setting and self- and cross-incompatibilities in the varieties of sweet potato. *Kyushu Agr. Expt. Sta. Bull.* 9, 123-246.
4. Ibanez, N.L. (1964) Cultivation of cacao embryos in sterile culture. *Trop. Agr.* 41(4), 325-8.
5. Laibach, F. (1925) Das Taubwerden der Bastardsamen und die kunstliche Aufzucht fruh absterbedu Bastardembryonen. *Zeits. Bot.* 17, 417-59.
6. — — — — (1929) Ectogenesis in plants. Genetic possibilities of propagating embryos otherwise dying in the seed. *J. Hered.* 20, 201-8.
7. Mangelsdorf, P.C. and Reeves, R.G. (1931) Hybridization of maize, *Tripsacum* and *Euchlena*. *J. Hered.* 22, 329-43.
8. Martin, F.W. (1958) Staining and observing pollen tubes in the styles by means of fluorescence. *Stain Technology*. 34, 125-8.
9. — — — — (1965) Incompatibility in the sweet potato — a review. *Econ. Bot.* 19, 406-15.
10. Martin, F.W. and Cabanillas, E. (1965) Mechanisms restricting seed-set in the sweet potato. *Proc. Carib. Food Crops*. 3, 66-7.
11. Martin, F.W. and Cabanillas, E. (1966) Post-pollen-germination barriers to seed set in the sweet potato. *Euphytica* 15, 404-11.
12. Martin, F.W. and Ortiz, S. (1966) Germination of sweet potato pollen in relation to incompatibility and sterility. *Proc. Amer. Soc. Hort. Sci.* 88, 491-7.
13. — — — — (1967) Anatomy of the stigma and style of sweet potato. *New Phytol.* 66, 109-33.
14. Martin, F.W. (1967) The sterility — incompatibility complex of the sweet potato. *Proc. Int. Symp. on Trop. Root Crops* 1, 3-15. 3
15. Togari, Y. and Kawahara, U. (1942) Studies on the different grades of self- and cross-incompatibilities in sweet potato. II. Pollen behaviour in the incompatible combinations. *Bull. Imp. Agr. Expt. Sta. Tokyo.* 52, 21-30.
16. van Schreven, A.C. (1953) Investigations on the flower biology and compatibility of sweet potato, including some preliminary trials on the germination of seed. *Landbouw.* 25, 305-46.
17. Wang, H. (1964) A study in self- and cross-incompatibilities in the sweet potato in Taiwan (Formosa). *Proc. Amer. Soc. Hort. Sci.* 84, 424-30.
18. Warmke, H.E. and Cruzado, H.J. (1949) Observations on flowering and fertility in some varieties of Jersey and moist-flesh sweet potatoes. *Proc. Amer. Soc. Hort. Sci.* 54, 391-8.
19. Williams, D.B. and Cope, F.W. (1967) Notes on self-incompatibility in the genus *Ipomoea* L. *Proc. Int. Symp. on Trop. Root Crops*. 1, 16-30.

TABLE 1

Description of plant material

<u>Species</u>	<u>Accession No.</u>	<u>Source</u>	<u>Description</u>
<i>I. batatas</i>	09/56	Trinidad	
	22/56	"	
	12/56	Barbados	Indigenous West
	13/56	"	Indian cultivars
	30/57	St. Vincent	
	02/59	Granada	
	C 9	Department of Progenies from	
	O 49	Crop Science, open-pollination	
	A26/74	UWI Trinidad of West Indian	cultivars
<i>I. trichocarpa</i>	01/64(strain 1)	Department of Wild species	
	03/64(strain 3)	Botany, UWI, Trinidad.	

TABLE 2

Mean number of pollen grains retained on stigmas and pollen germination and development in styles of *I. trichocarpa* after self- and cross-pollinations

Pollinations within and between strains of <i>I. trichocarpa</i>	Mean number of grains on stigma				Pollen germination and tube development				
	hours	2	4	6	12	2	4	6	12
3 x 3 (IC)		8	11	15	15	0	0	0	0
3 x 1 (C)		108	96	111	62	+	+	+	+
1 x 3 (C)		152	131	138	135	+	+	+	+

IC = incompatible pollination
C = compatible pollination

TABLE 3

Percentages of carpels on which pollen germination was observed

Treatments	ca. % of carpels on which pollen germinated	
	6 hr	24 hr
1. stigma 'cap' scraped	0	0
2. stigma 'cap' excised	100	100
3. style trimmed to half its length	50	25
4. style severed at the base	0	0

TABLE 4

What percentage depth of pollen tube penetration in styles of cultivars of *I. batatas* at 3, 6, 24 and 30 hrs.,
after self-cultivars of *I. batatas* at 3, 6, 24 and 30 hrs., after self-pollination

X percentage depth of tube penetration in styles									
Cultivars	Hours	Stigma retained				Stigma excised			
		3	6	24	30	3	6	24	30
09/56		58.0	100.0	100.0	100.0	69.0	100.0	100.0	100.0
12/56		0.0	0.0	100.0	100.0	12.5	100.0	100.0	100.0
22/56		0.0	100.0	100.0	100.0	12.5	100.0	100.0	100.0
20/57		0.0	63.0	100.0	100.0	53.0	100.0	100.0	100.0
02/57		100.0	100.0	100.0	100.0	88.0	94.0	100.0	100.0

TABLE 5

Effect of growth substances on the length of life of flowers in both species after incompatible pollination

Treatment	Conc. (ppm)	Average length of life of flowers (days after pollination)	
		<i>I. trichocarpa</i> (strain 3)	<i>I. batatas</i> (30/57)
Control	-	3	4
IAA	50	7	4
IAA	100	6	5
NAA	50	6	5
NAA	100	7	6
2,4-D	50	13	6
2,4-D	100	18	14
2,4,5-T	50	12	7
2,4,5-T	100	17	12

TABLE 6

Percentage seed-set in both species after 2,4-D (100 ppm) application at 3 frequencies

Number of applications at 16, 8 and 4 day intervals respectively	ca. % of flowers which set seed	
	<i>I. trichocarpa</i> (Strain 3)	<i>I. batatas</i> (30/57)
2	50	0
3	50	25
5	50	75

TABLE 7

Percentage seedlings developed from cross-compatible and self- and cross-incompatible pollinations following seed-set induction and embryo culture in *I. batatas*

Treat- ment	Pollinations		Number of capsules			Embryo excised			Embryo loss		Seedlings	
	p	♂	Flo- wers	Num- ber	%	Num- ber	A	D	% ab- orts	% dis- eased	Num- ber	%
1	A26/74 x R223	(C)	35	29	84.0	29	0	6	0.0	20.7	23	79.3
2	A26/74 x 30/57	IC	63	46	73.0	32	14	17	30.4	53.1	15	46.8
3	R223 selfed	(IC)	96	31	32.3	12	19	12	61.2	66.6	4	33.3

C = Compatible IC = Incompatible A = number of abortions
 D = number of diseased embryos

THE STERILITY-INCOMPATIBILITY COMPLEX IN SWEET POTATO

G.A.M. van Marrewijk*

SUMMARY

Compatibility relations in sweet potatoes were assessed from the results of hand pollinations and ultra violet fluorescence microscopy. Environmental conditions influenced compatibility reactions. Abnormal growth of pollen tubes in styles was common. Pollen sterility was assessed by germination on solid and liquid media and by staining with acetocarmine, lactophenol blue and tetrazolium salts and is not important. Female sterility however is a major factor determining the low seed set and seed viability.

RESUME

Les rapports de compatibilité dans la patate douce ont été évalués à partir de résultats de pollinisations à la main et de microscopie fluorescente ultraviolette. La croissance anormale des tubes polliniques dans les styles était fréquemment observée. La stérilité des pollens a été évaluée par la germination en milieu solide et liquide et par coloration aux sels acétocarmins, lactophénols bleus et elle n'est pas importante. Toutefois la stérilité femelle est un facteur important déterminant la formation lente des boutures et leur viabilité.

RESUMEN

Las relaciones de compatibilidad se determinaron a partir de resultados obtenidos por polinización manual y microscopía ultravioleta, fluorescente. El crecimiento anormal de tubos polínicos en los estilos fue común. La esterilidad del polen, la cual no es importante, se determinó mediante germinación en medio líquido y sólido y por coloración con acetocarmin, lactofenol azul y sales de tetrazolio. La esterilidad femenina, sin embargo, es un factor importante que determina la baja producción y viabilidad de semillas.

INTRODUCTION

Martin⁵ has reviewed previous studies on incompatibility in sweet potatoes. Most authors have attributed poor fruit set to incompatibility, and have classified cultivars into distinct compatibility groups based on results of pollination between them. However, there have been discrepancies between the classifications of different authors suggesting either errors or differences due to experimental conditions or systems of classifying data.

Martin and co-workers were the first to recognize that a more complex system is responsible for poor fruit and seed set. In various publications^{6,7,8} they pointed out that in sweet potato, beside the incompatibility system, there is a sterility complex which acts at different stages in the sexual cycle.

A study was started in 1969 at the Centre for Agricultural Research in Surinam to determine the relative importance of incompatibility and sterility mechanisms in reducing fruit set and seed formation in the sweet potato. This study included:

1. *In vivo* determination of compatibility relations.
2. Assessment of compatibility relations using fluorescence microscopy.
3. Pollen viability studies.
4. Female sterility studies.

METHODS AND RESULTS

Selfings and intervarietal crosses

About 35 cultivars of different origin were originally entered in the field pollination programme. Some of them flowered very poorly under our conditions and were excluded, when it appeared that classic ways to stimulate flowering, such as grafting on to non-tuberiferous *Ipomoea* species, shortday treatment, and nitrogen application, had little or no effect. This left only 27 clones in the programme. All clones were planted on ridges and trellised along chicken wire to promote flowering and to facilitate crossing. Pollinations were carried out between 7.00 and 9.00, since it had been established previously that pollinations made later, under sunny conditions, caused a further reduction in fruit set.

*Centre for Agricultural Research in Surinam, Paramaribo, Surinam, S. America.

As far as possible clones were selfed and crossed in all combinations. Altogether some 24,000 hand pollinations were made covering 404 out of a total of 702 possible combinations. Taking into account only those combinations that had been made at least twenty times, 378 combinations were available for analysis, comprising about 23,000 pollinations.

Fruit set was recorded about 10 days after pollination when unfertilized ovaries had already abscised, whereas fertilized ones were already visibly swollen. Fruits ripened four to five weeks after pollination but many fruits dropped before ripening.

To decide whether a combination is compatible or not is difficult. Some investigators set a threshold of 5 or 10% seed set beyond which a combination is considered to be compatible. This leads to an inextricable mixing of the effects of incompatibility and sterility components. However, considering a combination compatible only if it results at least in fruit set, might lead to an underestimation of compatibility, as incompatibility may be overcome under certain environmental and physiological conditions.

It was therefore decided to classify the intervarietal combinations into three provisional categories:

1. Incompatible. Combinations completely failing to give capsule set.
2. Compatible. Combinations with a percentage capsule set of two with a minimum of one ripe capsule.
3. Indefinite. Combinations not belonging to 1. or 2.

The compatibility relations between a number of cultivars are presented in Table 1. In some instances striking differences were found between reciprocal crosses (Table 2), but unilateral compatibility was not the rule.

Results of field pollinations were considerably influenced by environmental factors (Table 3) and therefore no attempt has been made to group them.

Besides unravelling compatibility relationships as such, it is interesting to learn the extent to which compatible combinations lead to capsule and seed set. Figure 1 represents the distribution of 278 crosses over fertility classes.

Table 4 clearly shows that distinct differences exist between clones in respect of capsule set, seed set and number of seeds per pollination.

Of the capsule sets, 75 percent were harvested. Generally they contained only one or two seeds; occasionally three seeds were found. Average number of seeds per capsule depended on the mother clones, varying from 1.07 for cultivar Hopi to over 1.50 for cultivars USA 130, Louisiana 6 and A28/7. The overall average was 1.34. No correlation was found between the number of seeds per pollination and the number of seeds per capsule.

Microscopic observations

The second method of establishing compatibility relations was based on *in vitro* tests of (i) pollen germination on the stigma and (ii) pollen tube penetration into the style.

To follow the pollen tubes in the stylar tissue, use was made of fluorescence microscopy. Penetrated pollen tubes could be distinguished from the stylar tissue by a yellowish fluorescence of callose plugs in them.

To date, 461 combinations, comprising 28 different clones have been studied. Each cross was done in triplicate and most were repeated once or more. In all instances the total number of pollen grains remaining on the stigmatic surface, the number of grains germinated, and the number of tubes in the upper, middle and lower part of the style were counted. On this basis the cultivars were classified into five groups (Table 5).

Group I consists of clones with a weak incompatibility system. In intra-group pollinations, often some pollen grains germinated and sometimes a few penetrated the stylar tissue. Germination depended very much on external conditions; in a particular combination it once failed entirely, whereas at a later date germination was abundant. In inter-group combinations germination and tube growth were profuse.

Group II includes only three related clones, two of which, cultivars Genjem 1 (1968) and Genjem 1 (1970), may be identical, though the latter resembles cultivar Genjem 2 in its abundant flowering. In this group a weak unilateral incompatibility against all clones of group I was observed. When used as maternal parent, the cultivars Genjem behaved similarly to the members of group I pollinators however. They were completely compatible with all other clones but were self-incompatible. This justifies, in our opinion, their separate classification.

Group III consists of four unrelated intra-incompatible, inter-compatible cultivars.

Group IV includes five cultivars with a very pronounced reaction pattern: almost complete failure of pollen germination in intra-group crosses but a high rate of germination and pollen tube growth in inter-group matings.

Group V comprises a number of cultivars that were, with a few exceptions, compatible in all matings, but in selfs pollen generally failed to germinate. Only cultivar Sunny Side appeared self-compatible. Some members of this group, i.e. cultivars Blauwkop and Sunny Side gave considerable capsule set in the field,

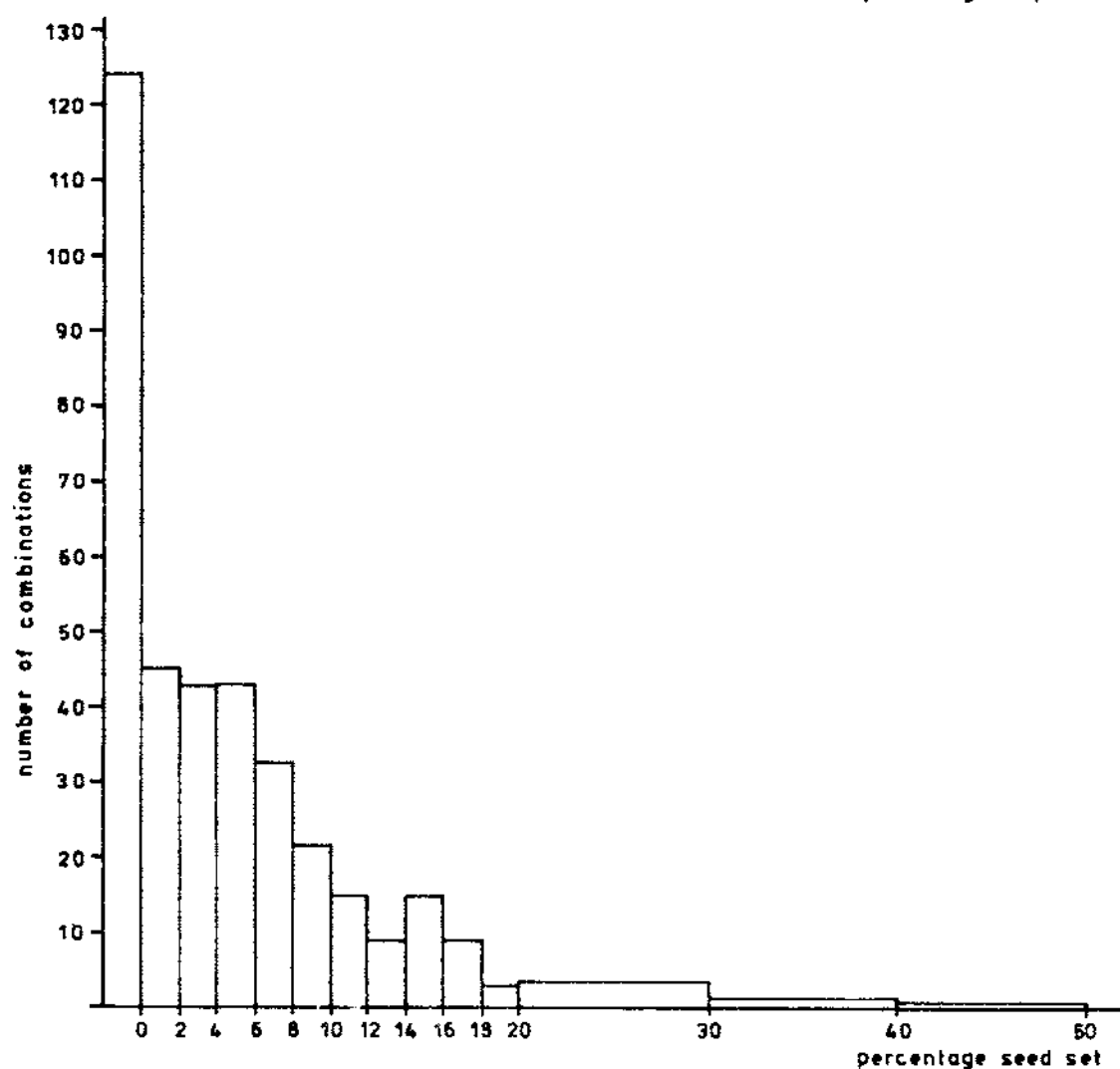
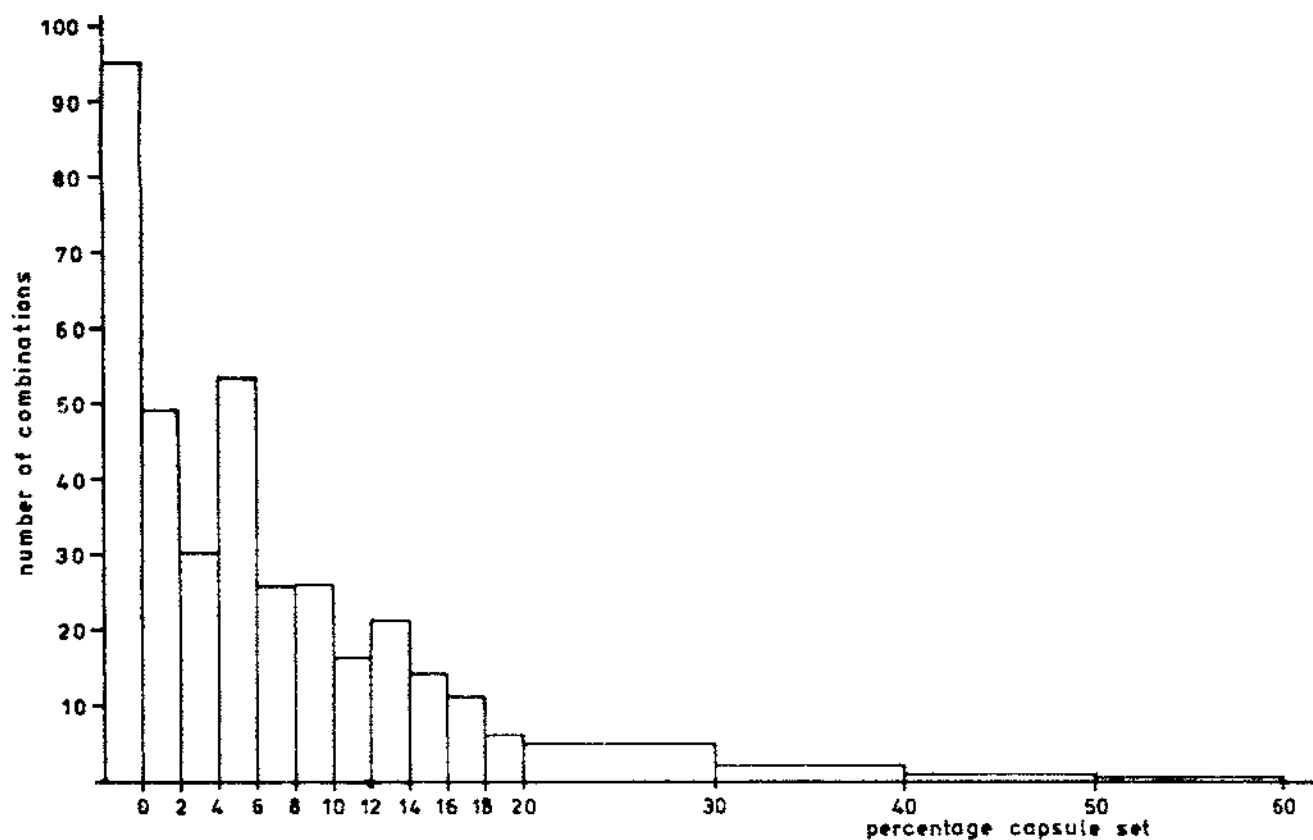


Fig.1. Distribution of capsule-set and seed-set data in 378 intervarietal combinations and settings of sweet potato.

whereas cultivars USA 130, Georgia Red and Louisiana 6 did not. Possibly this group should be subdivided into a self-compatible group and one or more small intra-incompatible group(s).

Between the various clones there was a large variation in average number of pollen grains per stigma, germination percentage, style penetration and number of pollen tubes in different regions of the style (Table 6).

On the whole only one out of five germinated pollen grains penetrated the style. Occasionally some pollen tubes with swollen tips were noticed on the stigma. More common were tubes with a thickened tip ending somewhere in the stylar tissue. This occurred in styles of nearly all clones. Only in two instances did pollen tubes continue to grow after swelling. This points to the existence of a second growth-inhibiting mechanism. The sharp decline in number of pollen tubes in the mid and lower style regions also indicates this. Generally, the relative decrease was larger between upper and mid-style than between mid and lower style, indicating that the inhibitor operates in the upper style.

In Table 6 seed-set data are included, both as obtained in the field and as computed, for compatible combinations (based on *in vitro* assessment) irrespective of whether they actually set seed or not. Assuming that all the tubes found in the lower style enter the ovary, our expectation based on microscopical observations is that average seed production per compatible pollination is about 1. However, only one tenth of this figure has been realized in our field crosses (Table 6). This implies that a further sterility component is operating in the ovarial region.

Of the 360 combinations assessed both in the field and *in vitro*, 270 (75%) behaved similarly. Of the remainder, 58 were compatible *in vitro* but did not give capsule set in the field, whereas 32 combinations were incompatible *in vitro* yet gave seed from capsules set in the field.

The failing of capsule set in combinations showing satisfactory pollen germination *in vitro* may have been caused by various factors such as female sterility because of heavy impediment of tube growth in stigma and style, failure of fusion between egg cell and male gamete, or seed abortion (Goldrush, Butikatoka), semi-sterile pollen (Goldrush), weak incompatibility genes, or chance. A majority of the failures related to mother clones with less than 0.05 seeds per pollination (27 cases) or a semi-sterile pollinator (6 cases).

The combinations which were incompatible *in vitro*, but still gave capsule and seed set are more remarkable but may be explained by more favourable external conditions or by physiological changes in the plant, or perhaps by occasional contamination with foreign pollen. In all instances the percentage capsule and seed set have been below 2.1. Of the remainder, some, but not all, are related to clones with a weak incompatibility allele.

Germination *in vitro*

Pollen germination *in vitro* was studied using a large range of liquid and solid media.

Several forms of pseudo-germination were observed, such as bursting, the formation of curling plasm strands, and, sporadically, bulging of the pollen grains within the exine wall. Once a distinct nucleus was found in such a bulge (Figs 2 and 4).

Pseudo-germination to some extent decreased with increasing saccharose concentration and higher temperatures. On agar, the percentage pseudo-germination rapidly decreased and very few cytoplasm protrusions were found when saccharose concentrations exceeded 25%. Boron did not influence this phenomenon, nor did salts of Ca, Mg and K or stigma-style press juice. Cultivars Djarak, Hopi and USA 130 all behaved similarly in this respect.

None of the media tested produced germination, though a small number of pollen grains was detected having tube-like structures covered by the intine wall (Fig. 5). These stopped growing after a few hours and they were observed only in concentrated saccharose solutions (35%) and on agar.

Pollen stainability

Pollen of the cultivars Djarak, Butikatoka and USA 130 was tested for its stainability with acetocarmine. All except Djarak were also stained in lactophenol cotton blue.

Pollen was collected at 8.00 and 10.00 h. and immediately stained. The results are compiled in Table 7. The mean percentage of stainable pollen was somewhat lower for USA 130 than for Djarak and Butikatoka and about 10 percent higher in cotton blue than in acetocarmine. Time of pollen sampling did not affect the stainability. However, as acetocarmine and cotton blue are non-vital stains, they differentiate mature from immature rather than viable from unviable pollen.

Tetrazolium salts are claimed to give a better estimation of viability. They are reduced to insoluble coloured products by the action of respiratory dehydrogenase enzymes, and therefore are commonly used to determine seed viability.

Pollen of ten cultivars was treated with solutions of four tetrazolium salts, viz. TTC, TR, INT and

MTT. Pollen was collected at 7.00, 10.00 and 13.00 h. Their percentage stainability was compared with those in solutions of acetocarmine and cotton blue.

In most clones stainability did not decrease during the course of the day. Cultivar Brokopondo was an obvious exception. Stainability, as determined with tetrazolium salts, dropped strongly between 10.00 and 13.00 h. In the non-vital stains the percentage stained remained at the same level (Table 9). This is a further indication these stains do not measure viability properly.

The differences between the various stains make it difficult to decide on the actual viability. In TTC percentage stainabilities are considerably lower than the proportion of pollen grains which germinate in compatible matings for three of the examined cultivars, especially for cultivar Willemrank (Table 6).

Seed emergence

At the end of three consecutive years seeds were tested for viability. Scales, aborted seeds and abnormally developed specimens were excluded prior to sowing. Seeds were treated in concentrated sulphuric acid for 10 minutes, followed by prolonged rinsing in running tap water. They were sown in small pots filled with a mixture of sand, peat and clay, and covered with a small layer of coarse sand. Counting of emerged plants continued for three months. Emergence started two days from planting and culminated at about the fourth day. Over 90 percent of the germinating seeds emerged within 10 days. Small numbers of emerging plants was, however, observed 1 – 2½ months after sowing. The results of the different tests were very similar and are, therefore, combined (Table 10).

Of a total of 1169 seeds 524 (46%) failed to emerge. Most non-emerging seeds were found in the lower seed weight classes, but also over 10% of the heaviest seeds (23 mg or more) did not germinate, indicating that instability or weakness of seeds occurs in all weight classes. Some seedlings, especially from lighter seeds, died shortly after emergence.

Clones differed considerably both for seed weight distribution and percentage non-germinating seeds. Emergence was by far the highest in cultivar Sunny Side, though this clone did not have the highest average seed weight.

DISCUSSION

The data confirm that poor seed set in sweet potato results from a complex of incompatibility and sterility mechanisms, in which sterility plays a dominant part. Pollen sterility appears to be of no importance except in some particular clones. Thus it was found that anthers of cultivars Jersey Orange did not dehisce and on mechanical opening shed very little pollen. Cultivars Goldrush and Puteri Selatan showed low percentages of pollen germination and tube growth even in compatible matings.

To explain low capsule and seed set, Martin and Cabanillas⁷ proposed the action of two growth barriers, one of which inhibits the pollen tubes from passing the border between stigma and style, and the second operating in the ovary. No inhibitory mechanism in their view was active in the style. However, in our investigations it seems that at least in some cultivars an additional growth barrier is operating in the upper region of the style. Whether this prevents or merely retards tube growth is not clear, but the formation of swollen tips on the pollen tubes suggest that growth may be terminated.

Since there is no evidence for low pollen viability, germination of pollen on the stigma is a reliable basis on which to define one kind of compatibility reaction. Capsule and seedset data are too crude a basis for describing compatibility relationships since they depend upon external influences and to chance as well as to the cumulative effects of different sorts of incompatibility reaction.

Capsule and seed-set data in instances where pollen germination is normal give information on the efficacy of the concerted action of additional components of female dependant sterility or incompatibility mechanisms in the stigma, style and ovary. Further cytological and chemical investigations will be needed to determine the nature of the sterility mechanisms. Ting and Kehr¹² suggested that meiotic abnormalities may account for low fertility in sweet potato, but Jones⁴, studying meiotic behaviour in 40 clones, found this to be normal.

Complete failure of pollen germination on liquid and solid media has previously been found by Fujise² and Martin and Ortiz⁸. According to Brewbaker¹ this behaviour is characteristic of trinucleate pollen.

Jones⁴ claimed to investigate the pollen fertility of 28 sweet potato clones by staining in acetocarmine. The percentage of stained pollen ranged from 64–95% and the main range was between 80–95%. These values are of the same magnitude as those obtained in our experiments, but the interpretation is somewhat dubious.

Several authors have previously studied pollen viability by the use of tetrazolium salts^{3,9,10} with indication that TTC and TR did not fully discriminate between viable and non-viable pollen, and that these salts may sometimes give an overestimation of viability. On the other hand, MTT was said to give very reliable viability percentages. In our trials, however, MTT gave much better indications of pollen viability than either TTC or TR. This anomaly needs further study.

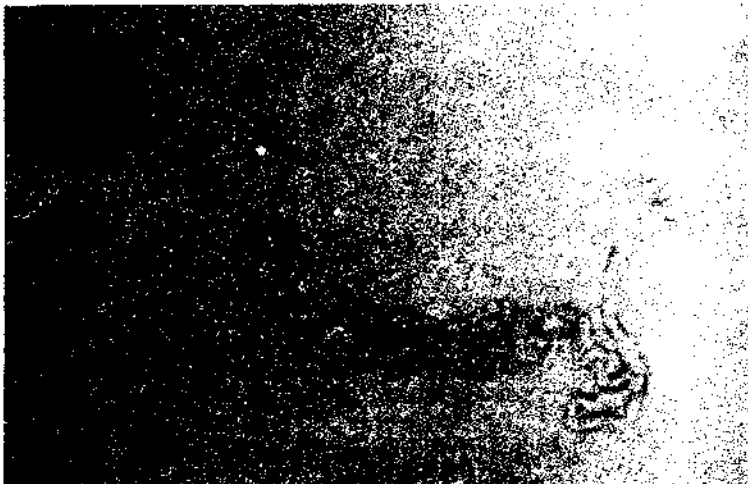


Figure 2. *Pseudo-germination in sweet potato; pollen grain producing cytoplasmic strands (x 350).*

Figure 3. *Pseudo-germination in sweet potato; pollen grain showing a bulge covered by the exine wall (x 1000).*

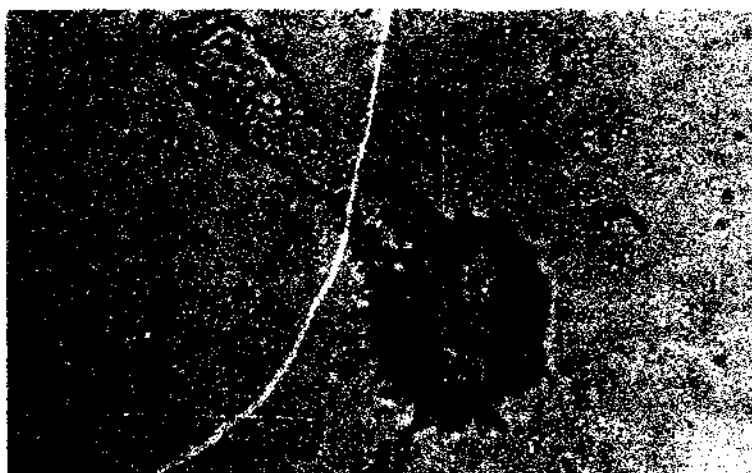
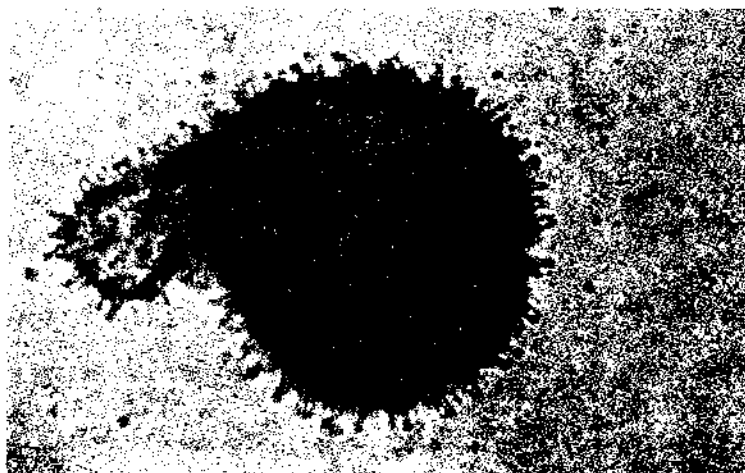
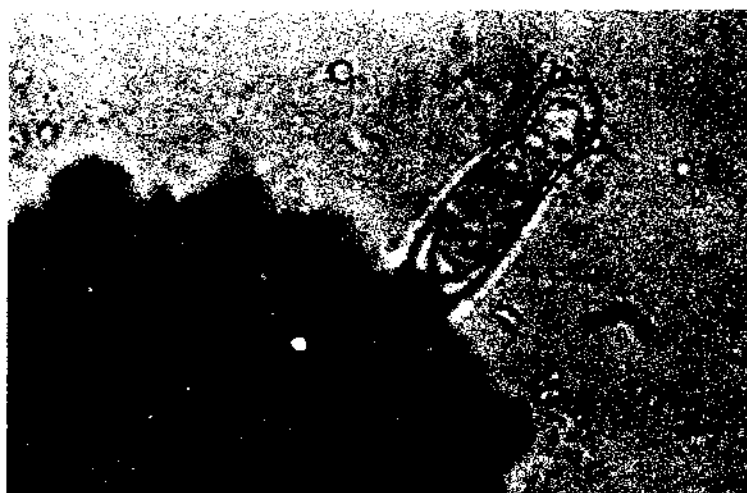


Figure 4. *Pseudo-germination in sweet potato; protuberant pollen tube containing nucleus-like organ (x 1000).*

Figure 5. *Pollen grain of sweet potato cv. Dharak in 35% saccharose solution with small tube (x 1600).*



ACKNOWLEDGEMENT

The author wishes to thank Dr. F.W. Martin for reading the manuscript and Dr. J.F. Wienk for commenting on the original English text.

REFERENCES

1. Brewbaker, J.L. (1957) Pollen cytology and self-incompatibility systems in plants. *J. Hered.* 48, 271-7.
2. Fujise, K. (1964) Studies on flowering, seed setting and self- and cross-incompatibility in the varieties of sweet potato. *Bull. Kyushu Agric. Exp. Stn.* 9, 123-46. Japanese: Engl. summary.
3. Hecker, R.J. (1963) Use of tetrazolium salts in determining viability of sugarbeet pollen. *J. Am. Soc. Sug. Beet Technol.* 12, 521-8.
4. Jones, A. (1965) Cytological observations and fertility measurements of sweet potato (*Ipomoea batatas* (L.) Lam.) *Proc. Am. Soc. Hort. Sci.* 86, 527-37.
5. Martin, F.W. (1965) Incompatibility in the sweet potato. A review. *Econ. Bot.* 19, 406-15.
6. — — — — — (1969) The sterility-incompatibility complex of the sweet potato. *Proc. Int. Symp. Trop. Root Crops*, St. Augustine, Trinidad. 1(1), 3-15.
7. Martin, F.W. and Cabanillas, E. (1966) Post pollen-germination barriers to seed set in sweet potato. *Euphytica* 15, 404-11.
8. Martin, F.W. and Ortiz, S. (1966) Germination of sweet potato pollen in relation to incompatibility and sterility. *Proc. Am. Soc. Hort. Sci.* 88, 491-7.
9. Norton, J.D. (1966) Testing of plum pollen viability with tetrazolium salts. *Proc. Am. Soc. Hort. Sci.* 10, 132-4.
10. Oberle, G.D. and Watson, R. (1953) The use of 2,3,5-triphenyl tetrazolium chloride in viability tests of fruit pollens. *Proc. Am. Soc. Hort. Sci.* 61, 299-303.
11. Schreven, A.C. van (1953) Investigations on the flower biology and compatibility of sweet potato (*Ipomoea batatas* Poir.) including some preliminary trials on the germination of the seed. *Landbouw* 25, 302-46.
12. Ting, Y.C. and Kehr, A.E. (1953) Melotic behaviour in the sweet potato (*Ipomoea batatas* Lam.). *Heredity* 44, 207-11.

Table 1. Compatibility relations between 23 sweet potato cultivars based on pollinations in the field.

+ = compatible; — = incompatible; ± = indefinite.

Incompatible combinations placed in brackets indicate 6-20 pollinations only.

♀ \ ♂		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Djarak	1	—	—	+	—	±	+	+	+	±	+	±	+	±	—	±	+	+	—	+	—	—	±	+
Hopi	2	±	—	+	—	—	+	+	—	+	±	+	+	—	±	+	+	+	+	±	—	±	±	—
U. S. A. 130	3	+	+	—	+	+	+	+	—	+	+	+	+	+	+	±	+	+	+	+	±	—	+	±
White Star	4	—	+	+	±	—	+	+	+	+	+	+	+	—	+	+	+	+	±	+	+	+	+	+
Bulikatoka	5	—	—	—	—	+	+	—	—	—	±	+	+	—	—	—	—	±	±	—	±	+	+	—
Genjem 1	6	—	—	±	+	+	+	+	o	+	(—)	o	(—)	(—)	o	o	o	o	o	o	o	o	o	o
Genjem 2	7	—	+	—	+	±	—	+	o	±	—	(—)	o	(—)	o	—	—	—	o	o	o	o	o	o
Goldrush	8	—	—	—	—	—	—	(—)	±	—	—	(—)	(—)	—	o	—	—	(—)	o	(—)	o	+	o	o
Centennial	9	±	+	+	—	+	+	+	—	+	+	+	±	+	+	±	+	+	(—)	+	—	+	+	+
Georgia Red	10	+	+	+	+	+	+	+	—	+	±	+	+	+	±	+	+	+	(—)	—	+	o	(—)	o
Blauwkop	11	+	—	±	+	+	+	+	—	±	+	+	+	±	—	+	—	+	—	±	+	+	—	±
Egeida	12	o	o	o	+	+	+	o	o	o	o	o	+	o	o	o	o	o	o	o	o	o	o	o
Julian	13	+	+	+	±	+	+	o	o	±	(—)	o	—	—	o	o	±	o	o	(—)	o	o	o	o
Blanquilla	14	—	±	(—)	o	o	o	+	o	(—)	+	—	o	o	—	o	o	—	o	o	o	o	o	o
Sunny Side	15	±	+	+	+	+	+	+	+	+	+	o	o	+	+	+	±	+	o	—	+	o	+	o
Willemsrank	16	+	+	+	+	+	+	—	—	—	+	+	+	+	+	+	+	±	+	+	+	+	±	—
Brakaponda	17	+	—	+	+	±	+	+	—	+	+	+	(—)	+	±	+	—	±	±	+	+	+	—	—
Louisiana 2	18	+	+	+	+	+	+	+	(—)	o	o	o	o	o	o	o	+	±	+	+	o	o	o	+
Louisiana 6	19	+	+	+	+	+	(—)	+	o	+	—	o	o	(—)	o	o	o	o	o	±	o	o	o	o
A 28/7	20	±	—	+	+	—	+	+	±	±	o	o	o	+	o	o	o	+	o	o	—	+	o	o
A 138	21	+	+	+	+	+	+	+	±	±	+	+	(—)	—	+	+	+	+	+	+	+	+	—	+
C 9/9	22	+	+	+	+	+	—	+	±	+	(—)	+	o	o	o	o	o	o	o	+	o	o	+	—
O 49	23	±	+	±	+	o	o	o	(—)	o	o	o	o	o	o	o	o	o	o	o	(—)	o	o	+

TABLE 2

Capsule and seed-set data for some intervarietal combinations showing striking reciprocal differences

Combination A x B	% capsule/% seed set	
	A x B	B x A
Djarak x A 138	0/0	17.4/17.4
Djarak x C 9/9	1.9/0	18.1/ 9.5
Hopi x Brokopondo	23.5/22.1	0/0
Hopi x Louisiana 6	0.9/0.9	16.7/12.1
Hopi x O 49	0/0	12.1/ 5.2
USA 130 x Butikatoka	10.4/4.5	0/0
USA 130 x A 28/7	5.7/0	35.0/31.7
White Star x Louisiana 2	1.9/0	51.9/42.9
Butikatoka x Georgia Red	2.0/0	22.0/18.0
Butikatoka x Sunny Side	0/0	37.7/28.5
Butikatoka x Willemsrank	0/0	17.1/20.7
Butikatoka x Louisiana 2	1.9/0	43.5/32.6
Butikatoka x Louisiana 6	0/0	30.2/26.4
Genjem 2 x Centennial	1.7/0	32.2/27.1
Genjem 2 x Sunny Side	0/0	16.0/12.0
Centennial x Blauwkop	1.6/0	17.8/11.1
Centennial x Brokopondo	20.7/15.5	2.7/0

TABLE 3

Capsule-set percentages for a number of combinations performed in different periods

Combination	1969	1970	1971	1972	1973
Djarak x Georgia Red	0	45.4	-	-	-
USA 130 x Djarak	1.1	45.6	-	0	-
USA 130 x Hopi	0	30.3	-	0	-
USA 130 x White Star	0	47.4	-	0	-
USA 130 x Georgia Red	0	41.7	-	-	-
Butikatoka x Blauwkop	0	-	-	20.0	-
Genjem 2	-	-	20.8	-	0
Willemstank x USA 130	-	-	0	33.3	-
Willemsrank x A 28/7	-	-	-	0	9.7
Louisiana 6 x Genjem 2	-	-	-	0	23.3
A 27/8 x USA 130	-	-	-	5.0	50.0
A 28/7 x Julian	-	-	0	0	33.3
C 9/9 x USA 130	-	-	0	0	42.9

Mother clones	Combinations	Pollinations	Capsule set	Seed set	Seeds obtained	% capsule set	% seed set	Seeds per pollination	Seeds per capsule
Djarak	13	945	86	67	82	9.1	7.1	0.09	1.22
Hapi	12	874	76	56	60	8.7	6.5	0.07	1.07
U. S. A. 130	19	1492	139	80	126	9.3	5.4	0.08	1.58
White Star	19	1445	180	154	213	13.1	10.7	0.15	1.38
Butikatoka	6	402	21	19	21	5.2	4.7	0.05	1.11
Genjem 1	2	114	8	8	12	7.0	7.0	0.11	1.50
Genjem 2	3	240	24	24	33	10.0	10.0	0.14	1.38
Goldrush	1	41	2	2	3	—	—	—	—
Centennial	16	895	102	75	97	11.4	8.4	0.11	1.29
Georgia Red	13	658	99	80	101	15.0	12.2	0.15	1.27
Blauwkop	13	820	97	69	86	11.8	8.4	0.10	1.24
Julian	3	123	14	11	14	11.4	8.9	0.11	1.27
Sunny Side	12	719	122	97	130	17.0	13.5	0.18	1.34
Willemsrank	20	1272	152	101	130	11.9	7.9	0.10	1.20
Brokopondo	14	840	71	55	75	8.5	6.5	0.09	1.36
Louisiana 2	9	537	129	105	145	24.0	19.6	0.27	1.38
Louisiana 6	7	398	66	55	83	16.6	13.8	0.21	1.51
A 28/7	5	265	37	32	51	14.0	12.1	0.19	1.59
A 138	19	1318	224	167	228	17.0	12.7	0.17	1.37
C 9/9	9	548	48	34	40	8.8	6.2	0.07	1.18
D 49	3	127	19	12	15	15.0	9.4	0.12	1.25
Okinawa 2	1	46	6	5	6	—	—	—	—
U. S. A. 21 X	3	151	33	33	45	21.9	21.9	0.30	1.36
total *		13428	1659	1247	1668	—	—	—	—
average *		—	—	—	—	12.4	9.3	0.12	1.34
range *		—	—	—	—	5.2-24.0	4.7-19.6	0.05-0.27	1.07-1.59

* exclusive clones with less than 5 combinations

Table 4. Capsule- and seed-set data of fertile matings with over 20 pollinations per combination.

Mother clones	Combinations	Grains per stigma	% germinated	% of germinated grains in upper style	Tubes per style			Seeds per pollination based on:	
					upper style	mid style	lower style	field data	in vitro assessment
Djarak	17	90	23.6	16.2	3.5	1.4	1.0	0.09	0.06
Hopi	13	79	21.2	15.6	2.6	1.0	0.3	0.07	0.04
U.S.A. 130	27	68	33.5	23.1	5.3	2.1	1.6	0.08	0.06
White Star	16	66	29.3	26.2	5.0	2.4	1.3	0.15	0.18
Butikatoka	14	52	34.9	13.4	2.4	0.1	0.0	0.05	0.02
Genjem 1 (1970)	14	115	13.3	9.0	1.4	0.8	0.7	(0.11)	—
Genjem 2	14	121	14.9	9.5	1.7	0.6	0.4	(0.14)	0.00
Goldrush	13	85	16.4	18.9	2.6	1.1	0.8	—	0.01
Centennial	16	94	27.6	20.0	5.2	2.6	1.3	0.11	0.14
Georgia Red	22	73	23.6	16.9	4.0	1.2	0.9	0.15	0.12
Blanquita	11	57	34.5	17.7	3.5	1.0	0.0	—	—
Blauwkap	20	35	50.1	23.6	4.2	1.5	0.7	0.10	0.06
Sunny Side	21	70	34.3	16.3	3.9	1.8	1.7	0.18	0.17
Willemsrank	23	75	42.0	23.3	7.4	4.0	2.4	0.10	0.09
Brokopondo	23	69	20.1	24.8	3.4	1.8	1.1	0.09	0.06
Louisiana 2	22	80	27.6	29.1	6.5	2.5	1.3	0.27	0.31
Louisiana 6	25	119	18.0	13.1	2.8	1.6	1.5	0.21	0.20
A 28/7	13	75	25.8	19.1	3.7	1.7	1.1	0.19	(0.42)
A 138	16	71	56.3	16.3	6.5	1.0	0.2	0.17	0.16
C 9/9	21	65	24.5	25.5	4.0	2.2	1.5	0.07	0.07
D 49	15	61	31.9	20.3	3.9	2.4	2.0	(0.12)	(0.10)
Okinawa 2	6	70	26.0	16.1	2.9	0.2	0.0	(0.13)	(0.09)
U.S.A. 21 X	14	123	17.1	18.8	4.0	2.4	2.3	(0.30)	(0.19)
Louisiana 3	11	144	16.6	15.0	3.6	1.9	1.8	—	—
Louisiana 5	13	118	14.5	23.2	2.2	1.3	0.8	—	—
Puteri Selatan	20	124	18.0	22.8	5.0	2.2	1.9	—	—
Palumeu	9	59	12.5	33.9	2.5	0.7	0.4	—	—
Tox Paars	12	115	16.5	19.4	3.7	2.2	1.8	—	—
average		85	25.9	19.5	3.8	1.7	1.1	0.12	0.10
range		35 - 144	12.5 - 56.3	9.0 - 33.9	1.4 - 7.4	0.1 - 4.0	0.0 - 2.4	0.05 - 0.30	0.00 - 0.42

Table 6. Average values of pollen germination, style penetration and pollen tube numbers in different regions of the style four hours after pollination in compatible matings of sweet potato. Seed set data are added for comparison.

Values in brackets are based on less than 5 cross-combinations.

TABLE 7

Stainability of pollen collected at 8.00 and 10.00 h in acetocarmine (AC) and lactophenol cotton blue (LC) for three sweet potato cultivars

	AC						LC	
	Djarak		Butikatoka		USA 130		Buti'ka	USA 130
	8.00	10.00	8.00	10.00	8.00	10.00	8.00	8.00
Number of flowers	24	25	29	17	19	15	10	11
Pollen grains counted	7161	8098	11633	7372	6952	5053	4884	3950
Well-stained	4967	5558	8170	5212	4238	2919	3966	2720
% well-stained	69	69	70	71	61	58	81	69

TABLE 8

Average percentages stainability in four tetrazolium salts (TTC, TR, INT and MTT), acetocarmine (AC) and lactophenol cotton blue (LC) of pollen from seven sweet potato cultivars. Averages computed from 10 replications

Clone	TTC 2%	TR 2%	INT 1%	MTT 1%	AC	LC	Average
Brokopondo	28	39	63	57	73	72	55
Willemsrank	15	24	37	42	33	58	35
Hopi	12	44	63	63	69	75	54
USA 130	19	40	63	64	79	81	58
White Star	29	48	63	66	69	81	59
Djarak	35	55	76	72	81	84	67
Butikatoka	56	69	74	71	75	77	70
Average	28	46	63	62	68	75	-

TABLE 9

Average percentages stainable pollen from cultivar Brokopondo collected at three different times

Solution	7.00 h	10.00	13.00
TTC 2%	28	23	9
TR 2%	39	38	17
INT 1%	63	65	46
MTT 1%	59	54	44
AC	73	77	70
LC	72	71	68

Mother clones	Seed weight (mg)								% not emerged
	≥ 10	11-13	14-16	17-19	20-22	23-25	26-28	total	
Djarak	5 (5)	6 (5)	7 (4)	29 (2)	23 (3)	—	—	70 (19)	27
Hopi	9 (9)	3 (3)	5 (3)	6	16 (1)	9 (1)	—	48 (17)	35
U.S. A. 130	19 (16)	6 (6)	11 (7)	43 (13)	29 (11)	11 (2)	—	119 (57)	48
White Star	4 (4)	5 (5)	6 (6)	18 (7)	47 (12)	7 (1)	1	88 (35)	40
Butikatoka	3 (3)	5 (4)	4 (3)	—	7 (2)	—	—	19 (12)	63
Genjem 1	5 (5)	1 (1)	2 (2)	2	2 (1)	1	—	13 (9)	69
Genjem 2	6 (6)	2 (2)	5 (5)	7 (1)	8 (1)	1	—	29 (15)	52
Goldrush	—	—	—	—	2 (1)	—	—	3 (1)	—
Egeida	—	—	2	8 (2)	1 (1)	—	—	11 (3)	27
Centennial	3 (3)	6 (4)	7 (4)	8 (5)	8 (1)	18 (5)	6 (1)	56 (23)	41
Georgia Red	6 (6)	6 (5)	19 (7)	22 (4)	11 (1)	—	—	64 (23)	36
Blauwkop	28 (28)	18 (11)	11 (1)	1 (1)	—	—	—	58 (41)	71
Julian	1 (1)	—	1 (1)	—	2	5	—	9 (2)	22
Sunny Side	—	7 (3)	16	16	1	—	—	40 (3)	8
Willemsrank	14 (14)	5 (5)	12 (4)	28 (8)	23 (1)	5	—	87 (32)	37
Brakopondo	6 (6)	4 (4)	7 (5)	5 (2)	16	10 (1)	3	51 (18)	35
Louisiana 2	16 (16)	11 (11)	8 (6)	13 (5)	38 (9)	23 (4)	—	109 (51)	47
Louisiana 6	2 (2)	—	2 (2)	4 (2)	4 (1)	3 (1)	—	15 (8)	53
A 28/7	4 (4)	6 (6)	6 (4)	6 (2)	—	—	—	22 (16)	73
A 138	44 (43)	40 (33)	51 (26)	69 (16)	17 (2)	1	—	222 (120)	54
D 49	2 (2)	—	—	—	—	—	—	2 (2)	—
C 9/9	5 (5)	4 (2)	10 (3)	2 (2)	—	—	—	21 (12)	57
Okinawa 2	—	—	1	—	—	—	—	1	—
U.S. A. 21 X	—	2 (2)	1	7 (1)	2	—	—	12 (5)	42
total	182 (180)	137 (112)	194 (93)	295 (75)	257 (48)	94 (15)	10 (1)	1169 (542)	46
% of grand total	15.6	11.7	16.6	25.2	22.0	8.0	0.9	100.0	
% not emerged	99	82	48	25	19	16	10		

Table 10. Percentages of emerged seeds and distribution over seed-weight classes for a number of sweet potato cultivars. Numbers in brackets indicate non-emerged plants.

SWEET POTATO BREEDING IN INDIA – PROBLEMS AND PROSPECTS

M.L. Magoon and R. Krishnan*

SUMMARY

A new, comprehensive breeding programme has so far produced six new high yielding sweet potato cultivars using Japanese, American and Indian parental material. Cytological studies based on pachytene analysis have elucidated the degree of chromosome homeology among three genomes of hexaploid sweet potatoes. Tetraploid *Ipomoea biloba*, which appears to be a segmental allotetraploid may be a bridging form between diploid taxa and the sweet potato. Diploid *Ipomoea biloba* shows a high level of homeology with diploid *Ipomoea crassicaulis*.

RESUME

Un vaste nouveau programme de sélection et d'amélioration a permis d'obtenir six nouveaux cultivars de patate douce aux rendements élevés à partir de matériel parental japonais, américain et indien. Des études cytologiques basées sur l'analyse pachytène ont permis de clarifier le degré d'homéologie des chromosomes entre trois génomes de patate douce hexaploïde. *Ipomoea biloba* tétraploïde qui semble être un allotétraploïde doit être une forme intermédiaire entre les diploïdes et la patate douce. *Ipomoea biloba* diploïde révèle un niveau élevé d'homéologie avec *Ipomoea crassicaulis* diploïde.

RESUMEN

Un nuevo y amplio programa de mejoramiento genético ha producido hasta ahora seis nuevos cultivares de camote de alto rendimiento usando material parental japonés, americano e hindú. Los estudios citológicos basados en análisis en fase de paquiteno han permitido elucidar el grado de homología cromosómica entre tres genomas de papa dulce hexaploide. El tetraploide *Ipomoea biloba*, que parece ser un alotetraploide segmental, puede ser un puente entre la forma diploide y el camote. El diploide *Ipomoea biloba* muestra un alto nivel de homología con el diploide *Ipomoea crassicaulis*.

INTRODUCTION

Sweet potato (*Ipomoea batatas*) has a long history of cultivation in India and its present area of cultivation is about 160,000 hectares. Bihar and Uttar Pradesh states account for nearly 60 percent of the total area under this crop in India. Sweet potatoes contain useful quantities of carotene or provitamin A, Vitamin C, calcium and phosphorous as well as starch. The nutritive value of sweet potato proteins compares well with other vegetable proteins⁴.

Little genetic improvement of this crop has been attempted in India⁵. The average yield is only 8 tons per hectare. A few high yielding clones of sweet potato were identified amongst introductions and have given increased yields in certain parts of the country¹⁶.

Most of the introductions made so far, as well as indigenous : sweet potato cultivars, flower little and seed set is rare. Recently, however, the induction of flowering has engaged the attention of research workers and treatments such as girdling, training of vines over trellises, varying photo-period, applying growth hormones and grafting on root stocks of related ornamental plants have been successfully tried^{10,11}.

There is a new, multi-disciplined, problem-and-production oriented research programme at the Central Tuber Crops Research Institute, Trivandrum, with sub-centres elsewhere in the country. Year-round cultivation of sweet potato is possible at Trivandrum, and a germplasm collection is maintained at the Institute. A high percentage of accessions produce flowers.

BREEDING OBJECTIVES

Objectives are higher tuber yield, responsiveness to fertilizers, low sugar and high starch content of tubers for industrial use, high sugar and carotene content for tubers for human consumption, resistance to diseases and to the sweet potato weevil, (*Cylas formicarius* Fab), drought resistance, wider adaptability and insensitivity to photo-period.

*Indian Grassland and Fodder Research Institute, Jhansi, (U.P.) India.

GERMPLASM COLLECTION AND UTILIZATION

Many sweet potato clones, including many promising exotic cultivars and the related *Ipomoea* species have been assembled. These collections have been screened and critically studied for several desirable attributes including disease and pest resistance. Apart from evaluation for direct utilization, the genetic diversity in the germplasm has been exploited by hybridization and mutation breeding programmes. The mutation breeding programme has been primarily concerned with attempting to rectify defects in otherwise desirable cultivars. As an aid to the interspecific hybridization programme, the ploidy status, crossability relationships and chromosomal inter-relationships of *Ipomoea* species were also investigated.

RESULTS OF THE PROGRAMME

Several high yielding hybrids such as H-41(2), H-42(1), H-42(2), H-74, H-66(2), H-72(2) have been obtained having desirable qualities. H-41(2) resulted from a cross between a Japanese cultivar and an indigenous one; H-42(1) and H-42(2) result from crosses between local cultivars and an American cultivar. In trials with six replications these had tuber yields ranging from 21.5 to 37.2 tons per hectare as compared with local control cultivars with a yield range from 6.8 to 20.8 tons per hectare. Spacing was 30cm x 45cm and N, P, and K were applied at 75, 40 and 40 kg/ha respectively. The new hybrid clones produced tubers of large to medium size of excellent quality which cook well and have good storage quality. They also possess a very high degree of field resistance to sweet potato weevil (*Cylas formicarius*), a serious and wide-spread pest of the crop¹³. Additional important features of these hybrids are their wide adaptability to climatic variation, and they can be grown throughout the year on an economic basis. All three hybrids have now been released for commercial cultivation.^{4,5,11}

SOME CYTOGENETICAL ASPECTS OF SWEET POTATO BREEDING

Studies of a fundamental nature and of potential value in sweet potato breeding have been carried out at some research centres in the country. Significant is the karyological analyses of diploid, tetraploid and hexaploid species of *Ipomoea*¹⁴. The small size of mitotic chromosomes in these species was a constraint until successful karyological analyses at pachytene stage were obtained with the American diploid species, *Ipomoea crassicaulis*³. In this species, all the 15 bivalents could be individually identified at pachytene, and by utilizing the criteria of total length, relative length, position of centromere, size, shape and distribution of chromomeres, lengths of dark and light-staining regions and nucleolar association, detailed diagnostic features of all the chromosomes belonging to the haploid complement could be established.

Such studies have been able to be extended to the hexaploid sweet potato despite its extremely high chromosome number, $2n = 90$. Cytological information from such studies⁸ referred not only to the karyological make-up of sweet potato but also to an understanding of genomic homology. General agreement in the gross pattern of the chromosome morphology of diploid and hexaploid *Ipomoea* species was apparent in pachytene chromosomes. Forty out of the 45 haploid chromosomes of sweet potato were identified and classified into three groups based on the position of the primary constrictions. Eight metacentric types, three sub-metacentric types and eight acrocentric types were recognized and to these 19 types all the 40 chromosomes could be assigned. Homological studies at pachytene brought out a maximum multivalent association of $1^{\text{VI}} + 2^{\text{V}} + 3^{\text{IV}}$. The multivalents were predominantly quadrivalents ranging from 1 to 4. The hexavalents never exceeded one per cell but could be assigned to two distinct types. Pentavalents were relatively rare and numbered one or two. The outstanding observation, at pachytene, in respect of chromosomal association was the discovery of hexavalent association for the first time and being able to identify the participating chromosomes. These studies provide clues to the origin and genomic interrelationships of the hexaploid sweet potato. Eight chromosomal types that are each represented by a single bivalent type in the haploid complement are apparently not common to all the three genomes. Six chromosomal types which occur in duplicate are common to two out of the three genomes and two triplicated chromosomal types are present in all the three genomes. The occurrence of hexavalents and the frequent formation of quadrivalents, reflects the prevalence of chromosomal homeology between the constituent genomes. Thus, it is suggested that (i) the three parental genomes are partly homeologous, (ii) two of the genomes show closer homeology to one another than to the third and (iii) the three genomes all differ from each other with respect to one or more of the eight chromosomal types which occur singly. This cytological information suggests a segmental allopolyploid origin for the sweet potato and that the parental genomes are from closely related taxa^{7,8}. A translocation and an interstitial inversion were also observed at pachytene. These indicate the existence of chromosomal structural changes in sweet potato. Both vegetative propagation and the high genetic buffering due to hexaploid nature are conducive to the preservation and propagation of chromosomal aberrations.

CHROMOSOMAL DIFFERENTIATION AT DIPLOID LEVEL

Investigations have been also conducted on diploid taxa of *Ipomoea*. In addition to *I. crassicaulis*, the diploid species of *I. biloba*⁹ and *I. paniculata*¹⁰ were also subjected to pachytene analyses. Comparison of the pachytene karyotypes of these species permitted the estimation of chromosomal differentiation at diploid level and its role in speciation. Comparison of the karyotypes of *I. crassicaulis* and *I. biloba* revealed homology between eight chromosomes in the two complements. Our data support those of Jones and Kobayashi² based upon metaphase studies. Of interest, phylogenetically, was the recognition of karyological differentiation between two collections of *I. paniculata* which were morphologically similar¹⁰.

ORIGIN OF TETRAPLOID IPOMOEA SPECIES

In a naturally occurring tetraploid form of *Ipomoea biloba*, data from pachytene analyses proved valuable in explaining how such forms could be bridging between many diploid species and the hexaploid sweet potato.¹⁶ Both diploids ($2n = 30$) and tetraploid ($2n = 60$) forms of *I. biloba* occur along the western coast of the country with sympatric distribution. Morphological differences between these are few, but chromosomal association studies at metaphase-I, as well as the pairing behaviour of marker chromosomes at pachytene, pointed to a segmental allopolyploid origin of the tetraploid form and confirmed the direct role played by diploid taxa in its origin.

REFERENCES

1. Gustafsson, A. and Gadd, I. (1965) Mutations and crop improvement. II. *Ipomoea* (L.) Polr (Convolvulaceae). *Hereditas* 53, 77-888.
2. Jones, A. and Kobayashi, M. (1969) Interspecific hybrids of *Ipomoea pescaprae* and *I. crassicaulis*. *Bot. Gaz.* 130, 164-6.
3. Krishnan, R., Magoon, M.L. and Vijaya Bai, K. (1969) The pachytene chromosomes of *Ipomoea crassicaulis*. *Theoretical and Applied Genetics (TAG)* 39, 274-8.
4. Magoon, M.L. (1967) Role of root and tuber crops in human nutrition. *Proc. Int. Symp. Sub-trop. and Trop. Hort.* New Delhi. 1, 46-61.
5. Magoon, M.L. and Krishnan, R. (1971) Genetic improvement of tuber crops in India. *Proc. 2nd Int. Symp. Sub-trop. and Trop. Hort.*, Bangalore. 2, 1-20.
6. ——— (1972) Plan and prospects for the improvement of tuber crops (other than potatoes). *Proc. All-India Symp. Advances in Cytogenetics*, Srinagar. 1, 1-19.
7. ——— (1971) Problems on the elucidation of genomic evolution in some important tuber crops. *Proc. Symp. Genomic Concept in Eukaryota*, Indian Sci. Congr. Calcutta.
8. Magoon, M.L., Krishnan, R. and Vijaya Bai, K. (1970) Cytological evidences on the origin of sweet potato. *Theoretical and Applied Genetics (TAG)* 40, 360-6.
9. ——— (1972a) Pachytene karyology of *Ipomoea biloba*. *Cytologia* 37, 335-43.
10. ——— (1972b) Chromosomal differentiation in the genus *Ipomoea*. *Tropical Root and Tuber Crops Newsletter* 5.
11. Magoon, M.L., Nair, S.G., Krishnan, R. and Mandal, R.C. (1970) Three promising high yielding hybrids of sweet potato. *S.A.B.R.A.O. Newsletter (Japan)* 2, 115-8.
12. Magoon, M.L. and Sinha, S.K. (1967) Non-conventional foods — Importance of subsidiary root and tuber crops in India. *Proc. Joint Symp. Sci. and India's Food Problem Natl. Inst. Sci. and I.C.A.R.*, New Delhi.
13. Pillai, K.S. and Magoon, M.L. (1969) Studies on chemical control measures for sweet potato weevil, *Cylas formicarius* F.B. *Ind. Jour. Hort.* 26, 202-8.
14. Sharma, A.K. and Datta, P.C. (1958) Cytological investigations on the genus *Ipomoea* and its importance in the study of phylogeny. *The nucleus*. 1, 269-75.
15. Singh, H.B. (1964) Cultivation of sweet potato. *Farm Bulletin No. 4, New Series. I.C.A.R.*, New Delhi. 32 pp.
16. Vijaya Bai, K., Magoon, M.L. and Krishnan, R. (1969) Cytological and morphological studies of diploid and tetraploid species of *Ipomoea biloba*. *Jap. Jour. Genet.* 44, 329-38.

BREEDING TECHNIQUES, HERITABILITIES, INSECT RESISTANCE AND OTHER FACTORS AFFECTING SWEET POTATO BREEDING

S.D. Thibodeaux, Teme P. Hernandez and Travis P. Hernandez*

SUMMARY

A substantially higher percentage of progenies was within the acceptable range for most horticultural characters in crosses of parents which themselves have desirable phenotype. Selection pressure for skin and flesh colour can be made at an early selection stage of seedling growth. The honeybee and the bumblebee were the most efficient pollinating insects in a polycross nursery and showed preferences for profusely flowering cultivars. The flowers of breeding parents could be grouped on the basis of flower colour, size of corolla and position of stamens in relation to flower stigma. Centennial and ten other cultivars have their stamens below the stigma and cross pollination is necessary for seed set. Centennial was poorly compatible with ten new breeding parents used in breeding at Baton Rouge.

RESUME

On rencontre un pourcentage nettement plus élevé de descendants dans la série acceptable pour la plupart des caractéristiques d'horticulture dans des croisements de parents qui eux mêmes possèdent un phénotype désirable. La pression de sélection pour la peau et la carnation peut être faite très tôt au moment de la sélection de croissance des plantules. Les abeilles domestiques et les bourdons sont des insectes de pollinisation les plus efficaces dans une pépinière de croisements multiples et sont plus attirés par les cultivars qui fleurissent abondamment. On peut grouper les fleurs des parents en cours de sélection en fonction de la couleur des fleurs, de la dimension de la corolle et de la position des étamines par rapport au stigmate. Le Centennial et six autres cultivars ont leurs étamines en dessous du stigmate, ce qui rend la pollinisation croisée nécessaire pour la formation des graines. Le Centennial est peu compatible avec dix parents nouveaux en cours de sélection à Baton Rouge.

RESUMEN

Un porcentaje substancialmente más alto de progenies estuvo dentro del rango aceptable de la mayoría de los caracteres hortícolas de cruza de padres con fenotipo deseable. La selección por color de la cáscara y de la pulpa se pueden hacer en etapas tempranas del desarrollo de las plántulas. Las abejas y los abejorros fueron los insectos polinizadores mas eficientes en un vivero para policruzas, mostrando preferencia por los cultivares que florecieron mas profusamente. Las flores de los padres hibridados pudieron ser agrupadas sobre la base de: color, tamaño de la corola y posición de los estambres en relación al estigma, lo que hace necesaria la polinización cruzada para la producción de semilla. Centennial fué poco compatible con diez nuevos padres híbridos.

INTRODUCTION

The polycross system³ of breeding as employed at Louisiana State University utilized additive gene effects by recurrent selection as well as employing the concept of homeostasis in assessing adaptation. Use is also made of epistasis and of the inheritance of major genes. As broad a gene base as possible is maintained.

Genetic characters for good horticultural traits have been selected since the inception of the sweet potato breeding programme in 1937, and most parental material is of such improved type. Only selected genotypes are used in the breeding nurseries for crossing by insects. Consideration is given to incompatibility groups in the establishment of nursery planting plans. *Ad hoc* nurseries have been used in the polycross system to breed for resistance to soil rot, soil insects, rootknot nematodes, other diseases and good horticultural characters^{3,7,8}. For genetic studies controlled crosses have been used^{1,2,3}.

It would be possible even with a low level of compatibility to obtain seed populations of sweet potato from known parents provided that the resources existed to make a large number of hand crosses. The polycross system on the other hand, using highly mobile insects as pollinators, affords the chance to obtain seed populations much more easily, but crosses are all of uncertain parentage.

*Louisiana State University, Baton Rouge.

MATERIALS AND METHODS

In this study pollinating insects were classified by their efficacy as pollinators and the effects of temperature on insect activity were studied. Floral colours were classified following Maerz and Paul⁴. Colours were assessed at the midpoint of the throat and on the external corolla.

Measurements were taken of corolla length and maximum width. The mean data for 10 fully opened flowers of each cultivar were calculated for flowers produced on plants growing at 80° F.

Ten flowers of each parent were classified for stamen position. If two or more flowers differed, the average condition was recorded, followed by an indication of variation.

Crosses were made between P.I. 343721 x W15-2, W15-2 x Centennial, and W51 x Centennial, to study the distribution among seedlings of skin and root colours. P.I. 343721 is a parental line introduced from East Africa and has a purple skin and a white flesh colour. W15-2 and W51 were received from the U.S. Breeding Laboratory, Charleston, South Carolina, and they contain carotenoid pigments. W-15-2 has a rose skin colour and W51 has a tan skin colour. Centennial is a cultivar released by Louisiana⁹.

Segregating seedling progenies from hand crosses between P.I. 343721 x W15-2 and W15-2 x Centennial were compared for genetical performance in seedlings with good horticultural characters.

The pollination technique used was similar to that used by Hernandez *et al.*³ Horticultural characters of seedlings in the above progenies were scored as follows: skin colour 1–6, representing the range white to purple, respectively; leaf shape 1–5, representing entire to deeply lobed; flesh colour 1–5, representing zero to very high carotenoid pigments; yield 1–5, representing very low to very high; root shape 1–5, representing very rough to very smooth; vine length 1–5, representing dwarf to very long; vine thickness 1–5, representing very small to very large; plant production 1–5, representing very poor to very good; storage ability 1–5, representing very poor to very high; and vine terminal colour 1–5, representing green to dark purple. Baking quality was determined using an average of several ratings in a scale of 1–10 with 10 representing the most favourable expression of characters for flesh colour, flavour, texture and fiber content. Parental cultivars were rated concurrently with seedlings.

The technique of handling polycrossed seedlings was similar to that for seedlings from hand crosses.

Fifteen breeding parents and other cultivars were planted in 8 replicated tests in 1971 using 10 plants per plot. Bedding roots of Centennial inoculated with sweet potato weevils were planted in rows on either side of each plot in this test. At harvest time roots of each cultivar were rated for horticultural characters and weevil infestation.

All data were analyzed in accordance with Stansfield¹².

RESULTS AND DISCUSSION

Insect pollinators of sweet potato flowers in Louisiana include an assemblage of leaf eaters, nectar feeding and predatory insects. Insects identified as pollen vectors were: (1) bumblebees (*Bombus* spp.); (2) honeybees (*Apis mellifera*); (3) digger bees (*Melissodes* spp.); (4) vespids wasps (*polistes* spp.); (5) bee killer wasp (*Philanthus ventrilabrus*); (6) brush footed butterfly (*Agraulis vanillae niger*); (4) skippers (*Lerema accivus*); (8) swallow tail butterfly (*Battus philenor philenor*); (9) sulfur butterfly (*Phoebus sennal ebule*); (10) milkweed butterfly (*Danaus blexippus*); (11) cucumber beetle (*Diabrotica balteata*); (12) soldier beetle (*Chauliognathus marginatus fabricatus*); (13) assassin bug (*Zebis bilobus*). All these insects had pollen on their bodies and moved from flower to flower to obtain nectar or to prey on others. Data for 8 consecutive weeks in September and October 1971 on each breeding parent showed that honeybees and bumblebees were the predominant visitors. The highest insect counts were associated with parents that bloomed most profusely. Thus, parents that flower profusely are flavoured with respect to crossing. Average daily body pollen count per insect was 130 on bumblebees, 397 on honeybees. The average daily pollen count on the bodies of other insects ranged from 3 to 28.

The mean number of pollen grains found on the stigmas of emasculated flowers was greatest at temperatures between 70 and 86° F when bumblebee and honeybee population and activity were at their highest.

W15-2, W51, and L6-5 were found to be compatible with Centennial, but L3-66, L3-64, L3-217, L9-23, L8-343, L9-192, L9-190 and L9-163 had low compatibility or were completely incompatible with it. Other workers^{5,6,13} have reported on incompatibility in the sweet potato. In this study a new form of incompatibility was found in which seed with normal endosperms but lacking embryos, arose in the cross between W51 x Centennial.

The method of handling polycross seed from the breeding nurseries was similar to that described by Hernandez *et al.*³ In this study, seedlings grown in the greenhouse from true seed were planted in January, 1971, and harvested and scored for flesh and skin colour in May, 1972, when the fleshy roots were one to two inches in diameter. Each seedling was transplanted into the field and again rated for flesh and skin colour in September. The frequency distribution for these characteristics was essentially the same for the ratings on May 5, 1972 and September 5, 1972, as shown in Table 1. This indicates that early selection is

practicable. In 10 years an average of approximately 90 percent of the seedlings have been discarded as phenotypically inferior in the first selection screening.

Progenies of two crosses, P.I. 343721 x W15-2 and W15-2 x Centennial, were grown and evaluated. Each seedling was vegetatively propagated and planted into a replicated test. Heritability values were computed for each of 11 genetic characters comparing crosses of W15-2 and P.I. 343721 with Centennial (Table 2,3).

Heritability in this study was in the broad sense involving all types of gene action^{10,11}.

In the cross of P.I. 343721 x W15-2, flesh colour, root shape and fleshy root exterior had low heritability, whereas in the cross W15-2 x Centennial heritability was medium to high as shown in Table 2. Skin colour, leaf shape, number of fleshy roots, vine length, storage ability, baking index, and vine colour were all medium to highly heritable in both progenies.

Fifteen cultivars were grown in an eight replicated test using 10 foot plots. These were exposed to heavy insect pest pressure, especially sweet potato weevil (*Cylas formicarius elegantulus*) in cooperation with Dr. Edmon Kantack, entomologist. Data in Table 4 show that the cultivars L3-64, Heartogold, P.I. 343851, P.I. 343721, W15-2, W19-2 and W51 have varying levels of resistance to sweet potato weevil.

The cultivars were grouped on the basis of colour and size of corolla of flowers and position of stamen in relation to stigma of flowers. Centennial, L0-240, L3-92, L3-217, L4-89, L8-67, L8-71, L9-159, L9-190, L9-219, and L9-47 have their anthers below the stigma, and hand pollination is a virtual necessity. Forty-seven other cultivars were classified as having anthers with stamens superior, equal or slightly sub-equal in relation to the stigma of the flowers. The corolla width of the flowers of the breeding parents varied from 5.6 cm for W15-2 to the smallest of 3.3 cm for L7-177.

REFERENCES

1. Harmon, S.A., Hammeth, H.L., Hernandez, T. and Pope, D.T. (1970) Progress in the breeding and development of new varieties. Thirty years of cooperative sweet potato research (1939-1969). Bul. No. 159, 8-17.
2. Hayes, H.K., Immer, F.R. and Smith, D.C. (1955) *Methods of Plant Breeding*. 2nd Ed. New York. McGraw Hill Book Co., Inc. 551 pp.
3. Hernandez, T.P., Hernandez, T., Constantin, R.J. and Kakar, R.S. (1967) Improved techniques in breeding and inheritance of some of the characters in the sweet potato, *Ipomoea batatas* L. Proc. Int. Symp. on Tropical Root Crops. 1, 31-49.
4. Maerz, A. and Paul, M.R. (1950) *A Dictionary of Color*. 2nd Ed. New York. McGraw Hill Book Co., Inc. 250 pp.
5. Martin, F.W. (1967) The sterility-incompatibility complex of the sweet potato. Proc. Int. Symp. on Tropical Root Crops. 1, 3-15.
6. Martin, F.W. and Ortiz S. (1967) Anatomy of the stigma and style of sweet potato, *New Physiologist* 66, 109-133.
7. Martin, W.J. and Hernandez, T.P. (1966) Multiple disease resistance in sweet potato selections. *Phytopath.* 56, 888. (Abstr.)
8. Martin, W.J., Nielson, L.W. and Morrison, L.S. (1970) Diseases. Thirty years of cooperative sweet potato research (1939-1969) Bul. No. 159. 46-71.
9. Miller, J.C., Hernandez, T.P., Hernandez, T. and Martin, W.J. (1960) Centennial, a new sweet potato variety. La. Ag. Exp. Sta. Circular No. 63.
10. Sprague, G.F. (1966) Quantitative genetics in plant improvement. In *Plant Breeding*. Ames, Iowa. Iowa State University Press. 315-366.
11. Sprague, G.F., Russell, W.A. and Penny, L.H. (1959) Recurrent selection for specific combining ability and type of gene action involved in yield heterosis. *Corn. Agron. Jour.* 41, 392-4.
12. Stansfield, W.D. (1969) *Theory and Problem of Genetics*. Schaum's outline series. New York. McGraw Hill. 281 pp.
13. Williams, D.B. and Cope, F.W. (1967) Notes on self-incompatibility in the genus *Ipomoea* L. Proc. Int. Symp. on Tropical Root Crops. 1, 16-30.

TABLE 1

A comparison of selection techniques of polycrossed seedling progenies at two time periods, May 5, 1972 and September 5, 1972

Maternal Parent	White	Skin colour (% seedlings)					Flesh colour* (% seedlings)			
		Cream	Tan	Copper	Rose	Purple	1	2	3	4
		May 5, 1972					May 5, 1972			
P.I. 343721	41.3	7.2	7.9	38.5	5.0	0	77.5	19.6	2.9	0
W15-2	34.7	13.9	11.1	30.5	9.8	0	66.6	11.1	19.4	0
Centennial (L3-77)	0	24.3	28.9	45.8	1.0	0	7.9	37.8	37.1	18.0
L8-343	0	45.1	15.8	39.0	0	0	0	14.8	80.4	4.7
L3-66	0	24.5	17.2	54.3	0	0	26.3	12.9	55.3	5.3

Reclassified September 5, 1972										
P.I. 343721	47.1	7.2	7.9	38.5	5.0	0	76.8	20.2	2.9	0
W15-2	38.8	16.6	4.1	30.5	9.8	0	73.6	6.9	19.4	0
Centennial (L3-77)	0	26.4	27.0	45.8	1.0	0	6.9	34.0	37.1	21.9
L8-343	0	46.3	14.6	39.0	0	0	0	14.8	79.2	6.0
L3-66	0	27.9	17.7	54.3	0	0	25.0	12.8	56.4	5.8

* Flesh colour: 1 is white and 4 is high total carotenoids.

TABLE 2

Mean, standard deviation and broad sense heritability¹² for 14 horticultural characters of three sweet potato progenies grown 1971-72

Horticultural character	PI 343721 x W15-2			W15-2 x Centennial			**W51 x Centennial		
	*Mean	S.D.	h ² †	*Mean	S.D.	h ²	*Mean	S.D.	h ²
Skin colour	3.82	.0035	.51	4.3	.00033	.68	3.5	.0025	.43
Leaf shape	1.64	.00014	.84	1.5	.00028	.97	1.4		
Flesh colour	1.75	.00058	.13	2.8	.0004	.51	2.9	.0039	.52
Yield	1.96	.00075	.08	3.1	.00014	.008	1.2	.01	0
Yield (number roots)	0.71	.00033	.32	8.7	.0005	.61	0.3	.0004	.72
Root shape	3.53	.0012	.04	3.0	.0001	.62	3.1	.0039	.27
Vine length	3.14	.0005	.42	2.8	.0003	.96	2.4	.0004	.83
Storage ability	1.41	.0005	.33	3.9	.00039	.54	3.1	.0043	.49
Baking index	1.5	.0057	.22	6.9	.00041	.71	5.9	.0036	.47
Vine colour	2.1	.000005	.96	3.3			2.2		
Vine colour terminal	1.64			3.2			1.5		
Fleshy root exterior	1.95	.0021	0	3.9	.0019	.67	3.7	.0009	.49
Vine thickness	3.2			3.3			2.5		
Pubesence				0.5			0		

* The higher the digital expression, the more favourable the horticultural characters, except for root shape with the 3 rating representing the optimum.

** Data of progeny of W51 x Centennial included in this table but no in the text of paper.

† Ratio of genetic gain to selection differential ($\Delta G/\Delta P$), (Reference 12, p.228-9). 0.5 high, .25 medium, 0.2 low heritable biometric traits.

TABLE 3

A comparison of progenies of control crosses as to distribution of segregating seedlings for skin and flesh colour

Parental crops	No	Flesh colour* (%)				
		1	2	3	4	
PI 343721 x W15-2	85	23.6	62.5	13.9		
W15-2 x Centennial	125		17.2	51.9	31.9	

		Skin colour (%)				
		White	Cream	Tan	Copper	Rose Purple
PI 343721 x W15-2	38.8	17.9	4.2	8.4	25.0	5.6
W15-2 x Centennial	0	38.7	19.8	39.6	1.7	0

* Flesh colour: 1 = white; 4 = high total carotenoids

TABLE 4

A comparison of cultivars as to resistance to insects*

Cultivar	Banded cucumber beetle**	Pale striped flea beetle**	Wireworm	Sweet potato flea beetle	Sweet potato weevil	Grubs	+Baking Index
Centennial	50.63	79.12	0.00	18.88	88.75	5.00	7.00
L3-64	12.50	20.25	3.50	12.38	7.38	0.0	6.40
L4-89	27.25	41.25	0.0	20.50	83.25	0.0	6.33
Heartogold	15.00	8.50	0.0	0.0	8.50	0.0	6.05
L8-71	182.43	159.00	2.50	15.88	270.25	6.25	7.00
L8-164	77.38	61.13	3.63	20.75	88.50	7.13	5.95
L3-66	98.14	150.00	3.14	29.86	183.57	9.14	6.13
W19-2	31.00	15.25	0.0	8.13	34.38	0.0	6.03
W51	30.38	14.00	0.0	8.38	61.63	1.25	5.78
W15-2	31.38	18.38	0.0	0.0	45.13	0.0	6.23
W26-2	14.57	12.43	0.0	0.0	21.29	0.0	4.10
W2-361	6.38	5.00	2.63	0.0	19.50	0.0	2.63
PI 343851	86.25	20.63	0.0	0.0	9.63	0.0	2.35
PI 343721	11.25	39.63	7.00	10.88	12.88	0.0	2.10
NCVQ	19.38	28.13	3.50	10.25	143.00	0.0	1.70

* Cultivars rated for insect damage in each of 8 replications by Dr Edmon Kantack, Entomology Department.

** Significant at the .01 and .025 level; the lower the indices, the more resistant are the cultivars. +Baking index - 10 represents most favourable reading.

EDIBLE AROIDS – NEW INSIGHTS INTO PHYLOGENY

R. Krishnan and M.L. Magoon*

SUMMARY

The New World *Xanthosoma sagittifolium* ($n = 13$) and the Old World *Amorphophallus campanulatus* ($n = 14$) and *Colocasia antiquorum* ($n = 14$) seem to have a lower base number than previously realized. Evidence for this comes from two heteromorphic bivalent associations recognized at pachytene, intragenomic pairing at metaphase-I and chromosomal counts in pollen of naturally occurring triploid *Colocasia*. Supporting evidence arises from studies of the control of desynapsis in diploids and triploids and from ecogeographical specialization and cytotaxonomic data of related aroid taxa. The value of these findings and the special problems that they create for conventional approaches to phylogenetic study of the aroids are discussed.

RESUME

Xanthosoma sagittifolium ($n = 13$) du Nouveau Monde et *Amorphophallus campanulatus* ($n = 14$) du Vieux Monde, de même que *Colocasia antiquorum* ($n = 14$) ont vraisemblablement un nombre de bases inférieur aux estimations antérieures. Deux associations hérétomorphiques bivalentes reconnues à l'accouplement pachytène et intragénomique à la métaphase-I et le chifrage des chromosomes dans le pollen de *Colocasia* triploïde naturel en donnent la preuve. Cela se confirme par des études menées pour contrôler la désynapse dans les diploïdes et les triploïdes et par la spécialisation écogéographique de même que par des données cytotaxonomiques de groupes arôides parentés. La valeur de ces découvertes et les problèmes particuliers qu'elles posent aux méthodes conventionnelles d'étude phylogénétique d'arôides sont en cours de discussion.

RESUMEN

Xanthosoma sagittifolium, del Nuevo Mundo, ($n = 13$) y *Amorphophallus campanulatus* ($n = 14$) y *colocasia antiquorum* ($n = 14$) del Viejo Mundo parecen tener un número básico de cromosomas menor del que había sido determinado. La evidencia de esto se deriva de dos asociaciones heteromórficas bivalentes reconocidas en fase de paquíteno, apareamiento intragenómico en metafase-I y conteos cromosómicos en polen de triploides naturales de *Colocasia*. La evidencia que soporta tal situación resulta de estudios de control de desinapsis en diploides y triploides y de la especialización ecogeográfica y datos citotaxonomicos de formas aráceas relacionadas. Se discute el valor de estos descubrimientos y los problemas especiales que crean a los enfoques convencionales sobre el estudio filogenético de las aráceas.

INTRODUCTION

Knowledge of the phylogeny of crop plants by throwing light on past evolution may provide a useful insight into the prospects for future genetic transformation and assist the formulation of breeding programmes.

Aroid genera of economic importance such as *Colocasia*, *Xanthosoma*, *Alocasia*, *Amorphophallus* and *Cytosperma* have received little attention from students of evolution. The edible aroids are well adapted to a variety of environments and under proper management conditions can give very high yields^{1,12,14}.

Because of the antiquity of their cultivation, plurality of uses and multiplicity of habitats of cultivation, a large diversity exists among the cultivated forms of *Colocasia*, *Xanthosoma* and other edible aroids. Cytotypes have been reported within the species¹⁴.

The poor flowering of these crops, while of no importance to production of the edible crop, hinders study of phylogeny. It would be helpful if ways could be found to improve this. The existing taxonomic treatment of the edible aroids is controversial, and this also hinders phylogenetic studies. Cytological investigations seem particularly useful in attempts to understand phylogeny and we have therefore concentrated our effort in this direction.

KARYOLOGICAL STUDIES IN *Amorphophallus campanulatus* AND *Xanthosoma sagittifolium*

The chromosomes are readily stainable. We have assessed the relative merits of the three commonest stages for chromosome studies, namely pollen metaphase, mitotic metaphase in root tip cells and pachy-

*Indian Grassland and Fodder Research Institute, Jhansi, (U.P.) India.

tene analyses in meiosis. In *A. campanulatus* the haploid set is $n = 14$ at root and pollen mitosis. The chromosomes could be separated into six types, including two nucleolar chromosomes. However, at pachytene all the 14 chromosomes of the haploid complement could be individually identified on the basis of relative length, nucleolar association, centromere position and total lengths of hetero- and euchromatin segments in the bivalents. Thus we stress the particular value of pachytene analysis.

INTER- AND INTRA- KARYOLOGICAL COMPARISONS IN *Amorphophallus* AND *Xanthosoma*

We have made intra- and inter- karyological comparisons of representatives of two aroid genera, *Amorphophallus* and *Xanthosoma*. The pachytene karyotypes of these exhibited a number of similarities^{5,6}. Two nucleolar chromosomes were present in each genus and they showed remarkable similarity in morphology. The nucleolar chromosomes of these aroids have a heteropycnotic short arm in intimate association with the nucleolus. Two other chromosomes with heteropycnotic short arms also occur in the karyotypes of both genera. It is remarkable that genera of the New World and the Old World aroids have such close karyological similarities.

Likewise, intra-karyological comparisons revealed similarity among several chromosomes in their morphology. In *x. sagittifolium* all the 13 bivalents at pachytene could be assigned to 12 types (A to L) with two similar bivalents in type B. The two type B bivalents were metacentric and rather similar to bivalent type C. The two nucleolar chromosomes, K and L were also homomorphic. Two non-nucleolar bivalents had a heteropycnotic short arm and the other bivalents, types A and I were submetacentric. Similarly, in *A. campanulatus* homomorphic bivalents included the two nucleolar chromosomes, and two non-nucleolar chromosomes with heteropycnotic short arms (chromosomes 3 and 10 and 7 and 11). Thus, in *x. sagittifolium* ($n = 13$) of the twelve chromosomal types distinguished at pachytene, eight of them including the two type B could be regarded as homeologous reducing the basic number to $N = 8$. Similarly in *A. campanulatus* eight of the bivalents could be regarded as homeologous which would reduce its basic number to $n = 10$.

COMPARATIVE KARYOLOGICAL AND CYTOLOGICAL STUDIES IN DIPLOID AND TRIPLOID *Colocasia* AND OTHER AROIDS

In the triploid *C. esculenta* ($3n = 24$) pachytene study, along with data on chromosomal association at metaphase-I and chromosomal counts in pollen provide clues that strongly support some basic numbers¹⁷. Diploid *C. esculenta* was investigated and found to have two nucleolar-associated bivalents at pachytene, like those of *Amorphophallus* and *Xanthosoma*. The occurrence of two such nucleolar trivalents with morphologically similar partners as well as high frequency of trivalent association at metaphase-I, suggests an autotriploid origin for triploid *Colocasia*. In this triploid intra-genomic pairing occurred involving one or two chromosomes in as many as 21.6% of pollen mother cells at diakinesis and two heteromorphic bivalent types were identified at pachytene. Thus studies on *Colocasia* provide direct evidence for a lower base than gametic number, in comparison with the less direct data for the same conclusion reached in *Xanthosoma* and *Amorphophallus*.

In *Colocasia*, chromosomal counts in the pollen of both triploids and diploids as well as fertility data provide additional proof in support of a lower base number than the gametic number. Although both diploids and triploids produce pollen of similar size, they are dissimilar in the chromosomal status of their pollen cells. The pollen of triploid plants contained a variable chromosome number ranging from 8 to 25: that of diploid plants contained uniformly 14. The number of triploid pollen carrying less than the 8, the base number, was low, accounting for only 3.5 percent of pollen mother cells seen at prophase or metaphase.

A review of the chromosomal status of some other Aracean genera reveals the existence of other taxa with low basic number. Among them those having low haploid numbers of $n = 7, 8$ and 9 are *Acorus* ($n = 9$), *Calla* ($n = 7$ and 9), *Aglaonema* ($n = 8$), *Dieffenbachia* ($n = 8$ and 9) and *Typhonium* ($n = 8$ and 9). The genus *Typhonium*^{3,4} is interesting because in the three species *Typhonium cuspidatum* ($n = 8$), *T. trilobatum* ($n = 9$) and *T. inapinatum* ($n = 13$), the former two each have one nucleolar chromosome whereas *T. inapinatum* has two such chromosomes in its haploid complement⁶. The number of nucleolar chromosomes in this genus seems to reflect the ploidy status. As a parallel, we have found in each of the genera *Amorphophallus*, *Colocasia* and *Xanthosoma* two nucleolar chromosomes.

Chromosomal counts reported for various cultivars (clones) of edible aroids have been widely different. In *Colocasia* the numbers reported included 14, 22, 24, 26, 28, 29, 38 and 42¹⁴. *Amorphophallus* has $n = 26$ or 28 and *Xanthosoma* $2n = 24, 26$ or 39 . A systematic and thorough screening of edible aroids may reveal new chromosomal races of value in breeding and further phylogenetic understanding. Ecogeographical specialization, and vegetative propagation over centuries of cultivation have strongly influenced chromosomal evolution favouring preservation of the cytotypes of clones selected for value in cultivation under different ecological conditions.

STUDIES ON DESYNAPSIS IN AROIDS

Among various abnormalities of chromosome behaviour desynapsis has been a subject of great interest and is better understood than are the genetic mechanisms exerting control over processes of meiosis. Information on the genetic control of desynapsis has been obtained from direct and indirect studies in several angiospermic taxa¹³. Desynapsis has been found to be usually due to one or a few pairs of recessive genes.

In the Araceae desynapsis has been reported in some cultures of *Amorphophallus campanulatus*¹³ and *Colocasia antiquorum*⁷. Although both these taxa were diploids, the degree of desynapsis in them differed markedly. The former was classed according to the classification of Prakken¹⁵, as 'medium strong' type and the latter as 'complete' desynapsis. Desynapsis of the 'complete' type was also reported in a triploid cultivar of *Colocasia antiquorum*⁸ which showed several differences in chromosome behaviour in comparison with the diploids.

On the available evidence, it seems that the origin of these desynaptic cultivars in the family Araceae results from spontaneous gene mutation. Such cultivars may prove useful for genetic studies on the inheritance of the trait. Such studies in turn may throw light on the mechanisms underlying chromosomal pairing and chiasma formation in meiotic prophase and hence relate to the possibilities for genetic recombination.

POLYPLOID ORIGIN OF EDIBLE AROIDS

The evidence presented on the polyploid origin of edible aroids, though somewhat indirect, is all mutually supporting. Taking a long term view on the breeding of edible aroids, the impact of these findings of cryptic polyploidy may have considerable significance since appropriate plant breeding procedures for true diploids are different from those for polyploids^{9,10,11}. It is possible that further investigations will throw light on the relation of the various cytotypes to potential productivity.

REFERENCES

1. Coursey, D.G. (1968) The edible aroids. *Wld. Crops*. 20, 25–30.
2. Jos, J.S., Vasudevan, K.N. and Magoon, M.L. (1967) In vitro germination of pollen in aroids. *Ind. Jour. Hort.* 24, 166–72.
3. ——— (1968) Structural hybridity in *Typhonium cuspidatum* Genet. Iber. 20, 1–11.
4. Jos, J.S. and Magoon, M.L. (1970) Pollen mitotic studies in some aroids. *Chromosome Inf. Serv. (Japan)* 11, 4–5.
5. Krishnan, R. Magoon, M.L. and Bai, K.V. (1970a) Karyological studies in *Amorphophallus campanulatus* *Canad. Jour. Genet. and Cytol.* 69, 187–96.
6. ——— (1970b) Cytological studies in *Xanthosoma sagittifolium* (L) Schott. *Nucleus* 13, 141–7.
7. ——— (1970c) Desynapsis in *Colocasia antiquorum* Schott. *Genetica* 41, 170–8.
8. ——— (1970c) Meiosis in a desynaptic triploid *Colocasia antiquorum* Schott. *Genetica Agraria (Italy)*.
9. Magoon, M.L. and Krishnan, R. (1971a) Problems on the elucidation of genomic evolution in some important tuber crops. Proc. Symp. Genomic concept in Bukaryota, Indian Sci. Congr., Calcutta.
10. ——— (1971b) Genetic improvement of tuber crops in India. Proc. 2nd Int. Symp. sub-tropical and tropical Horticulture, Bangalore.
11. ——— (1972) Plan and prospects for the improvement of tuber crops (other than potatoes). Proc. All-India Symp. Advances in Cytogenetics, Srinagar. 1, 1–19.
12. ——— (1967) Role of root and tuber crops in human nutrition. Proc. Int. Symp. sub-tropical and tropical Horticulture, New Delhi. 1, 46–61.
13. Magoon, M.L. and Sadasivalah, R.S. (1967) Studies of desynapsis in *Amorphophallus campanulatus* Blume. *Genet. Iber.* 19, 1–12.
14. Plucknett, D.L., de la Pena, R.S. and Obrero, F. (1970) Taro (*Colocasia esculenta*). *Field Crop Abstracts*. 23, 413–26.
15. Prakken, R. (1943) Studies of asynapsis in rye, *Hereditas*. 29, 475–95.
16. Sharma, A.K. and Mukhopadhyay, S. (1965) Cytological study on two genera of Araceae and correct assessment of their taxonomic status. *Genet. Agraria*. 18, 603–16.
17. Vijaya Bai, K. Magoon, M.L. and Krishnan, R. (1970) Meiosis and pollen mitosis in diploid and triploid *Colocasia antiquorum* Schott. *Genetica* 42, 187–98.

POTATO BREEDING FOR RESISTANCE TO BACTERIAL WILT IN KENYA

S.K. Njuguna*

SUMMARY

Pseudomonas solanacearum (bacterial wilt) is a major limiting factor in potato production in Kenya. In 1971 research was initiated to select potato cultivars resistant to bacterial wilt, to identify sources of resistance and to develop and maintain a potato germplasm collection. Seedlings grown in polythene sleeves are infected by soil inoculation. Survivors are transplanted to an infected plot and interplanted with highly susceptible clones. Resistant, flowering individuals are intercrossed and resulting seedlings screened again during the next season. Selected individuals are cloned for retesting and selection as commercial cultivars.

RESUME

Pseudomonas solanacearum (flettrissement bacterien) est un facteur limitant majeur dans la production de la patate au Kenya. En 1971 des travaux de recherche ont été entrepris pour sélectionner des cultivars de patate résistants à cette maladie, pour identifier les sources de résistance et pour développer et entretenir une collection de plâsme germinatif de la patate. Les plantules cultivées dans des manchons polythènes sont infectées par l'inoculation du sol. Les survivantes sont repiquées sur une parcelle infectée et plantée en mélange avec des clones qui ont une sensibilité élevée. Les individus résistants et fleuris sont entrecroisés et les plantules qui en sont issues triées de nouveau pendant la saison suivante. Les individus sélectionnés passent au clone pour être testé de nouveau et sélectionnés sous forme de cultivars destinés au commerce.

RESUMEN

Pseudomonas solanacearum (marchitez bacterial) es uno de los principales factores limitantes de la producción de papa en Kenya. En 1971 se iniciaron las investigaciones para seleccionar cultivares de papa resistentes a la marchitez bacterial, identificar fuentes de resistencia y desarrollar y mantener una colección de germoplasma de papa. Se infectan plântulas, desarrolladas en mangas de polietileno, por inoculación del suelo. Los sobrevivientes se transplantan a un lote infectado y se intercalan con clones altamente susceptibles. Los individuos resistentes que florecen se intercrucan y la progenie resultante se selecciona, otra vez, durante la siguiente temporada. Los individuos seleccionados se propagan como clones para continuar pruebas de selección como cultivares comerciales.

INTRODUCTION

Potatoes in Kenya in 1971 occupied approximately 60,699 hectares, mostly between 1371 and 2742 meters altitude⁴. It is the second root crop to cassava in production. The climate of these areas is ideal for potato cultivation^{1,8}. Approximately 98 percent of potatoes are grown by small-scale and the remainder by larger scale farmers⁴. Two potato crops per year are commonly grown in Kenya. Nutritionally, the potato is as good as any other tropical root crop.¹² Presently, due to the changing of eating habit, ease of growing and of food preparation potato has become the most popular root crop in Kenya. According to the Ministry of Agriculture Annual Report⁵ potatoes give a higher return per hectare than maize, sunflower, cassava groundnuts, bean or sorghum. That the potato still has the status of a minor crop in Kenya is due partly to late blight (*Phytophthora infestans*), bacterial wilt (*Pseudomonas solanacearum*) and other problems of potatoes which were reviewed by Moreau⁶.

In Kenya bacterial wilt (*Pseudomonas solanacearum*) is severe and widespread between about 1400 and 2000 m.³ Approximately half of the potato crop in Kenya is grown within this altitude range. Late Blight (*Phytophthora infestans*) is more severe at higher altitudes (about 1800–2750 m). While cultivars with high resistance to late blight (*Phytophthora infestans*) have been introduced from temperate countries and some have been bred in Kenya, there is no commercial cultivar with resistance to bacterial wilt (*Pseudomonas solanacearum*).

BREEDING FOR RESISTANCE TO BACTERIAL WILT

In 1964 Robinson and Ramos⁹ reported that potato cultivation in Kenya would cease unless resistant cultivars were developed. No material under Kenyan conditions had sufficient wilt resistance, and it was

*National Agricultural Laboratories, Nairobi, Kenya

considered necessary to exploit the resistance that exists in *Solanum phureja* as reported by Thurston and Lozano¹³ or *S. phureja* x *S. tuberosum* hybrids.¹¹

However, not until September 1971 was a research project to develop commercial potato cultivars resistant to bacterial wilt initiated in Kenya. Other objectives of the programme were to detect sources of resistance and to develop and maintain germplasm that would be useful for future potato breeding in Kenya. The Potato Research Project in Kenya is a joint effort between the British and the Kenyan Governments.

Three thousand seeds of the interspecific hybrid between Colombian *S. phureja* x *S. tuberosum* were received from Dr. P.R. Rowe as shown in Table 1. Where possible, approximately 100 seeds of each cross were planted in sifted loam soil in the greenhouse. Poor germination or poor growth reduced the number of the test plants considerably (see Table 1). After 21 days, individual seedlings were transplanted to polythene sleeves, gauge 150, size 3¼" x 5". The polythene sleeves were filled with steam sterilized soil mixture of 3 parts loam soil, 1 part sand, 1 part compost or coffee hull and 1 part 1/8" ballast. Plants were held in the greenhouse benches for six weeks after transplanting and watered daily. Two weeks after transplanting each seedling was watered in 25 cc dilute solution of 'solufeed' containing nitrogen 22.4% W/W, phosphoric acid P₂O₅ (Soluble) 19.2%, and potash K₂O 16.0%.

A single strain of *Pseudomonas solanacearum* (biochemical type 2/race 3) attacks potatoes in Kenya³. Investigations on the most efficient screening technique carried out by Harris (personal communication) showed that soil inoculation four to six weeks after transplanting was superior to stem inoculation and that the 'susceptibility' of seedlings increases with age from four to six weeks. Hence, each seedling received 10 cc from the 10⁸ cells/ml suspension. The inoculated seedlings were placed outside and records were kept daily for four weeks on the incidence of wilting. Survivors were planted in an infected field which had been planted with highly susceptible clones the previous season. Wilting plants were recorded daily for a further 90–120 days after planting in the field. Progenies which survived and produced flowers were intercrossed and resulting seeds were screened in the same routine the following season.

RESULTS AND DISCUSSION

Preliminary results show that some progenies from crosses previously rated as resistant in Wisconsin by Rowe and Sequeira¹⁰ gave several survivors during the first season and from these 33 clones were selected as provisionally resistant (Table 1). Subsequent planting in a highly contaminated field reduced this to only thirteen clones. The other twenty were either susceptible to storage rot or wilted during the second planting. Among the thirteen resistant clones, four have been selected for bulking and testing for quality with a view to release for commercial use.

Data in Table 1 shows that when two susceptible *S. phureja* parents are crossed some resistant plants may be obtained. Resistance to *Pseudomonas solanacearum* may therefore be partially regulated by recessive genes. Data in Table 2 indicate tremendous phenotypic variation within and between progenies. It appears that when two resistant parents are crossed transgressive segregation to greater resistance may occur in the progeny. Other tests have shown that *S. phureja* clones are more resistant to wilt than *S. tuberosum* clones. Some of the selected wilt resistant clones will be inter-crossed with a hope of developing highly resistant clones for tropical use.

REFERENCES

1. Cox, A.E. and Large, E.C. (1960) *Potato blight epidemics through the world*. U.S. Agricultural Handbook No. 174. 171–5.
2. F.A.O. *Production Yearbook*. Vol. 23, 1969.
3. Harris, D.C. (1972) *The significance of bacterial wilt in the development of potatoes in Kenya. Prospects for the potato in the developing world*. E.R. French (ed) Centro Internacional de la Papa, pp. 128–35.
4. Kenya Agricultural Census, (1971) Annual Report.
5. Kenya, Agriculture Ministry. (1972) Annual Report No. 3 F.A.O. Fertilizer Demonstration.
6. Moreau, R.E. (1944) The climatic background to the problem of potato varieties for East Africa. *E. Af. Agric. for. J.* 9, 127–35.
7. Nattrass, R.M. (1945) A new bacterial disease of potatoes in Kenya. *E. Af. Agric. for. j.* 10, 162–3.
8. Njuguna, S.K. (1972) Development of the potato in the developing world (1972) E.R. French (ed.) Centro Internacional de la Papa. pp. 25–31.

9. Robinson, R.A. and Ramos, A.H. (1964) Bacterial wilt of potatoes in Kenya. *E. Af. Agric. for. J.* 30, 59-64.
10. Rowe, P.R. and Sequeira, L. (1970) Inheritance of resistance to *Pseudomonas solanacearum* in *Solanum phureja*. *Phytopath.* 60, 1499-1501.
11. Sequeira, L. and Rowe, P.R. (1969) Selection and utilization of *Solanum phureja* clones with high resistance to different strains of *Pseudomonas solanacearum*. *Amer. Potato J.* 46, 451-62.
12. Simmonds, N.W. (1971) The potential of potatoes in the tropics. *Tropical Agric.* 48, 291-9.
13. Thurston, H.D. and Lozano, J.C. (1968) Resistance to bacterial wilt of potatoes in Colombian clones of *Solanum phureja*. *Amer. Potato J.* 45, 51-5.

TABLE 1
Seedling reaction to bacterial wilt (*Pseudomonas solanacearum*)

Ref. No.	Parentage	No. of seed- lings	% wilted* after 4 wks.	No. of plants out	Surviv- ors after 90-120 days	No. I % survi- vors	No. II % survi- vors
1.	1339.28(S) x 1350.42(R)	0	0	0	0	0	0
2.	1339.38(S) x 1386.12(R)	29	24	22	0	0	0
3.	1339.28(S) x 1386.13(R)	3	0	3	0	0	0
4.	1339.28(S) x 1386.26(R)	14	29	10	3	21.35	3
5.	1350.9 x 1350.42(R)	9	67	3	1	11.11	0
6.	1350.42(R) x 1386.15(R)	6	34	4	0	0	0
7.	1386.1(R) x 1386.13(R)	5	0	5	0	0	0
8.	1386.13(R) x 1386.26(R)	26	39	16	1	3.84	0
9.	1386.15(R) x 1339.28(S)	39	49	20	2	5.13	1
10.	1386.26(R) x 1339.28(S)	55	13	48	3	5.45	1
11.	2 - 1 x P - 7	11	0	11	1	9.10	0
12.	N-68 x 314.1	3	0	3	1	33.33	1
13.	N-68 x 317.2	0	0	0	0	0	0
14.	P-3 x 8-43	67	21	53	6	8.95	2
15.	Atzimba x 318.1	6	0	6	0	0	0
16.	Atzimba x P-3	59	10	53	4	6.82	1
17.	Atzimba x P-7	74	16	62	5	6.76	1
18.	Greta x P-3	63	16	53	5	4.76	0
19.	Greta x P-7	90	38	56	1	1.11	1
20.	8-14 x Atzimba	42	24	32	2	4.76	2
Total L clones kept				33			13

R - resistance

S - susceptible

* plants were classified as wilted as soon as advanced wilt symptoms were observed on haulms.

TABLE 2

Seedling reaction to bacterial wilt (*Pseudomonas solanacearum*)

Ref No	Parentage	No. of seed- lings	% wilt- ted after 4 wks*	No. plan- ted out	Sur- vi- vors after 90-120 days	% plants not wilt- ting
1.	(8-14 x Atzimba(2) x 1386.26 x 1339.28(4)	150	71.33	43	6	4.00
2.	8-14 x Atzimba(2) x P-3 x 8-43(4)	71	69.01	22	5	7.04
3.	1386.26 x 1339.28(3) x 8.-14 x Atzimba(2)	111	13.51	96	0	0.00
4.	Atzimba x P-7(4) x P-3 x 8-43(6)	52	71.17	15	2	3.85
5.	(1386.15 x 1339.28) x P-3 x 8-43	44	45.45	24	4	9.09
6.	1386.26 x 1339.28 x 1350(2)	428	58.64	177	28	6.54
7.	Atzimba x P-7 x NF/66	88	72.72	24	8	9.09
8.	(P-3 x 8 - 43) x KA	10	70.00	3	1	10.00
9.	2-1 x P-7 x P-3 x 8-43	21	57.14	9	2	9.52
10.	135) x 1339 x KA	37	91.90	3	0	0.0
11.	P-3 x 8-43 Selfed	295	93.22	21	2	0.68
12.	P-3 x 8-43 (1) Selfed	46	82.61	8	1	2.17
13.	P-3 x 8-43(3) Selfed	168	94.64	9	1	0.59
14.	1339.28 x 1386.26 x KA	158	82.91	27	4	2.53
15.	Atzimba x P-7(1) Selfed	400	81.25	75	7	1.75
16.	Atzimba x P-7(2)	233	79.11	51	8	3.43

* Plants were classified as wilted as soon as advanced wilt symptoms were observed on haulms.

ENVIRONMENTAL FACTORS AFFECTING TUBERIZATION

A.C. Posthumus*

SUMMARY

A review of literature of climatic and biotic factors affecting tuberization mainly of *Solanum* potatoes.

RESUME

Un aperçu des données sur les facteurs climatiques et biotiques sur la déterminisme de la tubérisation chez la pomme de terre et quelques autres cultures.

RESUMEN

Repaso de literatura de clima y factores bióticos patéticos la producción de tubérculos lo principal de *Solanum tuberosum*.

INTRODUCTION

Tuberization in plants showing this special morphogenetic feature does not take place at the same rate and intensity in different environments. Both climatic and edaphic and biotic factors, including pathogens, affect this phenomenon. The most important factors are photoperiod, temperature, light (intensity and quality), mineral nutrition, water availability and viruses.

The physical environmental factors act by the synthesis, destruction, transport and activation of growth substances. Minerals, water balance and viruses are also known to alter growth-substance balance in plants and hence environmental factors affecting tuberization may be at least partly explained by their influences on the growth substance. By affecting the intensity and duration of photosynthesis and respiration, the environment may also affect the level of photosynthate available for storage in tubers. According to one theory on the mechanism of tuberization, surplus photosynthate is required for the process.

Inductive and non-inductive environmental conditions have been distinguished. Kopetz and Steineck³⁵ claimed that differences in tuberization found between different cultivars may be explained by differences in critical daylength requirements defined as the daylength above which tuberization did not occur. However, perhaps it is better to distinguish favourable from unfavourable conditions, since it is now recognized that effects are apparently often quantitative not qualitative. Moreover, optimal environmental conditions differ for tuber initiation, growth and maturation and between different plant species and cultivars.

This paper will review knowledge collected mostly from temperate plant species, but in the expectation that such information may lead to a better understanding of tuberization in tropical species. However, there is danger in uncritical transfer of information from one species to another, or even from one cultivar to another within a species. The genetically determined tuber-forming potential of a plant, including the control of reaction to environment, is the most important factor in tuberization. Nevertheless, a knowledge and understanding of the influences of environmental factors may help to improve the yield and/or efficiency of cultivation of root and tuber crops in the tropics.

Tuberization has been reviewed in other crops by Courduroux, Dupaigne, Gregory and Jolivet^{14, 16, 24, 33}, but most work has been concerned with potatoes (*Solanum tuberosum* L.) only^{5, 41, 50, 58}.

EFFECTS OF PHOTOPERIOD

On potatoes

Garner and Allard²³ reported that tuberization in *Solanum* potato was promoted by short-day conditions. Although differences were later found between different cultivars of potato, the promotional effect of short days was confirmed.^{5, 66} Slater⁵⁷ took account of the differences in total radiation as well as the shortening of daylength. Driver and Hawkes¹⁵ demonstrated that many varieties of potato tuberize earlier in shorter than in longer days. Gregory^{25, 26}, Chapman⁹, Okazawa and Chapman⁴⁰, Madec⁴² and Purohit⁵⁴

*Centre for Plant Physiological Research, Bornesteeg, Wageningen, Holland.

all provided evidence for a specific tuberization factor formed in short days. Van der Planck⁵¹ pointed out that although final total tuber yield may be higher in long days than in short days, the yield per unit leaf area per unit of time is always higher in short days.

Short-day promotion of tuberization can be abolished by a short light interruption during the dark period, as for other photoperiodic phenomena. Thus, Slater⁵⁷ showed that tuber initiation in *Solanum tuberosum* was delayed for two weeks and in *Solanum demissum* did not occur at all, if a light break was applied in the middle of the dark period. Purohit⁵³ studied the photoperiodic reaction of four Indian potato cultivars in relation to tuberization and confirmed the existence of antagonism between vegetative growth and tuber formation. One cultivar appeared to be a quantitative short-day plant in relation to tuberization, while three were qualitative short-day plants in this respect.

Other crops

In most tuber-forming species other than the *Solanum* potato, short days either favour tuberization or have no effect on it. Positive influence of short-days was demonstrated by Nitsch⁴⁶ for *Dahlia* spp., *Begonia socotrana* and some cultivars of *Helianthus tuberosus*. Moser and Hess⁴⁵ proved that the phenomenon was one of photoperiodism in *Dahlia* spp. by application of a light break during the dark period. Zimmer⁷² did the same for *Begonia* spp. Courduroux^{12,13,14} reported different responses for different cultivars of *Helianthus tuberosus*. Some were day-neutral whilst others had either a short day or a long day response. According to Esashi and Nagao¹⁹, underground tuberization in *Begonia evansiana* is daylength insensitive, but the formation of aerial tubers has a short day response. Exceptionally, for a few species, either continuous illumination or long days (more than 12 hours) may favour tuberization. Le Clerch³⁹ claimed this for a tuberizing variety of *Arrhenatherum elatius* (L.) Mert. and K., although effects of total daily irradiation cannot be excluded in this response.

In tropical root and tuber crops photoperiod may not play a major role since differences in natural daylengths within the tropical belt are rather small and daylength in general is short compared to that in the growing conditions of temperate climate summers. Nevertheless, it is possible that artificial shortening of the day might accelerate tuberization in some crops, without necessarily however improving final yield. According to Bautista and Cadiz² in the yam bean (*Pachyrhizus erosus* L. Urb.) root production in the Philippines was greater in the cooler part of the year which also had shorter daylengths. Initiation of tuberization under the influence of daylength has been suggested for the same crop in Hawaii by Ezumah²⁰. Bolhuis⁶ suggested that optimal daylength for tuberous root formation in cassava (*Manihot esculenta* Crantz) was 12 hours, and cassava a short-day plant in this respect. Positive influence of short days on tuberization has also been found for yams (*Dioscorea* spp.) by Njoku⁴⁷ and cocoyams (*Colocasia antiquorum* Schott) by Tsukamoto and Inaba⁶⁴.

EFFECTS OF TEMPERATURE

On potatoes

Most of the information presently available on the influence of temperature on tuberization refers to potato. Both photosynthetic and morphogenetic processes mediate the effects of temperature on tuberization. Thus Burt⁸ demonstrated that sink (tuber) initiation, as well as the use of carbohydrates for tuber growth were sensitive to temperature. Low temperatures promoted sink initiation, whereas high temperatures promoted storage of carbohydrates by the sinks.

Gregory²⁵, Went⁵⁷, Borah and Milthorpe⁷ and others found that low temperatures, especially low night temperatures, promoted tuber formation. The temperature optimum for the process was 17°C (approx.) and tubers were seldom formed above 30°C. According to Bodlaender⁴ the number of tubers per plant was higher at low air temperature, especially at low night temperature, but larger tubers were formed at higher temperature. Soil temperature also had a clear influence on tuber yield, this influence being greatest when air temperature was unfavourable for tuber growth. Epstein¹⁷ and tuber development depended on the growth stage reached by the plant. Yamaguchi et al.⁷¹ demonstrated that there was more starch in the tuber cortex at low than at high temperature. Epstein¹⁸ confirmed Slater's⁵⁷ suggestion that tuber initiation occurred earliest in plants with a surplus of assimilates, by comparing the effect of soil temperatures of 5°C. and of 29°C. on the composition and morphology of the potato plant. At the high temperature, assimilates were used for root and shoot growth and there were only a few stolons and no tubers. At the low temperature, there was a surplus of assimilates, plants were smaller but flowered earlier and small tubers were formed.

Other crops

The positive influence of low temperature on tuberization has been demonstrated for several other

species: e.g. *Helianthus tuberosus* by Courduroux^{10,12,13,14} *Stachys sieboldi* Lagarde^{37,38}, *Ficaria renunculoidea* by Courduroux¹¹, aerial tubers of *Begonia evansiana* by Esashi and Nagao¹⁹ and *Ipomoea batatas* by Kim³⁴. On the contrary, Dupaigne¹⁶ reported that formation of aerial tubers on *Dioscorea batatas* was favoured by high temperatures.

INTERACTION BETWEEN DAYLENGTH AND TEMPERATURE

Sekioka⁶⁶ studied interrelationships between the temperature and various phases of translocation of carbohydrates in sweet potato. At low air temperatures (optimum at 15°C.) translocation to young leaves and growing points increased. The influence of the soil temperature was not clear. At high soil temperature, accumulation in the above ground parts was high, but accumulation in the underground parts was dependent on relative day/night temperatures. At low soil temperature, accumulation in the underground parts was also dependent on day/night temperatures.

EFFECTS OF LIGHT INTENSITY AND QUALITY

It might be expected that higher light intensity would lead to higher carbohydrate production and hence tuber yield. This was in fact demonstrated for *Solanum* potato by Bodlaender⁵ and by Posthumus (unpublished results) for radish (*Raphanus sativus* L. var. *radicula*) under phytotron conditions. With illumination of four different light qualities, but with equal amounts of energy irradiated per unit area, we found that greatest tuberization in radishes occurred in red light. This may therefore be a photo-morphogenetic rather than a photosynthetic effect and needs more investigation.

In *Solanum* potato, illumination of the stolon tips inhibits tuberization by converting these into leafy shoots. An instance of a negative influence of light on tuberization is the complete inhibition of tuber initiation in sweet potato that occurs by exposure of the root system to light⁶³.

The high light intensity in the tropics compared with that in temperate climates, should generate sufficient potential photosynthetic energy to produce abundant crop yields, through the process of tuberization.

EFFECTS OF MINERAL NUTRITION

Adequate supplies of macro and micro elements are of course required for optimal growth and development. However, as Werner⁶⁸ reported, abundant supply of nitrogen will favour top growth (stem and leaves) and impair the process of tuberization by diverting more energy to such vegetative growth. Relatively low doses of N, on the contrary, can reduce vigorous top growth and hasten the process of tuberization. However, yield is a product of bulking rate and bulking time, and high N-levels could lead to high yield by causing late bulking at a high rate.

There are also considerable differences in effects of mineral nutrition in tuber yields between different species and varieties. For *Solanum* potato, mineral nutrition has been investigated rather thoroughly as indicated by Watson⁶⁶ and Holliday²⁹. Tsuno and Fujise⁵¹⁻⁶³ studied dry matter product and distribution in sweet potato in relation to the absorption of mineral elements (N,P,K). Martin⁴³ discussed other tuber bearing crops in which nitrogen promoted juvenile growth until reduced N supply led to increases in the rate of starch storage.

Relatively few fertilizer experiments have been carried out with tropical root and tuber crops. Fujise and Tsuno²² demonstrated that K was most important for the dry matter production in sweet potato. Samuels⁶⁵ studied the influence of nutrient ratios on sweet potato yields and concluded that adverse effects could result from applied nitrogen at low K levels. Too much N promoted shoot growth and inhibited tuber growth. The same was found by Wilson⁶⁹. Effects of N, P and K on sweet potato yield were also studied by Liang Li⁴⁰. Krochmal and Samuels³⁸ found that high N levels promoted top growth and prevented tuberization in cassava and that increasing P levels increased tuber yield quite considerably. Irving³⁰ applied sulphate of ammonia to yams (*Dioscorea* spp.) with favourable results. Ferguson and Haynes²¹ studied the response of yams to N,P,K and organic fertilizers, and found a relatively small but positive response to nitrogen and organic matter. Reference was made to the importance of species and varietal differences in response potential, as indicated by Nye⁴⁸. According to Plucknett⁶² the aroids generally are very responsive to fertilizers, but little is known of their detailed nutritional requirements. Spence and Ahmad⁵⁸ described N,P,K,S,Mg, Ca and Fe deficiencies in *Xanthosoma saggitifolium*.

EFFECTS OF WATER REGIME ON TUBERIZATION

Water stress hastens tuberization in *Solanum* potato (Ito and Kato³¹). As a result of water stress-induced cessation of shoot and leaf growth, tubers are initiated much earlier but only grow slowly because of the much smaller productive leaf area.

Irrigation has been shown to be beneficial for tuber production in *Solanum* potato. Thus, Ivins³² showed that irrigating at the time of early tuberization produced a higher yield than irrigating either earlier or later during the early-bulking period of the crop. On the other hand too much water due to inundation or excessive irrigation may prevent tuberization completely if it creates an anaerobic soil environment. Togari⁶⁰ showed the dependence of tuberization in sweet potato on adequate soil aeration. Haynes²⁸ explained the seasonality of sweet potato production in Trinidad by suggesting that the high soil moisture and the consequent low soil oxygen content during the wet season might inhibit tuberization. Wilson⁷⁰ found that growth of sweet potato plants with total root systems submerged, even in well-aerated water cultures, completely inhibited tuber initiation, and that tuber initiation only took place if the upper half of the root system was exposed to air.

EFFECTS OF PATHOGENS ON TUBERIZATION

Bald and Hutton¹ and later Harmey *et al*²⁷ reported that viruses, such as the leaf roll virus, may accelerate tuberization in *Solanum* potatoes. This phenomenon may be explained by alteration of the balance of hormones in the host by the pathogen, but may also be the result of the restricted growth of the plant top.

CONCLUSION

Based on the extensive work, mainly with *Solanum* potato, but also with some other tuber crops in temperate climates, it can be stated that photoperiod and temperature, especially night temperatures favour, but are not indispensable for, tuber formation in many crops. Tuberization is also influenced by, but not specifically dependent on light intensity and quality and on mineral nutrition and soil moisture. As a result of the higher photosynthetic activity induced, tuber yield is higher in higher light intensity, but light quality seems to have a photomorphogenetic effect on tuberization. As for all growth and development phenomena, supply of water and minerals is a general pre-requisite for tuberization. But shortage of N-salts and water stress may cause accelerated tuber formation. The influence of a pathogen on tuberization is mentioned as an exceptional case. Thus, leaf roll virus in potato may hasten the tuberization process. But final yield in all these cases of precocious tuber formation is rather more dependent on the duration than on the intensity of the tuber bulking process.

As Milthorpe⁴⁴ stated at the first International Symposium on Tropical Root and Tuber Crops, many relevant aspects of the physiology and ecology of strictly tropical root crops are unknown. More precise experiments in controlled environments are necessary for understanding of the effects of environmental factors on tuberization in tropical root crops. More detailed studies on the response potential of different cultivars to N, P, K and organic matter are also necessary to improve the soil conditions so as to attain optimal yield in root crops.

REFERENCES

1. Bald, J.G. and Hutton, G.M. 1950. Some effects of leafroll virus on the development and growth of the potato plant. *Austr. J. Agr. Res.* 1, 3-17.
2. Bautista, O.D.K. and Cadiz, T.G. 1967. Sinkamas in the Philippines. In: *Vegetable production in South East Asia*. Ed. J.E. Knott and J.R. Deanon.
3. Bodlaender, K.B.A. 1958. The influence of various daylengths on the development of the potato (in Dutch). *Jaarb. Inst. Biol. Scheik. Onderz. Landbouwgew.*, pp. 45-57.
4. — — — — 1960. The influence of the temperature on the development of the potato (in Dutch). *Jaarb. Inst. Biol. Scheik. Onderz. Landbouwgew.* 69-83.
5. — — — — 1963. Influence of temperature, radiation and photoperiod on development and yield. In: *The growth of the potato*. Ed. J.D. Ivins and F.L. Milthorpe. Butterworths, London. pp. 199-210.
6. Bolhuis, G.G. 1966. Influence of length of the illumination period on root formation in cassava, *Manihot utilissima* Pohl. *Neth. J. Agric. Sci.* 14, 251-4.
7. Borah, M.N. and Milthorpe, F.L. 1963. Growth of the potato as influenced by temperature. *Indian J. Plant Physiol.* 5, 53-73.
8. Burt, R.L. 1966. Some effects of temperature on carbohydrate utilization and plant growth. *Austr. J. Biol. Sci.* 19, 711-14.
9. Chapman, H.W. 1958. Tuberization in the potato plant. *Physiol. Plant.* 11, 215-24.

10. Courduroux, J.C. 1960a. Le déterminisme de la tubérisation chez quelques variétés de topinambour. *Bull. Soc. Bot. Fr.* 107, 243-7.
11. ———— 1960b. Croissance et tubérisation chez la Ficairie (*Ficaria ranunculoides* Münch.). Effect de la température. *C.R. Acad. Sci. Paris* 251, 3054-6.
12. ———— 1962. Nouvelles observations sur le déterminisme de la tubérisation chez le topinambour. *Bull. Soc. Bot. Fr.*, 109, 59-63.
13. ———— 1966. Mécanisme physiologique de la tubérisation du Topinambour. *Bull. Soc. Bot. Fr.* 12, 213-32.
14. ———— 1967. Etude du mécanisme physiologique de la tubérisation chez le Topinambour (*Helianthus tuberosus* L.) *Ann. Sci. Nat. Bot.* 8, 215-56.
15. Driver, C.M. and Hawkes, J.G. 1943. Photoperiodism in the potato. Part I. General. Part II. The photoperiodic reactions of some south American potatoes. Techn. Comm. Imp. Bur. Plant Breed. and Genet. No. 36. London: Imp. Agric. Bur.
16. Dupaigne, G. 1967. Recherches sur la physiologie de la tubérisation. *D.E.A. Physiol. végét.* Giff/Yvette (France) 84pp.
17. Epstein, E. 1966. Effect of soil temperature at different growth stages on growth and development of potato plants. *Agron. J.* 58, 169-71.
18. Epstein, E. 1971. Effect of soil temperature on mineral element composition and morphology of the potato plant. *Agron. J.* 63, 664-6.
19. Esashi, Y. and Nagao, M. 1959. Studies on the formation and sprouting of aerial tubers in *Begonia evansiana* Andr. II. Effects of light and temperature on the sprouting of aerial tubers. *Sci. Rep. Tohoku Univ. Ser. IV, Biol.* 25, 191-7.
20. Ezumah, H. 1970. Miscellaneous tuberous crops of Hawaii Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu. Vol. I, 166-171.
21. Ferguson, T.U. and Haynes, P.H. 1970. The response of yams (*Dioscorea* spp.) to nitrogen, phosphorus, potassium and organic fertilizers. Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu. I, 93-8.
22. Fujise, K. and Tsuno, Y. 1967. Effect of potassium on the dry matter production of sweet potato. Proc. 1st Int. Symp. on Trop. Root Crops, Trinidad, Vol. I, II, 20-29.
23. Garner, W.W. and Allard, H.A. 1923. Further studies in photoperiodism: the response of the plant to relative length of day and night. *J. Agric. Res.* 23, 871-920.
24. Gregory, L.E. 1954. Some factors controlling tuber formation in the potato plant. Ph.D. thesis, Univ. of California, Los Angeles. 1-74.
25. ———— 1956. Some factors for tuberization in the potato plant. *Am. J. Bot.* 43, 281-8.
26. ———— 1965. Physiology of tuberization in plants (tubers and tuberous roots). *Encyclop. of Plant Physiology.* XV/1, 1328-54.
27. Harney, M.A., Crowley, M.P. and Clinch, P.E.M. 1966. The effect of leafroll virus on tuberization of *Solanum tuberosum*. *Irish J. Agr. Res.* 5, 163-76.
28. Haynes, P. 1970. Some general and regional problems of sweet potato (*Ipomoea batatas* (L.) Lam) growing. Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu. I, 10-13.
29. Holliday, R. 1963. Effects of fertilizers upon potato yields and quality. In: *The growth of the potato*. Eds. J.D. Ivins and F.L. Milthorpe. Butterworths, London. 248-263.
30. Irving, H. 1956. Fertilizer experiments with yams in Eastern Nigeria 1949-51. *Trop. Agri. (Trinidad)* 33, 67.
31. Ito, H. and Kato, T. 1951. The physiological foundation of the tuber formation of potato. *Tohoku J. Agric. Res.* 2, 1-14.
32. Ivins, J.D. 1963. Agronomic management of the potato. In: *The growth of the potato*. Eds. J.D. Ivins and F.L. Milthorpe. Butterworths, London. 303-10.
33. Jolivet, E. 1969. Physiologie de la tubérisation. *Ann. Physiol. vég.* 11, 265-301.
34. Kim, Y.C. 1961. Effects of thermoperiodism on tuber formation in *Ipomoea batatas* under controlled conditions. *Plant Physiol.* 36, 380-4.
35. Kopetz, L.M. and Steineck, O. 1954. Photoperiodische Untersuchungen an Kartoffelsamlingen. *Züchter*, 24, 69-77.

36. Krochmal, A. and Samuels, G. 1967. The influence of NPK levels on the growth and tuber development of cassava in tanks. Proc. 1st Int. Symp. on Trop. Root Crops, Trinidad. I(II), 97-102.
37. Lagarde, J. 1963. Influence d'une forte température (27-28°C) et de températures alternées sur le "boulage", la croissance et la tubérisation du Crosne du Japon. C.R. Acad. Sci., Paris. 267, 739-742.
38. — — — — 1964. Thermopériodisme et tubérisation chez le Crosne du Japon. C.R. Acad. Sci. Paris. 259, 1191-4.
39. Le Clerch, J. 1973. Influence du photopériodisme sur la tubérisation de l'Avoine à chapelet, *Arrhenatherum elatius* (L.) Mert. et K. var. *bulbosum* (Willd.) Spenn. à 18°C sous 5000 lux. *Physiol. Vég.* 11, 137-50.
40. Liang Li, L. 1970. Study of the effect of nitrogen, phosphorus and potassium on sweet potato yield by response surface. Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu, Vol. I, 13-15.
41. Madec, P. 1963a. Les développements les plus récents dans le domaine de la physiologie de la Pomme de terre. C.R. Assoc. Europ. Rech. Pomme de terre, Pise. 36-59.
42. — — — — 1963b. Tuber forming substances in the potato. In: *The growth of the potato*. Eds. J.D. Ivins and F.C. Milthorpe, Butterworths, London. 121-131.
43. Martin, F.W. 1970. Cassava in the world of tomorrow. Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu. Vol. I, 53-8.
44. Milthorpe, F.L. 1967. Some physiological principles determining the yield of root crops. Proc. 1st Int. Symp. on Trop. Root Crops, Trinidad, Vol II (1), 1-19.
45. Moser, B.C. and Hess, Ch.E., 1968. The physiology of tuberous root development in dahlia. *Proc. Am. Soc. Hort. Sci.* 93, 595-603.
46. Nitsch, J.P. 1968. Photopériodisme et tubérisation. *Bull. Soc. fr. Physiol. Vég.* 12, 233-248.
47. Njoku, A. 1963. The propagation of yams (*Dioscorea* spp.) by vine cuttings. *J. W. Af. Sci. Assoc.* 8, 29-32.
48. Nye, P.H. 1954. Fertilizer responses in the Gold Coast in relation to time and method of application. *Emp. J. Exp. Agr.* 22, 101.
49. Okazawa, Y. and Chapman, H.W. 1962. Regulation of tuber formation in potato plants. *J. Fac. Agric. Hokkaido Univ. Sapporo.* 15, 413-19.
50. Okazawa, Y. 1967. Physiological studies on the tuberization of potato plants. *J. Fac. Agric. Hokkaido Univ. Sapporo.* 55, 267-36.
51. Planck, J.E. van der, 1947. Some climatic factors determining high yield of potatoes. II. The potato at low latitudes and high altitudes. *Emp. J. Exp. Agric.* 20, 1-8.
52. Plucknett, D.L. 1970. *Colocasia, Xanthosoma, Alocasia, Cyrtosperma* and *Amorphophallus*. Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu. I, 127-35.
53. Purohit, A.N. 1970a. Photoperiodic control of synthesis of substances influencing tuber and root formation in the potato. *Potato Res.* 13, 139-41.
54. — — — — 1970b. The qualitative and quantitative photoperiodic response of Indian potato varieties. *New Phytol.* 69, 521-7.
55. Samuels, G. 1967. The influence of fertilizer ratios on sweet potato yields and quality. Proc. 1st Int. Symp. on Trop. Root Crops, Trinidad. I(II), 86-93.
56. Sekloka, H. 1970. The effect of temperature on the translocation and accumulation of carbohydrates in sweet potato. Proc. 2nd Int. Symp. on Trop. Root and Tuber Crops, Honolulu. Vol. I, 37-40.
57. Slater, J.W. 1963. Mechanisms of tuber initiation. In: *The growth of the potato*. Eds. J.D. Ivins and F.L. Milthorpe. Butterworths, London. 114-120.
58. Spence, J.A. and Ahmad, N. 1967. Plant nutrient deficiencies and related tissue composition of tannia (*Xanthosoma sagittifolium*). Proc. 1st Int. Symp. on Trop. Root Crops, Trinidad I(II), 61-7.
59. Tizio, R. 1964. Cycle végétatif et mécanisme de la tubérisation chez le tubercule de pomme de terre. *Pomme de terre, Fr.* 301, 1-18.
60. Togari, Y. 1945. A study on the tuberous root formation of sweet potatoes. *Bull. Nat. Agr. Exp. Sta. Tokyo.* 68, 1.
61. Tsuno, Y. and Fumise, K. 1964a. Studies on the dry matter production of sweet potato. III. The relation between the concentration of mineral nutrients in plant and distribution ratio of body matter produced. *Proc. Crop Sci. Soc. Japan* 32, 297-300.

62. — — — — 1964b. Studies in the dry matter production of sweet potato. IV. The relation between the concentration of mineral nutrients in plant and distribution ratio of dry matter produced. *Proc. Crop Sci. Japan*. 32, 301–5.
63. — — — — 1965. Studies on the dry matter production of sweet potato. VIII. The internal factors influence on photosynthetic activity of sweet potato leaf. *Proc. Crop Sci. Japan*. 33, 230–5.
64. Tsukamoto, Y. and Inaba, K. 1961. The effect of day length upon the cormel formation in taro (*Colocasia antiquorum*). *Mem. Res. Inst. Food Sci. Kyoto Univ.* 23, 15–22.
65. Wassink, E.C. and Stolwijk, J.A.J. 1953. Effect of photoperiod on vegetative development and tuber formation in two potato varieties. *Meded. Landbouwhogeschool Wageningen*. 53, 99–112.
66. Watson, D.J. 1983. Some features of crop nutrition. In: *The growth of the potato*. Eds. J.D. Ivins and F.L. Milthorpe. Butterworths, London 233–47.
67. Went, F.W. 1959. Effects of environment of parent and grand parent generations on tuber production by potatoes. *Am. J. Bot.* 46, 277–82.
68. Werner, H.O. 1934. The effect of a controlled nitrogen supply with different temperatures and photoperiods upon the development of the potato plant. *Res. Bull. Univ. Nebr. Agric. Exp. Stat.* 75, 1–132.
69. Wilson, L.A. 1964. Effect of increasing levels of nitrate-nitrogen on growth and chemical composition of sweet potato, *Ipomoea batatas* (Var. C. 104). *Ann. Rep. Centr. Exp. Sta. Trin. CES Library*.
70. — — — — 1969. Biochemical aspects of the mechanism of tuberization. *Half Yearly Rep. Fac. of Agr. U.W.I. St. Augustine*, 2, 62.
71. Yamaguchi, M., Timm, H. and Spurr, A.R. 1964. Effects of soil temperature on growth and nutrition of potato plants and tuberization, composition and periderm structure of tubers. *Proc. Am. Soc. Hort. Sci.* 84, 412–23.
72. Zimmer, K. 1973. Some photoperiodic responses of *Begonia*. *Acta Hort.* 31, 51–6.

TUBER DEVELOPMENT IN YAMS; PHYSIOLOGICAL AND AGRONOMIC IMPLICATIONS

T.U. Ferguson*

SUMMARY

The growth of tubers in *Dioscorea* spp. is described. Four phases of growth can be recognized with associated major physiological processes. The number of tubers initiated appear to affect yield with an optimum number about 7. The effects of some of the more important factors on tuber development and yield are reviewed and discussed. Set size affects tuber yield by shortening time before the start of rapid tuber bulking, lengthening the period of tuber bulking and increasing leaf area. Plant density, staking and nitrogen seem to affect yield by increasing leaf area index and also the rate of tuber bulking. The effect of potassium has been explained as an effect on the duration of tuber bulking. Organic matter and soil physical factors may obviously affect yield, but there is need for research into the way in which these factors affect tuber development.

RESUME

La croissance des tubercules de *Dioscorea* spp. a été exposée. On peut noter quatre phases de croissance avec les étapes de développement fondamentales qui y sont associées. Le nombre de tubercules essayés semblent affecter le rendement avec un nombre maximum d'environ 7. L'effet des facteurs les plus importants sur le développement et le rendement de l'igname a été passé en revue. La dimension des boutures a une influence sur le rendement en raccourcissant le temps avant que ne débute le développement accéléré de la tubercule, en prolongeant la période de développement de la tubercule et en augmentant la zone foliaire. La densité, le tuteurage et l'azote semblent affecter le rendement en augmentant l'index de la zone foliaire de même que la grosseur de la tubercule. L'effet du potassium a été exposé en tant que facteur ayant une influence sur la durée de développement de la tubercule. La matière organique et les facteurs physiques du sol ont certainement une influence sur le rendement, mais il faudrait, par la recherche, déterminer comment ces facteurs affectant le développement de la tubercule.

RESUMEN

Se describe el desarrollo de tubérculos en *Dioscorea* spp. Se pueden reconocer cuatro fases de crecimiento asociadas a los principales procesos fisiológicos. El número de tubérculos formados parece afectar el rendimiento, obteniéndose un óptimo de éste con un número cercano a 7. Se revisan y discuten los efectos de algunos de los más importantes factores que afectan el desarrollo del tubérculo y el rendimiento. El tamaño afecta el rendimiento de tubérculos acortando el tiempo en el que se inicia un rápido engrosamiento de los mismos, alargando el tiempo durante el que ocurre tal engrosamiento e incrementando el área foliar. La densidad de plantas, el estacado y el nitrógeno parecen afectar el rendimiento incrementando el índice de área foliar y también el grado de engrosamiento del tubérculo. El tiempo en el que el tubérculo permanece engrosando se explica como un efecto de potasio. La materia orgánica y los factores físicos del suelo pueden, obviamente, afectar el rendimiento pero es necesario investigar en que forma afectan estos factores, el desarrollo del tubérculo.

INTRODUCTION

Yield in yams (*Dioscorea* spp.) means tuber yield. The proportion of the CO₂ that is fixed by photosynthesis that is translocated to and stored in the developing tubers is clearly an important determinant of yield. Tuber yield is rate of tuber bulking integrated over the duration of tuber bulking. The physiological processes involved in tuber development can provide an explanation of the ways in which agronomic factors affect yield.

The growth of the tuber can be correlated with the growth of other plant organs. When compared to temperate crops such as the potato and sugar beet, there is scant information on tuber development in yams. We review available data and discuss these.

*Department of Soil Science, University of the West Indies, St. Augustine, Trinidad

TUBER DEVELOPMENT

Development patterns

The tuber of yams has been botanically regarded as a stem tuber which develops by the plagiotrophic lobing of a degenerate rhizome^{3,17}. The part of the tuber nearest to the vine is older (more physiologically mature) than the distal region.

Roots, stems and tubers all however seem to develop from a common tissue arising on the planting sett. This tissue seems to be structurally highly organized and was termed the 'primary nodal complex' by Ferguson¹⁰.

There is a lack of information on the time of tuber initiation in various species and cultivars, and also on morphogenetic and physiological processes involved in tuber initiation. In *D. esculenta*, where stolon-like structures precede tuber development, the time of tuber initiation is likely to be at the formation of these structures which are formed at about 2 months after planting. However, in the White Lisbon Yam (*Dioscorea alata*) the time of tuber initiation has been suggested to be at, or soon after, bud formation (i.e. at the time of 'germination' and formation of the primary nodal complex)¹¹. The first external signs of tuber development in the White Lisbon Yam occur about 3 months after planting^{16,4,6,11}. The corresponding time for *D. trifida* is about 4½ months⁹.

The growth of the tuber in yams follows a similar pattern to that outlined for the potato by Milthorpe and Moorby²⁰. At first there is a period of slow, more or less exponential growth and this is followed by a period of rapid tuber bulking and finally a period of reduced rate of increase (sometimes a decrease) and maturation (Fig. 1). This generalized sigmoidal pattern has been observed on *D. alata*^{16,18,4,6,11}, *D. trifida*⁹ and *D. esculenta*^{7,8,9}.

Tuberization on *D. alata*

In a detailed study on tuber development in White Lisbon Yam¹¹, I described four distinct phases of growth which represented periods of different physiological activities in the tuber. The first phase extended from emergence to 13 weeks, and consisted mostly of the development of the primary nodal complex. It is however difficult clearly to separate the tuber from the primary nodal complex in *D. alata* because the primary nodal complex and the tuber seem to grow as a single organ (Fig. 2). The primary nodal complex is therefore now regarded as an integral part of the tuber. The dry matter content of the tuber remained at about 13 percent during this period (Fig. 3).

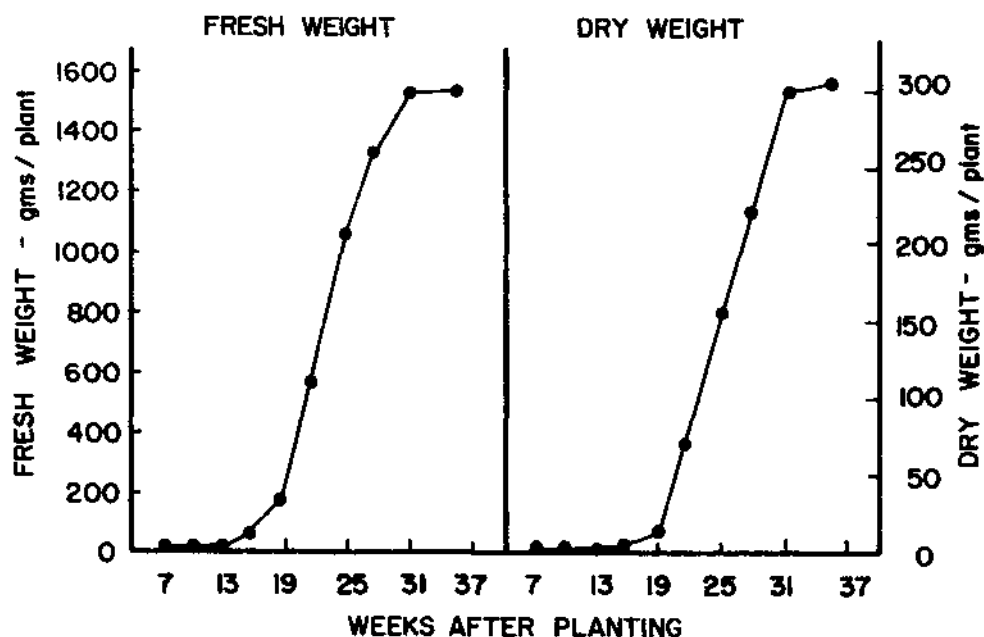


Fig 1. Tuber development in White Lisbon Yam (*D. alata*) - fresh and dry weight changes.

The second phase extended from 13 to 19 weeks. Active tuber development beginning at 13 weeks was associated with a reduction in percent dry matter accumulation began during this period (Table 1), but the fresh weight increased relatively faster than dry weight. This period was interpreted as one of rapid cell division and some cell expansion in which many of the cells involved in subsequent tuber bulking were laid down. Hence, factors which affect the rate of cell division and expansion occurring during this phase will be important in the determination of final yield. Growth up to the end of the second phase could be considered exponential. The third phase extended from the 19th to the 32nd week and was a period of rapid accumulation of dry matter in tubers. The percent dry matter of tubers also increased during this phase and hence tuber dry matter showed a relatively greater increase than tuber fresh weight. Dry weight could be considered to increase more or less linearly with time during this phase. During the final phase from week 32 to week 36 dry matter accumulation slowed down and ceased altogether as maturity approached.

The above description of tuber growth represents the mean trend in the growth of a number of tubers. The changes in tuber number with time in White Lisbon Yam were also studied¹¹ (Fig. 4). Mean tuber number per plant was observed to increase steadily between 13 and 28 weeks but then to decrease. The decrease suggests that possibly a number of small tubers are resorbed during the final weeks of growth. Many of the tubers produced at maturity were in any case small and unmarketable. In the White Lisbon Yam the average number of tubers per plant of marketable size are probably developed early whereas tubers which are initiated and begin bulking later may be poor competitors for available assimilates and hence are likely to remain small.

Tuberization in *D. esculenta*

D. esculenta produces many more tubers than *D. alata*, and according to Enyi⁷, tuber number seems to increase up to about six months after planting. Enyi also indicated that when many tubers are initiated the size of individual tubers is small and the proportion of initiated tubers that never reach harvestable size

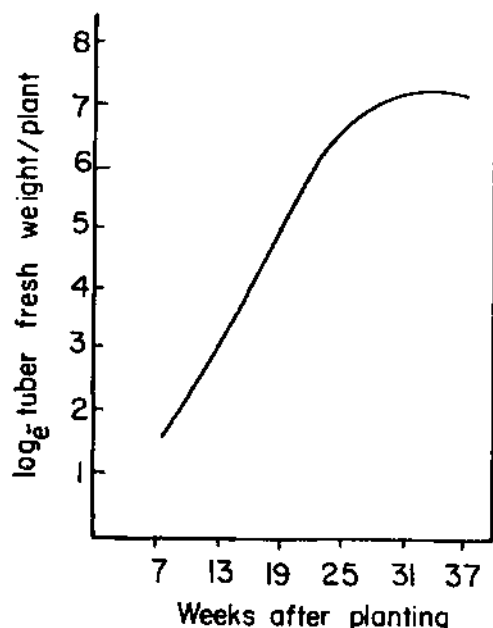


Fig.2. Tuber development in white Lisbon Yam (*D. alata*) $\log_e$ tuber fresh weight

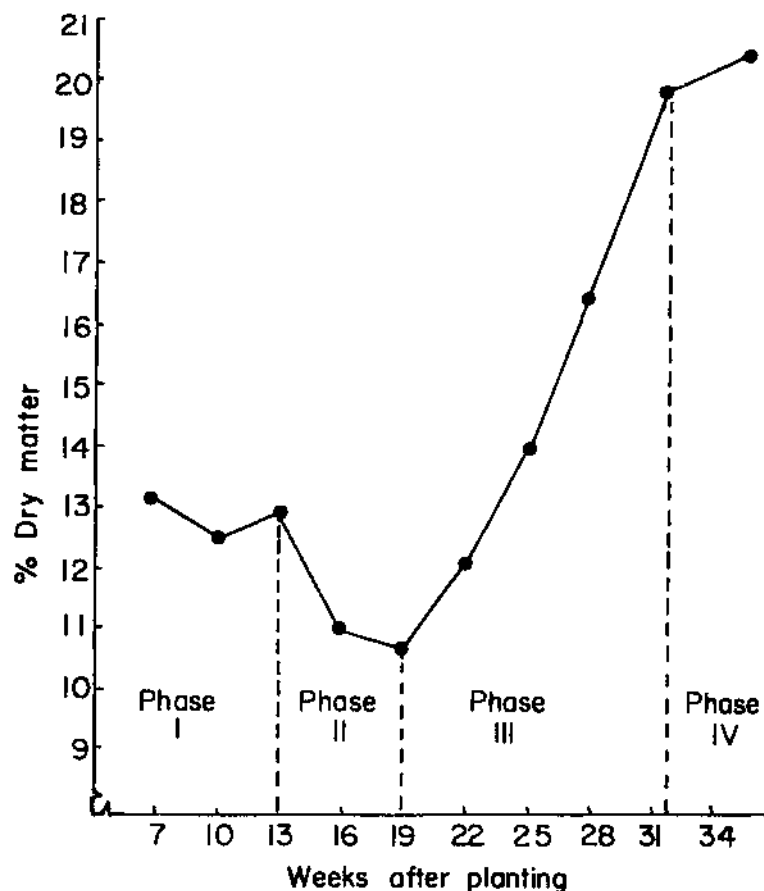


Fig.3. Changes in percent dry mater of tuber in White Lisbon yam (*D.alata*)

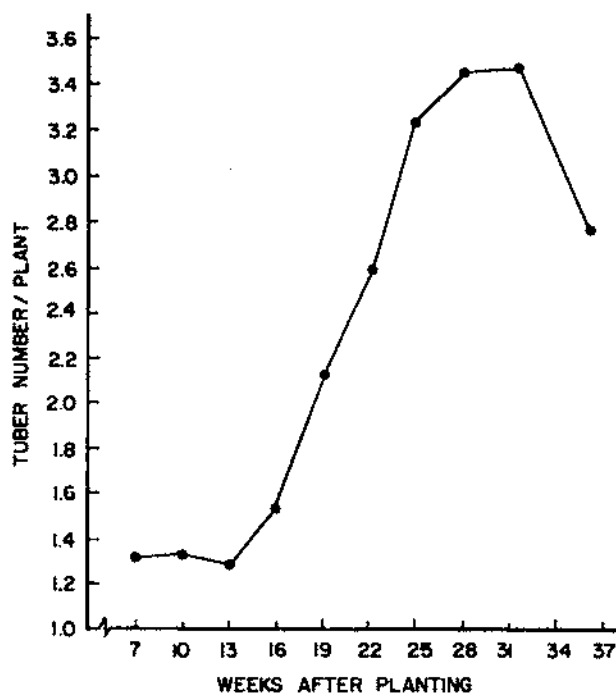


Fig 4. Changes in tuber number during growth of White Lisbon yam (*D. alata*)

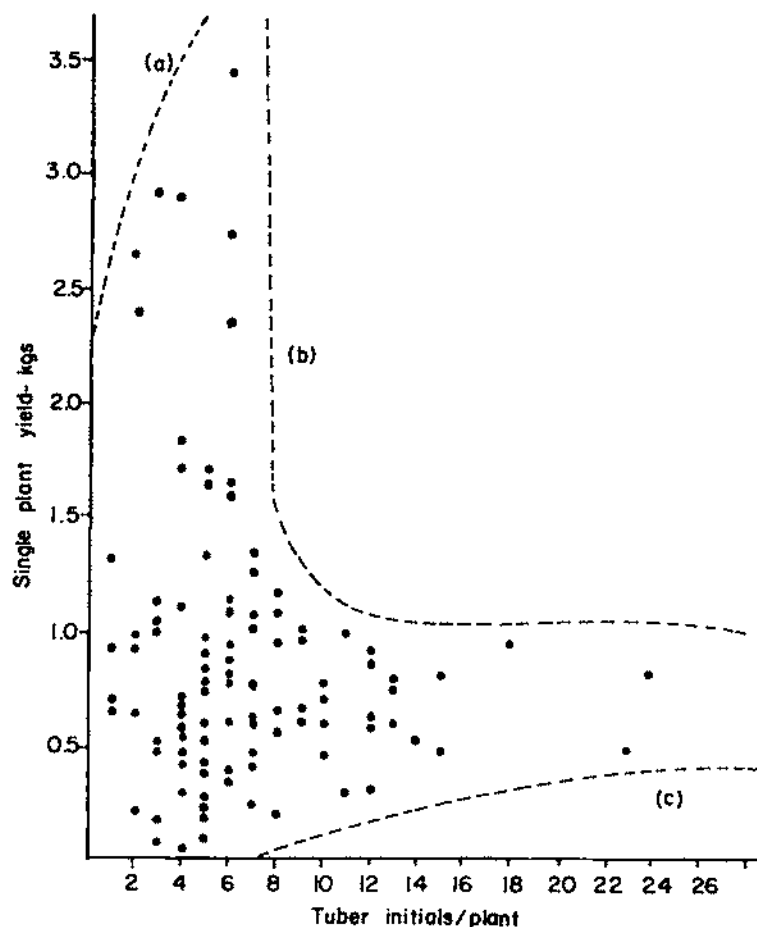


Fig. 5. The effect of the number of tuber initials on yield per plant in white Lisbon Yam (*D. alata*).

is greater. Ferguson⁹ had previously made a similar observation on *D. alata*. In this study the 'tubers' above 3 gm. are regarded as tuber initials. Yield per plant increased with tuber initials up to 7 per plant, but decreased markedly beyond this number (Fig. 5). It appears that factors which promote the initiation of an excessive number of tubers could therefore result in low yield in yams.

Aerial tubers are formed on the vines of some species of *Dioscorea*. Uduabo's data²³ indicate that the control of initiation of aerial tubers is under hormonal control. Sawada *et al.*²¹ found that aerial tuber size increases with increase in sugar concentration in sterile culture but noted that sugar was not responsible for the induction of aerial tubers. In the White Lisbon Yam aerial tubers may be formed just after the period of maximum tuber bulking, and the build-up of assimilates (especially sugar) in the phloem (occurring perhaps as a result of restricted tuber growth) may be a factor involved in the formation of aerial tubers¹¹. Aerial tubers in *D. alata* are also regarded as secondary sinks and seem to develop only after the primary sinks, the underground tubers, have passed their maximum period of tuber bulking.

FACTORS AFFECTING TUBER DEVELOPMENT AND YIELD

Tuberization

Many agronomic factors affect the yield of yams. There have been a few studies to determine the way in which these factors affect the growth and development of the plant. Haynes *et al.*¹⁴ indicated the value of growth studies as an adjunct to agronomic experiments.

Chapman⁶ found a strong correlation between leaf area and yield in White Lisbon Yam, and Ferguson¹¹, using the same cultivar related leaf area at 16 weeks with yield. Enyi^{7,8} obtained a linear regression of yield on leaf area duration in *D. esculenta*. The relationship was better when yield was regressed on leaf area duration measured from after the time of tuber initiation than throughout the growth period⁷. The rate of tuber bulking increased with leaf area up to 490 dm² and decreased thereafter⁷. All these findings indicate the importance of assimilate supply in determining yield. One might therefore expect that agronomic factors which enhance leaf area would increase yield.

We do not have much evidence yet on the importance of the ability of the tuber to accept assimilates as a factor in yield determination. Factors which affect the time of tuber initiation and the time from then

until rapid tuber bulking will affect the duration of tuber bulking and thus tuber yield. The time of tuber initiation was affected by K application and shown to affect yield in *D. esculenta*⁸. The time to rapid tuber bulking was shown to be shorter for plants grown from large setts of White Lisbon Yam, and also the size of the primary nodal complex at 8 weeks after planting (about 4–5 weeks old) was closely related to final yield¹¹. It thus appears that yield in White Lisbon Yam could be determined early in the life of the crop.

Effect of some agronomic factors

Yield has been shown to increase with increasing sett size^{1,2,7,11,19}. Plants from large setts of White Lisbon Yam were found to emerge earlier, produce larger primary nodal complexes, develop greater leaf area, begin rapid tuber bulking earlier and have a longer duration of tuber bulking than plants from small setts¹¹. With *D. esculenta* Enyi⁸ found that plants from large setts had greater leaf area duration and higher mean bulking rates than plants from small setts, but there was no difference in the duration of tuber bulking.

Yield of yams tends to increase with increasing plant density^{1,2,6,8,13,14,15}. In *D. esculenta* increasing plant density resulted in higher leaf area index, greater leaf area duration and higher tuber bulking rates per unit area⁸. Yield per plant in *D. esculenta* and *D. alata* increased with decreasing density and has been related to the higher bulking rates per plant more than the duration of bulking^{7,11}.

Yield increases with nitrogen application and staking. The increase in yield can be accounted for as due to an increase in leaf area^{6,8}. Treatments resulting in greater leaf area gave both a greater yield and higher tuber bulking rates.

Potassium has marked effect on the yield in *D. esculenta* and this seemed to result from a longer bulking duration because of earlier tuber initiation and also a small increase in leaf area⁸.

Organic matter gave a marked positive yield response. In addition to supplying nutrients and improving the physical condition of the soil the organic matter may have added compounds which had a stimulatory effect on tuber growth. This merits further investigation.

Tuber growth may be greatly restricted in compact soils and this factor also merits consideration in future research.

ACKNOWLEDGEMENT

The writer wishes to acknowledge the valuable assistance of Mr. P.H. Haynes and Dr. J. Spence in his studies.

REFERENCES

1. Afronja, B. (1967) The analysis of an experiment with plots of different sizes. *Trop. Agric. Trin.* 44, 39.
2. Baker, E.F.I. (1964) Plant populations and crop yield. *Nature* 204, 856.
3. Burkill, I.H. (1960) The organography and the evolution of Dioscoreaceae, the family of the yams. *J. Linn. Soc. (Bot.)* 56, 319.
4. Campbell, J.S., Chukweuke, V.O., Teriba, F.A. and Ho-a-Shu, H.V.S. (1962) Some physiological investigations into the White Lisbon Yam (*Dioscorea alata* L.) II. Growth period and out-of-season production. *Emp. J. Expl. Agric.* 30, 232.
5. Caro-Costas, R.B.E. and Servando, S. (1968) Effect of various cultural practices on yields of yams in Puerto Rico. *J. Agr. Univ. Puerto Rico* 52, 356.
6. Chapman, R. (1965) Some investigations into factors limiting yields of White Lisbon Yam (*Dioscorea alata* (L.) under Trinidad conditions. *Trop. Agric. Trin.* 42, 145.
7. Enyi, B.A.A. (1972a) The effects of seed size and spacing on growth and yield of Lesser Yam (*Dioscorea esculenta*). *J. Agric. Sci.* 78, 215.
8. ——— (1972b) Effect of staking, nitrogen and potassium on growth and development in Lesser Yams. *Dioscorea esculenta*. *Ann. appl. Biol.* 72, 211.
9. Ferguson, T.U. (1969) Yam agronomy. In Rep. Faculty of Agriculture 1968–69., University of the West Indies, Trinidad, Section E., pp. 29.
10. ——— (1972) The propagation of yams by vine cuttings: a critical review. *Trop. Root Crops News Letter*. No. 6, 4.

11. — — — — (1973) The effect of sett characteristics and spacing on growth, development and yield of yams (*Dioscorea* spp.). Ph.D. Thesis submitted to the Faculty of Agriculture, University of the West Indies, Trinidad.
12. Ferguson, T.U., Haynes, P.H. and Springer, B.G.F. (1989) A study of variability in yams (*Dioscorea* spp.). *Proc. Carib. Food Crops Soc.* 6, 50.
13. Gooding, E.G.B. and Hoad, R.M. (1967) Problems of yam cultivation in Barbados. *Proc. 1st Int. Symp. Trop. Root Crops.* 1, 111-137.
14. Haynes, P.H., Spence, J.A. and Walter, C.J. (1967) The use of physiological studies in the agronomy of root crops. *Proc. 1st Int. Symp. Trop. Root Crops.* 1, 100-1.
15. Henry, V.C.R. (1967) Studies on botanical and agronomic characteristics of cush-cush (*Dioscorea trifida*) Ph.D. Thesis, McGill University.
16. James, L.J. (1953) Study of the growth and development of yams (*Dioscorea alata* L.) in relation to planting methods. A.I.C.T.A., Thesis, University of the West Indies Library, St. Augustine, Trinidad.
17. Martin, F.W. and Ortiz, S. (1962) Origin and anatomy of tubers of *Dioscorea floribunda* and *D. spiculiflora*. *Bot. Gaz.* 124, 416.
18. Mason, T.G. and Lewin, C.J. (1926) On the rate of carbohydrate transport in the greater yam, *Dioscorea alata* (Linn. *Proc. Royal Dub. Soc.* 18, 203.
19. Meige, J. (1957) Influence de quelques caracteres des tubercules semences sur la levee et le rendement des ignames cultivees. *J. Agric. Trop. Bot. Appl.* 4, 315.
20. Milthopre, F.L. and Moorby, J. (1966) The growth of the potato. *Proc. 3rd Triennial Conf. EAPR.*
21. Sawada, E., Yakuwa, T. and Imakawa, S. (1958) Studies on the formation of aerial tubers in Chinese yam. II. On the aerial tuber formation in sterile culture of vine segments (Japanese). *J. Hort. Assoc. Japan* 27, 21.
22. Suboio, R.A. (1972) Studies on White Yam (*Dioscorea rotundata* 1. Growth analysis. *Expl. Agric.* 8, 99.
23. Ubuebo, A.E. (1971) The effect of external supply of growth substances on axillary proliferation and development in *Dioscorea bulbifera*. *Ann. Bot.* 35, 159.
24. Wood, R.C. (1933) Experiments with yams in Trinidad (1931-33). *Emp. J. Expl. Agric.* 1, 316.

TABLE 1

Mean bulking rates of four phases of tuber growth in White Lisbon Yam (*D. alata*)

Gms/plant/wk.			
Phase I 7-13 wks	Phase II 13-19 wks	Phase III 19-32 wks	Phase IV 32-36 wks
0.36	2.72	21.40	3.00
Source: Ferguson, 1973			
=====			

A COMPARATIVE STUDY OF THE ANATOMICAL CHANGES ASSOCIATED WITH TUBERIZATION IN THE ROOTS OF CASSAVA AND SWEET POTATO

P. Indira and T. Kurian*

SUMMARY

In cassava, starch deposits are largely confined to the secondary xylem tissue. In sweet potato, starch is mainly stored in the cortex. Cassava and sweet potato differ in the pattern of anatomical differentiation preceding tuberization. In cassava, rapid proliferation of secondary xylem begins three weeks after planting and this is followed by starch deposition. In sweet potato starch is already occurring in the cortical region by one week after planting, and discrete cambia arise round individual vessels.

RESUME

Dans le manioc, les dépôts d'amidon sont largement confinés au tissu secondaire du xylème. Dans la patate douce l'amidon est essentiellement concentré dans le cortex. Le modèle de différenciation anatomique précédant la tubérisation diffère chez le manioc et la patate douce. Dans le manioc la prolifération rapide du xylème secondaire commence trois semaines après le semis suivi par le dépôt d'amidon. Dans la patate douce l'amidon se produit déjà dans la région corticale une semaine environ après le semis, et des cambiums discrets se forment autour des vaisseaux individuels.

RESUMEN

En yuca, los depósitos de almidón están mayormente confinados en los tejidos del xilema secundario. En el camote, el almidón se almacena principalmente en el cortex. La yuca y el camote se distinguen en cuanto al patrón de diferenciación anatómica precedente a la formación de tubérculos. En yuca, una rápida proliferación del xilema secundario se inicia tres semanas después de la siembra con una subsecuente deposición de almidón. En camote el almidón ya se encuentra presente en la región cortical alrededor de una semana después de la siembra, observándose aparición de cambios en forma discreta alrededor de vasos individuales.

MATERIAL AND METHODS

Stem cuttings of cassava having 6—8 buds and sweet potato vines were planted in pots containing sawdust, since uprooting of plants from sawdust was easy and cause least damage to roots. Watering was done as and when required. Three days after planting plants were carefully uprooted daily and observations were made on the formation of roots. Microscopic studies were carried out on thin transverse sections of roots stained with iodine. The occurrence of starch was defined as the criterion for differentiation of roots to tuber initials.

RESULTS

Root initiation

In cassava, callus formation occurred before the formation of roots at the distal end of the cutting within a week from planting. Roots originated from the callus within two to three days. In sweet potato rooting usually took place within three to five days from planting the vine cuttings.

Anatomy of normal roots

In cassava, the outer epidermal layer of the root is uniseriate. There is a cortex comprising ten to thirteen layers of parenchymatous cells. The cortical cells are closely packed. Within the cortex is an endodermis with casparian strips on its anticlinal walls. Within the endodermis is a pericycle which later may give

*Central Tuber Crops Research Institute, Trivandrum, Kerala, India.

rise to vascular secondary cambium. The vascular tissue comprises exarch xylem and phloem i.e. protoxylem and protophloem both occur on the outside). To start with, the xylem is either tetrarch or pentarch. The xylem and phloem are alternating with each other. Within the vascular region thin walled parenchymatous cells can be seen (Fig. 1).

In sweet potato also the structure is rather similar, but the epidermal layer gives rise to abundant root hairs. The number of primary xylem strands varies from five to eight (Fig. 4).

Anatomical changes during tuberization.

In cassava, the starch deposition in roots is always preceded by secondary growth in the vascular region. The secondary growth (formation of secondary xylem) began by about 21 days after planting. At this stage the roots themselves were only ten days old and starch grains could not be found. Starch deposition was first observed on 26th day and was found in the secondary xylem tissue consisting of massive xylem parenchyma is interlaced by strands of vessels accompanied by fibres. Thus in cassava it appears that the secondary xylem constitutes the bulk of the storage tissue. Enhanced formation of secondary xylem tissue followed by starch deposition can be considered as the first stage of tuberization in cassava (Fig. 3).

In sweet potato, starch was found only in cortical tissue. But at that stage there were only very few starch grains. By the 14th day, the cortical cells were almost filled with starch grains (Fig. 5), and 'anomalous secondary thickening' was seen in the vascular region. The 'anomalous' cambia occur around vessels. These cambia produce phloem containing much phloem parenchyma. By the 20th day starch grains occurred in the vascular region as well as the cortex (Fig. 6).

DISCUSSION

In both cassava and sweet potato the tubers are morphologically roots. There is thus no easy parallel to the situation in potatoes in which tuberization can be explained in terms of the differentiation of a stem apical meristem^{1,5}. The polarity of root growth similarly changes from longitudinal to radial. In cassava this occurs through secondary vascular growth⁴.

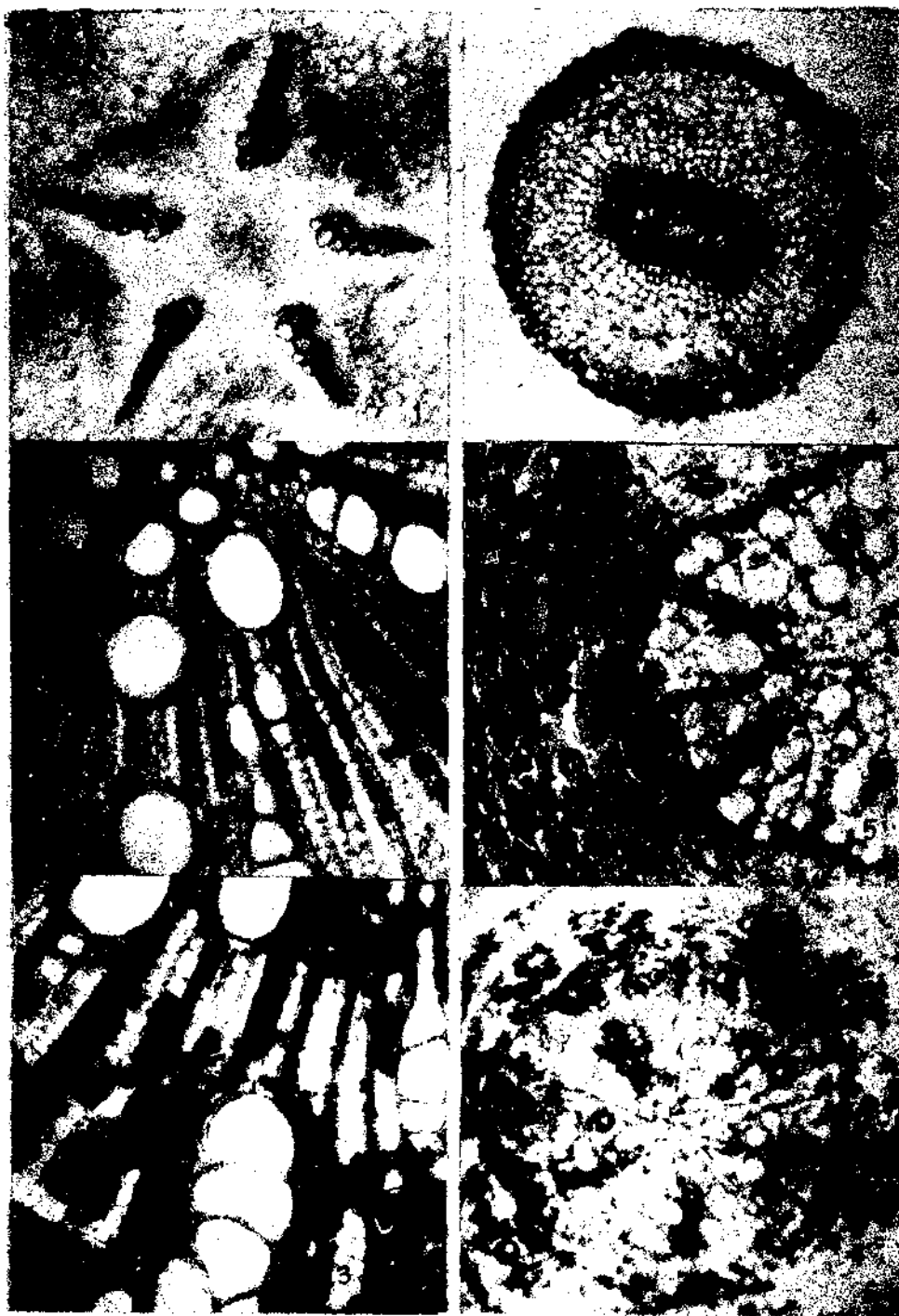
Esau² long ago described the anomalous secondary growth that occurs in the vascular region of roots of sweet potato during tuberization. Here a second cambium arises in the parenchyma situated outside the primary cambial zone; it is only active for a limited period and is in its turn succeeded by a third cambial layer, which originates at the outer limit of the phloem. This process is repeated several times, finally resulting in the formation of concentric zones composed alternatively of xylem and phloem, the latter constituting the bulk of the storage tissue³.

ACKNOWLEDGEMENT

Authors are thankful to Dr. N. Hrishy, Director, Central Tuber Crops Research Institute, Trivandrum for providing facilities and encouragement during the course of this work, and to Shri C.S. Antonisami for the preparation of photoplate.

REFERENCES

1. Booth, A. (1963) The role of growth substances in the development of stolons. In: *The growth of the potato*. Ed. J.D. Ivins and F.L. Milthorpe. pp. 99-113.
2. Esau, K. (1960) *Anatomy of seed plants*. John Wiley, N.Y.
3. Haberlandt, G. (1965) *Physiological plant anatomy*. Macmillan and Co., London. pp. 698.
4. Indira, P. and Sinha, S.K. (1970) Studies on the initiation and development of tubers in *Manihot esculenta* Crantz. *Indian J. Plant Physiol.* 13(1), 24-39.
5. Milthorpe, F.L. and Moorby, J. (1966) The growth of the potato. Proc. 3rd Triennial Conf. EAPR. 51-70.
6. Weaver, J.E. (1926) *Root development of field crops*. McGraw Hill Book Company, New York.



LEGEND FOR FIGURES

Fig. 1 - 3. Anatomical changes in cassava root. Transections (x 650)

1. Normal root showing the primary pentarch xylem.
2. & 3. Initial stages of tuberization.
(A portion of the vascular region from the transection magnified. Note the starch deposition in the secondary xylem region).

Fig. 4 - 6. Anatomical changes in sweet potato root transections (x 650)

4. Normal root
5. Initial state of tuberization.
Note the cortical cells filled with starch grains.
6. The deposition of starch grains extending to the vascular region.

CHANGES IN SOLUBLE AMINO ACIDS OF SOME TROPICAL STARCHY ROOTS DURING CHILLING

O.L. Oke*

SUMMARY

Preliminary qualitative results on the loss of free amino acids during and after chilling storage roots and tubers, and also plantain and banana fruits, throw some light on the changes during chilling injury. Loss of free amino acids is less in the cold resistant potato than in the tropical roots and fruits, and the loss of free amino acids seems to be associated with the degree of browning.

RESUME

Les résultats qualitatifs préliminaires sur la perte en acides aminés libres pendant et après la conservation des racines et tubercules au froid, de même que le plantain et les fruits de banane, jettent la lumière sur les changements subits par l'effet du froid. La perte en acides aminés est moindre dans la patate résistante au froid que dans les racines et fruits tropicaux, et la perte en acides aminés semble être liée au degré de brunissement.

RESUMEN

Resultados preliminares cualitativos, sobre la pérdida de aminoácidos libres, durante y después de la refrigeración de aminoácidos libres, durante y después de la refrigeración de raíces y tubérculos y también de plátano para cocinar y banano, dan alguna luz sobre los cambios que ocurren durante el dano que provoca la refrigeración. La pérdida de aminoácidos libres es menor en la papa resistente al frío que en las raíces y frutos tropicales y parece estar asociada con el grado de coloración café que se observa.

INTRODUCTION

Starchy roots and tubers such as yams are now increasingly being exported from Nigeria to overseas countries, especially Britain, partly as food for immigrant populations, but also because some species contain diosgenin, a steroid drug precursor. Preservation in transit is the most important factor in this marketing.

These foodstuffs have to be transported under refrigeration. It has been found that despite reduced losses from many other factors, they suffer low temperature breakdown. Attention has been focused by most workers on the lipid fraction of foodstuffs to explain the low temperature decay phenomenon. We have begun to investigate changes in soluble amino acids induced by low temperature.

MATERIALS AND METHODS

Samples of yams, cassava, cocoyam, bananas and plantains were collected from the University of Ife farm. Half of each sample was kept in the deep-freeze at 10°C for 2 months.

To determine soluble amino acids, 100g samples were removed from the middle of the fresh tuber. These were cut into very small pieces, mixed with 100 ml. of distilled water and homogenized in a stainless steel blender. To prevent foaming, a few drops of amyl alcohol were added. The homogenate was then centrifuged. The supernatant was collected and made up to a roughly 70% alcoholic solution by the addition of ethanol. The deproteinised extract was vacuum-dried. The solution was then chromatographed after being taken up with iso-propanol if it was too viscous.

The same extraction method was applied to corresponding samples taken after chilling for about two months at about 10°C .

Chromatography was carried out using Whatman No. 1 chromatography paper and the one dimensional ascending technique with n-butanol: acetic acid: H_2O [(12:3:5) by volume 3] and Phenol: H_2O (80:20w/v) as solvents, or 2-dimensional chromatography using the first of these solvents in the first dimension and the other in the second. This gave good separation of the amino-acids. The papers were then sprayed with ninhydrin and dried at $80\text{--}100^{\circ}\text{C}$ for two minutes when most of the amino acids show up brightly.

*Chemistry Department, University of Ife, Ife-Ife, Nigeria.

RESULTS

The one-dimensional chromatogram using phenol: water was not successful. Butanol: acetic acid: water gave better separation but still some of the acids such as glycine, serine and arginine were still difficult to separate. However, good results were obtained with the two-dimensional chromatograms. Pure amino acids were used as standards.

The following 20 free amino acids were identified from yam extracts: cystine, aspartic acid, serine, asparagine, glycine glutamic acid, histidine, arginine, threonine, glutamine, alanine, tryptophan, tyrosine, methionine, valine isoleucine, leucine, phenylalanine, proline and aminobutyric acid. There were 2 spots that could not be identified with certainty. The first is above tyrosine and is suspected to be alanine, from the R_f value and comparison with a pure sample. The other one below proline is unknown. The spots for lysine and asparagine for potato were more intense than for yam.

After chilling most of the free amino acids had disappeared and for yam only 6 spots were obtained. There were 3 bright spots corresponding to aspartic acid, glutamic acid and asparagine and traces of histidine, tryptophan and valine. More spots persisted in the comparative study on chilled potato. These were aspartic acid, glutamic acid, asparagine, serine, glutamic acid, threonine, alanine, tryptophane, valine and leucine.

Cassava differed from yam and potato in containing fewer free amino acids in fresh samples. Only aspartic acid, serine glutamic acid, glycine, arginine, alanine, tryptophan and valine were identified. After chilling only aspartic acid, glutamic acid and tryptophan could still be detected.

Unripe plantains and bananas each contain 17 free amino-acids. A few unidentified spots occurred in the chromatograms of unripe plantain. After chilling only about 9 spots (amino acids) remained for each. The ripe plantain and banana each contained about 13 free amino-acids each. After chilling they give streaks instead of well defined spots. It became difficult to separate arginine and histidine and there appeared 2 broad unknown streaks, probably peptides. In each only 5 spots could be identified with certainty.

DISCUSSION

The free amino acids, comprising a metabolic pool usually comprise about 70–80 percent of the non-protein nitrogen. Sometimes compounds are found which may be specifically important in nutrition, such as the toxic amino-acid e.g. β -amino propionitrile of some *Lathyrus* species which is supposed to be responsible for the incidence of lathyrism.

Our results have failed to show the occurrence among the soluble amino acids of cassava any sulphur-containing amino acids, or phenylalanine, or histidine, or amino-butyric acid, all of which were present in the other fresh foodstuffs.

Yam and potato seem to contain all of the most important amino acids and amino-butyric acid is present in unripe banana, but disappears during ripening. Other amino acids that disappear during ripening are aspartic acid, glutamic acid and phenylalanine, so that it appears that these acids may have some part to play in the ripening process.

Potato was the only crop tested that still contained an appreciable content of free amino acids after chilling, and it was also the foodstuff that was injured least (least browning). Yam, cassava, plantain and banana however suffered severe browning during chilling and it appeared that the more browning the sample suffered the greater was the numerical loss of amino acids.

The disappearance of amino acids during chilling suggests that they may either have been incorporated into the body of the foodstuff and rendered insoluble or else have formed peptides (which are probably the chemicals causing the streaks in chromatograms of plantain and banana). There has been chromatographic evidence for more than eight glutamyl peptides in plants. Dipeptides have been isolated mainly from storage tissues chiefly from seeds, bulbs and fruits. These facts indicate the possibility that glutamyl dipeptides may have widespread occurrence in various types of tissues throughout the plant kingdom. Even though glutamic acid is usually a prominent constituent of the non-protein fraction, the glutamyl-peptides have been found present in concentrations as high or higher than that of glutamic acid. The presence of glutamyl peptides will probably account for the deep-coloured large spots designated as unknown on the chromatograms.

Work is in progress on the identification of the unknown ninhydrin-positive spots and the quantitative analysis of the amino acids changes.

COMPONENTS OF TUBER YIELD IN SWEET POTATO

L.A. Wilson*

SUMMARY

Studies on the relationships of components of yield with yield itself using correlation and regression analysis lead to a conclusion that the maintenance of the potential for growth in girth of the roots during the latter half of the vegetative growth cycle may be an important determinant of potential yield in the sweet potato.

RESUME

Des études sur les rapports entre éléments du rendement et le rendement lui-même au moyen d'analyse de corrélation et de régression ont permis de conclure que l'entretien du potentiel de croissance de la partie périphérique des racines pendant la dernière moitié du cycle végétatif doit avoir une importance déterminante dans le potentiel de rendement de la patate douce.

RESUMEN

Estudios sobre las interrelaciones entre los componentes del rendimiento, con el rendimiento en sí mismo usando análisis de correlación y regresión, condujeron a la conclusión de que el mantenimiento del potencial para el crecimiento perimetral de las raíces, durante la segunda mitad del ciclo vegetativo de crecimiento, puede ser un factor determinante del rendimiento potencial en camote.

INTRODUCTION

At the crop level, the numbers and sizes of organs per plant are the immediate components of yield, e.g. in cereals,^{1,8} number of grains and mean grain weight, and in root crops,⁴ number and size of roots. In root crops the economic yield is often not the total yield, but that of roots which have attained a minimum size and weight at harvest⁹.

Tuber volume and tuber density may be considered as further sub-components of tuber weight, and tuber cell number and the mean size of tuber cells may, in turn, be considered as sub-components of tuber volume. To obtain a fully analysed understanding of tuber crop yield and to identify possible limitations to tuber yield development, yield components can be considered both at the crop level and at the plant and tuber levels.

In this paper, interrelationships between crop yield in six sweet potato cultivars of different foliage¹⁰ and tuber³ characteristics are examined. Effects of tuber shape on the volume component of tuber weight and of some anatomical attributes of tuber meristems which relate to cell numbers in tubers are outlined. Possible implications of tuber shape and tuber meristem characteristics on tuber crop yield are discussed.

MATERIALS AND METHODS

The six cultivars used in the study include a commercial cultivar 049 as well as A28/7, C9/9, 162, A16/15 and a low yielding cultivar 03/62. Agronomic, physiological and anatomical techniques used in the study are described elsewhere and reference is made to the sources of these techniques in the text. All tuber weights referred to are fresh weights.

RESULTS AND DISCUSSION

Components of sweet potato crop yield

The immediate components of sweet potato crop yield, mean tuber weight and tuber number were found to be in different relationships with tuber yield in the six sweet potato cultivars studied⁴. In a comparison of within-cultivar correlation and regression coefficient among tuber number, mean tuber weight and yield, there were significant positive correlations between tuber number and yield in cultivars A28/7

*The University of the West Indies, Department of Biological Sciences, St. Augustine, Trinidad, West Indies.

and 03/62. Correlations between mean tuber weight and total yield were significant for all cultivars except cultivar 049. Cultivars could be grouped into three types as follows:

1. Types in which both components were positively correlated with tuber yield, A28/7, 03/62.
2. Types in which only tuber weight was positively correlated with yield, C9/9, 162, A16/15.
3. A type in which neither yield component was significantly correlated with yield, 049.

There were significant negative correlation coefficients between the two yield components in all cultivars except cultivar 03/62. This is an expression of the usual compensatory relationship between tuber number and mean tuber weight. This compensatory relationship was most prominent in cultivar 049, where an increase in tuber number by one resulted in a 50 g (approx.) reduction in mean tuber weight. In this cultivar also there was not a significant relationship between either yield component and yield which is another reflection of the same compensatory interaction.

For the combined data for five of the six cultivars studied (excluding 03/62), there was a negative regression coefficient for mean tuber weight on tuber number (Fig. 1), indicating that the relationship between the two components in these cultivars was similar to that observed for individual cultivars. Optimal tuber number for maximal yield in the cultivars studied was four, and it is suggested that there may be an optimal tuber number/mean tuber weight relationship for maximal tuber yield in the sweet potato.

Contribution of yield components to variability in total yield

Sweet potato yield in a crop population is characterized by considerable plant to plant variability^{7,2}. However, the contribution of individual yield components to this variability depends on the relationship between yield and the component⁶. Thus, in cultivars A16/15 and A28/7, there were positive regressions of total yield on tuber number and in these cultivars, 16 and 26 percent respectively, of the variability in total yield was attributable to the regression of yield on tuber number (Table 1). Similarly, there were positive regressions of yield on mean tuber weight in all cultivars, except 049 and in these cultivars, 16–48 percent of the variability in total yield can be accounted for by the regression of yield on mean tuber weight. In cultivar A28/7, regressions of yield on tuber number and mean tuber weight together accounted for more than 50 percent of the total yield variability in this cultivar. Moreover, in cultivar 049, in which there was no significant relationship between either yield component and total yield, yield was most stable (lowest variability) between plants.

Variability in mean tuber weight appears therefore to be a more important contributing factor to between plant variability in total yield than tuber number in the cultivars studied. Since tuber initiation was completed in all cultivars except 162 by 8 weeks after planting, the variation in tuber weight observed was due to different rates of growth of individual tubers on a single plant.

Interrelationships between tuber shape and yield

In tubers of two sweet potato cultivars with contrasting tuber shapes (globular vs. narrowly fusiform), it was shown by Lowe and Wilson⁶ that the development of tuber weight was related to tuber shape. Also, that longitudinal and lateral growth associated with changes in shape occurred at different times in the tuber growth cycle. Increase in tuber length occurred in the period up to 16 weeks after planting and major increases in tuber diameter took place in the period 16–24 weeks after planting. These increases in tuber diameter were related to increase in mean tuber weight and changes in tuber shape (Fig. 2). Thus, the more globular tubers of cultivar 049 showed major increases in mean tuber weight in the latter half of the tuber growth cycle whereas in the narrowly fusiform tubers of cultivar A16/15 changes in mean tuber weight related to change in tuber shape were minimal.

Tuber meristems and tuber growth

Tuber growth in sweet potato is effected by the meristem activity of the primary cambium as well as of secondary and tertiary meristematic strips¹¹. It has been shown that in the globular tubers of cultivar 049 rapid increase in tuber diameter is associated with the presence of numerous active secondary and tertiary meristems. These provide for the rapid proliferation of storage parenchyma cells. In contrast, such secondary and tertiary meristems are relatively little developed in the narrowly fusiform tubers of cultivar A16/15¹¹ and the tuber growth even in the latter half of the cycle continues to be largely mediated by the activity of the primary cambium.

Thus it seems that relatively poor development of secondary and tertiary meristems in tubers of cultivars A16/15 is responsible for the low mean tuber weight and narrowly fusiform tuber shape in this cultivar.

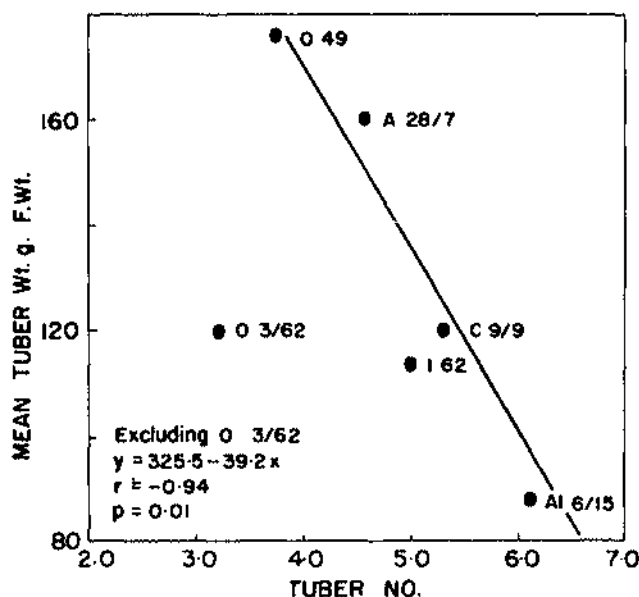


FIG. 1 RELATIONSHIP BETWEEN TUBER NO. & TUBER WEIGHT IN SIX SWEET POTATO CULTIVARS

(From Lowe & Wilson (1974))

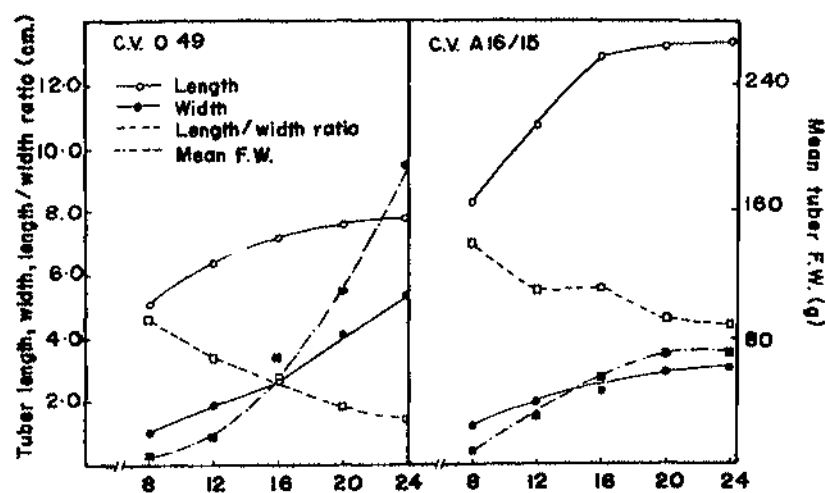


FIG. 2 Changes in tuber dimensions and length/width ratios in two sweet potato cultivars with development.

Tuber number and tuber meristems

In cultivar 049, in which secondary and tertiary tuber meristems are active, the mean tuber number per plant is low (3.8). Conversely, in cultivar A16/15, tuber number per plant is high (6.1).¹¹ These characteristics are associated with high tuber yield per plant in cultivar 049 (526 g/plant). It is suggested, therefore, that an important component of tuber crop yield in sweet potato may be the prolongation of the activity of tuber growth potential by secondary and tertiary meristems developing during the latter half of the growing season (extending the sink potential). A limiting factor in sweet potato tuber yield may be a quantitatively generated cell division factor promoting the development and continued activity of secondary and tertiary meristems.

REFERENCES

- Engledow, F.L. and Wadham, S.M. (1923) Investigation on yield in the cereals. *J. Agric. Sci.* 13, 390.
- Haynes, P.H. and Wholey, D.W. (1971) Variability in commercial sweet potatoes in Trinidad. *Exptl. Agric.* 7, 27-32.
- Lowe, S.B. (1971) M. Sc. Thesis, U.W.I. Library (unpubl.)
- Lowe, S.B. and Wilson, L.A. (1974a) Yield and yield components of six sweet potato cultivars. I. Contribution of yield components to tuber yield *Exptl. Agric.* 11 (1), 39-48.
- (1974b) Yield and yield components of six sweet potato cultivars. II. Variability and possible sources of variation. *Exptl. Agric.* 11 (1), 49-57.
- (1974c) Comparative analysis of tuber development in six sweet potato cultivars. 2. Interrelationships between tuber shape and yield. *Ann. Bot.* 38, 319-26.
- Steinbauer, C.E., Hoffman, G.P. and Edmond, J.B. (1943) Why are single plant yields of sweet potato (*Ipomoea batatas* (L.) Lam.) highly variable within plots. *Proc. Amer. Soc. Hort. Sci.* 43, 249-54.
- Thorne, G.M. (1966) In *Growth of cereals*. Milthorpe, F.L. and Ivins, J.D. (Eds) Butterworths, London.
- Toosey, R.D. (1960) In *Growth of the potato*. Ivins, J.D. and Milthorpe, F.L. (Eds) Butterworths, London.
- Wholey, D.W. and Haynes, P.H. (1969) Root Crop Programme Half Yearly Report 1968/69. University of the West Indies, Trinidad.
- Wilson L.A. and Lowe, S.B. (1973) The anatomy of the root system in West Indian sweet potato (*Ipomoea batatas* (L.) Lam) cultivars. *Ann. Bot.* 37, 633-43.

TABLE 1

Percentage of total yield variability due to regression of yield on mean tuber weight and tuber number

<u>Yield component</u>	<u>Percentage of total yield variability</u>					
	<u>049</u>	<u>A2817</u>	<u>C9/9</u>	<u>I62</u>	<u>A16/15</u>	<u>03/62</u>
Mean tuber wt.	N.S.	28	35	39	16	27
Tuber no.	N.S.	26	N.S.	N.S.	N.S.	16
Total	-	54	35	39	16	43

GROWTH, DEVELOPMENT AND YIELD OF SOME TROPICAL ROOT CROPS

B.A.C. Enyi*

SUMMARY

The effect of size of the vegetative planting propagule on tuber yield is attributable mainly to its effects on rate of bulking and leaf area duration. The difference in root tuber yield between cultivars within species of root crops is due mainly to the differences in their rate of bulking and, in some instances, to the duration of bulking and leaf area duration.

Time of planting and mulching influence yield via leaf area duration. Spacing affects leaf area duration and rate of bulking. Staking increases leaf area duration and rate and duration of bulking. Age of planting sets affects leaf area index and leaf area duration.

Greater leaf area duration can be achieved by a combination of high leaf area index with a short period of leaf growth or low leaf area index with longer period of leaf growth. The latter combination is a better one provided that the leaf area index does not remain below the optimum for maximum dry matter production for a long period. Plant breeders should try to produce plants with rapid leaf development between the time of planting and tuber initiation and after tuber initiation plants should maintain an optimum leaf area index for a long period.

RESUME

L'effet de la dimension de la propagule végétative sur le rendement des tubercules est surtout attribuable à ses effets sur le taux de développement de la tubercule et de la durée de zone foliaire. La différence de rendement entre cultivars de même espèce de plantes à racine est essentiellement due aux différences de leur taux de développement et dans certains cas, à la durée de développement des tubercules et à celle de la zone foliaire. La période de semis et le paillage influencent le rendement sous l'effet de la durée de zone foliaire. L'espacement affecte la durée de la zone foliaire et le taux de développement de la racine, le tuteurage prolonge la durée de la zone foliaire, de même que le taux et la durée du développement de la racine. L'âge des boutures de semis affecte l'index de la zone foliaire et la durée de la zone foliaire.

On peut obtenir une durée de la zone foliaire par la combinaison d'un index élevé de la zone foliaire à une courte période de la croissance foliaire, ou d'un index bas de zone foliaire à une période plus longue de la croissance foliaire. La dernière combinaison est plus intéressante pourvu que l'index de la zone foliaire ne reste pas en dessous des conditions optima pour la production de matière sèche maximale sur une longue période. Les phytogénéticiens devraient s'efforcer de produire des plantes au développement foliaire rapide entre le temps de semis et l'initiation des tubercules; de plus, les plantes devraient conserver un index de zone foliaire optimale sur une longue période après l'initiation des tubercules.

RESUMEN

El efecto del tamaño de los propágulos vegetativos para siembra, sobre el rendimiento de tubérculos, se atribuye principalmente al grado de engrosamiento y duración del área foliar que produce. La diferencia del rendimiento de tubérculos entre cultivares dentro de especies de cultivos con tubérculos es debida principalmente a las diferencias en su grado de engrosamiento y en algunos casos, a la duración del engrosamiento y área foliar.

La época de siembra y la cobertura tienen influencia a través de la duración del área foliar. El espaciamiento afecta la duración del área foliar y el grado de engrosamiento. El estacado aumenta la duración del área foliar y del engrosamiento. La edad de los propágulos afecta el índice de área foliar y la duración de la misma.

La mayor duración del área foliar puede lograrse con una combinación de un índice elevado de área foliar con un período corto de crecimiento de la hoja o un índice bajo de área foliar con un período mas largo de crecimiento de la hoja. Esta última combinación es mejor, siempre que el índice de área foliar no permanezca por debajo del óptimo, para una producción máxima de materia seca, por un período largo. Los fitomejoradores deberían de tratar de producir plantas con un desarrollo rápido de hojas en el período desde la siembra hasta la iniciación de tubérculos y las plantas deberían obtener un índice óptimo de área foliar por un período largo.

*University of Papua, New Guinea.

INTRODUCTION

This paper is concerned mainly with cassava, yams and tannia. Cassava is usually propagated by stem cuttings. When the stem cuttings are planted they usually produce many shoots and in most cassava cultivars there is a period of growth of about four to eight months. During this period most of the assimilates are diverted into the leaf blades and stems. This is followed by a period of tuberization, and at this stage there is competition between the stems and roots for the available assimilates. The proportion of assimilates diverted into the root tubers varies with cultivar, spacing and the number of shoots developed per plant.

Yams are usually propagated by stem tubers. The tubers usually produce aerial stems which are weak, and in cultivation the plants are usually supported by long poles up which they twine in either a clockwise or an anti-clockwise direction, depending on the species. Sobulo²³ considered the growth cycle of white yam as comprising four stages. The first is that in which the sett is still dormant; the second is that in which growth of the main shoot and root occurs; the third stage is the period of tuber initiation, leading to rapid tuberization and the senescence of roots and shoots; the fourth stage is the loss of stem and root material while tuber dry matter reaches a maximum value.

Tannia plants are propagated by means of corms. The growth cycle in this crop can similarly be considered to comprise four different stages. The first is the period during which the sett remains dormant; the second is the period of the growth of the primary shoot and roots; in the third period, initiation of the secondary corms is followed by rapid tuberization, and in the fourth stage there is rapid senescence of the leaves with the approach of the dry season.

In most root crops, tuber yield depends on two main factors, firstly, the rate at which assimilates are translocated into the storage organs and, secondly, the duration of such translocation. The rate at which assimilates are translocated to the tubers will depend on the total amount of assimilates available, the proportion of the assimilates available for tuber development, and the number of tubers initiated. The total amount of assimilates available will in turn depend on the leaf area of the plants and the photosynthetic efficiency of the leaves. Duration of assimilate translocation is dependent on the time at which tuber initiation occurs and the leaf area duration after this time.

These physiological factors which operate at different stages of growth of the crops, and which determine the final yield of the tubers are influenced by agronomically determined variables, such as (a) the size of the planting sett, (b) the age of the planting sett, (c) cultivar, (d) fertilizer application, (e) time of planting, (f) number of shoots per plant, (g) mulching, (h) spacing and (i) staking. This paper deals with the effect of the above agronomic factors on growth and tuber yield of cassava, yams and tannia.

REVIEW OF THE EFFECTS OF AGRONOMIC FACTORS ON YIELD

Effect of size of planting sett on growth and yield

The dry matter available for the growth of the young shoots after planting will usually depend on the dry weight of the planting sett and this in turn will depend normally on the size of the sett. Since the size of the sett is likely to affect at least the early growth of the plants, it might be expected that it will also affect the final tuber yield. Bremer and Taha² noted that in the Irish potato, large sized seeds produced plants with longer leaf area duration and associated greater dry weight and tuber yield than small sized ones. In cassava, Jergaseelan¹⁸ showed that root tuber yield increased with increasing length of planting sett. In yams, a relationship exists between weight of sett planted and yield of tubers^{15,19}. Experiments with tannia (*Xanthosoma sagittifolium* Schott)⁷ and lesser yam (*Dioscorea esculenta*)¹¹ showed that corm and tuber yield respectively increased with the increase in seed size. (Table 1)

In the second tannia experiment, which included the following additional treatment: ridge, flat, very large setts, extra large setts, mulched or bare, final corm yield was shown to be closely related to mean maximum leaf area index (LAI) (Table 2).

The correlation coefficient between LAI and corm yield in this experiment was 0.93. The increase in corm yield with increase in the size of sett may therefore be attributed to the increase in maximum LAI obtained by increasing the size of sett. In this experiment, the difference in the corm yield from the use of very large and extra large setts was not significant. The lack of significant difference in the corm yield between these treatments can be attributed to their not bringing about significant differences in the LAI. Enyi⁸ also showed that fresh weight yield of corm (Y) was closely associated ($r=0.71$) with leaf blade areas (X) with a linear regression $Y=0.107X-19.4$.

Purewal and Dargan²² found a close correlation between LAI and corm yield in *Colocasia* sp. In an experiment with lesser yam, increase in seed size led to an increase in tuber number per plant (Fig. 1) and an increase in tuber weight per plant (Fig. 2). However, the proportion of tubers that did not reach harvesting size increased with an increase in sett size. LAI also increased with size of planting sett (Fig. 3) and the maximum number of tubers initiated appeared to be related to the leaf area of the plant achieved at the start of tuber initiation.

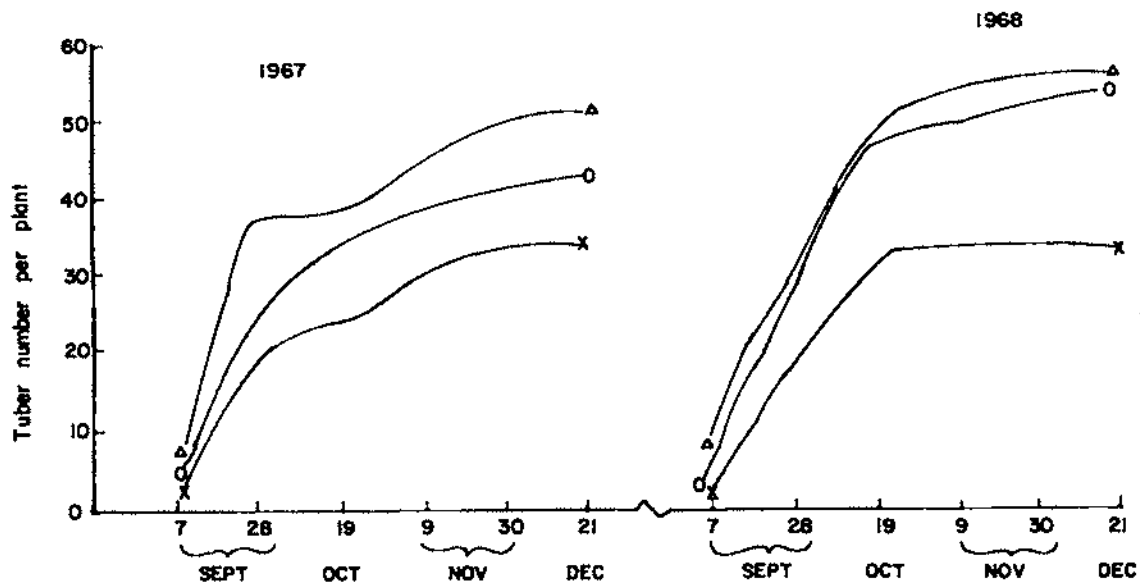


Fig. 1. Effect of seed sett on tuber number in 1967 and 1968. Large sett ———, medium sett o-----o, small sett ----- (Means of spacing treatments) (Lesser yam)

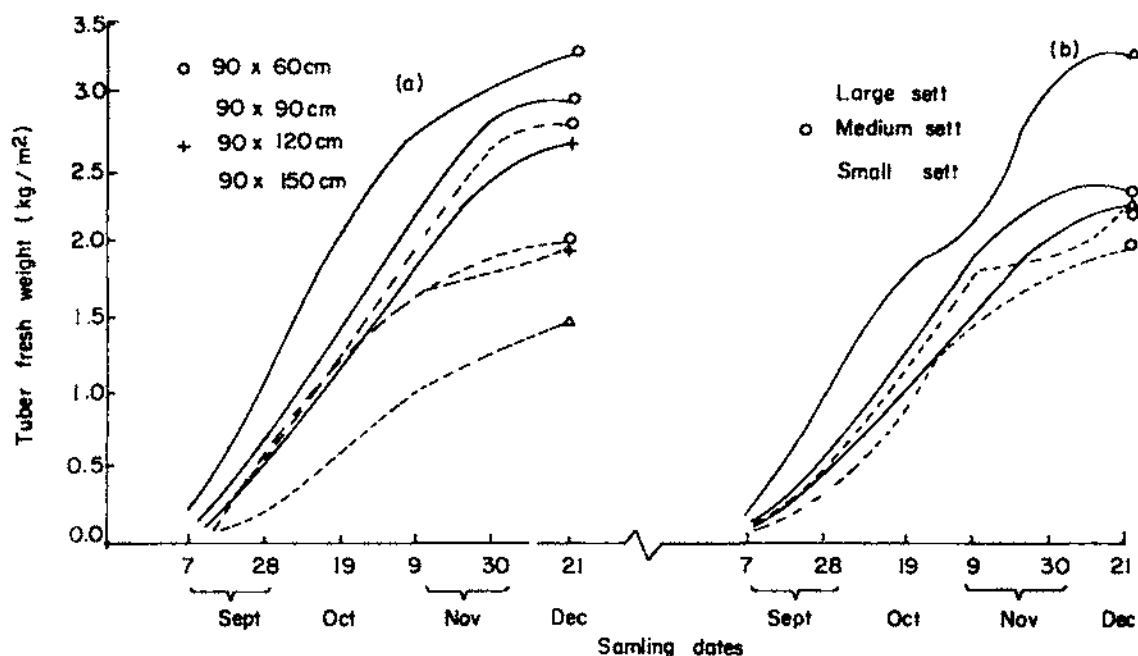


Fig. 2. The change with time in tuber fresh weight in 1967(—) and 1968(---) (a) Effect of spacing treatment (b) Effect of seed size (Lesser yam)

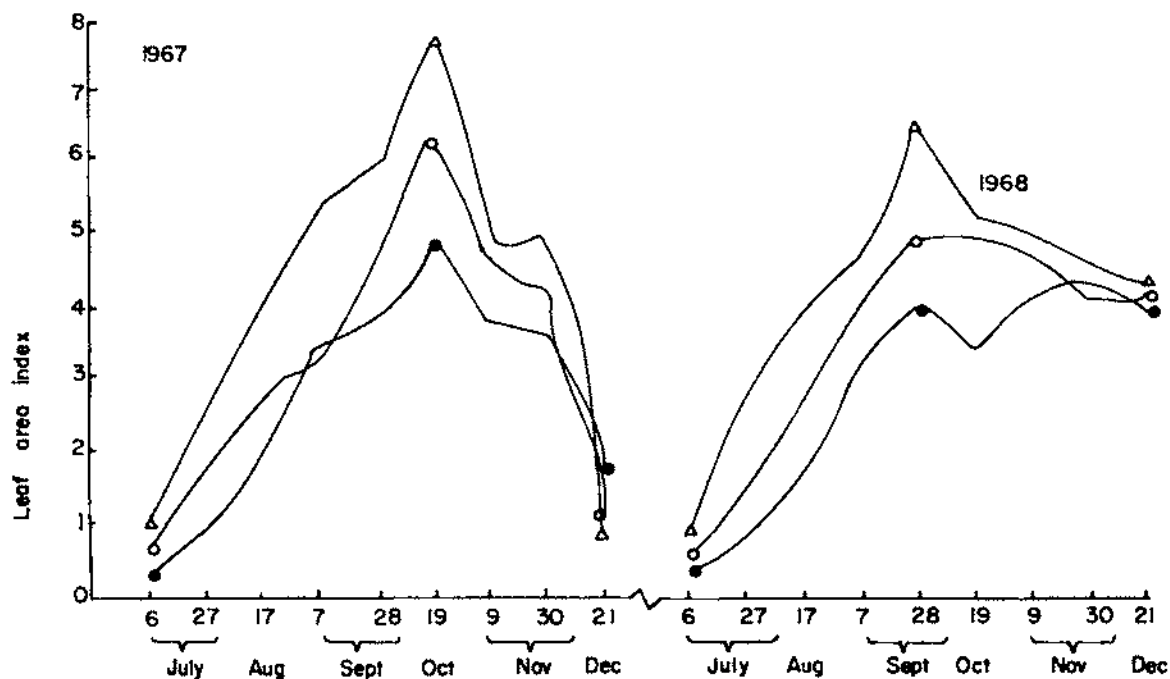


Fig. 3. The change with time in leaf area index. Effect of sett size. Large sett ———, medium sett o-----o, small sett ----- (means of spacing treatments) (Lesser yam) Arrow indicates time of tuber initiation.

Leaf area duration increased with the increase in sett size and in this experiment tuber yield (X) was shown to be closely related ($r=0.932$) to leaf area duration between time of tuber initiation and final sampling (DF) according to the regression $X=376DF + 8233$. In lesser yam, it can be concluded that increase in tuber yield with increasing seed size is due to the associated increase in tuber number, leaf area duration and bulking rate (Table 3).

Effect of age of sett on growth and yield

For yams the most successful planting material is the small whole tuber or seed yam. If sufficient seed yams are not available, then setts cut from the tuber are used and are referred as tops, middles and bottoms. The top is morphologically the oldest section of the tuber, while the bottom is the youngest. The tops are usually preferred to bottoms or middles.

Morphologically the primary 'corm' of cocoyam (*Xanthosoma sagittifolium*) is the main stem of the plant and the secondary 'corms' are its branches. The age of the planting sett when the main stems are cut to produce setts will depend on its position on the corm, those produced from the top being the youngest and those from the bottom the oldest.

Chemical analysis of the various sections of the main corm used for planting experiments by Enyi⁸ showed that the concentration of N, P and K decreased in the top four sections followed by an increase in the age of the corm. It is likely that the differences in the chemical composition of the sett may affect the growth of the plants and therefore may influence the final yield of corms. It was also found that plants produced from the last two sections of the corm developed much greater leaf areas and total dry weight than those produced from the first four sections. In the present experiment, there was a close association ($r=0.98$) between Ca% in the setts and the subsequent dry weight of the plants produced from them. The linear regression was $X=412Y - 187$ where X = the dry weight and Y = Ca% in the sett. There was also a close ($r=0.71$) association between leaf blade areas and fresh weight yield of corm with linear regression $Y=0.107X-19.4$ where Y = yield of tuber and X = leaf blade area. It appears that the differences in the corm yield brought about by differences in the age of the planting sett may be due to differences in the chemical composition of the setts.

The nutrient content (g/sett) of planting setts in cassava is shown in Fig. 4 (Enyi¹⁰). N, K, Mg and Ca content increased with the age of the sett and data in Table 4 shows that root tuber yield increased with an increase in the age of the planting sett.

The increase in yield of the tuber with increasing age of the sett may be due to the higher dry matter content of the older setts. This experiment also shows that there is a positive linear relationship between dry matter of the sett and the yield of tuber ($X=0.072Y - 0.196$, $r=0.959$) where X is the tuber yield in Kg/plant and Y the dry weight of sett. The advantage of the older setts over the younger ones in production of root tuber yield may also be due to the higher N and K content in the former compared with the latter setts, and the results show that root tuber yield is positively and linearly related to N content in the sett ($X=7.93Y + 0.37$, $r=0.985$) where Y is the N content in the sett and also linearly related to K content in the sett ($X=8.89Y + 1.010$, $r=0.926$) where Y is the K content in the sett. Although leaf area measurements were not carried out in this experiment, it is likely that the higher dry matter N and K contents in the older setts encouraged greater leaf area development, and therefore led to greater yield of root tubers. The effect of age of sett on root tuber yield reported in this experiment is similar to that reported by Jergaseelan¹⁸.

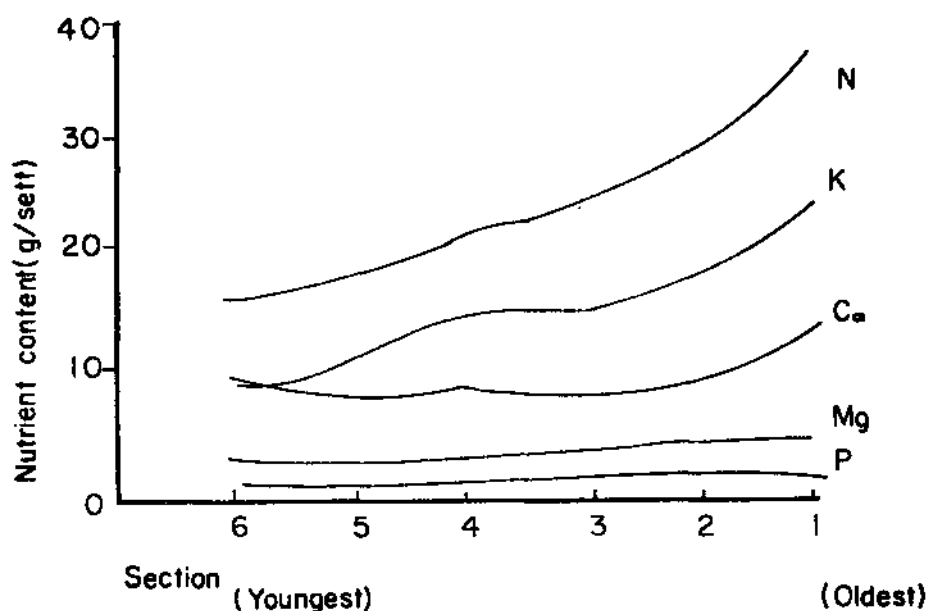


Fig.4. Nutrient content in the various planting setts

Effect of fertilizer application on growth and yield

In most root crops, the most important elements in applied fertilizers are nitrogen and potassium. Increase in tuber yield in yams by application of nitrogenous fertilizers have been shown by a number of workers (Vine²⁵, Nye²⁰, Irving¹⁷, Giradot¹⁵, Obi²¹, Stephens²⁴, Djokoto and Stephens⁵, Chapman³, Anon.¹). The yield increased between 10–20%. In an experiment with lesser yam nitrogen application encouraged greater total dry matter production and had a favourable effect on dry matter accumulation in the vine and petioles. Nitrogen application also increased the proportion of dry matter being diverted into the tubers of staked yams (Table 5).

Nitrogen application also increased leaf area duration and tuber number per plant (Table 5) and mean bulking rate (Table 6).

In this experiment, the regression of tuber yield on leaf area duration (D) shows that tuber yield is highly and positively related ($r=0.97$) to D. Since tuber yield is positively related to D, the increase in tuber yield as a result of nitrogen application might be attributed to the favourable effects of this treatment on leaf area development. In this experiment, increased leaf area was connected with increased vine growth and the calculated correlation coefficient for the relationship between leaf area index (L) and dry weight of vine at time of maximum L was 0.95. Since nitrogen increased dry matter accumulation in the vines, it therefore increased L by encouraging the growth of vine.

Yams have been shown to respond to low levels of potash applications (Irving¹⁷, Giradot¹⁵, Ferguson and Haynes¹⁴).

In an experiment with lesser yam, Enyi showed that the application of potassium increased dry matter accumulation in the tubers but had no effect on the other organs and at final sampling it increased the proportion of dry matter diverted into the tubers of both staked and unstaked plants (Table 5).

Potassium had no significant positive effect on leaf area duration (Table 5) but increased the rate of bulking (Table 6). In tannia (Enyi⁹) the application of fertilizer increased leaf area index (Fig. 5) and also the dry weight of both primary and secondary corms (Fig. 6). Since in tannia corm yield is positively related to maximum leaf area index, fertilizer application appears to increase corm yield mainly by encouraging greater leaf area development.

Effect of mulching on growth and yield

Mulched tannia plants had a significantly greater leaf area index than unmulched plants (Enyi⁷). Mulched plants also outyielded unmulched plants (Table 7).

In this experiment, corm yield was directly related to maximum leaf area index (Table 2) so that the beneficial effect of mulching on the corm yield of this crop may be attributed to its favourable effect on leaf area development.

Effect of time of planting on growth and yield

In most crops, greater yields are usually associated with early planting or sowing. For example, in potatoes, Dyke⁶ showed in a survey that the yield of main crop potatoes declined at the rate of about 753kg/ha for each week's delay in planting beyond the second or third week in April.

In cassava experiments (Enyi¹²), early planting also led to an increase in the yield of root tubers, root tuber number per plant, individual tuber weight and root tuber: stem weight ratio (Table 8).

Relative leaf area duration in this experiment decreased with delay in planting because of the reduction in the period of leaf growth brought about by late planting (Table 9).

In the 1967 and 1968 trials, the rate of bulking decreased when planting was delayed until after 29th April and 13th May respectively. The decrease in root tuber yield resulting from late planting therefore might be attributed to the decrease in both the rate and period of bulking.

Root and tuber yield was also associated with leaf area duration and, since leaf area duration decreased with delay in planting, the decrease in root tuber yield might also be attributed to the decrease in leaf area duration.

In lesser yam, delay in planting also led to decrease in the yield of tubers (Table 10), tuber number per plant and relative leaf area duration.

In the late planted setts (T5 and T6), tuber initiation was delayed so that the period of bulking and tuber growth was reduced. The rate of bulking of these plants was also lower than those of early planted setts. These two factors probably contributed to the lower yield of T5 and T6 treatment plants. Enyi¹¹ showed that in lesser yam, a close and positive relationship exists between the number of tubers initiated and the leaf area index at the time of initiation. Since leaf area indices of plants from late planted setts were low at the time of initiation, the number of tubers initiated by these plants were probably lower than early planted ones.

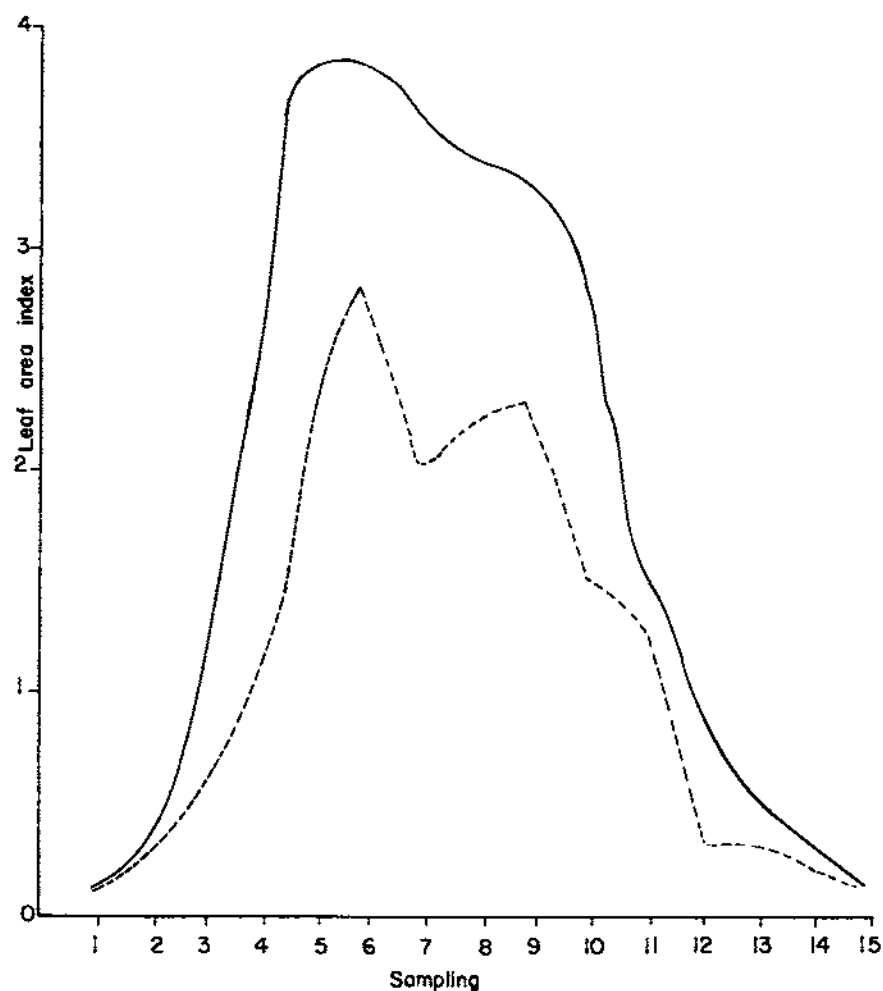


Fig.5. Changes with time in leaf area index (Tannia)
 — fertilized plants, - - - unfertilized plants.

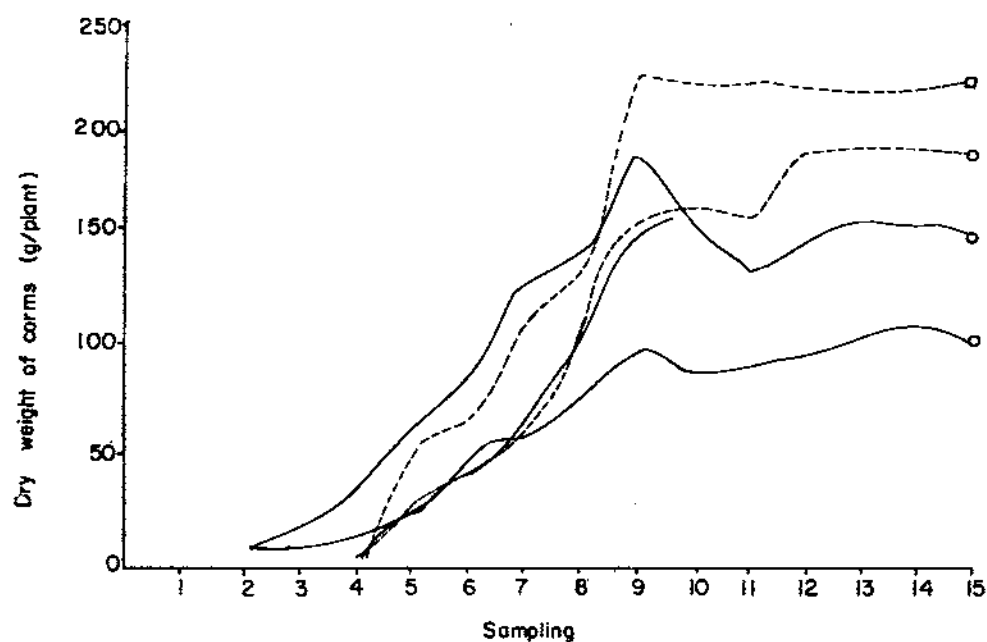


Fig.6. Changes with time in dry weight of corms (Tannia) ●—● Primary corms of fertilized plants; ○—○ Primary corms of unfertilized plants; □—□ Cormels of fertilized plants; ■—■ Cormels of unfertilized plants

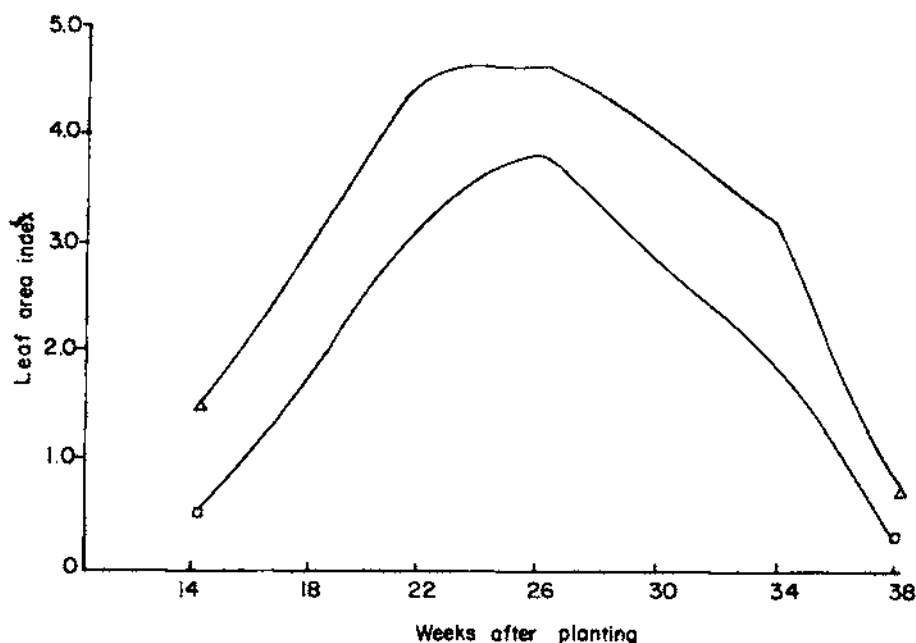


Fig. 7. Mean leaf area index Δ, mulch; □, no mulch (Tannia)

The lower number of tubers initiated by plants from later planted setts might have been responsible for the low tuber number of these plants at harvest (Table 10). In the date of planting experiment with lesser yam, tuber yield was shown to be positively related to leaf area duration with a correlation coefficient of 0.93 in 1967 and 0.95 in 1968. The decrease in tuber yield with delay in planting may therefore be attributed partly to the reduction in leaf area duration with delay in planting.

Effect of spacing on growth and yield

In a spacing experiment with tannia, (*Xanthosoma sagittifolium*) (Enyi⁷) the yield of corms increased with wider spacing (60 X 60cm, 90 X 90cm, 120 X 120cm and 150 X 150cm = 38.0, 41.2, 50.8 and 62.8kg/45dm² of land surface respectively. Corm yield in tannia was also closely and positively associated with maximum leaf area index (LAI) and, since LAI normally increases with increasing plant density, one would expect an increase in the yield of this crop to occur with increasing plant density. It is probable that at high plant density, the number of secondary corms formed from the main corm was reduced, and this probably led to the reduction in the number of 'sinks' available to accommodate the product of photosynthesis. In lesser yam, Enyi⁷, increasing plant density led to an increase in tuber yield (Fig. 2), relative leaf area duration, and mean bulking rate per hectare (Table II).

In this experiment there was a closer relationship between tuber yield and leaf are duration from tuber initiation onwards (D_F) than between yield and total leaf area duration, (D_T). The regression equation for the relationship between D_T and tuber yield (X) is $X=201D_T + 12876$ ($r=0.735$) and that between D_F and tuber yield is $X=376D_F + 8233$ ($r=0.932$). The highly positive linear relationship between D_F and tuber yield shows the importance of achieving and maintaining high leaf area during the period of tuber initiation and growth. Fig. 8 shows that leaf area duration achieved with increasing plant density was mainly due to the increase in leaf area index.

In lesser yam, the spacing effect was achieved by increasing leaf area duration and bulking rate per unit area.

In a cassava variety trial in Tanzania (1971/72 growing season), increase in plant density led to an increase in the yield of root tubers per hectare, the rate of bulking per hectare and relative leaf area duration (Table 12).

Most workers have reported that tuber yield in root crops is highly and positively correlated with leaf area duration. (Bremner and Taha², Enyi^{11,12,13}) In the result presented in Table 12, a reduction in the interrow spacing from 120 to 60cm led to an increase in the yield of tuber and rate of bulking by about 92 and 120% respectively, and an increase in leaf area duration by about 6%. In this experiment therefore, root tuber yield was more dependent on bulking rate than on leaf area duration.

Increase in plant population therefore led to an increase in tuber yield by increasing the rate of bulking per unit area.

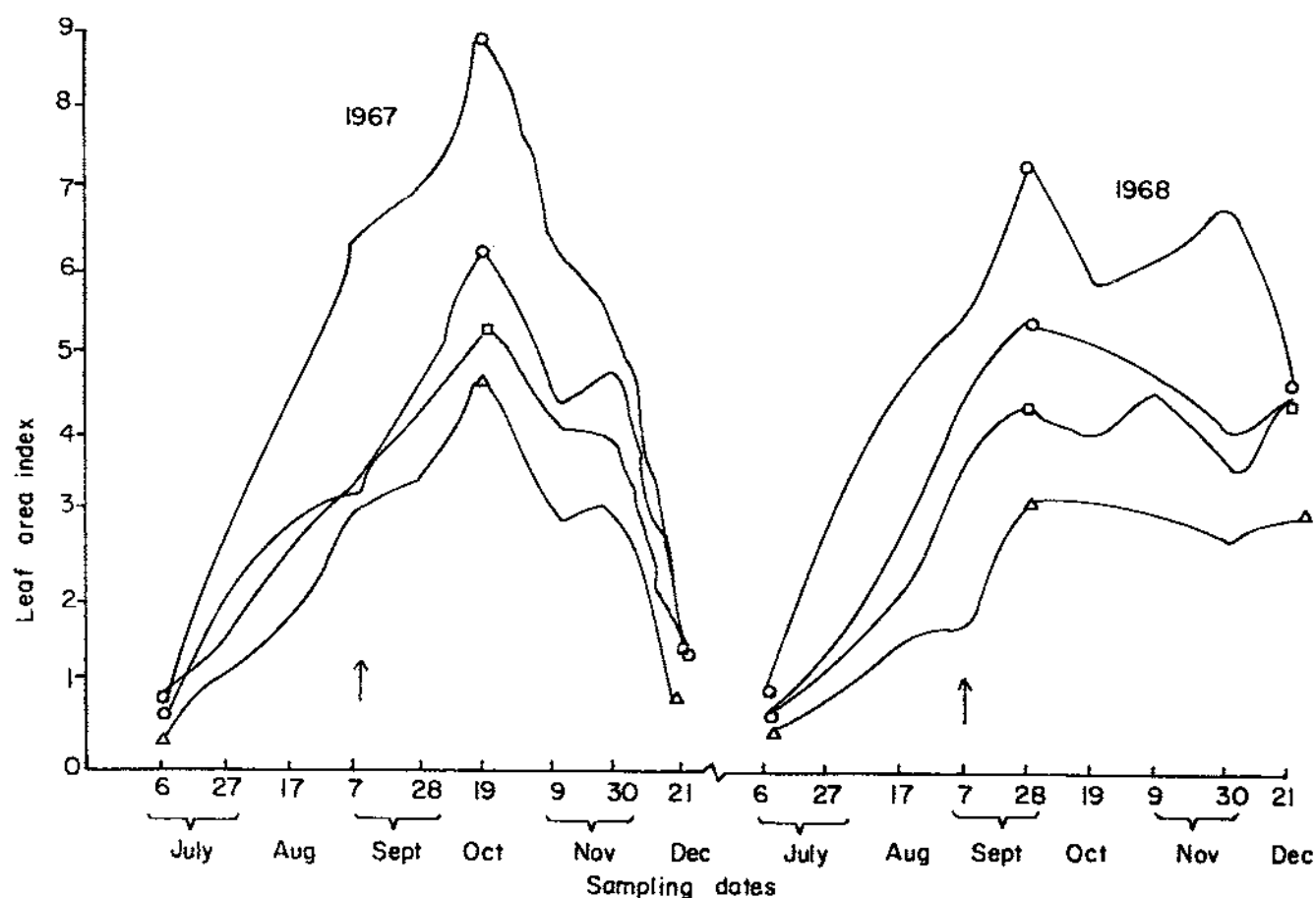


Fig.8. Effect of spacing treatments of leaf area index (lesser yam) O, 90 x 60m; o, 90x 90cm; □, 90 x 120 cm; Δ, 90 x 150 cm. Arrow indicates time of tuber initiation.

Effect of cultivar on growth and yield

Bremer and Taha² reported that there were differences in leaf area duration (D) of two cultivars of Irish potatoes studied by them and, as a result of this, cultivar Majestic produced more tuber dry weight than King Edward because of the greater D of the former than of the latter. The total tuber yield of Majestic at final harvest was greater than that of King Edward, due mainly to the longer period of tuber bulking in the former cultivar.

In cassava, a cultivar experiment, in Tanzania during the 1971/72 growing season showed Msitu Zanzibar outyielding Aipin Valenca, and the two cultivars in turn outyielded Amani 4026/16 (Table 13).

From these results however it can be seen that root tuber yield was poorly correlated with leaf area duration. The calculated correlation coefficient between root tuber yield and leaf area duration was 0.44.

In this investigation root tuber yield was positively and highly correlated with the rate of bulking per unit area ($r=0.866$). The relationship between tuber yield (metric t/ha) (Y) and bulking rate (kg/ha/wk) (B) is $y=0.0053B + 10.3$. Since in this investigation there was no difference in the period of bulking between the cultivars, the cultivar difference in tuber yield can be attributed to differences in their bulking rates. William and Ghazali²⁷ reported that in the three cassava cultivars studied by them, the lowest yielding had the highest leaf area per stem. They also showed that the leaves of the highest yielding cultivar possessed attenuated lobes with a more vertical midday orientation. In the cassava cultivar investigation in Tanzania (Enyi^{11,12,13}), the highest yielding cultivar had the highest leaf area per plant, and although Amani 4026/16 possessed narrower individual lobes, its root tuber yield was lower than that of Aipin Valenca, which possessed broad lobes. Also the mean angle of orientation of the leaves from the horizontal was greater in Amani 4026/16 than in Aipin Valenca. In this investigation therefore, there was no definite relationship between size of lobes, mean angle of the leaves from horizontal and root tuber yield.

Effect of staking on growth and yield

The aerial stems of yams are weak and in cultivation are usually supported by long poles up which they twine in a clockwise or anti-clockwise direction. Irvine¹⁶ demonstrated that if the vines were supported by stakes to a height of 6 ft. their yield was almost double that of those supported to a height of only

3 ft. Similar results have been reported by Correll, Schubert, Gentry and Hawley⁴ and Waitt²⁵. The effect of staking on tuber yield in yams has been attributed to greater exposure of the leaves to sunlight.

In an experiment with lesser yam (*Enyi*¹¹), staking increased tuber yield, tuber number per plant, mean tuber weight and mean bulking rate, and reduced the number of days between planting and tuber initiation (Table 14).

Staking also increased leaf area index (Fig. 9) and leaf area duration (Table 14). The increase in leaf area duration was due mainly to the effect of staking on increasing leaf area index and not on the duration of leaf growth. Increased leaf area was associated with increased vine growth, and the calculated correlation coefficient for the relationship between leaf area index (L) and dry weight of vine at time of attainment of maximum L was 0.95. Thus staking increases leaf area development by increasing the growth of vine. In this experiment, tuber yield was highly and positively correlated with leaf area duration (D) so that staking increased tuber yield by increasing D. The staking effect can therefore be associated with the difference in tuber number, rate and period of bulking, leaf area duration and individual tuber size.

Effect of shoot number per plant on growth and yield

Cassava setts when planted usually produce many shoots. Competition between these for nutrients and assimilates is likely to be great and could result in the reduction of the final tuber yield. If the shoot number from the cassava sett is reduced early in the growth stage of the plant, then competition between the shoots for the assimilates will be reduced and this may lead to a greater diversion of the assimilates to the root tubers, thereby resulting in an increase in the final yield of the root tubers.

In an experiment with cassava, (*Enyi*¹²), single shoot cassava plants (S_1) outyielded multi-shoot plants (S_m). Mean net assimilation rate, rate of bulking, individual tuber size and root tuber/stem weight ratio were all greater in S_1 than in S_m plants. However, S_m plants had greater tuber number and leaf area duration than S_1 (Table 15).

Yield results indicate that competition between shoots and roots for assimilates was more intense in the multi-shoot than in the single shoot plants. The accumulation of dry matter in the root tubers may be determined by the amount of assimilates available for tuber growth or by the capacity of the tubers for absorption of assimilates, the former being dependent on the rate of production of assimilates and the latter on the number and rate of growth of the tubers. In this trial, there was little or no difference in the mean root tuber number of single-shoot and multi-shoot plants, so that the difference in dry matter accumulation in the tubers of the two types of plant can be attributed to the difference in the amount of assimilates available for root growth.

Calculation of mean bulking rate (B) and net assimilation rate (E) for the period between samplings two and seven in the 1968 trial revealed that (B) was positively related to (E). The regression equation for

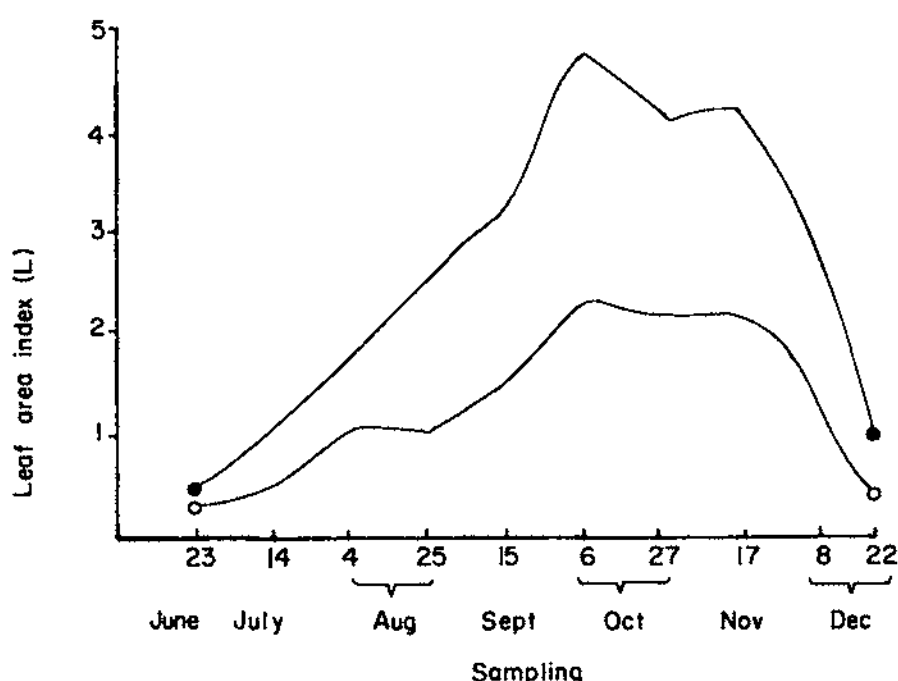


Fig.9. Changes with time in leaf area index in staked (●—●) and unstaked ○—○ lesser yam.

the relationship between ϵ and B being $B=1165E + 1340$. Higher E in single shoot plants is therefore the probable cause of their greater bulking rates.

In the same investigation, only 27% of the variation in root tuber yield between treatments could be attributed to variation in leaf duration (D). However, the product of D and mean net assimilation rate accounted for 75% of the variation in yield between the treatments.

When D values of single-shoot plants were plotted against their yields the latter was found to be closely related to D , variation in D accounting for 95% of the total variation in tuber yield between the treatments.

Single-shoot plants were therefore superior to multi-shoot plants with regard to root tuber yield because of the greater bulking rate due to their high net assimilation rate.

The greater bulking rate brought about by the high net assimilation rate of the single shoot plants resulted in their greater root tuber yield than the multi-shoot plants. The increase in net assimilation rate of single shoot plants was due to the reduction in leaf area index brought about by the reduction in the number of shoots per sett.

REFERENCES

1. Anon. (1966) Consolidated review of trial and demonstrations results 1961–1964. F.F.H.C. Fertilizer Program F.A.O. Rome.
2. Brenner, P.M. & Taha, M.A. (1966) Study in potato agronomy. The effects on variety seed size and spacing on growth, development and yield. *J. Agric. Sci. Camb.* 66, 241–52.
3. Chapman, T. (1965) Some investigations into factors limiting yields of the White Lisbon Yam under Trinidad conditions. *Trop. Agric. Trin.* 42, 145–51.
4. Correll, D.S., Schubert, B.G., Gentry, H.S. & Hawley, W.O. (1955) The search for plant precursors of cortisoma. *Econ. Bot.* 9, 107–75.
5. Djokoto, R.K. & Stephens, D. (1961) Thirty long-term fertilizer experiments under continuous cropping in Ghana. *Emp. J. Exp. Agr.* 29 (114): 181 (115): 245.
6. Dykes, G.V. (1956) The effect of date of planting on the yield of potatoes. *J. Agric. Sci. Camb.* 47, 122–8.
7. Enyi, B.A.C. (1967a) Effect of spacing, sett size, ridging and mulching on the development and yield of cocoyam (*Xanthosoma sagittifolium* Schott) *Trop. Agric. Trin.* 44, 53–60.
8. ——— (1967b) Effects of age on an establishment and yield of cocoyam setts *Xanthosoma sagittifolium* Schott)
9. ——— (1968) Growth of cocoyam (*Xanthosoma sagittifolium* Indian *J. Agric. Sci.* 38, 627–33.
10. ——— (1970) The effect of age on establishment and yield of cassava setts (*Manihot esculenta* Crantz). *Beitrage zur tropischen und subtropischen Land wirtschaft und Tropenveterinarmedizin* 8, 71–5.
11. ——— (1972a) The effects of seed size and spacing on growth and yield of lesser yam (*Dioscorea esculenta*) *Ann. Appl. Biol.* 72, 221–9.
12. ——— (1972b) Effect of shoot number and time of planting on growth, development and yield of cassava (*Manihot esculenta* Crantz) *J. Hort. Sci.* 47, 457–66.
13. ——— (1972c) The effect of spacing on growth, development and yield of single and multi-shoot plants of cassava (*Manihot esculenta* Crantz). II. Physiological factors. *E. Afr. Agric. For. J.* 38, 27–34.
14. Ferguson, T.U. & Haynes, P.N. (1970) The response of yams (*Dioscorea* spp.) to nitrogen, phosphorus, potassium and organic fertilizers. *Proc. Second Int. Symp. Trop. Root Crops* 1, 93–8.
15. Giradot, L.V. (1956) Planting and fertilizer experiments with yams. *Liberia (Suakoko) Cent. Agric. Exp. St. Note* 9.
16. Irvine, F.R. (1940) *A text-book of West African Agriculture*. Oxford University Press.
17. Irving, H. (1956) Fertilizer experiments with yam in Eastern Nigeria. *Trop. Agric. Trin.* 33, 67–8.
18. Jergaseelan, K.N. (1951) Studies in the growth and yield of cassava. *Trop. Agric.* 107, 168–71.
19. Nakanishi, H. & Negura, Y. (1958) Productivity of (a) pieces of tubers of Chinese yam in relation to their position on the tuber from which they were cut, and (b) of whole tubers raised from aerial tubers in relation to their size, for early harvesting *J. Hort. Ass. Japan* 27(2), 120–4.
20. Nye, P.H. (1954) Fertilizer responses in the Gold Coast in relation to time and method of application. *Emp. J. Exp. Agric.* 22(86), 101.

21. Obi, J.K. (1959) The standard D.N.P.K. experiments. Reg. Res. Sta. Samaru. Min. Agr. N. Reg. Nigeria. Technical Report No. 8.
22. Purewal, S.S. & Dargan, K.S. (1956) Effect of spacing on development and yield of arum (*Colocasia esculenta*) *Indian J. Agric. Sci.* 27, 151.
23. Sobulo, R.A. (1972) Studies on white yam (*Dioscorea rotundata*). I. Growth analysis. *Expl. Agric.* 8(2), 99–106.
24. Stephens, D. (1960) Fertilizer trials on peasant farmers in Ghana. *Emp. J. Exp. Agr.* 28 (109), 1.
25. Vine, H. (1953) Experiments on the maintenance of soil fertility at Ibadan, Nigeria. *Emp. J. Expl. Agr.* 21(81), 85.
26. Waitt, A.W. (1961) Review of yam research in Nigeria. Memoir 31. Dept. of Agric. Res. Nigeria.
27. Williams, C.N. & Ghazali, S.J. (1969) Growth and productivity of tapioca (*Manihot utilisima*) (1) Leaf characteristics and yield. *Expl. Agric.* 5, 183–93.

TABLE 1

Effect of seed size on yield of tannia and lesser yam

Sett size	Tannia (kg/45dm ²)	Lesser yam 1967 experi- ment. (kg/ha)	Lesser yam 1968 experi- ment. (kg/ha)
Small	42.5	20,583	15,060
Medium	48.6	24,598	20,080
Large	53.4	25,853	23,343
	l.s.d. (p=0.05)	2,058	2,008

TABLE 2

Relationship between mean maximum LAI and corm yield

	Ridge	Flat	Mulched	Unmulched	Very large setts	Extra large setts
Max.LAI	4.8	4.2	5.0	3.9	4.1	4.9
Corm yield (kg/plot)	17.5	15.8	21.4	11.9	15.0	18.3

TABLE 3

Effect of seed size on bulking rate, relative leaf area duration (RLAD) and final tuber number in lesser yam

	Bulking rate(kg/ha)		Tuber number/plant		RLAD(D _F)
Year	1967	1968	1967	1968	1967
Large sett	1556	1456	32	40	48.7
Medium sett	1456	1355	31	37	41.2
Small sett	1330	1255	28	29	34.7

TABLE 4

Yield of setts and dry weight per sett

	1 (Bottom)	2	3	4	5	6 (Top)	SE
Yield of root (kg/plant)	3.42	2.65	2.35	1.98	1.65	1.80	3.3
Dry weight sett (g/sett)	47.2	41.0	36.6	32.6	27.2	24.2	-

TABLE 5

Dry weight of tubers as % of total dry weight (CI) and relative leaf area duration (RLAD) for the entire sampling period

Sampling dates	No	N ₁	CI% Ko	K ₁	SE(22D _F)
27.X.67	17.5	11.6	16.5	12.6	± 1.9
8.X.ii67	54.5	57.4	55.6	56.3	± 1.1
27.X.67	7.2	8.8	5.3	10.6	± 1.9
8.X.ii67	53.9	53.5	49.9	57.5	± 1.1
RLAD (mean for staked and unstaked)	61.1	77.9	66.7	72.3	± 4.5
Tuber no/plant	31	35	34	32	± 1.2

TABLE 6

Effect of N, K and staking on mean bulking rate (kg/ha/wk)

	Ko	K ₁	No	N ₁
Unstaked plants	1054	1280	1141	1193
Staked plants	2222	2459	2184	2497

TABLE 7

Effect of mulching on yield of corms (kg/plant)

	Ridge	Flat	Very large setts	Extra large setts	LSD (P=0.05)
Mulched	23.7	19.1	19.6	23.3	5.6
Bare soil	11.3	12.5	10.5	13.3	

TABLE 8

Root tuber yield and yield attributes at final harvest

	Planting dates			
	29th April (T1)	13th May (T2)	27th May (T3)	10th June (T4)
Root tuber yield kg/ha	30,622	22,590	20,833	16,064 $\pm$ 679
Root tuber no/plant	13.3	10.6	11.6	8.9 $\pm$ 0.67
Weight/root tuber	265	242	206	203 $\pm$ 17
Root tuber:stem weight ratio	1.7	1.6	1.4	1.1 $\pm$ 0.09

TABLE 9

Relative leaf area duration (T1 Sm=100.0)

	Planting dates(see Table 8)							
	T1		T2		T3		T4	
Year	S1*	Sm**	S1	Sm	S1	Sm	S1	Sm
1967	65.6	100.0	47.2	73.9	41.1	64.9	33.1	47.8
1968	66.8	100.0	53.2	79.1	49.2	71.6	35.7	56.7

S1*= single shoot plants

Sm**=multi-shoot plants

TABLE 10

Effect of date of planting on tuber yield: tuber number/plant: bulking rate and relative leaf area duration

	Time of planting					
	10 Apr. (T1)	24 Apr. (T2)	8 May (T3)	22 May (T4)	5 June (T5)	19 June (T6)
Tuber yield (kg/ha)	20,331	24,849	14,056	15,060	12,801	8534±1179
Tuber number/plant	36	37	29	22	21	21
Bulking rate kg/ha/wk	1,593	1,982	1,381	1,481	904	1,155 (LSD at 5%=226)
Relative leaf area duration (T2=100.0)	97.2	100.0	66.8	52.8	38.8	25.7

TABLE 11

Effect of spacing on tuber yield, leaf area duration and bulking rate

	Spacing treatments			
	90 x 60cm	90 x 90cm	90 x 120cm	90 x 150cm
Tuber yield (kg/ha)	30,120	25,100	21,586	17,820
Relative leaf (DT)	76.4	54.3	49.3	36.4 (large seed)
Area dura- tion (Df)	57.2	41.7	37.2	28.9 (Df=100.0)
Bulking rate	1,883	1,657	1,406	1,205

TABLE 12

Effect of spacing on root tuber yield, rate of bulking and relative leaf area duration (Tanzania 1971/72)

	Spacing treatments		
	90 x 60cm (S1)	90 x 90cm (S2)	90 x 120cm (S3)
Root tuber yield metric t/ha	66.6	69.0	36.1±4.8
Rate of bulking (kg/ha/wk)	11,760	10,310	4,560±485
Relative leaf area duration	79.2	70.6	67.4±4.3

TABLE 13

Effect of variety on root tuber yield, rate of bulking and relative leaf area duration

	Varieties		
	Amani 4026/16	Aipin Valenca	Msitu Zanzibar
Root tuber yield metric t/ha	43.0	61.1	67.6±4.8
Rate of bulking (kg/ha/wk)	6,400	11,030	9,200±485
Relative leaf area duration	62.2	56.8	98.2±4.3

TABLE 14

Effect of staking on tuber yield at harvest and yield attributed

	Staked	Unstaked	SE
Root tuber yield (metric t/ha)	20,331	13,303	± 577
Rate of bulking (kg/ha/wk)	2,340	1,167	± 65
Relative leaf area duration	80.2	58.7	± 6.5
Tuber number per plant	36	30	± 1.2
Mean tuber weight (g)	47.3	36.2	± 1.8
Number of days from planting to tuber initiation	146.3	160.1	± 1.7

TABLE 15

Effect of shoot number on yield, yield attributes, leaf area duration and net assimilation rates
(All data as differences between S. and Sm)

	1967	1968
Root tuber yield kg/ha (S1-Sm)	4,016 $\pm$ 679	14,558 $\pm$ 1,380
Root tuber number/plant(S1-Sm)	-2.2 $\pm$ 0.95	-1.5
Weight/root tuber (S1-Sm)	265 $\pm$ 17	146 $\pm$ 26
Root tuber/stem W.ratio(S1-Sm)	0.6 $\pm$ 0.16	1.3 $\pm$ 0.17
Relative leaf are duration(S1-Sm)	-34.4	- 33.2
Net assimilation rate (S1-Sm) (g/dm ² /wk)	0.17	0.22
S1=single shoot, Sm=multi-shoot		

BENEFICIAL EFFECTS OF CHLORMEQUAT (CCC) ON ROOT CROPS UNDER EGYPTIAN FIELD CONDITIONS

M.M. El-Fouly*

SUMMARY

Potato plants grown both in winter or in summer, treated with CCC produced more tubers and higher yield. This also occurred in preliminary studies on the sweet potato. Leaves of treated plants had higher chlorophyll content, a higher dry matter content and had higher amylase activity than controls. Increases in amylase activity are not considered to be a direct effect of CCC but to be a response of the plant to greater sink strength resulting from increased tuberization. Protein and carbohydrates composition in tubers and roots were not affected. Residues were found in potato tubers under high treatment rates in both winter and summer seasons, and also at the two lower rates in the summer seasons.

RESUME

La patate cultivée en hiver ou en été donne plus de tubercules et assure un rendement plus élevé lorsqu'on la traite avec du CCC. La même chose a été observée lorsque des études préliminaires ont été effectuées sur la patate douce. Les feuilles des plantes traitées ont une teneur en chlorophylle plus élevée et une activité d'amylase plus élevée que chez les témoins. L'augmentation de l'activité dans l'amylase n'est pas directement attribuée à l'effet du CCC, mais à la réponse de la plante à une plus grande force de pénétration due au renforcement de la tubérisation. La protéine et la composition des hydrates de carbone dans les racines et tubercules ne sont pas affectées. On trouve des résidus dans les tubercules de la patate lorsque les taux de traitement sont élevés que ce soit en hiver ou en été et aussi aux deux taux plus bas en été.

RESUMEN

Plantas e papa cultivadas tanto en invierno como en verano, trata as con CCC, produjeron más tubérculos y más alto rendimiento. También ocurrió esto en estudios preliminares con camote. Las hojas de las plantas tratadas tuvieron un contenido más alto de clorofila, de materia seca y una mayor actividad de la amilasa en comparación con los testigos. No se considera que el incremento en la actividad de la amilasa sea un efecto directo del CCC, sino una respuesta de la planta a la mayor capacidad de almacenaje resultante del incremento en la producción de tubérculos. La composición de los tubérculos y raíces en cuanto a proteína y carbohidratos, no fué afectado. Se encontraron residuos de CCC en los tubérculos de papa en los tratamientos más elevados, tanto en la temporada de invierno como en la de verano, así como en la temporada de verano, en los tratamientos más bajos.

INTRODUCTION

In Egypt potato is becoming an important export crop, and sweet potato cultivation is increasing both for direct human consumption and starch production. Potato is planted in Egypt twice a year, in February—March for harvest in May and June and in October—November for harvest in February—March.

WINTER AND SUMMER GROWTH OF POTATOES

Growth patterns and yield potential vary according to the climatic differences of the two seasons with in any location. The summer season is characterised by higher mean temperatures, warmer nights and longer day length. The day length in the Egyptian summer is shorter than that in temperate areas, but the winter day length is longer than that further North. Growth patterns for cultivar Alpha, which is the commonest Egyptian cultivar, for both seasons are shown in Table 1. Data are tabulated for observations at seven and eleven weeks after planting.

Although the summer plants became much taller, they still produced lower dry matter per plant than the winter plants. The distribution of dry matter in favour of tubers is influenced by the winter climate. These growth patterns explain the higher tuber yield per plant obtained in winter than in summer.

*Botany Laboratory, National Research Centre, Cairo-Dokki, Egypt.

EFFECT OF CCC ON POTATOES

Chlormequat (CCC) retards stem elongation and leads to earlier tuberization in potato^{1,6,11}. Papadakis⁸ suggested that growth retardants like CCC could help in increasing yields of tuber and root crops under conditions of long warm nights. This was confirmed in Argentina, where higher yields were achieved when potato plants were sprayed with CCC⁹. In Italy CCC is being used to promote tuberization in potatoes.⁶ Field trials with CCC in different root and tuber crops under Egyptian conditions have been carried out since 1967^{2,4,5,10}. In general, CCC treatment increased yields but to different degrees in different crops, and depending on the dose rate and the time of application.

The inhibition of stem elongation by CCC increased with doses (Table 2). Winter plants which were naturally shorter than the summer plants, were relatively more affected by CCC.

Dry matter accumulation in the foliage was enhanced by a CCC dose of 2.5 l/ha in winter as well as in summer. The 5 l/ha dose in both seasons induced leaf chlorosis and necrotic spots and reduced dry matter accumulation.

Tuberization and tuber dry matter accumulation increased by treatment with 1.25 or 2.50 l/ha CCC at the apparent expense of foliage. Leaves of treated plants were darker green. Preliminary studies indicated increased amylase activity in leaves of treated plants, but in vitro experiments gave inconclusive results. The effect of CCC on tuberization occurs before any change in amylase activity is observed, suggesting that the latter may occur as a response to the development of the greater physiological sink of the tubers.³

Field trials (Table 3) tended to support the increase of potato yield by the use of CCC. In one experiment carried out in North Delta in WS (exp. 7), a higher incidence of *phytophthora infestana* was observed in CCC treated areas than in untreated.

RESIDUES IN POTATO TUBERS

The chemical composition of tubers was not affected due to CCC treatment, however, considerable amounts of residues were detected, especially in summer (Table 4).

TRIALS OF CCC ON SWEET POTATOES

Trials with sweet potato in 1970 (Table 5) indicate a positive effect on yield which will be followed up.

REFERENCES

1. Dyson, P.U. and Humphries, M.C. (1966) Modification of growth habit of Majestic potato by growth regulators applied at different times. *Ann. appl. Biol.* 58, 171-82.
2. El-Fouly, M.M., Massoud, Y.A. and El-Hindi, M.H. (1971) Stimulating sweet potato yields. *World Crops* 23, 133.
3. El-Fouly, M.M. (1973) Evidence on the indirect effect of chlormequat (CCC) on activities of amylase and invertase in leaves of different plants during development. Abst. 8th Int. Con. Plant Growth Subst. Tokyo, Aug. 26-Sept. 1.
4. El-Mansy, A.A., El-Behidy, M. and El-Fouly, M.M. (1972) Growth and yield responses of carrots to chlormequat chloride (CCC). *Gartenbauwiss* 37, 511-17.
5. El-Mansy, A.A., El-Behidy, M. and El-Fouly, M.M. (1973) Increases in root yield and changes in growth of table beet after treatment with chlormequat chloride (CCC). *Qualit. Plant. et Mat. Veget.*
6. Gifford, R.M. and Moorby, J. (1967) The effect of CCC on the initiation of potato tubers. *Eur. potato J.* 10, 235-8.
7. Lindley, C.D. (1972) A review of some practical uses of Cycocel plant growth regulant. Proc. 1st Egypt. Congr. Bot. Cairo 25-27 March.
8. Papadakis, J. (1968) *Growth retardants and fertilizers*. Buenos Aires pp. 28.
9. Papadakis, J. (1970) *Fundamentals of Agronomy (Compendium of crop ecology)* Buenos Aires, pp. 73.
10. Radwan, A.A., El-Fouly, M.M. and Garas, N.A. (1971) Retarding stem elongation and stimulating dry matter production and yield of potato with chlormequat chloride (CCC). *Potato Res.* 14, 173-80.
11. Tizio, R. (1969) Action du CCC (chlorure de (2-chlorethyl) - triméthylammonium) sur la tubérisation de la pomme de terre. *Eur. Potato J.* 12, 3-7.

TABLE 1

Growth patterns of potato grown in different vegetation seasons.

Cultivar: Alpha		
Location: Giza		
	Summer	Winter
Date of planting	2.3.1967	10.10.1967
Date of harvesting	30.6.1967	18.2.1967
Planting - harvesting (days)	120	130
<u>7 weeks after planting</u>		
Height (cm)	30.0	34.0
<u>Dry matter/plant(g)</u>		
Leaves	7.5	14.8
Stem	4.5	6.0
Total foliage	12.0	20.8
Tubers	3.0	10.0
Total plant	15.0	30.8
Leaves: tubers	2.50	1.48
Foliage: tubers	4.00	2.04
<u>Eleven weeks after planting</u>		
Height (cm)	86.5	51.5
<u>Dry matter/plant (g)</u>		
Leaves	21.5	17.5
Stem	20.5	15.5
Total foliage	41.0	40.0
Tubers	24.0	56.0
Total plant	65.0	96.0
Leaves:tubers	0.90	0.31
Foliage:tubers	1.71	0.71
Yield g fr/plant	286	424

TABLE 2

Effect of CCC on potato growth (spraying 49 days after planting)

		CCC dose (l/ha) (Cycocel 40% sol.)			
Days after spraying		Summer			
		0	1.25	2.50	5.0
14	Height(cm)	48	45	44	43
	Dry matter/plant(g)				
	Leaves	19	17	22	13
	Stem	14	15	15	9
	Total foliage	33	32	37	22
	Tubers	8	12	14	5
	Total plant	41	44	51	27
	Leaves:tubers	2.38	1.42	1.57	2.60
	Foliage:tubers	4.13	2.67	2.64	4.40
	Amylase activity(%)	100	100	100	100
28	Height(cm)	86	70	65	58
	Dry matter/plant(g)				
	Leaves	22	22	33	18
	Stem	19	21	27	17
	Total foliage	41	43	60	35
	Tubers	23	24	46	26
	Total plant	64	67	106	61
	Leaves:tubers	0.96	0.92	0.72	0.69
	Foliage:tubers	1.78	1.79	1.30	1.35
	Amylase activity(%)	100	233	1166	1208
	Yield Fr.Wt. g/plant	286	294	390	408
		Winter			
14	Height(cm)	46	40	39	34
	Dry matter/plant(g)				
	Leaves	17	19	21.5	14
	Stem	13	9	10.5	6
	Total foliage	30	28	32	20
	Tubers	38	48	42	40
	Total plant	68	76	74	60
	Leaves:tubers	0.45	0.40	0.51	0.35
	Foliage:tubers	0.79	0.58	0.76	0.50
	Amylase activity(%)	100	109	100	100
28	Height(cm)	52	42	39	37
	Dry matter/plant(g)				
	Leaves	17.5	18.5	21.5	14
	Stem	12.5	9.5	10.5	6
	Total foliage	30	28	32	20
	Tubers	55	76	70	65
	Total plant	85	104	102	85
	Leaves:tubers	0.32	0.24	0.31	0.22
	Foliage:tubers	0.55	0.36	0.22	0.31
	Amylase activity(%)	100	140	122	98
	Yield Fr.Wt.g/plant	424	526	466	478

TABLE 3

Effect of CCC on potato yield

No.	Year	Sea- son	Cultivar	Days from planting to spraying	Yield tons/ha CCC dose 1/ha			
					0	1.25	2.50	5.0
1	1967	SS	Alpha	49	20.4	21.0	27.9	29.2
2	1967	SS	Alpha	64	20.4	26.2	28.7	33.4
3	1967	WS	Alpha	49	30.3	37.6	34.9	34.2
4	1967	WS	Alpha	64	30.3	44.1	35.0	36.8
5	1969	SS	Alpha	63	18.7	-	22.8	22.2
6	1969	WS	Alpha	53	32.1	-	-	34.1
7	1969	WS	Alpha	55	20.8	-	-	18.3
8	1971	SS	Condia	60	11.9	12.2	12.0	10.8
9	1971	SS	Condia	75	11.9	13.0	14.0	14.3

1 - 4 are calculated from small experimental plots

SS = Summer Season

WS = Winter Season

TABLE 4

Chemical composition and residue analysis of tubers from CCC-treated plants

Dose	Protein %	Carbohydrate %	CCC-residue ppm	
			SS	WS
0	100	100	0	0
1.25	107	102	1.50	-
2.50	98	107	2.82	-
5.00	95	105	6.82	2.55

TABLE 5

Effect of CCC on sweet potato yield (Cultivar: Mabroaka)
Giza: 1970

CCC dose l/ha	Days from planting until spraying.	Yields.
C	75	90
0	17.8	17.8
0.75	21.1	20.6
1.50	23.8	20.9
3.00	21.3	19.1

SOME PHYSIOLOGICAL ASPECTS OF YIELD IN CASSAVA (*MANIHOT ESCULENTA* Crantz)

J.H. Cock

SUMMARY

The importance of dry matter production and factors affecting it, such as leaf area index and leaf inclination, are discussed. The relative importance of dry matter production and its distribution in relation particularly to spacing are reviewed.

The author suggests a plant ideotype based on these observations.

RESUME

L'importance de la production de la matière sèche et les facteurs qui l'affectent, tels que l'index de la zone foliaire et l'inclinaison des feuilles ont été abordés. L'importance relative de la production de la matière sèche et de sa distribution surtout par rapport à l'espacement ont été passés en revue.

L'auteur propose un idéotype végétal fondé sur ces observations.

RESUMEN

Se discute la importancia de la producción de materia seca y los factores que la afectan, tales como el índice de área foliar y la inclinación de la hoja. Se revisa la importancia relativa de la producción de materia seca y su distribución en relación, particularmente, con el espaciamiento.

El autor sugiere una planta ideotipo basado en esas observaciones.

INTRODUCTION

The physiology of *Manihot esculenta* Crantz has received little study. In this paper I shall endeavour to assess some of the physiological variation present within the species that may be used to produce higher yielding types.

For high productivity of carbohydrate it is necessary to have (a) high dry matter production and (b) favourable distribution of dry matter to the economically useful root tubers. Harvest index, the economic yield divided by total yield, can be used to describe this distribution.

MATERIALS AND METHODS

a) CMC 84, a high yielding cultivar, was grown at 1 x 1m spacing, and observations on its growth were taken at seven intervals, up to sixteen months after planting.

b) Cultivars CMC 84, CMC 39 and Llanera were planted at plant populations ranging from 3,000 to 30,000 plants/ha using a systematic design of the type described by Bleasdale². Harvests for fresh yield, dry yield and total dry matter were taken at three, five, seven and eleven months. All results use a three point moving average.

c) Four cultivars, M Colombia 22, CMC 39, M Colombia 1080 and M Mexico 12, were also planted in the systematic spacing design.

Leaf area index was estimated using the grid method and interception of total radiation was measured using Monteith type solarimeters four to five months after planting. Leaf angle was estimated by measuring the angle between the midrib of the central lobe and the horizontal.

d) Eighteen cultivars of different gross morphology were compared in an unreplicated trial; Llanera was repeated three times as a check, making a total of 20 plots. Plant population was 20,000/ha and harvests were taken at approximately 120, 180, 240, and 360 days. Data were corrected to the exact date.

The other trials referred to are described in the text.

*Centro Internacional de Agricultura Tropical, (CIAT) Apartado Aereo 67-13, Cali, Colombia.

DRY MATTER PRODUCTION

Dry matter production depends on the absorption of light and its utilization by leaves to produce carbohydrates from CO_2 and water. It is obvious that to obtain high levels of production it is necessary to absorb as much of the incident radiation of effective wavelengths as possible, then to use it efficiently in photosynthesis.

To intercept as much incoming light as possible it is necessary to have a sufficient leaf area index. Cultivar CMC 84 was grown for almost a year and a half on a soil of good water-holding capacity without prolonged water stress. The leaf area index was never greater than 2.2 and was less than 1.5 for most of the growth period (Fig. 1). This is considerably less than leaf area indices quoted for some other crops (e.g. cotton, 3 to 7.6⁸; kale, 3.5 to 5^{14,15}) which do not have erect leaves.

In another experiment, the leaf area index of CMC 84 was modified by leaf clipping and apex removal, the crop growth rate (corrected for the apices removed and clipped leaves) had not apparently reached a plateau level at LAI of 3 to 4 (Fig. 2). Sinha and Nair¹² and Doku⁴ have reported differences in leaf area duration between cultivars and related these to yielding ability.

In a study of LAI development in eighteen cultivars, Colombia 113 retained its leaves during its total growth period whereas, with most cultivars there was a marked decline in leaf area index after 180 days (Fig. 3). This decline was particularly pronounced in cultivar Colombia 22.

A series of experiments were performed to investigate the causes of leaf fall. Leaves covered with silver paper abscised and fell within a few days, whereas uncovered leaves remained attached for a longer period. This suggests that light on the surface of the lamina is one factor necessary to prevent leaf fall (Table 1). Leaf fall was not, however, solely the result of shading since all leaves fell sooner or later, even if normally exposed to light. When the plant apices were removed, leaf fall was delayed, suggesting a direct influence of the apex itself (Table 1).

Leaf fall causes a substantial loss of dry weight from the plant. In cultivar CMC 84 it was estimated as more than two t/ha during the period from three to five months after planting. When apices were continuously clipped to prevent the formation of new leaves, leaf fall was reduced to 1.3t/ha (Table 2). No reduction in crop growth rate was observed as a result of this treatment, showing that the remaining old leaves can continue photosynthesis efficiently (Fig. 2). This suggests that plants could produce and retain more dry matter if they produced fewer leaves, but retained them for a longer time and hence giving a larger leaf area index because of reduced leaf loss.

The dry matter production of Colombia 113 was similar to the mean of the other cultivars up to 120 days, as was its leaf area index, suggesting a somewhat similar efficiency of assimilation (Figs. 3,4). After 120 days the greater production of dry matter in Colombia 113 can be ascribed to its increased leaf area index. Colombia 22, on the other hand, always has a small leaf area index in comparison with the mean, and yet its total dry matter accumulation was remarkably similar. To speculate on these somewhat limited data, it would appear that there may be differences in the efficiency of photosynthesis either of the canopy or of the individual leaf that can be used to give higher yielding potential. Unfortunately, I know of no direct measurements made of photosynthesis on this crop. These are desperately needed to increase our understanding of its productivity in terms of dry matter.

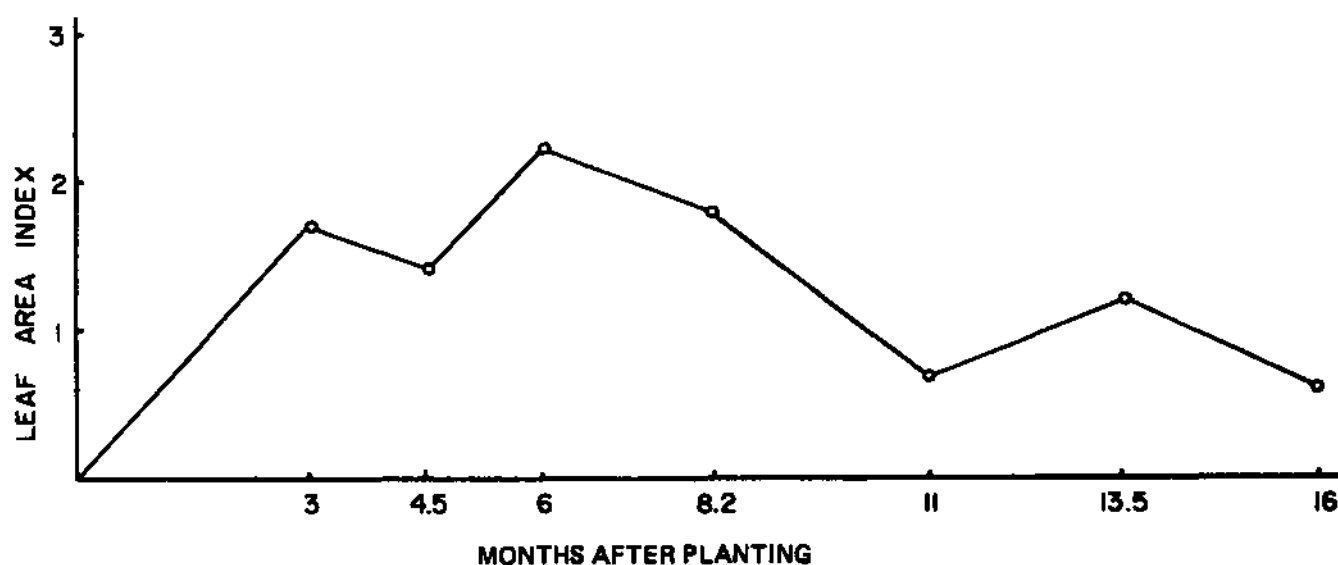


Figure 1: Changes in leaf area index of CMC 84 with time

Photosynthesis is not a linear function of light intensity above a certain level. Consequently, it is not sufficient just to have a crop canopy that intercepts all the incoming radiation. It is necessary to intercept almost all the light in such a manner that a large proportion of the leaves receive a low level of illumination that is still nevertheless sufficient to support photosynthesis.

In the tropics where the sun angle is high, this can be achieved by having more erect leaves. This is especially important in the middle of the day when the light intensity is greatest. At this time the elevation of the sun is nearly vertical and will illuminate leaves at low intensity when they tend to be more vertical. Williams¹⁶ also showed that leaf conductivity fell, showing a reduction in stomatal aperture, during the day after reaching a maximum in the morning. This suggests the possibility that leaf angle changes were asso-

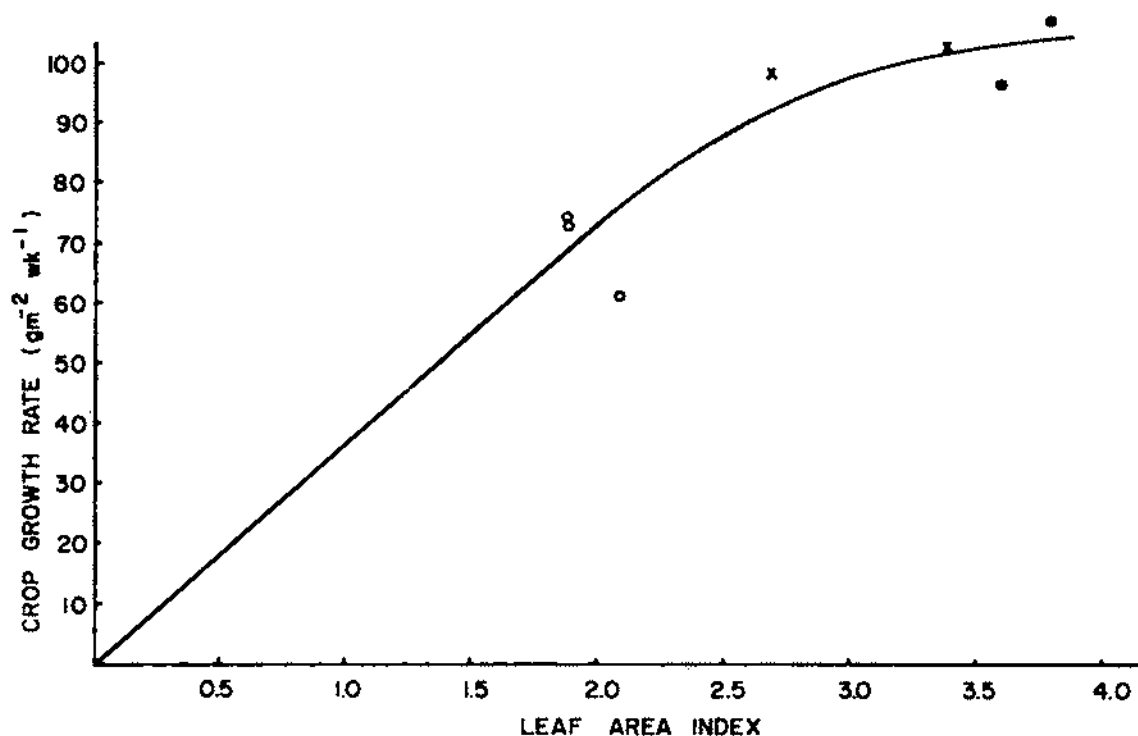


Fig.2: Crop growth rate of CMC 84 from 3 - 5 months as related to leaf area index. The leaf area index was modified by cutting the apex (x) by leaf clipping (°) and control (°). (Source: Cock and Acuña unpublished).

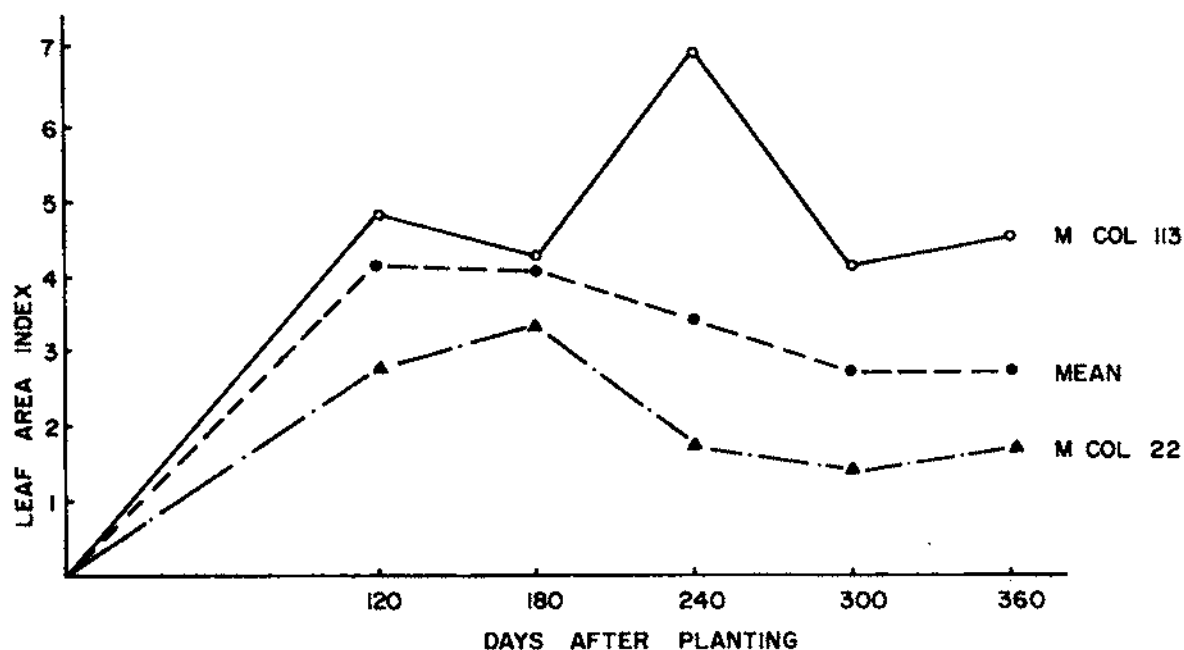


Fig.3: Leaf area index of M Colombia 113 and 22 compared with the mean of sixteen varieties.

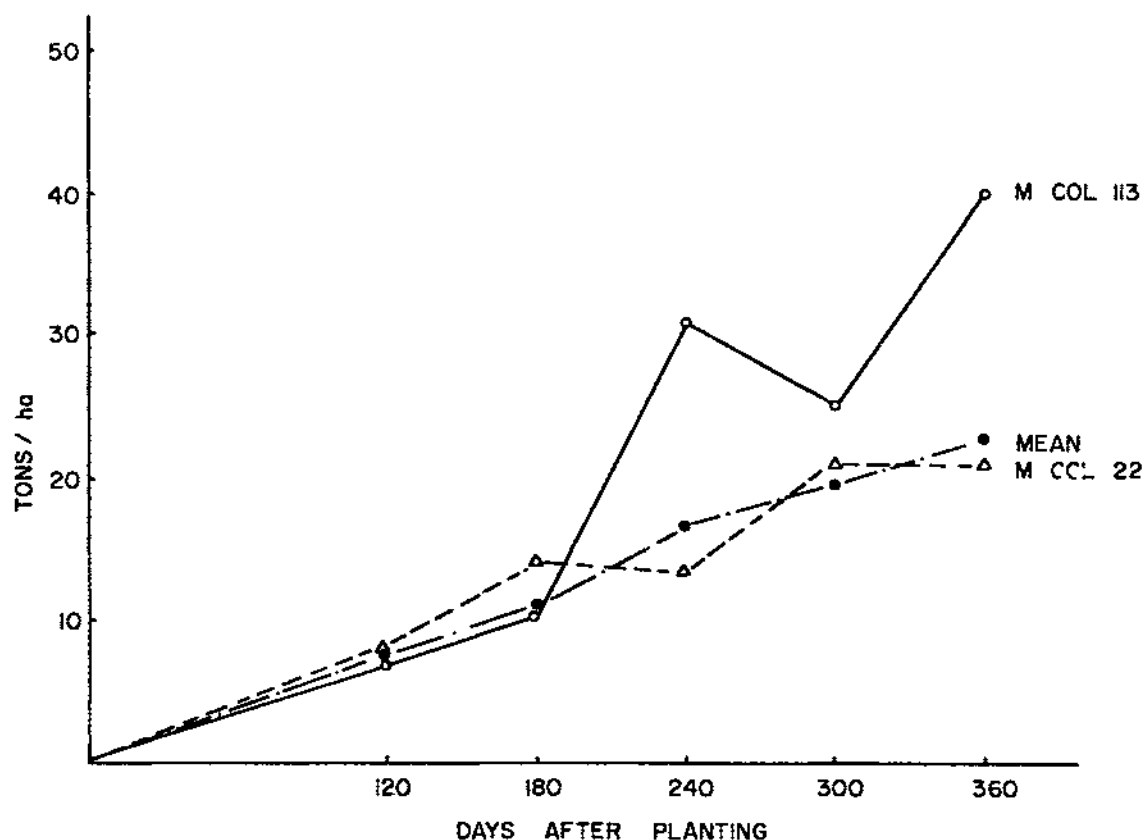


Fig 4. Changes in total dry matter of M Colombia 113 and 22 and the mean of 16 other varieties.

ciated with wilting and stomatal closure. It can be seen that this may not be the case, in cultivar Ecuador 44 the stomatal resistance of an upper leaf apparently decreased as the leaf became more vertical (Fig. 5). The lower leaves show less leaf angle change which could be advantageous. When leaf area index is small, it is necessary to have the lower leaves horizontal so as to absorb all the light which penetrates to the lower levels of the canopy.

The interception of total radiation was measured in four cultivars of cassava at midday on a clear day. There were large differences in the extinction co-efficient (Fig. 6). The extinction coefficient is closely related to the leaf angle (Fig. 7). Consequently it appears that there is a large degree of variability in leaf angle that can be used to obtain uniform light interception within the crop canopy, and that this is not associated with the detrimental effects of midday stomatal closure.

HARVEST INDEX

The potential production of root crops has been suggested as substantially greater than that of the grain crops. One of the reasons is that a crop such as cassava that may grow for twelve months, starts filling its storage organs after about two months (Wholey and Cock, unpublished) and hence uses more than 80% of its total growth period in what may be described as the productive phase. A cereal crop such as rice that grows to 120 days has thirty days of productive phase, representing only 25% of its total growth period. Improved rice cultivars have harvest indices of about 50%, and one might expect high values in cassava.

In the trial with eighteen cultivars, harvest indices reached only a mean value of 36%. The two highest yielding cultivars Colombia 113 and 22, however, had indices of 54% and 57% respectively, and there was a reasonably close correlation between yield and harvest index. Selection for this character could lead to higher yielding types (Fig. 8). The low mean value of harvest index may possibly be ascribed to the dense plant population (about 20,000 plants/ha).

After seven months growth the harvest index of three cultivars showed a sharp decline as a function of increasing plant population (Fig. 9) and also a decline in dry matter root (tuber) yield with increasing plant population (Fig. 10) above an optimum density which however was different for each cultivar. By eleven months the decline in harvest index was less pronounced in CMC 39 and only occurred at high plant populations in CMC 84.

The data from Llanera were variable and difficult to interpret (Fig. 10). However, there was no evidence of the steep decline seen at seven months (Fig. 9). It appears that not only are there differences in harvest index but also that some cultivars can withstand more dense plantings than the others without adverse effect on their harvest index.

Increased production of crops has to a large extent been associated with the increased use of fertilizers, particularly nitrogen. Consequently, reports that high levels of nitrogen may increase foliage production at the expense of roots are disconcerting.^{6,7} This is in spite of reports suggesting a neutral or positive yield response to nitrogen^{1,3,6,7,11}. In a trial in which up to 300 kg N were applied there was an indication of increased yield with increasing levels of N, but this trend did not reach statistical significance. There was no significant difference between the weight of the aerial parts of the plant at the different nitrogen levels (Fig. 12). Consequently, cultivars such as Llanera may be able to utilize increased nitrogen levels without decreasing harvest index.

GENERAL

Productivity does not depend on just one of the two components discussed in the previous two sections. It depends on the successful combination of the two.

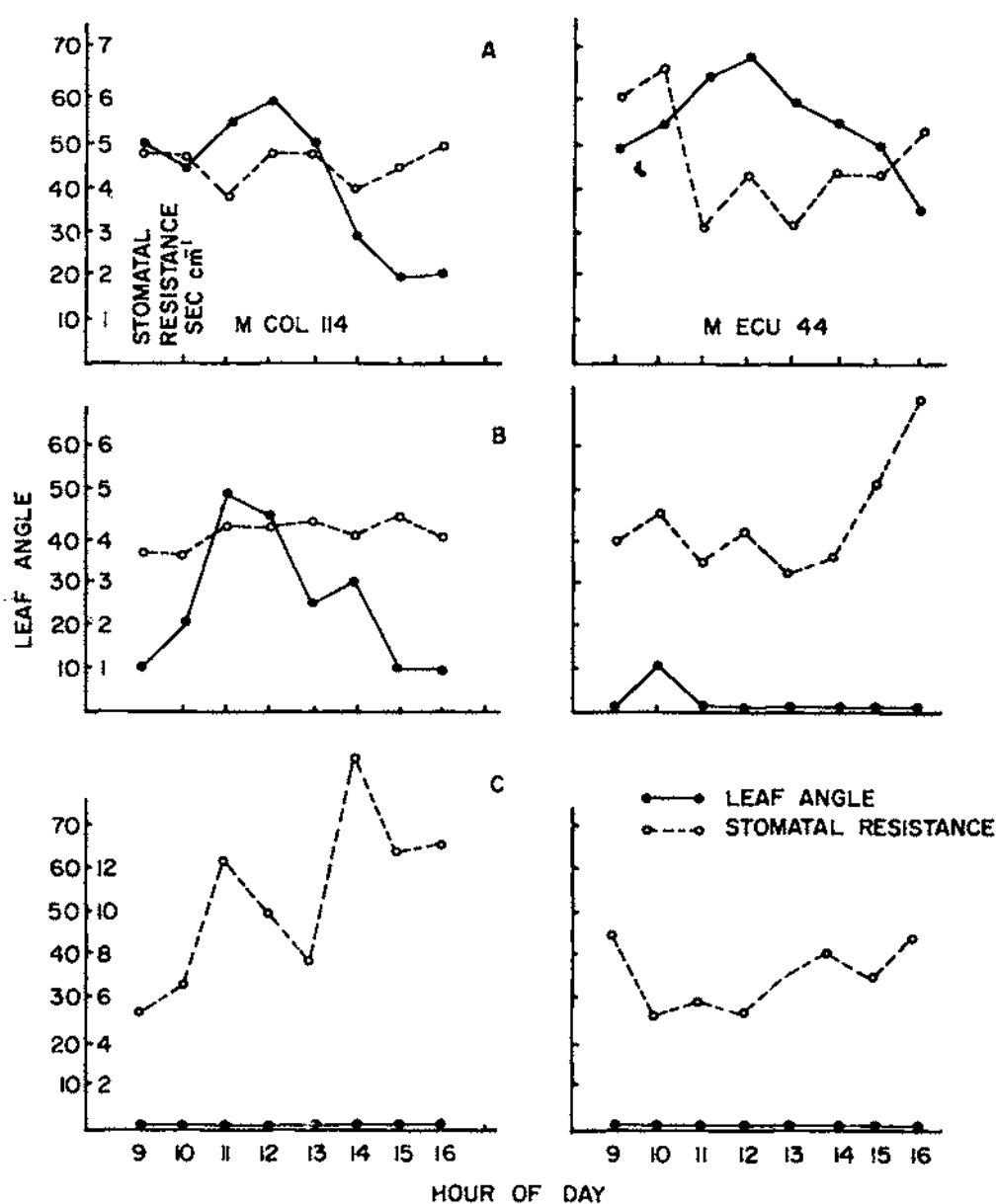


Fig.5: Leaf angle changes in two cassava varieties.
A. Upper leaf, B. Middle leaf, C. Lower leaf

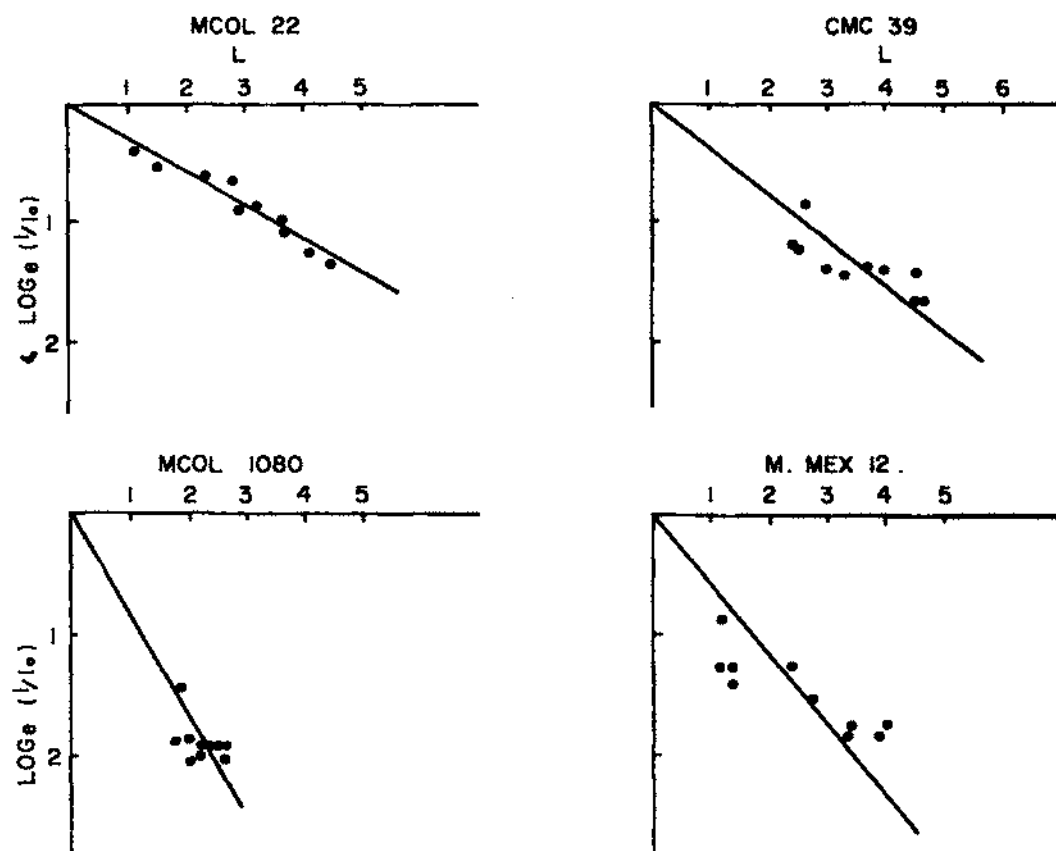


Fig.6: The relation between light interception and leaf area index (L) four varieties of cassava (I_0 is radiation above crop, I is radiation below crop).

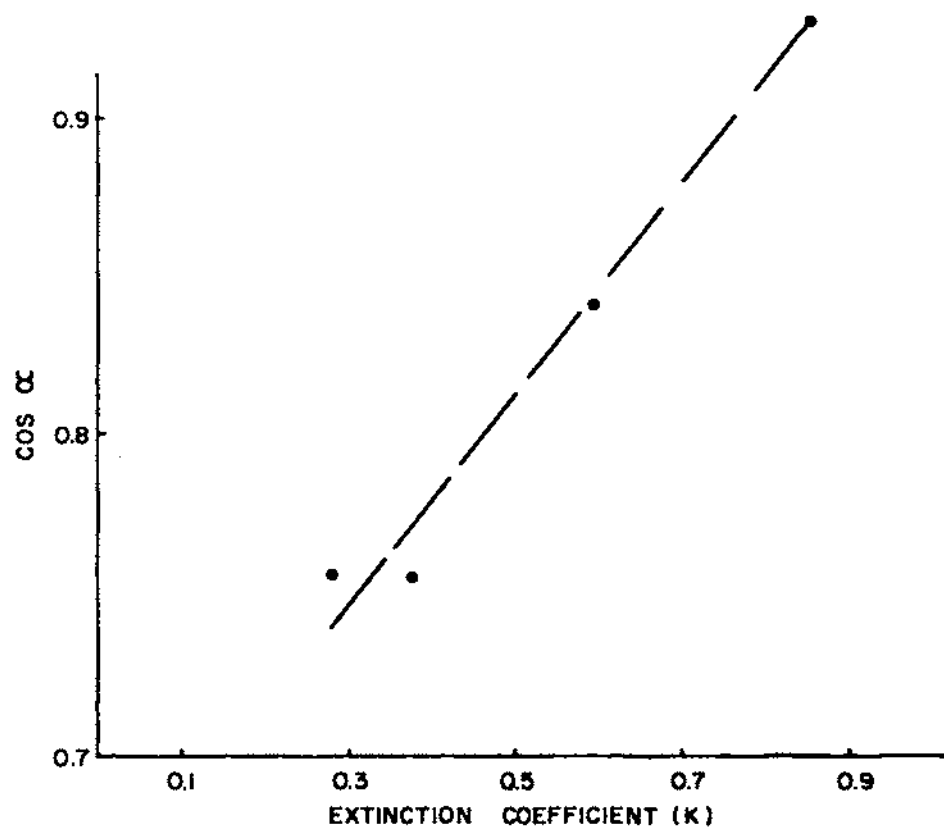


Fig.7: The relation of the light extinction coefficient (K) to the cosine of the leaf angle ($\cos \alpha$)

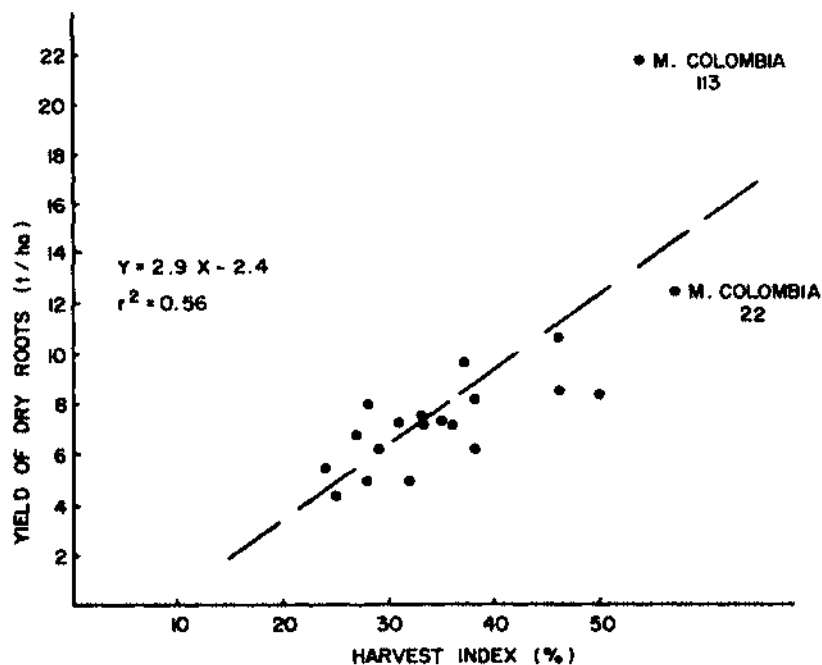


Fig.8: Relation ship between yield of dry roots and harvest index 360 days after planting.

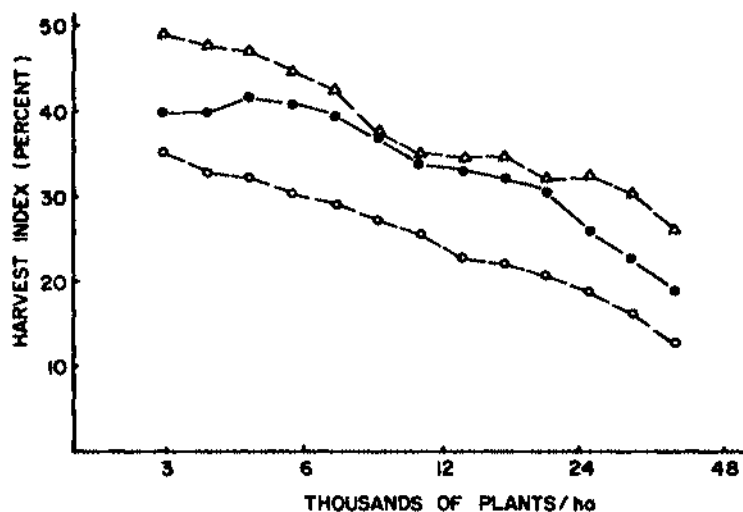


Fig.9. Harvest index of CMC 84 (●—●), Lianera (▲—▲) and CMC 39 (○—○) at 7 months (i) and 11 months

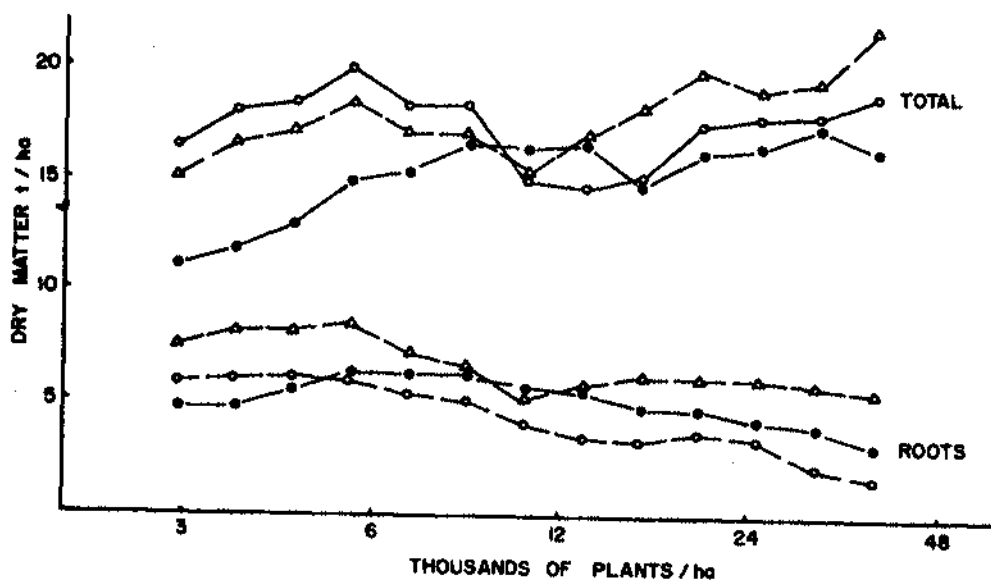


Fig.10: Changes in total and root dry weight of Lianera (▲—▲), CMC 84 (●—●) and 39 (○—○) at different plant populations after 7 months.

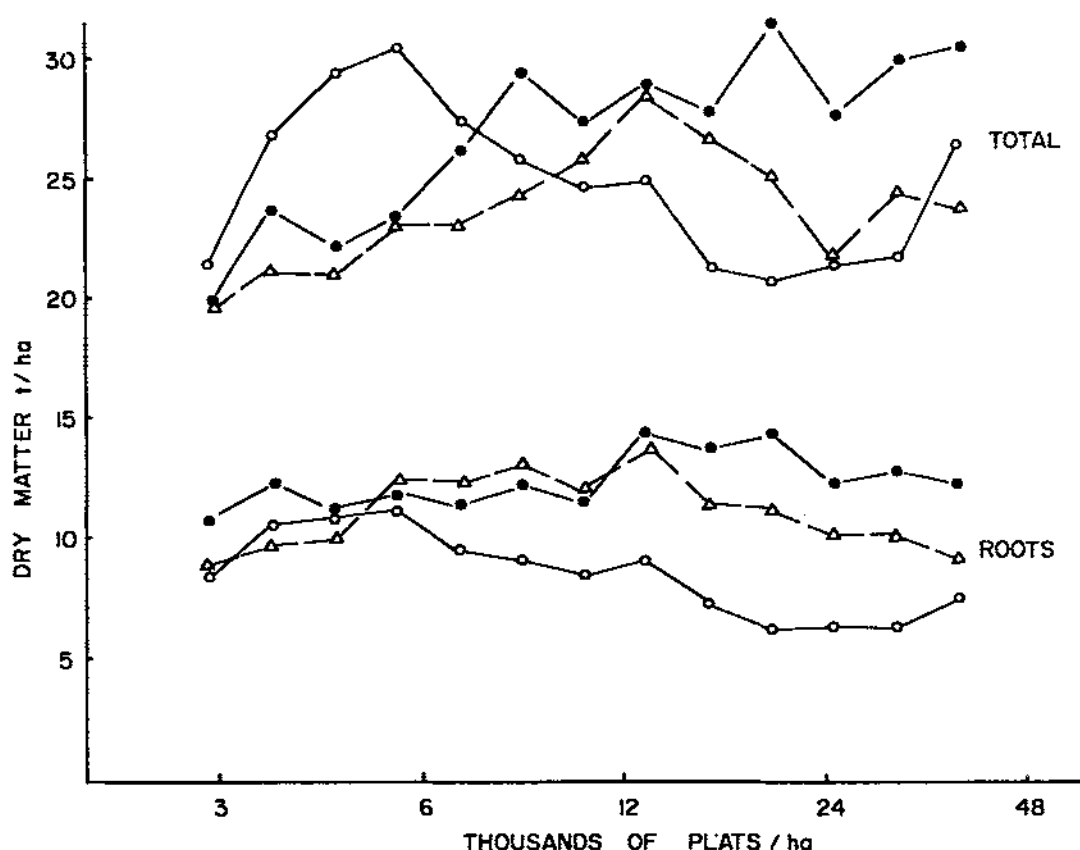


Fig.11: Changes in total and root dry weight of Lianera ($\Delta-\Delta$), CMC 84 ($\bullet-\bullet$) and CMC 39 ($\circ-\circ$) at different plant populations after 11 months.

In general cassava does not have sufficient leaf area for maximum dry matter production after six months. One way to increase leaf area is to increase plant population, but this leads to a crop in harvest index in certain cultivars. It appears that cultivars can be found that can withstand high plant populations.

CMC 84 increases its dry matter production with increasing plant population and harvest index only declines at the higher populations used. Thus its total dry root yield tends to increase with increasing plant population up to about 20,000 plants/ha (Fig. 11). In contrast, tall variety CMC 39, lodged at high plant populations and showed a decline both in total dry matter production and in harvest index at high plant populations. (Figs. 10, 11).

CONCLUSIONS

From the results presented, the cassava breeder seeking high yield potential should try to combine first of all:

1. A short stature that will give a low dry weight of stem and hence a potentially high harvest index.
2. Retention of leaves so as to maintain a large leaf area index.

As the level of breeding becomes more refined, he may also search for (a) low rate of leaf and inter-node production to produce a minimum of stem dry matter, (b) erect leaves during the middle of the day to use light efficiently in photosynthesis and to illuminate the lower leaves to delay leaf fall, (c) the ability to maintain a large harvest index at high nitrogen levels and plant population which give a rapid build up of leaf area index even in varieties with low rates of leaf production.

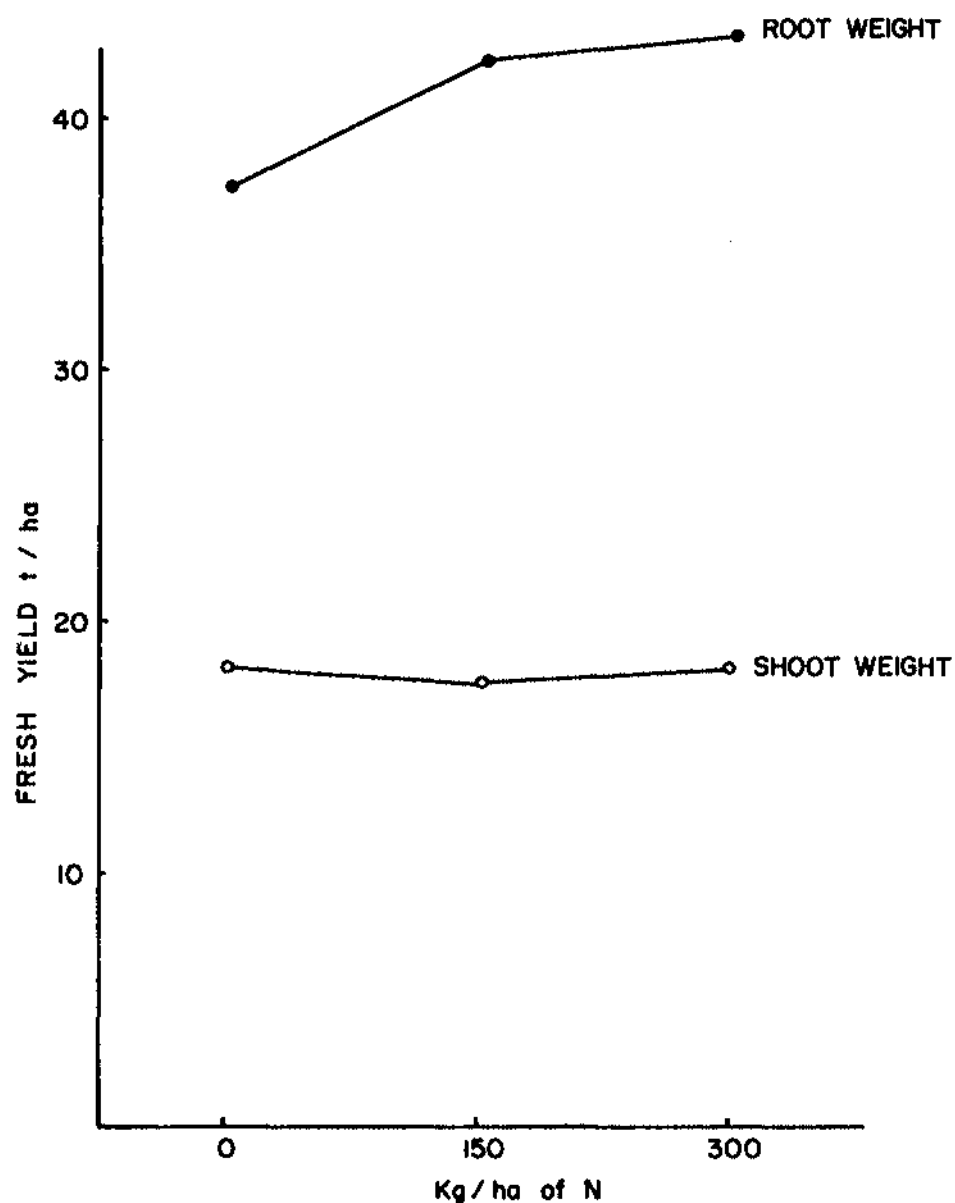


Fig.12. Response to nitrogen of Llanera. The nitrogen at 150kg/ha was applied all at planting, all at 3 months or half at each time. The nitrogen at 300kg/ha was applied all at planting or 3 months or split at planting and 3 months, 3 months and 6 months or planting, 3 months and 6 months. The means are presented here. Growth duration: one year.

REFERENCES

1. Albuquerque, M. de (1958) Estudio de fertilidade con mandioca em latosoio amarelo esgotado da Zona do Estudario Amazonico. *Boletim Informativo do Instituto de Pesquisas e Experimentacao Agropecuarias do Norte*. No. 134, 5 p.
2. Bleasdale, J.K.A. (1967) Systematic designs for spacing experiments. *Expl. Agric.* 3, 73-85.
3. Chew, W.Y. (1970) Varieties and NPK fertilizers for tapioca (*Manihot utilissima* Pohl) on peat. *Malaysian Agricultural Journal* 47(4), 843-91.
4. Doku, E.V. (1965) Breeding for yield in cassava. I. Indices of yield. *Ghana Journal of Science*. 5(1), 52-9.
5. De Geus, J.G. (1967) Root crops. In De Geus, J.G. *Fertilizer guide for tropical and subtropical farming*. Zurich, Centre d'Etude de l'Azote. pp. 181-5.
6. Jacob, A.A. and Von Uexkull, H. (1966) Fertilization de los cultivos tropicales y subtropicales: yuca o mandioca. In Jacob, A and Von Uexkull, H. *Fertilizacion* 3ed. Hannover, Kali und Salz. pp. 153-9.
7. Krochmal, A. and Samuels, G. (1970) The influence of NPK levels on the growth and tuber development of cassava in tanks. *Ceiba* 16(2), 35-43.
8. Ludwig, L.J.T.S. and Evans, L.T. (1975) Photosynthesis in artificial communities of cotton plants in relation to leaf area. I. Experiments with progressive defoliation of mature plants. *Aust. J. Biol. Sci.* 18, 103-8.
9. Normanha, E.S. (1951) Adubacao de mandioca no estado de Sao Paulo. I. Efeito da adubacao mineral. *Bragantia* 11(7-9), 181-94.
10. Sinha, S.K. and Nair, T.V.R. (1971) Leaf area during growth and yielding capacity of cassava. *Indian J. Genetics and Plant Breeding* 31, 16-20.
11. Silva, J.R. da and Freire, E.S. (1968) Efeito de doses crescentes de nitrogenio, fosforo e potassio sobre a producao de mandioca em solos de baixa e alta fertilidade. *Bragantia* 27(29), 357-64.
12. Vries, C.A. de, Ferwerda, J.D. and Flach, M. (1967) Choice of food crops in relation to actual and potential production in the tropics. *Netherlands J. of Agr. Sci.* 15, 241-8.
13. Watson, D.J. (1958) The dependence of net assimilation rate on leaf area index. *Ann. Bot.* 22, 37-54.
14. Watson, D.J. and French, S.A.W. (1962) An attempt to increase yield by controlling leaf area index. *Ann. Appl. Biol.* 50, 1-10.
15. Williams, C.N. (1971) Growth and productivity of tapioca (*Manihot utilissima*) II. Stomatal functioning and yield. *Expl. Agric.* 7, 49-62.
16. Williams, C.N. and Ghazali, S.M. (1969) Growth and productivity of tapioca (*Manihot utilissima*) I. Leaf characteristics and yield. *Expl. Agric.* 5, 183-94.

TABLE 1

Effect of various treatments on time of leaf fall (days to the time when the third of five marked leaves fall).

Treatment	With Apex	Apex Removed
All leaves removed except five	26	61
Five leaves covered with silver paper	8	9
Leaf lamina of five leaves removed	7	7
Part of leaf lamina of five leaves removed	19	20
Control	42	61

L.S.D. = 12.4 (p = 0.05)

TABLE 2

Leaf fall data of CMC 84 from 3 to 5 months after planting (Source: Cock and Acuna, unpublished)

	Leaf fall t/ha	Leaf fall leaves/plant/week
Control	2.1	17.8
Apex removed	1.3	7.6

THE EFFECT OF DEFOLIATION ON THE YIELD OF COCOYAMS

S.K. Karikari*

SUMMARY

Removal of any leaf of *Xanthosoma cocoyams* before the plant attained the age of 23 weeks significantly lowered cormel production. After 23 weeks, up to 4 leaves could be removed without any significant reduction in yield. Two clones showed differences in response.

RESUME

Le retrait de feuille du tarot *Xanthosoma* avant que la plante n'ait 23 semaines, entraîne une baisse appréciable de production de la tige bulbeuse. Après 23 semaines on peut enlever jusqu'à 4 feuilles sans que le rendement ne soit réduit de façon sensible. Deux clones ont montré des différences de réponse.

RESUMEN

La remoción de cualquier hoja de *Xanthosoma* yautía antes de que la planta alcance la edad de 23 semanas redujo significativamente la producción de cormillos. Después de 23 semanas, se pudieron remover hasta 4 hojas sin alguna reducción significativa del rendimiento. Dos clones mostraron diferencias en su respuesta.

INTRODUCTION

In Ghana, cocoyam (*Xanthosoma* spp and *Colocasia* spp.) known as tannia and dasheen respectively, are vegetable as well as root crops. The leaves are nutritious food⁴. When the leaves are picked periodically for food, corm yield may be slightly reduced and there may be a critical intensity of leaf picking beyond which corm yields will be drastically affected. No previous critical study has been made to establish the nature of the relationship between leaf picking and corm yield.

MATERIALS AND METHODS

Two cultivars of cocoyam were used in this study, Mankani fufuo (i.e. white cocoyam) and Mankani pa (good cocoyam) also known as Mankani koko (red cocoyam). These were assigned separately to the sub-plots. Mankani pa has been grown in this country for a long time but Mankani fufuo has only recently been brought into cultivation.³

Corm setts weighed 140–150 gms each and were obtained from healthy growing mother corms. Two adjacent areas termed A and B measured 120 m x 120 m. In each area there were 4 plots (replicates) of 60 x 60 m each with each plot further divided into two sub-plots (cultivars) of 30 x 60 m each. Within each sub-plot, there was a further sub-division into 9 equal parts (degrees of defoliation, including a zero defoliation control) each of 6.6 x 30 m.

Planting was on the square, with 1 m spacing between adjacent plants. Each sub-plot carried approximately 180 plants. Leaves numbering 1–8 were removed from plants in each sub-plot at regular intervals of 2 weeks. In the plot A leaf removal was started on 3rd June, 1970, when plants were 10 weeks old. The last picking was done on 9th September. In plot B leaf removal started when the plant was 23 weeks old, and the last picking was done on 30th December 1970.

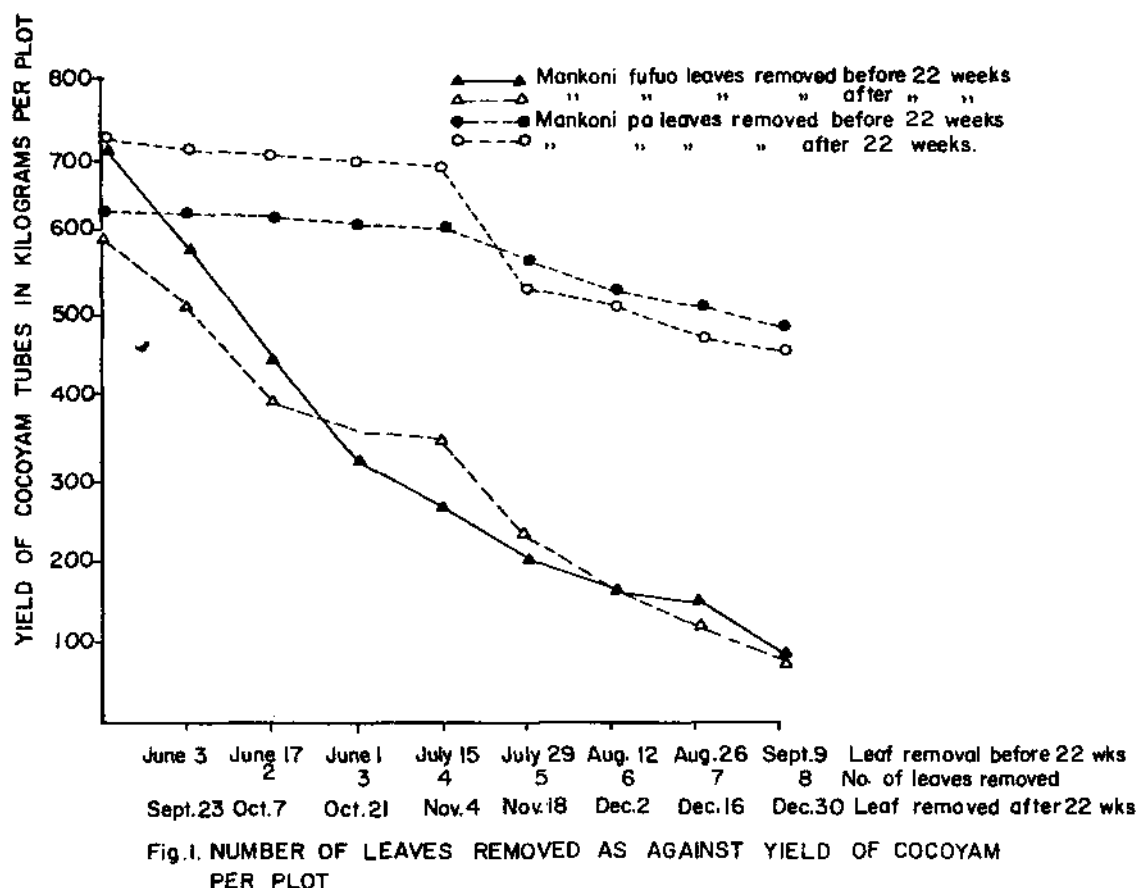
The plants were harvested on 20th April, 1971 (55 weeks after planting) when the tubers were taken. At each harvest records were taken of the fresh weight of cormels for each treatment.

RESULTS

There were significant yield differences due to cultivars, to the degree of defoliation and also to the interactions between cultivars and degree of defoliation.

Yields are summarized in Table 1 and Table 2 and Fig. 1.

*University of Ghana, Agricultural Research Station, P.O. Box 43, Kade, Ghana.



In the area where the leaf removal treatments occurred on plants less than 23 weeks old, yield difference for defoliation treatments and for the interaction of cultivar and defoliation were significant at 1 percent.

In area B, where leaf removal only started after the plants were 23 weeks old, significant reduction in tuber yield only occurred when more than 4 leaves were removed.

DISCUSSION

Enyi² found that cormels are not produced until 19 weeks after planting. It seems that any defoliating before the plants attain the age of 23 weeks retarded cormel formation, and hence impairs sink capacity. After 23 weeks, cormel initiation would have been almost completed and so leaf removal would not alter 'sink capacity' but may cause only a reduction in yield only when it is sufficiently severe to reduce the production of assimilates to a level too low to fill the available initiated cormels.

REFERENCES

1. Anon. (1968) Estimate of crop production of main staple food crops in long tons. Report on current Agricultural Statistics 1968. Economics and Marketing Division, Ministry of Agric. Accra.
2. Enyi, B.A.C. (1968) Growth of cocoyam (*Xanthosoma sagittifolium* Schott). *Indian J. Agric. Sci.* 38(4), 627-33.
3. Karikari, S.K. (1971) Cocoyam cultivation in Ghana. *World Crops* 23(3), 118-22.
4. Watson, J.D. (1971) Investigation on the nutritive value of some Ghanaian foodstuffs. *Ghana Jnl. Agric. Sci.* 4, 95-111.

TABLE 1

The effect of defoliation before 22 weeks on the yield of two cultivars of cocoyam

Kilograms of cormels per plot										
<u>Cultivar</u>	Number of leaves removed per plant									Cultivar mean
	0	1	2	3	4	5	6	7	8	
<u>Mankani fufuo</u>	602	516	508	362	350	236	161	148	80	317
<u>Mankani pa</u>	708	588	450	329	270	200	166	120	78	323
Degree of defoliation mean	655	552	424	346	310	247	164	134	79	
L.S.D. 5% for interaction 9.86; average effect of cultivar 3.27; average effect of defoliation 5.66.										
L.S.D. 1% for interaction 13.15; average effect of cultivar 4.37; average effect of defoliation 8.76.										

TABLE 2

The effect of defoliation after 22 weeks on yield of two cultivars of cocoyam

Kilograms of cormels per plot										
<u>Cultivar</u>	Number of leaves removed per plant									Cultivar mean
	0	1	2	3	4	5	6	7	8	
<u>Mankani fufuo</u>	630	628	624	617	611	565	530	512	488	578
<u>Mankani pa</u>	716	609	702	694	681	530	514	476	455	609
Degree of defoliation mean	673	669	663	656	649	548	523	494	472	
L.S.D. 5% for interaction 8.67; average effect of cultivar 2.89; average effect of defoliation 7.13.										
L.S.D. 1% for interaction 11.56; average effect of cultivar 3.85; average effect of defoliation 8.18.										

"MERICLONING" OF TARO (*COLOCASIA ESCULENTA*)*

M.O. Mapes and W.J. Cable**

SUMMARY

Calluses from mature taro tissues are difficult to obtain, but shoot production can be induced with the shoot meristem technique. To achieve maximum growth and multi-propagation of desirable clones, an effective procedure appears to be a combination of the shoot meristem technique and a supplementary treatment for callus formation.

RESUME

Il est difficile d'obtenir des cals des tissus du tarot, mais on peut provoquer la production des pousses par la méthode de méristème appliquée aux pousses. Pour obtenir la croissance maximale et la pluripropagation de clones désirables, il se révèle efficace de combiner la méthode de méristème des pousses à un traitement supplémentaire pour la formation des cals.

RESUMEN

Los callos de tejidos maduros de malanga son difíciles de obtener, pero la producción de follaje se puede inducir con la técnica de meristemas del follaje. Para lograr el máximo crecimiento y propagación de los clones deseables, la combinación de la técnica de meristemas del follaje y un tratamiento suplementario para la formación del callo, parece ser un procedimiento efectivo.

INTRODUCTION

Aseptic propagation of monocots has been achieved with members of diverse families. Among them are orchids^{10,13,18}, asparagus^{8,14,15,17}, sugarcane^{1,5}, grasses⁷ (and unpublished data of U. Urata), oats², rice¹² and bromeliads⁹. More recently, Hartman and Zettler³ reported that meristem-tip cultures of aroids could be successfully used for rapid propagation and for obtaining pathogen-free plants⁴. For rapid multiplication of desirable clones of taro it would be useful to find rapid means of propagation.

Attempts were made in Hawaii by Kikuta and Parris⁶ to multiply planting material rapidly by propagating from the axillary buds on the mature corm and on 'huli' (a Hawaiian word for taro stem cuttings containing 1.2 mm of the corm tip and 15 to 25 cm of petiole base). Their idea was to stimulate the growth of normally dormant axillary buds. By destroying the growing point of the corm, the apical dominance inhibiting the development of the lateral buds was removed and a number of shoots developed. The present study began in 1972 assessing the feasibility of utilizing tissue cultures to obtain larger numbers of clonal plantlets of the taro cultivar 'Niue'.

MATERIALS AND METHODS

Taro cultivars were obtained from Lyon Arboretum of the University of Hawaii in 1971 and 1972. The following plants showing special features were selected for culturing.

Taro Niue, preferred Samoan taro,	Accession No L-69.500
Niue Uli, " " "	L-70.253
Eleele Naioea, somewhat resistant to <i>Phytophthora</i> ,	No L-68.133
Makoko,	No L-69.047
Elapaio, an ornamental with variegated leaves.	No L-68.124
Uahiapele (Smoke of Pele), maroon coloured leaves,	No L-69.049
Manini Kea, an ornamental with white stripes on petiole,	No L-68.138

Preliminary studies with Taro Niue indicated that calluses were difficult to induce from various plant parts.

* Published with the approval of the Director, Hawaii Agricultural Experiment Station, as Journal Series No. 1694

**Agronomy and Soil Science Department College of Tropical and East-West Center grantee in Botany Department, University of Hawaii, Honolulu, Hawaii, respectively.

Sections of petioles, corms, spadices (staminate and carpellary tissues) and roots were cultured aseptically on solid media in Falcon plastic, snap-on dishes. For surface sterilization, 10 to 15 percent chlorox solution was used. Cultural treatments were carried out in a Latin square design on Murashige and Skoog's basal medium¹¹, which was supplemented with gradients of coconut water (as a source of natural cytokinins) at 0, 2.5, 5.0 and 10 percent by volume, and auxins. Gradients for naphthaleneacetic acid (NAA) were 0, 1.25, 2.5 and 5.0 ppm, and for indoleacetic acid (IAA) were 0, 0.1, 0.5 and 1.0 ppm. These gradients were useful in studying auxin-cytokinin interactions with coconut water. The cultures were placed under continuous light and examined at intervals for callus formation. Additional tests were carried out in White's basal medium¹⁶ supplemented at 10 percent by volume with coconut water, and with 2,4-dichlorophenoxyacetic acid (2,4-D) at 5 ppm, and adenine at 20 ppm. Unfortunately, none of the tissues responded positively to these treatments. Most of them turned dark brown. The spadix segments became large and swollen, probably due to the enlargement of the cells, but calluses were not formed.

Since the callus method on taro explants failed completely with the media tried, an alternative shoot meristem technique described by Sagawa *et al.*¹³ was attempted. Shoot tips, rather than strictly apical meristems, of the taro cultivars listed above were cultured, both from the apical shoot and lateral buds. They were surface sterilized with 15, 10, 5 and 1 percent chlorox solutions, in descending order as the tender tissues become exposed when the outer leaves were carefully removed under the low power microscope. A drop of 'Ivory' liquid was added as a wetting agent into the 15 percent chlorox solution.

The cultures were grown in modified Knudson's C liquid medium supplemented with coconut water at 10 percent by volume, and by adenine at 20 ppm. About 10–15 ml. of the medium were pre-sterilized in 50 ml. Erlenmeyer flasks, and after inoculating one shoot tip per flask, the cultures were shaken continuously on the gyrorotary shaker under continuous light.

Difficulties were encountered in obtaining bacterial free cultures from shoot tips. The bacteria were probably lodged between the apparently tightly-folded young leaves. If endogenous, the same contaminant would have appeared in the plate cultures, but the plates were negative. When the liquid medium showed slight turbidity, the shoot tip was immediately removed and re-sterilized with 15 percent chlorox solution containing a drop of detergent. The material was next immersed in 5 percent and 1 percent chlorox solutions. In the latter one or two more leaves were removed aseptically, taking precautions not to injure the apical meristem proper. It was rinsed in sterile distilled water and transferred to a fresh medium. Tissue from a few of the contaminated flasks, after re-sterilization and trimming down of outer tissues, were stored overnight in a 20 ml. of sterile water containing a drop of 15 percent chlorox solution. The tissues remained alive while the contaminant was eliminated.

RESULTS AND DISCUSSION

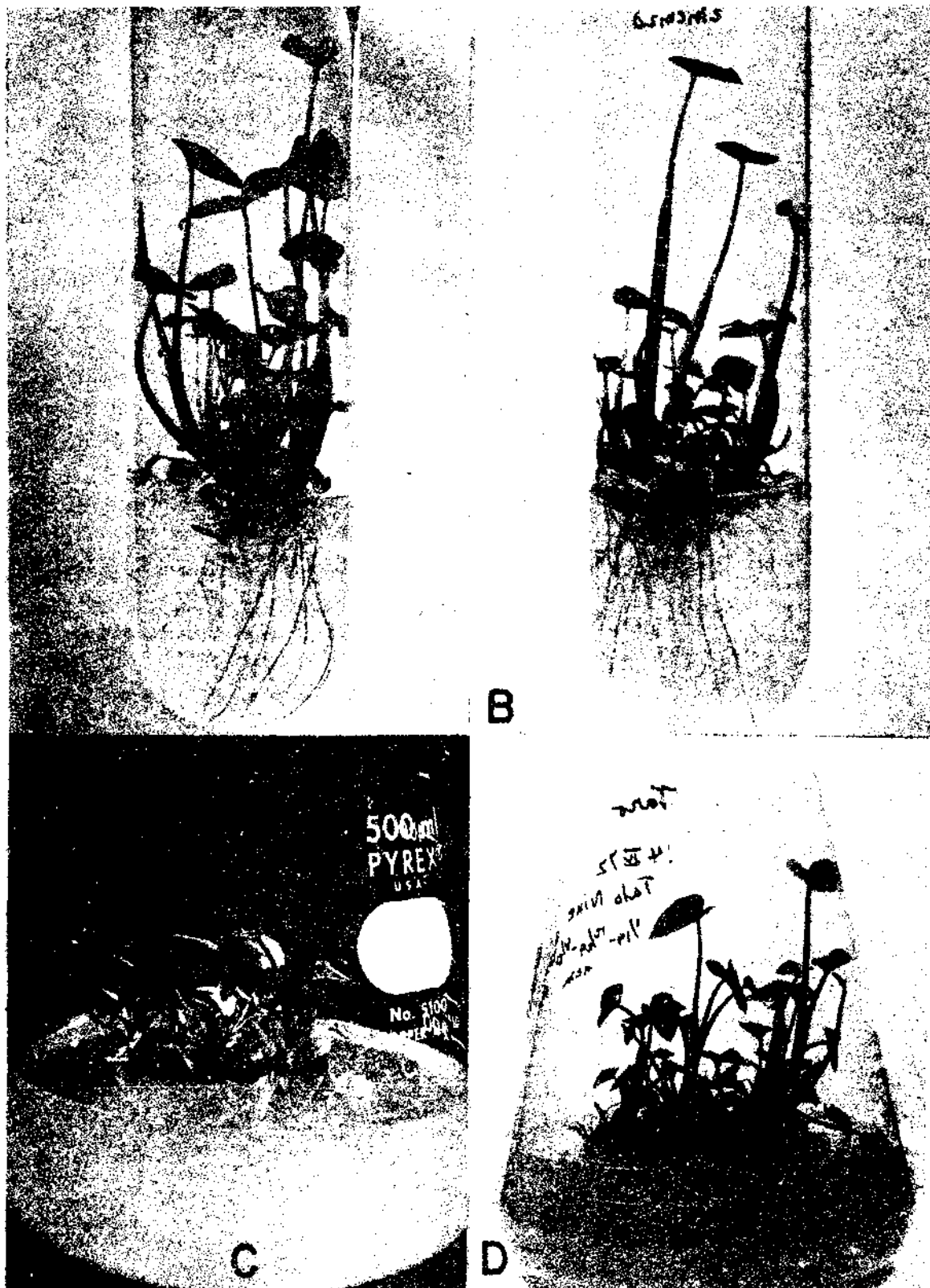
After 6–8 weeks the cut ends of shoot tip explants showed visible proliferation of new tissues. When there was shoot elongation without proliferation at the base, the shoot tip was removed aseptically, washed in 1 percent chlorox solution and a fresh cut made closer to the apical meristem. After a quick rinse in sterile distilled water, the tip was inoculated into a fresh liquid medium and returned to the shaker. This extra step aided proliferation.

When the bases became swollen and protocorm-like bodies appeared, the cultures were transferred to solid media of different composition. Modified Murashige and Skoog's basal medium, supplemented with 10 or 20 percent coconut water by volume, supported excellent growth of the shoot tip as well as a ring of new plantlets at its base. Usually 4 to 8 plantlets appeared from the proliferated based upon transfer to a solid medium. Additional plantlets were formed in older cultures, particularly when tube cultures were transferred to flasks with fresh medium. Plate I shows three cultivars of taro with plantlets which were grown from shoot tip cultures: A, Taro Niue; B, Eleele; C, Uahiapele and D. Taro Niue. D is a shoot culture from one of 11 plantlets which proliferated from one shoot. A was grown with 10 percent coconut water while cultures B–D were grown with 20 percent coconut water in the basal medium. In A, the terminal shoot was accidentally decapitated at transfer, thus removing its apical dominance, and the lateral buds were stimulated to grow into shoots. Studies are in progress to find better media for inducing callus growth and unlimited production of plantlets after the shaker treatment, as was achieved with the pineapple⁹.

REFERENCES

1. Barba, R. and Nickell, L.G. (1969) Nutrition and organ differentiation in tissue cultures of sugarcane, a monocotyledon. *Planta (Berl.)* 89, 299–302.
2. Carter, O., Yamada, Y. and Takahashi, E. (1967) Tissue culture of oats. *Nature* 214, 1029–30.
3. Hartman, R.D. and Zettler, F.W. (1972) Mericloning as a potential means of obtaining virus free plants from aroids commercially produced in Florida. *Proc. Fourth Org. Soil Vegetable Crops Workshop* 60–62. (Cited but not used).

4. Hartman, R.D., Zettler, F.W., Knauss, J.F. and Hawkins, E.M. (1972) Seed propagation of *Caladium* and *Dieffenbachia*. Proc. Florida State Horticultural Soc.
5. Heinz, D.J. and Mee, G.W.P. (1969) Plant differentiation from callus tissue of *Saccharum* sp. Crop Sci. 9, 346-8.
6. Kikuta, K. and Parris, G.K. (1941) Propagating taro by the normally dormant buds present on huli and corm. Prog. Notes Hawaii Agric. Exp. Stn. No. 21.
7. Long, P. P. (1969) Callus and organized growth in the Gramineae. Univ. of Hawaii. Master's thesis.
8. Loo, S.W. (1945) Cultivation of excised stem tips of *Asparagus* *in vitro*. Amer. J. Bot. 32, 13-17.
9. Mapes, M.O. Tissue culture of bromeliads. In Proc. of 14th Ann. Meeting of the Int. Plant Propagator's Soc. (Ed) H.T. Hartmann.
10. Morel, G. (1964) Tissue culture - a new means of clonal propagation of orchids. Amer. Orchid Soc. Bull. 33, 473-8.
11. Murashige, T. and Skoog, F. (1962) A revised medium for rapid growth and bioassays with tobacco tissue cultures. Physiol. Plantarum 15, 473-98.
12. Nishi, T., Yamada, Y. and Takahashi, E. (1968) Organ redifferentiation and plant restoration in rice callus. Nature. 219, 508-9.
13. Sagawa, Y., Shoji, T. and Shoji, T. (1966) Clonal propagation of *Cymbidiums* through shoot meristem culture. Amer. Orchid. Soc. Bull. 35, 118-22.
14. Steward, F.C. and Mapes, M.O. (1971) Morphogenesis and plant propagation in aseptic cultures of *Asparagus*. Bot. Gaz. 132, 70-8.
15. Takatori, F.H., Murashige, T. and Stillman, J.I. (1968) Vegetative propagation of *Asparagus* through tissue culture. Hort. Sci. 3, 20-22.
16. White, P.R. (1943) *A handbook of plant tissue culture*. Jacques Cattell Press, Lancaster, Pa. USA.
17. Wilmar, C. and Hellendoorn, M. (1968) Growth and morphogenesis of *Asparagus* cells cultured *in vitro*. Nature 217, 369-70.
18. Wimber, D.E. (1963) Clonal multiplication of *Cymbidium* through tissue culture of the shoot meristem. Amer. Orchid Soc. Bull. 32, 105-7.



EXPLANATION OF PLATE *

Plate 1. Growth of taro plantlets under aseptic conditions. Plantlets were obtained from shoot tip cultures after shaking them on the gyro-rotary shaker and transferring them to solid media. A. Taro Niue cultivar which produced several plantlets after the terminal shoot was decapitated at transfer, grown in Mura-shige and Skoog's (M-S) basal medium which was supplemented with coconut water, 10 percent by volume; B. Eleele cultivar with plantlets in M-S medium plus coconut water, 20 percent by volume; C. Uahiapele cultivar proliferating in a flask containing the same medium as in B; D. Taro Niue cultivar grown in the same medium as in B, grown from one of 11 plantlets which appeared in an earlier treatment with 20 percent coconut water.

SCREENING SWEET POTATOES FOR LOW CO₂ COMPENSATION POINT

S. Sadik*

SUMMARY

Sweet potato lines from four populations obtained from Japan, Puerto Rico and the United States were screened for low CO₂ compensation concentration. Some of the tested plants from each of the four populations appear to have lower CO₂ compensation points than others.

RESUME

Des lignées de patate douce appartenant à quatre populations et obtenues du Japon, de Porto Rico et des Etats Unis ont été étudiées pour en dégager celles qui présentent une concentration de compensation basse en CO₂. Certaines des plantes tirées des quatre populations et soumises à l'essai paraissent avoir des points de compensation plus bas en CO₂.

RESUMEN

Se seleccionaron líneas de camote procedentes de cuatro poblaciones de Japón, Puerto Rico y los Estados Unidos por baja concentración de CO₂ en el punto de compensación. Algunas de las plantas probadas, de cada una de las cuatro poblaciones parecen tener más bajos puntos de compensación de CO₂ que otras.

INTRODUCTION

Net photosynthetic rates of up to 60 mg CO₂ dm⁻² hr⁻² have been reported in maize, sorghum and sugarcane, and they are also known to occur in the Amaranthaceae and Chenopodiaceae.³ These high rates are almost twice those of temperate zone grasses^{3,4}. The lower net photosynthetic efficiency of the temperate species is associated with a higher rate of photo-respiration and high carbon dioxide compensation points².

Because of the established correlation over a number of plant species^{1,6}, between low carbon dioxide compensation concentration and high photosynthetic efficiency, the sweet potato germplasm collection at the International Institute of Tropical Agriculture (IITA) in Nigeria is being screened for low CO₂ compensation concentration with a view to using this characteristic in the breeding programme.

The method of screening is that of Menz *et al.*⁸ and is based on the assumption that if plants possessing low and high CO₂ compensation concentration values ('efficient' and 'inefficient' respectively) are grown together in a continuously illuminated gas-tight chamber, then the CO₂ concentration within the chamber will decrease with time and eventually fall below the CO₂ compensation concentration of the 'inefficient' plants. At such low CO₂ concentration, 'inefficient' plants show a net efflux of CO₂ since they respire CO₂ at a rate faster than CO₂ fixation by photosynthesis, and ultimately die. 'Efficient' plants, on the other hand, remained green since they utilize the CO₂ respired by the 'inefficient' plants. Plants surviving in such a system would have low CO₂ compensation points.

MATERIALS AND METHODS

The sweet potato collection of IITA contains some 10,000 plants which were grown from seeds obtained from Japan, Puerto Rico and the United States. Five single-node leaf cuttings from each plant, each with one fully expanded leaf, were excised from sweet potato vines under water and potted immediately in coarse sand and then placed in a humid propagation box. Maize seedlings were planted at the same time in sand. Both maize seedlings and sweet potato cuttings were irrigated with Hoagland solution every two days. Two weeks after planting, the cuttings established good root systems. Axillary shoots were removed in order to accelerate the screening test by reducing photosynthetic sources and to help overcome differential sink effects. The sweet potatoes and the maize seedlings were transferred to an airtight chamber built

*International Institute of Tropical Agriculture, Ibadan

and used according to Menz *et al.*⁶ The ratio of sweet potatoes to maize was 4:1. The chamber was illuminated continuously with a 3:1 mixture of cool and warm fluorescent lights giving approximately 18,000 lux at the leaf surface. The test was usually terminated after 1 week at which time the sweet potatoes were removed from the chamber and the five leaves from each parent plant were classified into three categories; green, yellow and dry.

RESULTS AND DISCUSSION

The response of the five replicate cuttings of some of the sweet potato clones was uniform in either remaining green or drying completely by the end of the test. However, non-uniform response was exhibited by some other clones. In order to amplify the presentation of results, the 21 possible combinations of green, yellow and dry leaves in each sweet potato population were divided according to their response into one of three groups:

1. Uniform response, those in which all leaves of a plant responded alike.
2. Partly uniform response, those which showed green and yellow leaves but no dry leaves and those which showed yellow and dry but no green leaves.
3. Non-uniform response, those which showed both green and dry leaves.

The 'expected' frequencies of leaf responses based on a null hypothesis for differences in behaviour between clones, were calculated by the expansion of a trinomial, based on the total observed frequencies for the three reactions. These frequencies were compared with the observed frequencies and it was obvious that the observed cases in which all leaves of a plant responded alike far exceeded the expected values (Table 1).

The lack of leaf uniformity within a clone in its response is not likely to be attributable to genetical differences, since all leaf cuttings were obtained from a single plant. It may thus be speculated that the variability within a clone could have resulted from quantitative differences in food reserves or from micro-climatic differences in the C_0 concentration around the leaves within the chamber. Neither one of these possibilities has yet been fully determined. The existence of genetic differences between clones is supported by the fact that there were significant differences between the four populations. A χ^2 analysis of the total frequencies of the three leaf responses showed that populations 11 and 12 were virtually identical to each other and had a significantly higher proportion of dry leaves than populations 3 and 4. Although population 4 showed a higher proportion of green leaves than population 3, the number of plants was too small to draw any definite conclusion as to whether this superiority was significant.

The method described in this study proved to be practicable for rapid screening of large populations of plants. Twenty lines of sweet potatoes could be tested each week in one chamber. No attempt, at this time, was made to make direct measurement of the CO_2 compensation concentration of plants that remained green.

Measurements of gas-exchange properties, linked with anatomical and enzymological investigations are being conducted to seek an explanation for the observed survival of some sweet potatoes at low CO_2 concentration.

It also remains to be demonstrated whether selection for efficient photosynthesis, in terms of low CO_2 compensation concentration, is correlated with superior performance of plants in their growth and yield characteristics.

REFERENCES

1. Downton, W.J.S. and Tregunna, E.B. (1968) Carbon dioxide compensation: its relation to photosynthetic carboxylation reactions, systematics of the Gramineae, and leaf anatomy. *Canad. J. Bot.* 46, 207-15.
2. Downton, J., Berry, J. and Tregunna, E.B. (1969) Photosynthesis: temperate and tropical characteristics within a single grass genus. *Science* 163, 78-9.
3. El-Sharkway, M. and Hesketh, J.D. (1965) Photosynthesis among species in relation to characteristics of leaf anatomy and CO_2 diffusion resistance. *Crop. Sci.* 5, 617-21.
4. Hesketh, J.D. and Moss, D.N. (1963) Variation in the response of photosynthesis to light. *Crop. Sci.* 3, 107-110.
5. Johnson, H.S. and Hatch, M.D. (1968) Distribution of the C^{14} dicarboxylic acid pathway of photosynthesis and its occurrence in dicotyledonous plants. *Phytochemistry* 7, 375-80.
6. Menz, K.M., Moss, D.N., Cannell, R.Q. and Brun, W.A. (1969) Screening for photosynthetic efficiency. *Crop. Sci.* 9, 692-4.

TABLE 1

Observed and expected frequencies of three classes of leaf response in 4 populations of sweet potatoes

Leaf response	Population							
	3		4		11		12	
	O	E	O	E	O	E	O	E
Uniform	67	7.6	3	0.4	25	1.4	27	1.6
Partly uniform	187	124.5	9	6.9	27	15.1	26	16.4
Non-uniform	64	185.9	3	7.7	23	58.5	22	57.0
Total	318	318	15	15	75	75	75	75

O = observed

E = expected

POTASSIUM REQUIREMENT OF TARO IN RELATIONSHIP TO GROWTH, FOLIAR ANALYSIS, YIELD, AND QUALITY AS GROWN IN SOLUTION CULTURE

W.J. Cable*

SUMMARY

Small plantlets were grown on half-Hoagland and various potassium-deficient solutions which changed weekly. KNO_3 was added daily to the solutions. Extensive data, analysed by computer is tabulated and highlights discussed. Growth measures could often be fitted to $\ln\text{-}\ln$ functions. Leaf K measured at 91 days can be correlated with yield. Corms from plants grown in solution culture were usually rich in N, P, K and nitrate. The Mg content was significantly higher in Lowthan Complete—K treatments. Taste testing revealed poor panel discrimination with large differences in assessment between coded replicate samples. However, there was generally preference indicated for baked over steamed corms and for the Low-K grown corms.

RESUME

Des plantules sont cultivées sur sol semi-“Hoag” et des solutions déficientes en potassium qui changent chaque semaine. Chaque jour on ajoute du KNO_3 aux solutions. Des données détaillées, analysées à l'ordinateur sont classifiées et les éléments discutés. Souvent les mesures de croissance peuvent correspondre aux fonctions $\ln\text{-}\ln$. La feuille K mesurée à 91 jours peut correspondre au rendement. Les tiges souterraines bulbeuses des plantes cultivées en solution de culture sont habituellement riches en N, P, K, et en nitrate. La teneur en Mg est nettement plus élevée avec les traitements bas K qu'avec les traitements de K complet. Lorsqu'on teste le goût il se révèle que le panneau de discrimination est pauvre avec des écarts sensibles dans l'évaluation des échantillons de répliques codés. Toutefois les tiges bulbeuses cuites au feu ou ayant une quantité basse de K sont généralement préférées à celles qui sont cuites à la vapeur.

RESUMEN

Se cultivaron pequeñas plántulas en solución un medio-Hoagland y en varias soluciones deficientes en potasio las cuales se cambiaron semanalmente. Se añadió KNO_3 diariamente a las soluciones. Se tabulan datos extensivos, analizados por computadora y se discuten los puntos mas sobresalientes. Las medidas de crecimiento pudieron ser frecuentemente ajustadas a funciones $\ln\text{-}\ln$. Se pueden correlacionar el potasio foliar medido a los 91 días, con el rendimiento. Los cormos de las plantas que crecieron en soluciones nutritivas, fueron generalmente ricos en N, P, K y nitratos. El contenido de Mg fue significativamente mas rico en los tratamientos de bajo K que en los que el K estaba completo. Las pruebas de palatabilidad revelaron una baja capacidad de discriminación de parte del jurado con grandes diferencias de opinión sobre muestras repetidas, codificadas previamente. Hubo, sin embargo, preferencia generalizada pro cormos porneados sobre los procesados al vapor y por los cultivados con bajo potasio.

INTRODUCTION

At alafua, W. Samoa, soil N was low, K was also deficient² and there were frequently symptoms of marginal scorch and interveinal chlorosis on taro like those described for *Xanthosoma* sp.¹⁸. Most taro is planted in lowland and foothill gardens under rainfed culture in Samoa on soil which is highly leached and on which K is usually limiting to production.

On the Dala series soils of Malaita Island (Solomon Islands) Gollifer has reported responses to K fertilizer in taro⁷. Foliar analysis of samples collected on a field study there confirmed K deficiency¹. Samples for foliar analysis from Keravat, New Britain, P&NG indicated K deficiency and this was associated with excess Mg concentrations. Response to K and P occurred on soils of Moorea I., Society Islands¹².

When high concentrations of K are in petioles and leaf blades^{14,15} this is associated with highest total yields of sucker and main corms. The high K requirement of taro is traditionally met by the usual practice in Pacific Islands of planting taro after a tree fallow which would return K to the surface by leaf fall. Such

*University of Hawaii, Department of Botany, Honolulu, Hawaii 96822, U.S.A.

areas are seldom replanted to taro but are returned to bush fallow after less demanding crops have followed taro. K is perhaps the most common limiting element in the nutrition of taro.

MATERIALS AND METHODS

Buds of taro cultivar Niue, which is the most popular cultivar in Samoa, were obtained from corms at harvest. These were used for propagating in vermiculite watered with one-tenth Hoagland solution without micronutrients¹⁰. Plantlets having one and two leaves were transferred after 1½ months to 1-gallon jars and watered with half-Hoagland solution with modified micro-nutrients⁸. The plantlets were supported in these containers on nylon mesh with polyester fiberfill. On 11 January 1972, 16 plantlets were transferred to plastic buckets for treatment with different levels of K and other nutrients (Table 1). The plants were supported in black polycans from which the bottoms had been removed. These were surrounded by wide rubber mesh so that the plants could be suspended over buckets of aerated nutrient solution with just their roots submerged. Later, support was provided for the top heavy plants by means of wires suspended from the ceiling of the plant house.

To facilitate changing the root solutions each week, and to make additions from time to time, an ordered arrangement within the plant house was adopted with two rows of 8 plants oriented north-south and fans giving air movement from west to east. Weekly changes of position were made to randomize position effects within replicates. Spacing within rows averaged 0.404 m. and between two rows 1.16 m.

Complete half-Hoagland solution, solutions with graded levels of K-deficiency were provided (Table 1). Micronutrients were supplied at levels 0.54 ppm B, 0.55 Mn, 0.065 Zn, 0.064 Cu, 0.048 Mo, 2.3 Na and 4.4 ppm Cl. Solution samples were taken, at first daily, later twice weekly for analysis by atomic absorption spectrophotometer or flame photometer. Cs was added to compensate when K was below 10 ppm. Use of nitrate electrode indicated when KNO_3 additions were required.

Analysis of P by ascorbic acid reduction⁹ indicated rapid uptake in some cases, necessitating a mid-weekly addition of KH_2PO_4 . Ca and Mg were more than sufficient. Mn was nearly completely taken up and was quadrupled to 2.2 ppm in three steps, while Fe sequestrene was reduced from 0.5 to 0.1 ppm.

The dry matter content of fallen leaves was determined. Number of leaves and dimensions for estimating area were also taken. The lengths of fallen petioles and the fourth and final leaf samples, by cutting, were measured as well as all fresh weights. Suckers were cut and counted, or removed when possible. Where this stimulated further suckering and this could be identified, the secondary suckers were not counted. Deionized water was added daily to replace transpiration and guttation loss. K-use was calculated from K added and change in solution from the nominal values. pH was determined twice weekly and $\text{Ca}(\text{PH})_2$ was added as required to maintain it about 6.0.

The first sample was taken after 91 days when there was considered to be sufficient growth that the removal of a leaf would not greatly affect photosynthetic rate. Successive samples were taken only after all the cut petioles had fallen away. At harvest corms and roots were sampled. Foliar samples were oven dried for one day at 85°C, weighed, ground to 40 mesh, and bottled samples redried at 70°C for one day before taking one gram samples for dry ashing at 550°C overnight. After cooling they were wetted and heated with 5 ml. 5N HCl, filtered and made up to 25 ml. for micronutrient analysis. Dilutions were made for P and K, and with 0.5% La to compensate for Ca and Mg. Nitrogen was determined on a separate sample by the Kjeldahl modification for auto-analyzer¹⁹.

Corm cores were taken for analysis. The remainder of corms were divided for cooking tests. One half was baked at 325° for 1.5 – 2 hours and the other steamed 1.5 hours to 200–210° F internal temperature for ½ hour.

Difference and preference tests¹¹ had been previously tried using Hawaiian taros on a panel of Pacific Islanders and Caucasians. The earlier questionnaire was modified to include colour, smell, taste, flavour, fibrousness and hardness.

Data were analyzed as though the treatments had been given in a complete randomized design. Means were compared by Duncan's multiple range test⁵. Linear and some multiple regression analyses were carried out using a Wang 700 calculator. The University of Hawaii Computer Center's programme for multiple regression with transgeneration⁴ was used, checking F values for significance. Analysis of co-variance³ was applied to growth data with weekly change.

RESULTS AND DISCUSSION

Growth measurements

Total K uptake could be described on the basis of a ln-ln relationship with number of changes of solution (Fig. 1a). K 'use' per week taken over the first 14 changes, gave highly significant fit to a ln-ln exponential function. Early uptake from the high-K treatment was similar to that from the 'complete' solution, later decreased to a rate similar to that with the medium-K treatment but finally overtook the latter near the end of the treatment period (Fig. 1b).

A double reciprocal function relating total K-use with mean weekly (K^+) produced a significant 'fit' occurring during growth (Fig. 2). Half maximal uptake was calculated on the basis of such relationship to be 0.021 meg./l.

Number of leaves accounted for about 85 percent of the variation Total AA (as indexed at leaf area). Leaf area increased almost linearly with time until the 28th change of solution. Petiole length was significantly associated with the amount of $\text{Ca}(\text{OH})_2$ added to the nutrient solution.

Nutrient levels in foliar samples

Leaf K was significantly correlated with leaf nitrate and leaf P over all sampling dates. This may be explained on the basis of K being as either KNO_3 or KH_2PO_4 .

Data are presented in Table 3, for example; leaf Ca and Mg were significantly correlated at every sampling date. Leaf Mn was significantly correlated with dry matter.

Leaf K decreased from Complete through High and Medium to Low K when K was sampled at 91 days or 206 days (Table 3). Leaf nitrate decreased from Complete to High to Low K treatment at 91 days, but increased from High to Medium and Low K at 135 days. Leaf P decreased from Low to Medium, High and Complete at 91 days, but increased from Low to Medium and Complete at harvest. Ca decreased from Low to Complete K at 91 days. Leaf total N, Mg and Cu did not differ significantly between K treatments.

Leaf number and area

Leaf number at harvest was significantly affected by K-treatments and related to the concentrations of other nutrients except %P and nitrate.

Leaf area was significantly correlated with dry matter, but accounted for only about 38 percent of the variation in the latter. Petiole fresh weights were significantly correlated with leaf area.

Roots and corm samples

Root Mg was significantly greater for the Low-K and Medium-K than for Complete nutrient treatment. Root K and Ca were highly correlated both with each other and with NO_3 . Corm Mg was also significantly higher for low than High and Complete K treatments (Table 2). Concentrations of N, P and K in corms in this experiment were about twice those found by de la Pena and Plucknett¹⁴.

Corm weight was correlated significantly with the Total AA measure of leaf area at changes 12 and 20, but accounted for less than half of the variation. Yield was only significantly correlated with leaf %K at the first sampling date (Fig. 3), but better correlation was obtained for $(\text{yield})^2$ with K.

The specific gravity of corms was highly correlated with corm nitrate, root fresh weight and corm percent dry matter.

Totals

Table 4 presents data on cumulative totals over all sampling occasions of all the measured parameters for the four different K-treatments.

Fig. 1a. Mean Total K-Use to Change 12

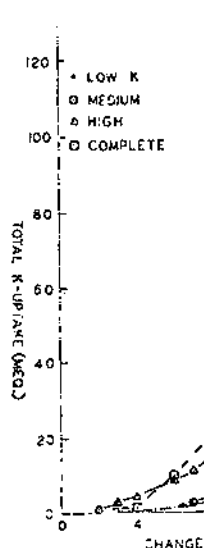


Fig. 1b. Mean Total K-Use For the Rest of the Changes for K treatments.

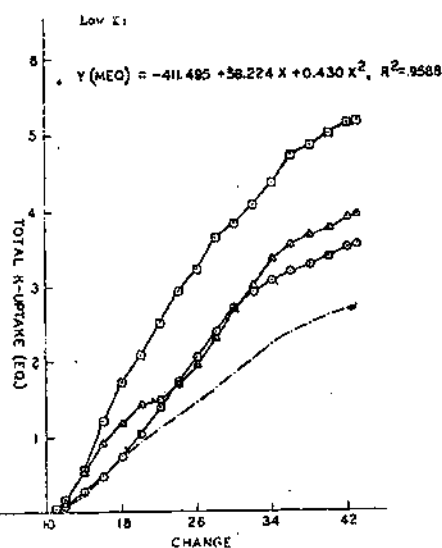


Figure 2. Double Reciprocal Graph of K-Uptake and Solution-K for Replicate 4 of K-Treatments From Changes 12 to 15.

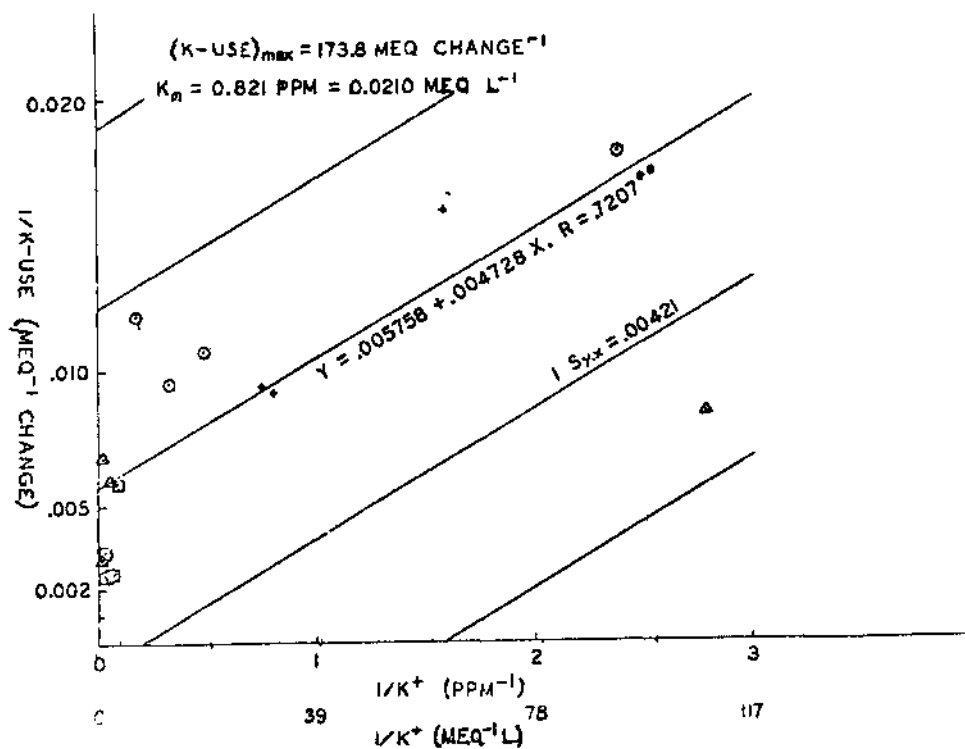
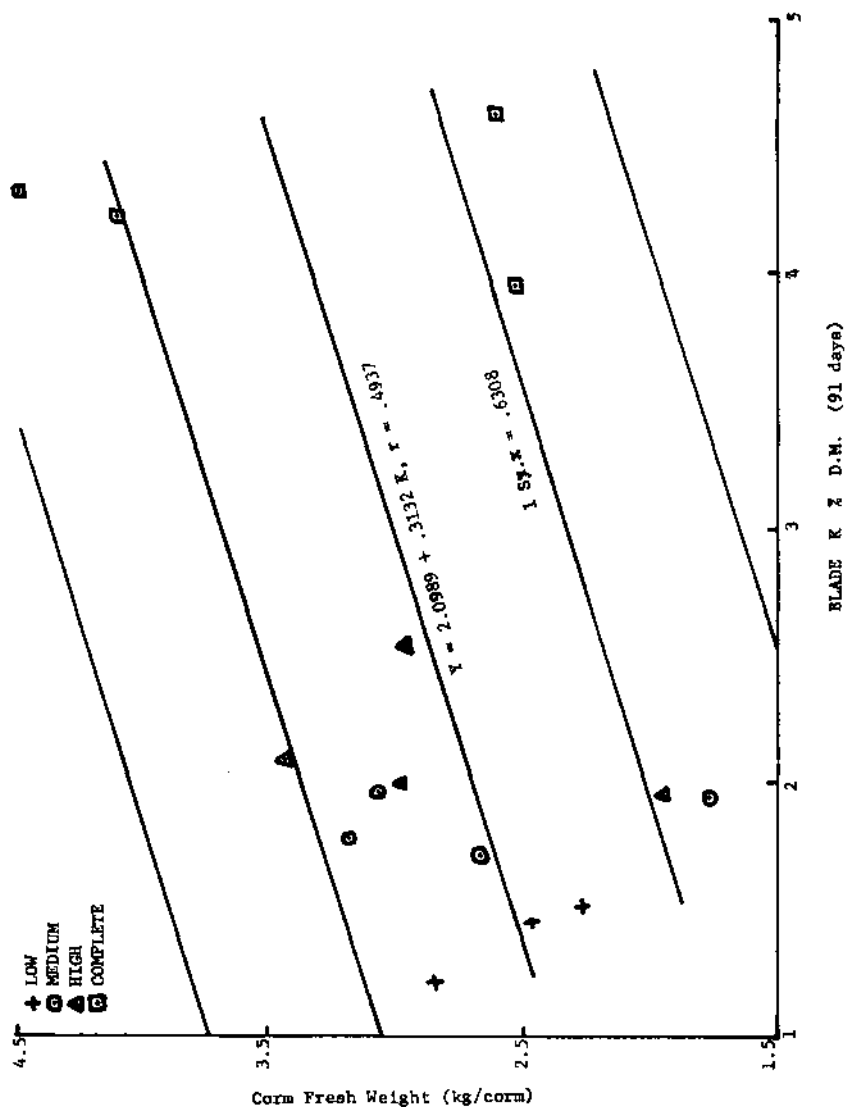


Fig. 3. Corn Fresh Weight with Leaf Blade K % D.M. at 91 days.



Taste testing

Differences were generally as great for coded replicates of corms from complete K treatment as among other treatments either steamed or baked, indicating differences within corms or failure of the tasters adequately to discriminate differences. However, Complete-K (coded but unknown) baked samples were given better colour but poorer taste scores than standard samples, and conversely Low-K baked corms were generally preferred to Complete-K samples. As a steamed food, the Medium-K samples were generally preferred to either Low- or High-K. High-K baked corms may have had better smell but poorer taste than standards.

REFERENCES

1. Cable, W.J. (1973) Report of a field study on taro research in the S. Pacific. 1. Cultural factors. SPRCTA, Alafua, W. Samoa.
2. ——— (1971) Results of some taro (*C. esculenta* L. Schott) trials. Res. Paper Series No. 9, SPRCTA, Alafua, W. Samoa.
3. Dixon, W.J. (1968) *Biomedical Computer Programs*. X-series supplement. UCLA publications on Automatic Computation No. 3.
4. ——— (1970) *Biomedical Computer Programs*. 2nd Ed. revised, UCLA Publications In Automatic Computation, No. 2.
5. Duncan, D.B. (1955) Multiple range and multiple F test. *Biometrics* 11, 1–40.
6. Epstein, E.E. (1966) Dual pattern of ion absorption by plant cells and by plants. *Nature* 212, 1324–7.
7. Gollifer, D.E. (1972) Effect of applications of potassium on annual crops grown on soils of the Dala series in Malaita, Br. Solomon Is. *Trop. Agr., Trin.* 49, 261 f.
8. Hewitt, E.J. (1966) *Sand and water culture methods used in the study of plant nutrition*. 2nd Ed.
9. John, M.K. (1970) Colorimetric determination of phosphate in soil and plant materials with ascorbic acid. *Soil Sci* 109, 214–20.
10. Kikuta, K and Parris, G.K. (1971) Propagating taro by the normally dormant buds present on huli and corms. *Prog. Notes*. No. 21. HAES.
11. Merck Tech. Bull. (1963) An introduction to taste testing of goods. *Fd. Prods. Dept.*, Merck Chem. Div., Merck & Co., Inc., Rahway, N.J.
12. Millaud, R. (1971) Taro. SPC Info. Circ. No. 34.
13. Orion Res. Inc. (1969) Determination of nitrate in plant tissue. *Applications Bull.* Applic. Bull. No. 7.
14. Pena, R.S. de la and Plucknett, D.L. (1967) The response of taro (*C. esculenta* (L.) Schott) to N, P and K fertilization under upland and lowland conditions in Hawaii. *Proc. Int. Symp. Trop. Root Crops*, Trin. 1(2), 70–85.
15. Plucknett, D.L. and Pena, R.S. de la (1971) Taro production in Hawaii. *World Crops*. 23, 244–9.
16. Reddy, V.B. et al. (1968) Note on the relationship between corm yield and certain leaf measurements of taro (*C. esculenta* L. Schott). *Trop. Agr. Trin.* 45, 243–5.
17. Snedecor, G.W. and Cochran, W.G. (1967) *Statistical Methods*. 6th Ed.
18. Spence, J.A. and Ahmad, N. (1967) Plant nutrient deficiencies and related tissue composition of tannia (*Xanthosoma sagittifolium*) *Proc. Int. Symp. Trop. Root Crops Trin.*, 1(2), 61–7.
19. Warner, M.H. and Jones, J.B. (1970) A rapid method for N determination in plant tissue. *Soil Sci. and Plant Anal.* 1(2), 109–14.

TABLE 1

K Treatments

Nutrient Ion	Solution Complete	K Low	Medium	High
NO_3^-	7.5	5.0+.02	+.06	+.20 meq/l
H_2PO_4^-	0.5	0.5	0.5	0.5
K^+	3.0	.02	.06	.20
Ca^{++}	2.5	2.75	2.75	2.75
Mg^{++} , SO_4^{--} each	1.0	1.0	1.0	1.0
	15.5	10.25 meq./l		

TABLE 2

Corm Macro-elements % D.M. at harvest

K	%N	NO_3^-	P	K	Ca	Mg
Low	1.74	.34	.33	1.84	.128	.100 ^a
Medium	1.68	.32	.30	1.94	.055	.080 ^{ab}
High	1.80	.35	.32	2.20	.070	.074 ^b
Complete	1.70	.41	.30	2.30	.053	.064 ^b
	±.42ns	±.40ns	±.24ns	±.5ns	±.16ns	.025 ^{*1}

*1 means significantly different beyond the 5% level throughout this paper; values with the same letter in the superscript are not significantly different (ns).

TABLE 3

Third leaf element concentrations in dry matter at all sampling dates for K treatments

Days		%N	%NO ₃ ⁻	%P	%K	%Ca	%Mg	ppm Fe	Mn	Cu	Zn	%SO ₄ -S
91	Low	3.45	.212 ^c	.69a	1.43b	3.2 ^x	.65	87bc	124a	7.3	56 ^x	.135 ^x
	Medium	3.76	.31 ^{bc}	.40b	1.82b	2.3 ^{xy}	.50	82 ^c	141a	6.9	51 ^{xy}	.098 ^y
	High	3.80	.41 ^b	.42b	1.98b	2.2 ^{xy}	.43	103a	65b	6.2	35 ^y	.091 ^y
	Complete	3.80	.60 ^a	.30 ^b	4.28a	1.4 ^y	.27	95ab	134a	5.8	36 ^y	.066 ^z
		+ .67 ^{ns}	± .19 [*]	± .23 [*]	± .65 [*]	± 1.4 [*]	± .32 ^{ns}	± 12 [*]	± 42	± 1.7 ^{ns}	± 17 [*]	± .017 [*]
		3.70 ^c	.38ab	.45	2.38 ^c	2.3a	.46	92	116a	6.6	44	.098
135	Low	3.92	.55a	.44	4.3	1.01	.103	69	38	6.1	30b	
	Medium	4.40	.56a	.44	4.0	1.06	.106	65	43	5.9	68ab	
	High	3.96	.26b	.33	4.0	1.05	.098	53	36	6.2	95a	
	Complete	4.46	.51ab	.43	4.8	.84	.087	108	43	6.1	43b	
		+ .74 ^{ns}	± .26 [*]	± .12 ^{ns}	± .88 ^{ns}	± .65 ^{ns}	± .062 ^{ns}	± 46 ^{ns}	± 32 ^{ns}	± 2.0 ^{ns}	± 39 [*]	
		4.18b	.47a	.42	4.2a	0.99b	.098d	74	40b	6.1	59	
206	Low	4.09	.35	.36ab	3.0b	1.14	.117	83	45	7.4	37ab	
	Medium	4.17	.39	.137ab	3.8ab	.95	.102	85	45	7.1	31b	
	High	4.05	.44	.34b	3.7ab	.94	.102	71	45	7.6	32b	
	Complete	4.16	.53	.48a	4.5a	1.03	.114	74	43	6.8	47a	
		+ .94 ^{ns}	± .29 ^{ns}	± .13 [*]	± 1.3 [*]	± .50 ^{ns}	± .046 ^{ns}	± 20 ^{ns}	± 21 ^{ns}	± 2.7 ^{ns}	± 11 [*]	
		4.12	.43	.39	3.8ab	1.02b	.109cd	78	44b	7.2	37	
259	Low	4.27	.20	.45	3.8	2.6	.32					
	Medium	4.10	.21	.44	4.1	2.4	.23					
	High	4.36	.32	.50	5.0	1.8	.24					
	Complete	4.56	.31	.44	5.1	2.1	.26					
		+ .80 ^{ns}	± .19 ^{ns}	± .08 ^{ns}	± 2.1 ^{ns}	± 1.6 ^{ns}	± .17 ^{ns}					
		4.32	.26	.46	4.5a	2.2a	.28b					
301-4	Low	4.62	.208	.51a	3.2	2.12	.28					
	Medium	6.90	.160	.37a	2.7	1.66	.25					
	High	4.88	.224	.36ab	2.9	1.49	.21					
	Complete	4.88	.125	.31b	2.6	1.12	.22					
		+ .60 ^{ns}	± .093 ^{ns}	± .06 [*]	± 1.4 ^{ns}	± .15 ^{ns}	± .15 ^{ns}					
		4.82a	.18b	.36	2.8bc	1.6ab	.24					
		± .36 [*]	± .22 [*]	± .16 ^{ns}	± 1.4 [*]	± .81 [*]	.14 [*]					

TABLE 4

Totals of K treatments

Total	Low K	Medium K	High K	Complete K	LDs
Leaf weight, kg/plant	0.506	.63	.492	.45	ns
Petiole weight, kg/plant	2.53	2.77	2.24	2.14	ns
Sett weight, kg/plant	2.18	2.80	2.31	2.15	±.77ns
Root weight, kg/plant	0.90	.76	.67	.56	ns
Corm weight, kg/plant	2.38	2.69	2.85	3.4	±1.6ns
Total weight, kg/plant	8.50	9.6	8.56	8.8	ns
Ratio (top/corm)	2.66	2.09	2.14	1.63	±1.7ns
% Corm	28.4	28.1	30	39.4	ns
Leaf D.M., g/plant	459	467	479	510	±190ns
L.A.I.	2.57ab	3.47a	2.60ab	1.99b	±1.1*
Leaf production, days/leaf	7.34	7.16	6.99	7.07	±.40ns
Number of petioles	39	38.5	41	42	±9.3ns
Suckers	30.8	36.2	46	64	±41ns
Corm D.M., g.	540	620	570	640	ns
Water, L.	810	840	800	890	±290ns
Water use, l./kg	345y	320xy	287xy	264x	±59*DMRT
K-use, g./plant	106c	136bc	157b	204a	±34*
Nitrate-use, g./plant	64.8b	74.2ab	74.9ab	89.7a	±8.4**
P-uptake, g./plant	8.4b	9.1b	7.8b	12.7a	3.1*
% leaves	5.92	5.57	5.72	5.15	ns
% petioles	29.7	28.7	26.1	24.1	ns
% sett weight	25.7	29.4	26.9	24.9	ns
% roots	9.2	7.93	7.9	6.4	ns
Corm % D.M.	22.4	22.7	19.19	19.3	ns
Sp.Gr.	.902	.888	.893	.881	ns

MINERAL NUTRITION OF TARO (*COLOCASIA ESCULENTA*) WITH SPECIAL REFERENCE TO PETIOLAR PHOSPHORUS LEVEL AND PHOSPHATE FERTILIZERS

R.B. Kagbo, R.S. de la Pena, D.L. Plucknett and R.L. Fox*

SUMMARY

Soil and plant analyses can serve as guides for taro fertilization but care must be exercised in interpretation. Composition of taro leaf blades and petioles changes with advancing age so that plant age at sampling must be standardized. Leaf blades are more stable in composition than petioles. Luxury nutrition can be detected from petiole analyses but probably not from leaf blade analyses. Petioles sampled at about 8 months of age will serve as sensitive tissue for indicating the phosphorus status of taro. Petiole composition at 8 to 9 months ranges from 0.10 to 0.48% P, depending on levels of available soil phosphorus.

A leaf petiole phosphorus content of 0.23% at about 9 months age, and a soil solution concentration of about 0.16 ppm P are suggested as reasonable levels for good phosphorus nutrition of taro. Two soils developed from highly weathered alluvium required 500 to 600 kg/ha P to attain these levels.

RESUME

On peut se baser sur les analyses pédologiques et végétales pour fertiliser le taro, mais il faut que l'interprétation soit faite avec précaution. La composition des limbes foliaires du taro et des pétioles change à mesure que l'âge avance, ce qui nécessite que l'âge des plantes soit standardisé au moment de l'échantillonnage. Les limbes foliaires ont une composition plus stable que les pétioles. On peut déceler une nutrition de haute qualité à partir d'analyses des pétioles mais probablement pas des analyses de limbes foliaires. Des pétioles échantillonnés à l'âge de 8 mois environ serviront de tissus sensibles pour indiquer le statut du phosphore du taro. La composition des pétioles de 8 à 9 mois va de 0.10 à 0.48% de P, en fonction des niveaux du phosphore disponible dans le sol.

Une teneur de 0.23% en phosphore de pétiole foliaire de 8 mois environ, de même qu'une concentration de solution du sol d'environ 0.16 de ppm P sont considérés comme des niveaux acceptables pour une bonne nutrition du taro en phosphore. Deux sols développés à partir d'alluvion soumis aux effets d'intempéries ont besoin de 500 à 600 kg de P/ha pour atteindre ces niveaux.

RESUMEN

Los análisis de suelos y plantas pueden servir como una guía para la fertilización de la malanga pero debe tenerse cuidado en su interpretación. La composición de los limbos de hojas y pecíolos cambia con la edad, de manera que debe estandarizarse la edad a la que se muestrean. Los limbos de las hojas son mas estables que los pecíolos en su composición. La nutrición superflua puede detectarse a partir de análisis del pecíolo pero probablemente no, a partir de análisis del limbo de la hoja. Los pecíolos muestreados alrededor de los ocho meses de edad servirían como un tejido sensible para indicar el estado del fósforo en la malanga. La composición de los pecíolos a los 8—9 meses varía de 0.10 a 0.48% P, dependiendo de los niveles de fósforo disponible en el suelo.

Se sugiere un contenido en el pecíolo de la hoja de un 0.23% a los ocho meses de edad — aproximadamente — y una concentración de la solución del suelo de cerca de 0.16 ppm P, como niveles razonables para una buena nutrición fosfórica de la malanga. Dos suelos desarrollados a partir de aluvión altamente intemperizado requirieron 500 a 600 kg/ha P para alcanzar esos niveles.

*International Institute of Tropical Agriculture. Ibadan.

INTRODUCTION

Taro is widely cultivated in the tropics and subtropics. Common names for taro vary from one culture to another. In West Africa, it is known as cocoyam, whereas in the Philippines it is known as gabi or aba. Records of its cultivation date back to 400 B.C., thus making it one of man's oldest food crops⁴. Taro can be cultivated both on upland and lowland, waterlogged conditions because of its ability to transport oxygen from the leaves to the roots^{2,5}. Taro can be grown under other adverse conditions, thus making it a good subsistence crop for underdeveloped areas. In Egypt, it has been used as the initial crop for reclaiming salt-affected sandy soils¹⁰.

As a food crop, taro compares favourably in nutritional value with other root crops as cassava, yams, sweet potato and other edible aroids¹². In Africa, Samoa, and other parts of the world, taro leaves are cooked as a vegetable and contain relatively high amounts of Ca, P, Fe, K, Vitamin A and ascorbic acid. The protein of the leaves has most of the essential amino acids¹². Taro flour can be used for making bread and cookies, while slices can be baked or made into chips. The staple food of ancient Hawaiians was poi⁵. This has unique characteristics as food for babies.

Published information on the mineral nutrition of taro is limited, but the few available publications suggest that it responds well to fertilization, particularly when it is grown on highly leached tropical latosols^{5,8}. Most of the published investigations have been done in Hawaii. The aim of this paper is therefore to bring together the scattered pieces of available literature, and to discuss some new fertilizer developments in the crop, especially with regard to phosphorus.

EFFECTS OF MANAGEMENT SYSTEMS

Response of taro to fertilization varies with the type of management practice. In Hawaii, for instance, lowland taro responds most to N, while the upland crop responds most to P and then to N¹². Thus, with N, P and K at 400, 600 and 300 kg/ha respectively in lowland conditions under sprinkler, furrow and flood irrigation, Ezumah⁶ observed no effect of the method of irrigation on the concentrations of N, P, K, Ca, Mg, Fe and Mn in petioles at three months of age. At six months however, all elements studied were significantly higher in petioles under sprinkler and furrow irrigation than under flood irrigation. A similar trend was observed in main corms at seven months. This phenomenon is attributed to a redistribution of the elements from the rapidly declining top to the steadily growing corms, and to dilution effects of better yields under flooded conditions^{5,6}. Plucknett et al.¹² stressed the significant role of fresh water in taro not only for maintenance of maximum vegetative growth and leaf production in the period of starch storage, but also because most taro cultivars are more susceptible to root rot in warm stagnant water.

Ezumah⁶ has also reported an increase in amounts of N, K, Fe and Mn in taro at three months of age under ridged culture, although ridging had no effect on concentration of all elements in corm at seven months, and on Ca and Mg in petioles at all ages.

Other investigations⁴ were also conducted on the island of Kauai, on effects of N, P, and K on growth and nutrient uptake of taro under upland and wetland conditions. Fertilizer rates used were: 0, 280, 560 and 1120 kg/ha of each element. Also N, P, and K treated plants received 280 kg/ha of each: P and K; N and K; and N and P respectively. Control plants received no fertilizer.

EFFECTS OF FERTILIZERS ON LEAF NUTRIENT COMPOSITION

Reports from several workers^{3,6,10}, indicate increased N content with N fertilization, but the dilution effect of increased growth decreased P and K foliar percentages. Fertilization with P increased P content in the leaves but decreased K percentage, particularly when the crop was grown on highly weathered upland soils. Application of K significantly increased K content in both upland and lowland taro leaves, and also increased total N in the upland crop. Production of sugar in leaf blades and starch in corms has also been associated with K application¹². Because of competition among the cations Ca^{++} , Mg^{++} , K^{+} and NH_4^{+} for uptake by plants, decreased Ca and Mg percentages of leaves of upland and lowland taro should be expected when K fertilizers are applied. Effects on N uptake will depend upon the form of N being taken up. Ammonium is nitrified slowly in some highly weathered soils of Hawaii¹⁵. Contents of K of lowland taro leaves are consistently higher than upland taro regardless of treatment. This is associated with high amounts of K and Mg in the lowland soils³.

EFFECTS OF FERTILIZERS ON CORM DEVELOPMENT, DRY MATTER AND ROOTS

Corms begin to make significant growth about three months after planting and continue to grow until maturity. Nitrogen applications increase corm weights of both lowland and upland crops whereas application of K seemed to increase corm weight of lowland crop only³. Concentrations of N, P, K, Mg, and Fe at seven months have been reported⁶ to be significantly higher in sprinkler irrigated than in flooded plots, but

levels of K and P in corms were equal under sprinkler and furrow irrigation. Phosphorus applications apparently increased specific gravity, and hastened corm maturity as shown by yield decrease of dryland taro occurring when harvesting was delayed from ten to fifteen months. When upland taro depends upon rainfall, a short drought may accelerate maturation and starch storage but late rains may cause renewal of growth with hydrolysis of stored starch in the corms leading to reduce corm quality and starch content¹⁰. Furthermore, corms assume a dumb-bell shape when rains are erratic, globular at time of active vegetative growth but constricted at maturation. Bowers, Plucknett and Younge¹ report a direct correlation between poi recovery and specific gravity of corms, and de la Pena³ indicated correlation coefficients of 0.626** and 0.68** respectively for specific gravity with percentage dry matter of apical and basal parts of dryland main corms, and 0.76** for sucker corms. In potted plants, both N and P increased corm dry matter, whereas in the absence of P, there was no response to N beyond the 400 kg/ha application.

Growth of roots was considerably less in non-flooded than flooded treatments regardless of P fertilizer rates. Thus limited root development rather than a lack of nutrients may account for the superior growth of flooded taro as compared with upland taro.

YIELDS

In Hawaii, N, P and K applications increased yields of upland taro significantly. Dryland taro yields of 40 tons/ha harvested at 15 months using 560 kg/ha P applications have been reported from the Kauai Branch Station, Hawaii by Plucknett¹⁰. These yields are also greatly superior to those reported from Malaya, Trinidad, India and West Africa where yields are usually about 7–9, 4.5, 22–31 and 3–8 metric tons/ha respectively.

However, only N and P applications increased flooded taro yields significantly. In one of de la Pena's investigations³, the greatest yield, 58 metric tons/ha of flooded taro, was obtained by the use of 1120 kg/ha N. The yield was 33 tons/ha for 0 kg/ha N. In contrast, the greatest yield of the upland taro achieved was only 26 tons/ha, and this was obtained by the use of 250 kg/ha application of N. No N under comparable conditions gave 9.8 tons/ha and 1120 kg/ha N gave 17 tons/ha. Imbalance among nutrients which may occur with heavy use of single nutrients on soils of low initial fertility, such as highly weathered upland soils, may be responsible for decreased yields of the heavily, as opposed to moderately, N fertilized plots.

INTERNAL AND EXTERNAL PHOSPHORUS REQUIREMENTS OF FLOODED TARO

There has been a tendency to neglect the phosphorus nutrition of paddy crops since it has been generally believed that the reducing conditions will solubilize iron phosphates and keep existing phosphorus available to the crop. The process may be inadequate to provide sufficient phosphorus if the parent alluvium is derived from a highly weathered land surface. Such alluvia usually have capacities to absorb much phosphate with little change in the availability of soluble phosphate.

Taro in Hawaii is often heavily fertilized with phosphate¹¹. This suggests that the crop has a high requirement for phosphorus in solution (external requirement). Work is now in progress to determine the external phosphorus requirement of taro in comparison with rice. At the same time, leaf and petiole analyses are being made to arrive at the internal phosphorus requirement. The plots used are being monitored through several crop cycles to measure long-term phosphate fertilizer requirements and residual effects of phosphate fertilizer.

Field experiments are being carried out at the Paddy Crop Experiment Station, Hawaii Agricultural Experiment Station, Wailua, Kauai. The soil, Hanalei silty clay, is a poorly drained alluvium with a watertable at about 40 cm but an impervious layer in the soil which effectively restricts water transfer into the surface soil from the watertable. The soil is classified as Typic Tropaquept. The source of alluvium was the highly weathered upland of Kauai. Minerals are predominantly hydrated iron and aluminum oxides.

Ten levels of phosphate in the soil were established by adding concentrated superphosphate in amounts designed to give 0.003, 0.006, 0.012, 0.025, 0.05, 0.1, 0.2, 0.4 and 1.6 ppm phosphorus in solution. Amounts of phosphate required to establish the various concentrations of phosphorus were taken from a phosphate absorption curve based on equilibrating the original soil with several concentrations of phosphate in 0.01 M CaCl₂ for 6 days (Fig.1). The plots were initiated in July 1970 with corn as the initial crop, which however was destroyed by flooding. The soil was allowed to dry and new phosphate adsorption curves were constructed using data from fresh soil samples. In this exercise no evidence could be found of residual effects from the previously applied phosphate (Table 1). These results have important implications for alternate uses of paddy soils.

Phosphate was reapplied and rice was seeded. Yields of IR-8 and IR-22 rice were about 65% of maximum when no phosphate was added and were about 95% of maximum when phosphate was added to give 0.012 ppm P in solution equilibrated with the oxidized soil. (This gives about 0.07 ppm P in solution under strongly reduced conditions in the field).

Plots were kept flooded after the rice was harvested; ceramic filter candles were embedded in each plot; and, after several days of equilibration, solutions were withdrawn for phosphate analyses. A large syringe fitted with a small bore plastic tube was used to withdraw a 25 ml sample. The first samplings were discarded. The solution was injected below the surface of molybdate-sulphuric solutions. Phosphomolybdate blue colour was developed immediately in the field. Residual effects from the previously applied phosphorus fertilizers were now evident. The original phosphate adsorption curve was used to calculate amounts of phosphate fertilizer to re-establish phosphorus concentrations. Taro was planted in July 1972.

Plant tissue samples and soil solution samples from the filter candles were taken in March 1973. Residual phosphate fertilizer clearly increased phosphate concentrations in soil solutions eight months after fertilizer was applied (Fig. 2). Results were reasonable considering that only one filter candle was sampled per plot. The phosphorus range in fertilized plots was about 0.04 to 0.4 ppm — a much narrower range than was originally hoped for. Actual concentrations were higher than intended except for the two highest phosphorus levels. Solutions from the plot which received no phosphate fertilizer contained about 0.02 ppm phosphorus while the adsorption curve based on soil sampled taken before flooding (oxidized soil) indicated that the no P treatment should equilibrate at about 0.002 to 0.010 ppm P.

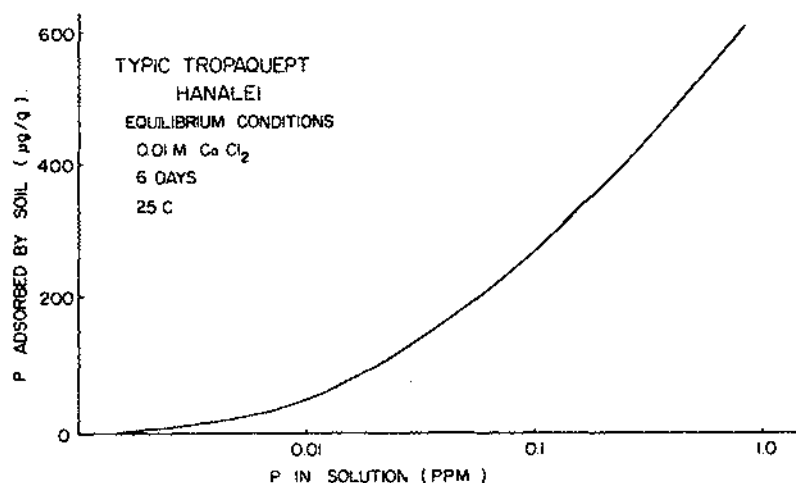


Fig 1. Phosphate adsorbed by the Hanalei soil in relation to phosphorus concentrations in equilibrated solutions. The soil had been drained for several years before this isotherm was constructed.

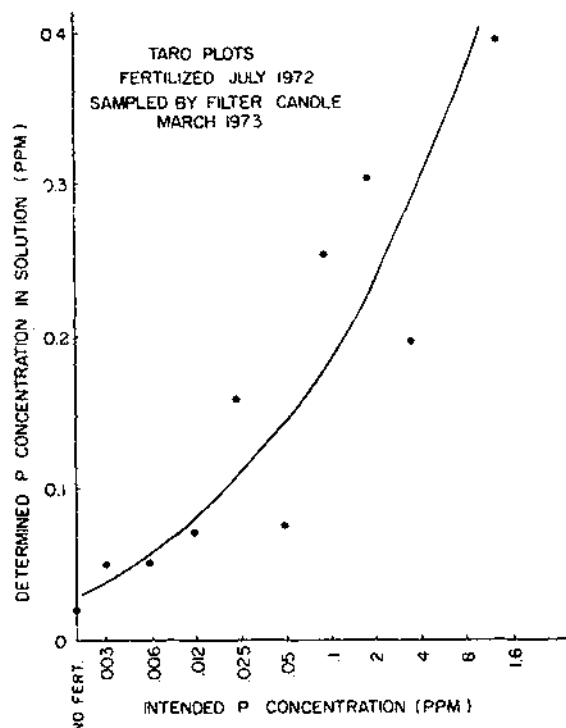


Fig 2. Phosphate concentrations of soil solutions extracted from field plots by means of filter candles in relation to intended concentrations of phosphate established by fertilizing 8 months earlier according to the phosphate adsorption curve illustrated in figure 1.

These data confirm the solubility effects of a reducing environment on phosphate. They also demonstrate that intensity of phosphorus nutrition from flooded alluvial soils can be inadequate. Not all flooded soils will equilibrate at such low phosphate concentrations. Soils in which 2:1 type clays predominate and in which soluble Si is high usually adsorb relatively much less phosphate than the soil investigated here. It follows then that phosphate released upon flooding should be more effective in increasing the phosphorus concentration of soils with 2:1 type clays.

Phosphate fertilization increased the phosphorus percentage of both leaf blades and petioles (Table 2). Leaf blades were less influenced by phosphate fertilization than were petioles which suggests that if foliar diagnosis is to be used, then petioles will be a superior indicator tissue for evaluating the adequacy of phosphorus nutrition. Visual observations of growth at 8 months indicate that most of the response from applied phosphate was attained with the treatment that was originally designed to give .006 ppm P in solution. The data suggest that the internal P requirement for taro vegetative growth is about 0.42% in the leaf blade or 0.16% in the petiole. This treatment was associated with about 0.05 ppm P in the soil solution 8 months after the taro was planted.

The foliar P data presented in Table 2 are in general agreement with composition of petioles and leaf blades of upland taro which have been previously determined on Kauai (Table 3). The data for flooded taro demonstrate that petioles can accumulate phosphorus. The data on flooded taro presented in Table 3 evidently represent luxury phosphorus consumption at the 6 and 9 month sampling dates since high concentrations of phosphorus in the petioles were associated with elevated phosphorus contents of leaf blades as well.

The upland taro clearly responded to phosphate fertilization while there was little if any response to phosphate by flooded taro growing on Hauula Paddy soil (Table 3). Based on these results a value of 0.23 percent P in petioles at nine months age should indicate adequate phosphorus nutrition. This level was attained by adjusting phosphorus to 0.1 ppm according to the isotherm for oxidized soil (Table 2). The actual concentration of phosphorus in solution after flooding was probably about 0.16 ppm.

REFERENCES

1. Bowers, F.A.I., Plucknett, D.L. and Younge, O.R. (1964) Specific gravity evaluation of corm quality in taro. Hawaii Agric. Exper. Station, Circular No. 61.
2. Cherian, E.C., Gary, M.P. and Murphy, L.S. (1968) Nutrient uptake by lowland rice under flooded and non-flooded soil conditions. *Agron. J.* 60, 554.
3. de la Pena, R.S. (1967) Effects of different levels of N, P and K fertilization on the growth and yield of upland and lowland taro. Ph.D. Dissertation, Univ. of Hawaii.
4. de la Pena, R.S. and Plucknett, D.L. (1967) The response of taro (*Colocasia esculenta* (L.) Schott) to N, P and K fertilization under upland and lowland conditions in Hawaii. *Proc. Int. Symp. Trop. Root Crops*, Trinidad, 1(2), 70-85.
5. de la Pena, R.S. and Plucknett, D.L. (1972) Effects of N fertilization on growth, composition and yield of upland and lowland taro (*Colocasia esculenta*) *Expt. Agric.* 8, 187-94.
6. Ezumah, H.C. (1972) Growth and development of taro (*Colocasia esculenta*) in relation to selected cultural management practices. Ph.D. Dissertation, Univ. Hawaii.
7. Hartt, C.E. (1970) Effect of potassium deficiency upon translocation of ^{14}C in detached blades of sugarcane. *Plant phys.* 45, 183.
8. Hodnet, G.E. (1958) A fertilizer experiment on dasheen. *Trop. Agric. Trin.* 35, 205.
9. Jensen, C.R., Stolzy, L.H. and Letley, J. (1967) Tracer studies of oxygen diffusion through roots of barley, corn and rice. *Soil Science* 103, 23.
10. Plucknett, D.L. (1970) The status and future of the edible aroids: *Colocasia*, *Xanthosoma*, *Alocasia*, *Cyrtosperma* and *Amorphophallus*. *Proc. 2nd Int. Symp. Trop. Root Crops*. Univ. of Hawaii. 1, 127-35.
11. Plucknett, D.O. and de la Pena, R.S. (1971) Taro production in Hawaii. *World Crops*. 23, 244-9.
12. Plucknett, D.L., de la Pena, R.S. and Obrero, F.P. (1970) Taro (*Colocasia esculenta*). *Field Crop Abstracts*. 23, 413-26.
13. Plucknett, D.L. and Fox, R.L. (1965) Effects of P fertilization on yields and composition of pangola grass and *Desmodium intortum*. *Proc. 9th Int. Grassland Congress*, Sao Paulo, Brazil. 2, 1525-9.
14. Sanford, W.G., Smith, D.H., Krauss, B and Young, H.Y. (1961) Plant nutrition and soil fertility aspects of pineapple. Research Report No. 84, Pineapple Research Inst. (Hawaii).

15. Thiagalingam, K. and Kanehiro, Y. (1971) Effects of two fumigating chemicals, 2-chloro-6-trichloromethyl pyrimidine and temperature on nitrification of added ammonium in Hawaii soils. *Trop. Agric. Trin.* 48, 357-64.
16. Yamasaki, T. (1952) Studies on the 'excess-moisture injury' of upland crops in overmoist soil from the viewpoint of soil chemistry and plant physiology. *Bull. Natn. Inst. Agric. Sci., Tokyo (ser. B)*.

TABLE 1

Phosphate added to plots in 1970 and 1971 before adjusting P levels and planting taro in 1972

Intended P concentration	(P added Kg/ha)	
	1970	1971
--	0	0
.003	26	36
.006	54	72
.012	116	113
.025	224	268
.05	358	274
.1	510	507
.2	698	752
.4	896	932
1.6	1434	1164

TABLE 2

Phosphorus content of taro leaves in relation to established levels of phosphate in soil solutions*

Treatment No.	Assumed P concentration in soil solution (ppm)	Leaf P (% dry weight)	
		Leaf blade	Leaf petiole
1	No P added	.35	.11
2	.003	.36	.10
3	.006	.42	.16
4	.012	.41	.16
5	.025	.41	.16
6	.05	.42	.17
7	.1	.45	.23
8	.2	.39	-
9	.4	.46	.25
10	1.6	.42	.25

* Treatments 4 to 7 were replicated 3 times. All other treatments were unreplicated.

TABLE 3

Influence of phosphate fertilization on the yield and phosphorus composition of taro grown as upland and flooded crops*

P added (kg/ha)	Yield (t/ha)	<u>Leaf blades</u>					<u>Petioles</u>		
		Age in months							
		3	6	9	12	3	6	9	12
Upland (Hanamaulu)									
0	15	.23	.25	.24	.27	.12	.13	.12	.16
230	21	.34	.28	.29	.30	.16	.16	.28	.28
560	40	.34	.29	.31	.32	.24	.14	.23	.31
1120	30	.41	.28	.32	.38	.31	.15	.24	.46
Flooded (Hauula paddy)									
0	39	.49	.53	.36	.34	.33	.67	.42	.29
280	44	.46	.52	.38	.32	.38	.64	.48	.34
560	38	.48	.56	.39	.33	.37	.67	.47	.30
1120	49	.46	.57	.37	.34	.37	.64	.43	.29

* Unpublished data of Ramon de la Pena.

THE BIOGENESIS AND METABOLISM OF CYANOGENIC GLUCOSIDES IN GERMINATING CASSAVA SEED AND SEEDLINGS

F. Nartey*

SUMMARY

Analyses of the storage lipids (47%) and proteins (34%) of cassava seeds indicate that these could be nutritionally and industrially useful sources of vegetable fats and proteins. Seedlings have high lipolytic and proteolytic activities. In seedlings storage lipids are converted to carbohydrates. Valine and Isoleucine are incorporated respectively into the cyanogenic glucosides linamarin and lotaustralin. Seedlings of both bitter and sweet cultivars contain large amounts of cyanogenic glucosides. Electronmicroscope and tracer studies showed that the biosynthesis and metabolism of cyanogens, cyanide, proteins and lipids are associated with specific organelles and microbodies which become apparent after 10 days active seed germination.

RESUME

Les analyses du contenu de lipides (47%) et de protéines réservées (34%) ont montré que les graines de la cassave forment une source de graisses et de protéines végétales utilisables en industrie. Les germes portent une grande activité de lipolyse et de protéolyse, reconvertissent les lipides réservés en carbohydrates, et ils peuvent incorporer la valine et l'isoleucine dans les glycosides cyanogènes linamarine et lotaustraline, respectivement. La microscopie électronique et l'utilisation des substrats radioactifs ont montré que la biosynthèse et le métabolisme de substances cyanogènes, du cyanure, des protéines et des lipides sont liés à des organelles spécifiques et à des 'microbodies' qui se développent clairement au cours de 10 jours de germination active de graines.

RESUMEN

Los análisis de las reservas de lípidos (47%) y de proteínas (34%) en semillas de yuca, indican que podrían ser nutricionalmente e industrialmente fuentes útiles de grasas vegetales y proteínas. Las plantas tienen actividades lipolíticas y proteolíticas elevadas; en ellas las reservas de lípidos son convertidas en carbohidratos. La Valina y la Isoleucina se incorporan respectivamente a los glucósidos cianogénicos linamarina y lotaustralina. Las plántulas tanto de cultivos agrios como dulces, contienen grandes cantidades de glucósidos cianogénicos. La microscopía electrónica y los estudios con trazadores demostraron que la biosíntesis y metabolismo de cianógenos, cianidas, proteínas y lípidos se asocian con organelos y corpúsculos específicos que se hacen aparentes a los 10 días de la germinación de la semilla activa.

INTRODUCTION

The potential, and ultimate usefulness of cassava and all its products are expressions of genetic, biochemical and physiological processes and mechanisms we are investigating in Denmark.

CONSTITUENTS OF CASSAVA SEED

Localization of lipids and proteins

The cassava seed kernel contains 47% lipids and 34% proteins as major reserves, and 0.13% soluble nitrogenous compounds, 0.3% starch and 3.8% soluble carbohydrates as minor constituents¹⁷. Thus the major constituents of the cassava seed compare favourably with those of typical useful oil seeds such as those of *Ricinus*, *Sesamum*, *Elaeis* and *Glycine*³.

The bulk of cassava seed storage lipids and proteins are localized in the endosperm, although cotyledonary and radicle tissues show a similar distribution of storage materials. Figures 1 and 2 are electron-micrographs of thin sections through the endosperm and radicle tissues of a dry cassava seed. They show

*University of Copenhagen, Institute of Plant Physiology, Ø. Farimagsgade 2A, 1353 Copenhagen K, Denmark.

cells filled with large lipid bodies (sphaerosomes) and protein bodies (aleurone grains), as well as some cytoplasmic organelles.

Lipid and protein composition

Triglycerides comprise 98% of the total cassava seed lipids, with di- and monoglycerides, phospholipids, glycolipids and steroids constituting only 2%. This is a similar distribution to that in most important oil-bearing seeds¹⁸.

Cassava seed fats are characterized by a high content of linoleic, oleic and palmitic acids which occur as their triglycerides. Table 1 shows the fatty acid composition of the total lipids and triglycerides of cassava seed kernel²⁰.

Cassava seed proteins are largely salt-soluble, and may readily be obtained as concentrates or meals free from lipids, and with high amino acid content. Table 2 shows the concentrations of total amino acids (protein-bound and free) of cassava seed kernels expressed as mg amino acid per 100g dry tissue, and as g



Figure 1. *Electronmicrograph of a thin section through the endosperm of a dry cassava seed. The cells are filled with lipid bodies (Sphaerosomes, Sp) and protein bodies (Aleurone Grains, AG). Nucleus (N), Nucleolus (Nu). Sections of seed tissues were fixed in 6% glutaraldehyde in phosphate buffer pH 7.2, and post-fixed in 2% osmium tetroxide. x 14,000.*



Figure 2: *Electronmicrograph of a thin section through the radicle of a dry mature cassava seed. The cells contain large amounts of lipid bodies (Sphaerosomes, Sp). Cytoplasmic and Organelle Membranes are poorly defined. Nucleus (N), Plastid (P1), Mitochondrion (M). x 14,000.*

amino acid per 16g nitrogen. A comparison of the amino acid profiles of cassava seeds, leaves and tubers^{19,23} shows that seeds contain higher levels of both essential and non-essential amino acids, and therefore better quality proteins. Cassava seed proteins may therefore be of potential nutritional use in cassava-growing countries.

The low starch content of the cassava seed kernel is accompanied by a relatively high level of soluble sugars almost entirely composed of sucrose.

Cyanogenic glucosides

Generally, variations in the concentration of cyanide in cassava root tubers, as well as the morphological characteristics of the plants, form the basis of a taxonomic differentiation between the bitter (high cyanide content) and the sweet (low cyanide content) cultivars²². This basis for delineation does not offer an adequate means for differentiating all cassava cultivars; it implies that tissues of all cassava cultivars are potentially cyanophoric. Seeds of cassava cultivars generally characterized as sweet do not contain cyanogenic glucosides, whereas those of bitter cultivars contain low levels of cyanogenic materials. Table 3 shows the concentrations of cyanogenic glucosides in seeds and other tissues of sweet and bitter cultivars of cassava.¹⁶

CHANGES IN THE MAJOR CONSTITUENTS DURING GERMINATION AND GROWTH

Conversion of lipids to carbohydrates

In seeds beginning to germinate in the dark, total cassava seed storage lipids remains largely unchanged. After about 4 days of germination, total lipids decrease gradually, and then rather steeply. Dormant cassava seeds have weak lipase activity which increases several fold during active germination, with the resultant formation of free fatty acids. As free fatty acids accumulate, the activities of enzymes involved with the β -oxidation of the fatty acids also increase several fold. The over-all results are that large amounts of storage lipids are mobilized and converted to non-lipid materials. The rate of lipid degradation is remarkably higher in light-grown seedlings than in etiolated seedlings¹⁸. Figure 3 shows the changes in the concentration of total lipids as a function of growth condition and period. These changes are accompanied by both qualitative and quantitative variations in the composition of fatty acids (Table 4). From Table 4 it can be seen that although etiolated and light-grown seedlings degrade storage lipids at different rates that no specific fatty acids are preferentially metabolized²⁰.

As the lipid concentration falls, the carbohydrate levels undergo striking changes. Figures 4 and 5 show variations in the concentrations of starch and soluble sugars as a function of growth condition and period. The variations in the concentrations of starch and soluble sugars are more pronounced in etiolated seedlings, where sucrose is the major carbohydrate. This provides evidence for the operation of a fat to carbohydrate conversion in cassava through sucrose. A similar mechanism operates in some other oil seeds such as *Ricinus* through the glyoxylate cycle in which cassava seedlings rapidly convert storage lipids to sucrose, which is readily channelled into starch synthesis^{1,8,9}.

Mobilization of amino acids from storage proteins

One of the earliest metabolic events in germinating cassava seeds involves the degradation of storage proteins. Electronmicroscopic studies indicate that reserve proteins disappear at a faster rate than lipids. This is illustrated in Figure 7 which shows variations in the concentration of proteins in dark and light-grown seedlings. Data in Figure 6 show that imbibed seeds rapidly lose proteins within 8 days of germination. During this period, there is a high increase in the activities of proteolytic enzymes, as shown by experiments with seedling extracts. Except for a transient period, light-grown seedlings generally contain higher levels of proteins.

CYANOGENESIS IN CASSAVA

As shown in Table 3, seeds of sweet cassava cultivars do not contain cyanogenic glucosides, and are therefore non-cyanophoric. On the other hand, seeds of bitter cassava cultivars contain low levels of cyanogenic glucosides, and are therefore cyanophoric. However, 10-day-old seedlings of both bitter and sweet cultivars synthesize and accumulate large amounts of cyanogenic glucosides, namely, linamarin and lotaustralin (methyllinamarin). Linamarin, 2(β -D-glucopyranosyloxy) isobutyronitrile, accounts for 93%, while lotaustralin, 2(β -D-glucopyranosyloxy) 2-methylbutyronitrile, accounts for 7% of the total cyanogens in cassava. Cyanogenesis in cassava therefore involves enzyme-catalysed hydrolysis of linamarin and lotaustralin with the resultant release of hydrogen cyanide from these glucosides. The structures and hydrolytic products of linamarin and lotaustralin are illustrated in Figure 7.

The hydrolysis of linamarin and lotaustralin is catalysed by linamarase, a β -glucosidase which is very active in all tissues of the growing plant; young cassava seedlings and leaves are particularly rich sources of the enzyme¹³. Other cyanophoric plant genera such as *Trifolium*, *Linum*, *Lotus* and *Phaseolus* which also contain linamarin and lotaustralin, contain the same enzyme; however, some *Trifolium* species may contain the glucosides but not the enzyme^{6,10}.

ULTRASTRUCTURAL DEVELOPMENTS ASSOCIATED WITH METABOLIC CHANGES

As shown in Figures 1 and 2, the endosperm, cotyledonary and radicle tissues of resting cassava seeds are filled mainly with large fat bodies (spherosomes) and protein bodies (aleurone grains), both of which are membrane-bound reserves utilized during germination and growth. The fat bodies are electrontransparent, while the protein bodies are electrondense. Few cytoplasmic organelles such as mitochondria, proplastids, Golgi apparatus, endoplasmic reticulum and microbodies are present. This state is one of low cellular organization and low metabolic activity, and it is typical of the state of dormancy.

The onset of active germination (ca. 4 days after imbibition) is accompanied by a gradual concurrent increase in metabolic activities and ultrastructural development. Whilst proteolysis is initiated immediately after imbibition, lipolysis, fat to carbohydrate conversion and cyanogenesis are detectable 4 days after germination. Figures 8a and 8b are electronmicrograph of a thin section through the cotyledon of a 10-day-old etiolated cassava seedling. Both fat and protein bodies are now in the process of degradation, and cytoplasmic organelles are more discernible. Figure 11 illustrates the ultrastructural and metabolic characteristics of root cells. Tightly packed fat bodies of the resting radicle are electron-dense, suggesting a higher level of unsaturation. Profiles of the endoplasmic reticulum, Golgi apparatus, mitochondria, plastids, lomasomes and microbodies are well developed. Figures 10 and 11 are electronmicrographs of thin sections through the leaf and root tissues of a 17-day-old etiolated seedling, showing the metabolic state and the fine structure of cells apparent at this time. Storage proteins are absent, and only a few fat bodies are present. The ultrastructure of the cells is much more elaborate. Several cytoplasmic organelles with well defined profiles are present, indicating a high level of organization and metabolic activity.

Figures 12 and 14 are electromicrographs of thin sections through the leaf and root tissues of a 17-day-old seedling which has received light over the last 7 days. The leaf cells contain well developed chloroplasts and some electron-dense lipid bodies. The ultrastructure and metabolic state of leaf, stem and root tissues of a mature cassava plant are illustrated in Figures 14, 15 and 16. All cells contain several cytoplasmic organelles with well defined membranes. Leaf and stem cells contain well developed chloroplasts filled with starch, and root cells contain large vacuoles also filled with starch grains.

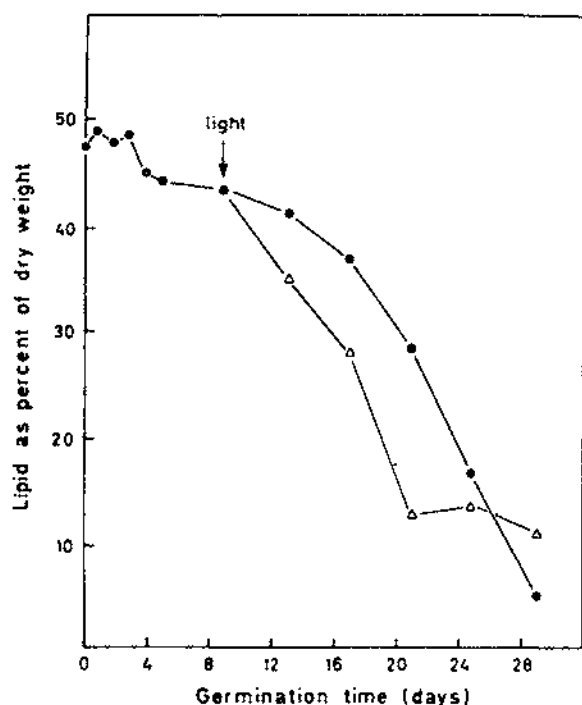


Figure 3. Changes in the concentration of total lipids in cassava seedlings as a function of germination and growth condition and period.

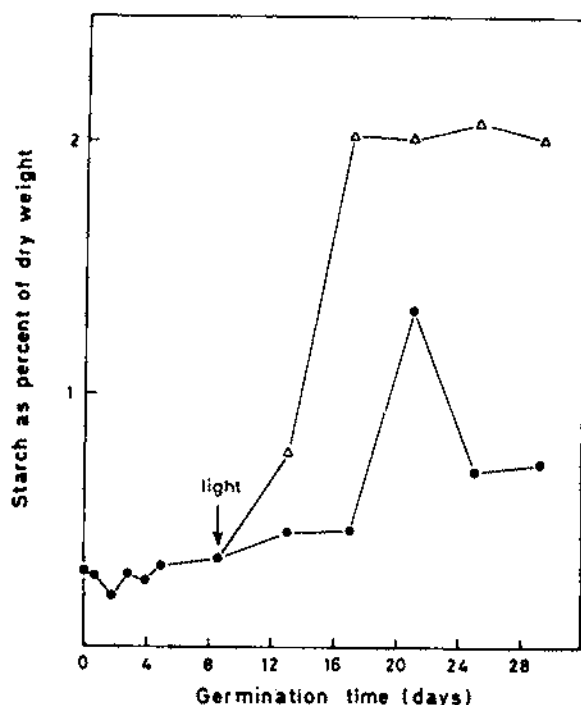


Figure 4. Changes in the concentration of starch in cassava seedlings as a function of germination and growth condition and period.

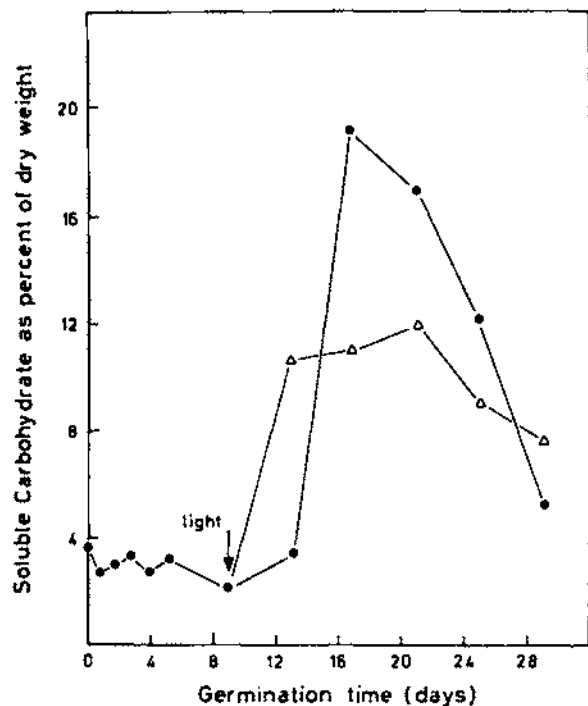


Figure 5. Changes in the concentration of soluble carbohydrates in cassava seedlings as a function of germination and growth condition and period.

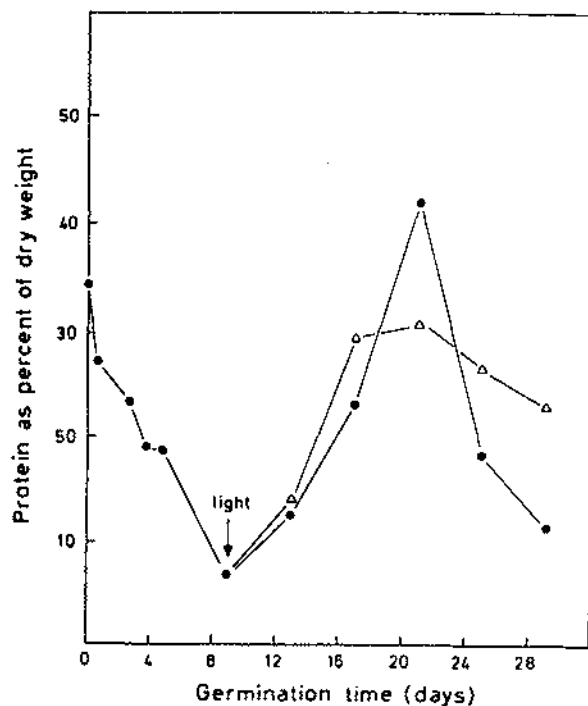


Figure 6. Changes in the concentration of proteins in cassava seedlings as a function of germination and growth condition and period.

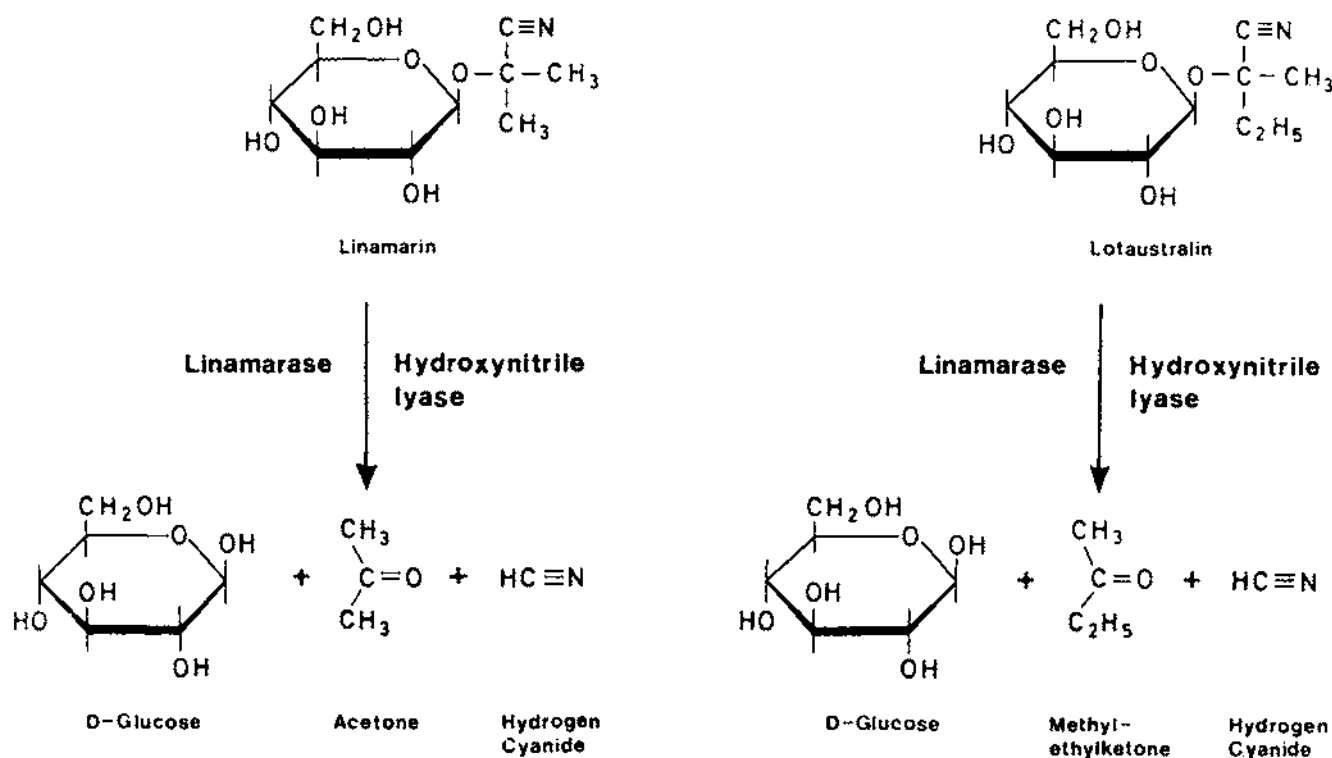


Figure 7. The structures of linamarin and lotaustralin and their hydrolytic products.

The overall changes in the ultrastructure and metabolic state of the cells of cassava seeds during germination and growth show striking similarities with changes that occur in the seed of castor, *Ricinus communis*. Thus, in the early germinative period, aleurone grains are rapidly hydrolysed; the active degradation of spherosomes is concurrent with the appearance of well defined organelles such as mitochondria and glyoxysomes in endosperm tissue. The latter organelles contain enzymes of the glyoxylate cycle as well as the enzymes for the β -oxidation of fatty acids, and are therefore directly involved with the conversion of storage lipids to carbohydrates in the endosperm of germinating oil-seeds^{1,8,9,24}.

ULTRASTRUCTURAL DEVELOPMENT AND CYANOGENESIS

The active accumulation and degradation of linamarin and lotaustralin can be detected between 10–14 days after seed germination. Electronmicroscopic studies reveal that in 10-day-old seedlings the root cells are more highly organized than the cotyledonary cells, indicating a more active metabolic state. This suggests that the biosynthesis and degradation of cyanogenic glucosides in actively germinating cassava seeds may occur initially in the roots and be localized in specific cells or cell organelles. Autoradiographic studies are now being conducted to investigate this.

BIOSYNTHESIS OF LINAMARIN AND LOTAUSTRALIN

From structural considerations, it can be inferred that the aglucone moieties of linamarin and lotaustralin may be derived from the amino acids valine and isoleucine, respectively. Similarly, the aglucone moiety of acacipetalin may be derived from leucine, those of prunasin, sambunigrin, amygdalin and vicianin from phenylalanine, dhurrin and taxiphyllin from tyrosine, and zierin from m-hydroxyphenylalanine. These inferences have been tested by several tracer studies^{6,7,14}. The mechanism of the biosynthesis involves decarboxylation of the precursor amino acid, the conversion of its α -amino group and α -carbon to a nitrile function and the hydroxylation of the β -carbon, followed by glycosylation. Figure 17 illustrates the structural relationships of some cyanogenic glucosides and their amino acid precursors^{6,7}.

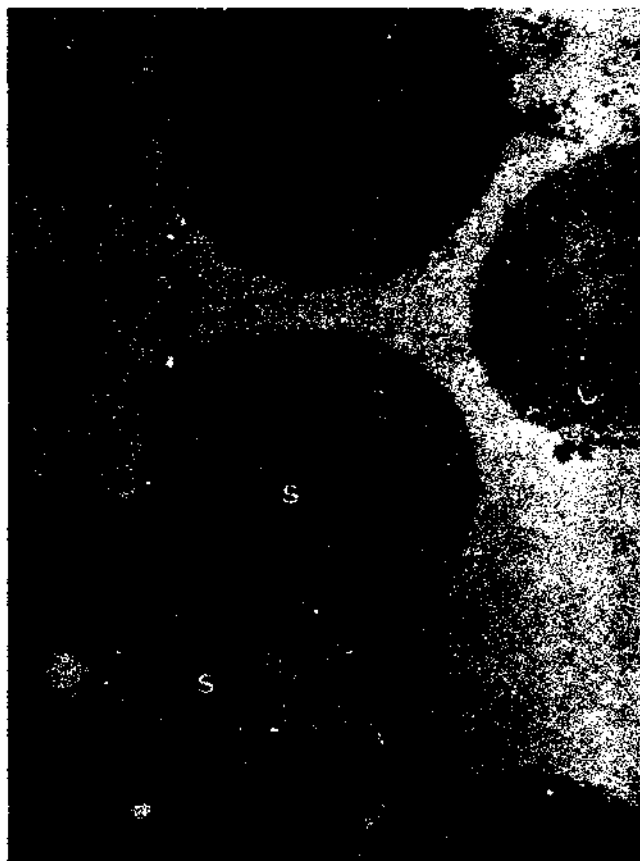


Figure 8a. Electronmicrograph of a thin section through the endosperm of a 10-day-old etiolated cassava seedling. Spherosomes and Aleurone Grains are being rapidly degraded. Several microbodies (glyoxysomes) are present. $\times 28,000$.



Figure 8b. Electronmicrograph of a thin section through the cotyledon of a 10-day-old etiolated cassava seedling. The cells are packed with lipid (Sp) and protein (P) bodies. $\times 14,000$.

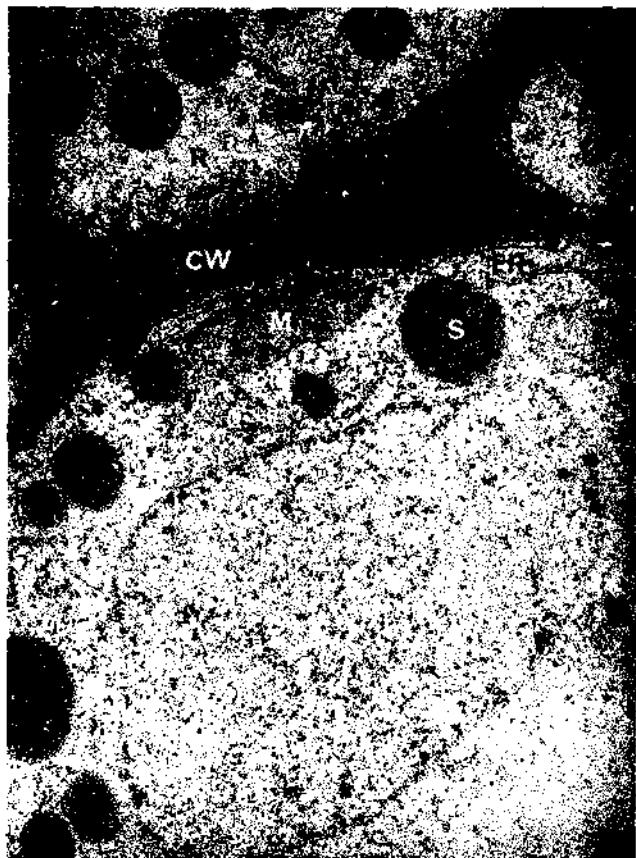


Figure 9. Electronmicrograph of a thin section through the root of a 10-day-old cassava seedling. Lipid bodies (Sp) are scattered through the cytoplasm. Profiles of the endoplasmic reticulum (Er) and golgi apparatus (G) are well defined. Plastid (Pl), spherosome (Sp), mitochondrion (M). $\times 32,000$.



Figure 10. Electronmicrograph of a thin section through the leaf of a 17-day-old etiolated cassava seedling. Cytoplasmic organelles are well defined, few lipid bodies are present. Spherosome (Sp), mitochondrion (M), endoplasmic reticulum (Er), golgi apparatus (G), cell wall (CW). $\times 10,000$.



Figure 11. Electronmicrograph of a thin section through the root of a 17-day-old cassava seedling. Cytoplasmic membranes are well defined. Lipids bodies are absent. Mitochondrion (M), Cell Wall (CW), Crystalloid containing microbody (Cr). $\times 10,000$.



Figure 12. Electronmicrograph of a thin section through the leaf of a 17-day-old cassava seedling which had light over the last 7 days. The cells contain well-developed chloroplasts with starch granules. Chloroplast (Ch), Starch (S), Mitochondrion (M). $\times 28,000$.

Seeds of both sweet and bitter cassava cultivars contain low levels of free valine and isoleucine^{14,19}. However, on germination, the activation of proteolytic enzymes leads to the accumulation of high levels of free amino acids, notably valine and isoleucine. Concurrent with this accumulation, the concentrations of linamarin and lotaustralin increase sharply. When uniformly labelled L-valine-¹⁴C and L-isoleucine-¹⁴C are administered to seedlings during the period of active cyanogen synthesis (10–14 days after germination), large amounts of radioactivity are incorporated in the aglucone moieties of linamarin and lotaustralin, respectively^{13,14}. Table 5 illustrates the incorporation of radioactive valine and isoleucine into the aglucone moieties of cassava cyanogens, but also into asparagine; the latter is significant with respect to the mechanism for cyanide detoxification and metabolism in cassava.

The biosynthesis and accumulation of cassava cyanogens are influenced by such factors as protein degradation and synthesis, and photosynthesis¹⁴. Other factors such as the activities of the enzymes involved in the biosynthesis of cyanogens, the concentrations and availability of substrates, as well as the rates of transport, storage and degradation of cyanogens in specific tissues, influence variations in the concentrations of cyanogenic glucosides in tissues of different cultivars²¹.

The concentrations of cyanogens in cassava plants generally fluctuate, indicating enzyme catalysed degradation and resynthesis, and therefore, the dynamic nature of these compounds. The biosynthesis of linamarin and lotaustralin is illustrated in Figure 18. This pathway is operative in a variety of cyanophoric plant species which accumulate linamarin and lotaustralin during germination and growth⁷.

The concentration of cyanogenic glucosides in cassava plants fluctuates with growth period and condition. If cassava is grown in a closed container, decreases in cyanogen content do not lead to the release of HCN into the surrounding air. Furthermore, cassava plants kept in closed systems containing high levels of HCN appear to grow normally, in spite of the fact that cyanide normally inhibits plant respiration. Investigations on the fate of HCN released intracellularly from linamarin and lotaustralin show that cassava plants possess two enzyme catalysed systems for the detoxication of cyanide.

DETOXIFICATION AND METABOLISM OF HCN

Cassava seedlings metabolize ¹⁴C-labelled HCN, CO₂ and acetate equally efficiently. However, the labelling patterns found in metabolites from seedlings fed these compounds are different. Whereas small frac-

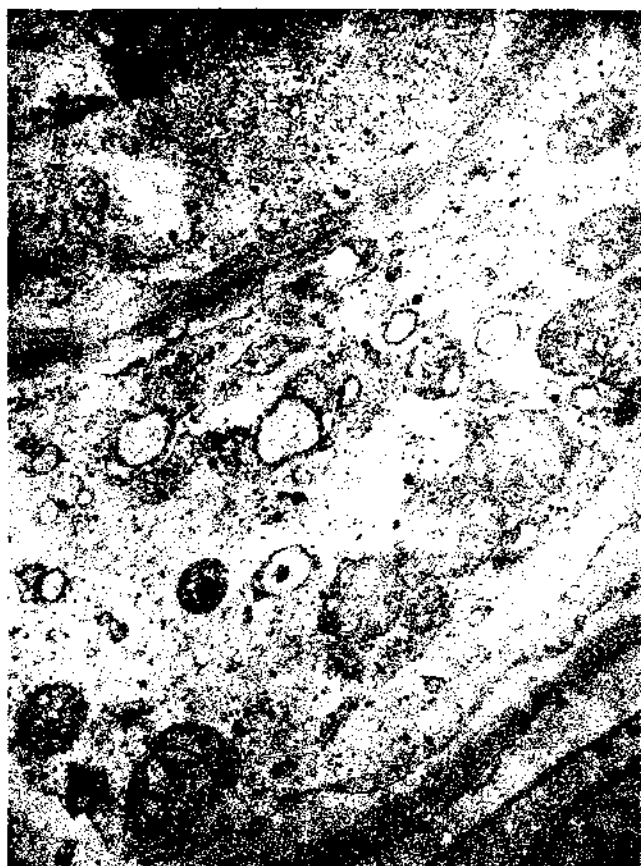


Figure 13. Electronmicrograph of a thin section through the root of a 17-day-old cassava seedling which had received light over the last 7 days. Cytoplasmic membranes are well defined. Lipid bodies are absent. x 32,000.



Figure 14. Electronmicrograph of a thin section through the leaf of a 5-month-old cassava plant. The cells contain well developed chloroplasts and other cytoplasmic organelles. x 5,000.

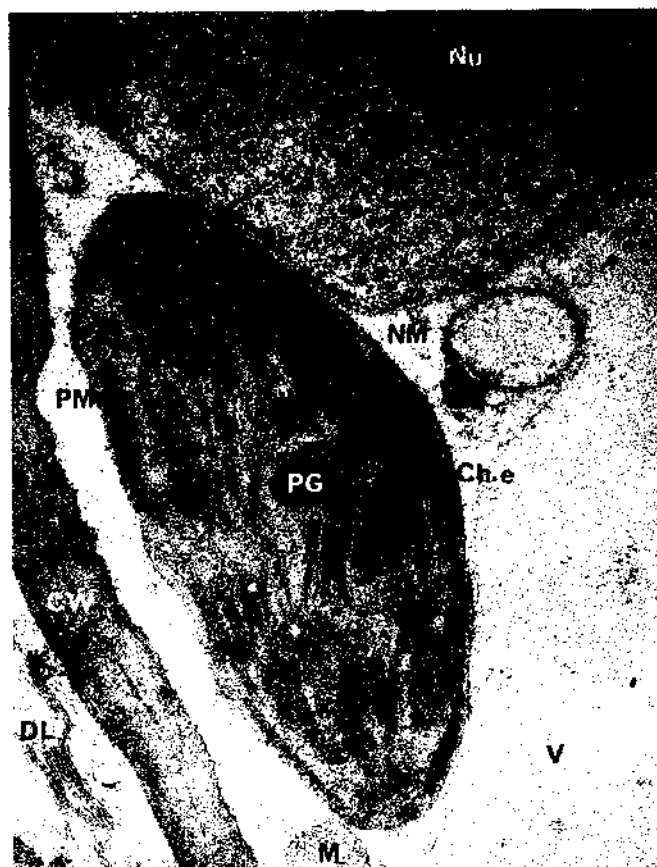


Figure 15. Electronmicrograph of a thin section through the stem tissue of a 5-month-old cassava plant, showing the presence of a chloroplast containing starch, mitochondrion and other cytoplasmic organelles. $\times 10,000$.



Figure 16. Electronmicrograph of a thin section through the root of a 5-month-old cassava plant. Many cells are vacuolated. Several lomasomes and other cytoplasmic organelles are present. $\times 5,000$.

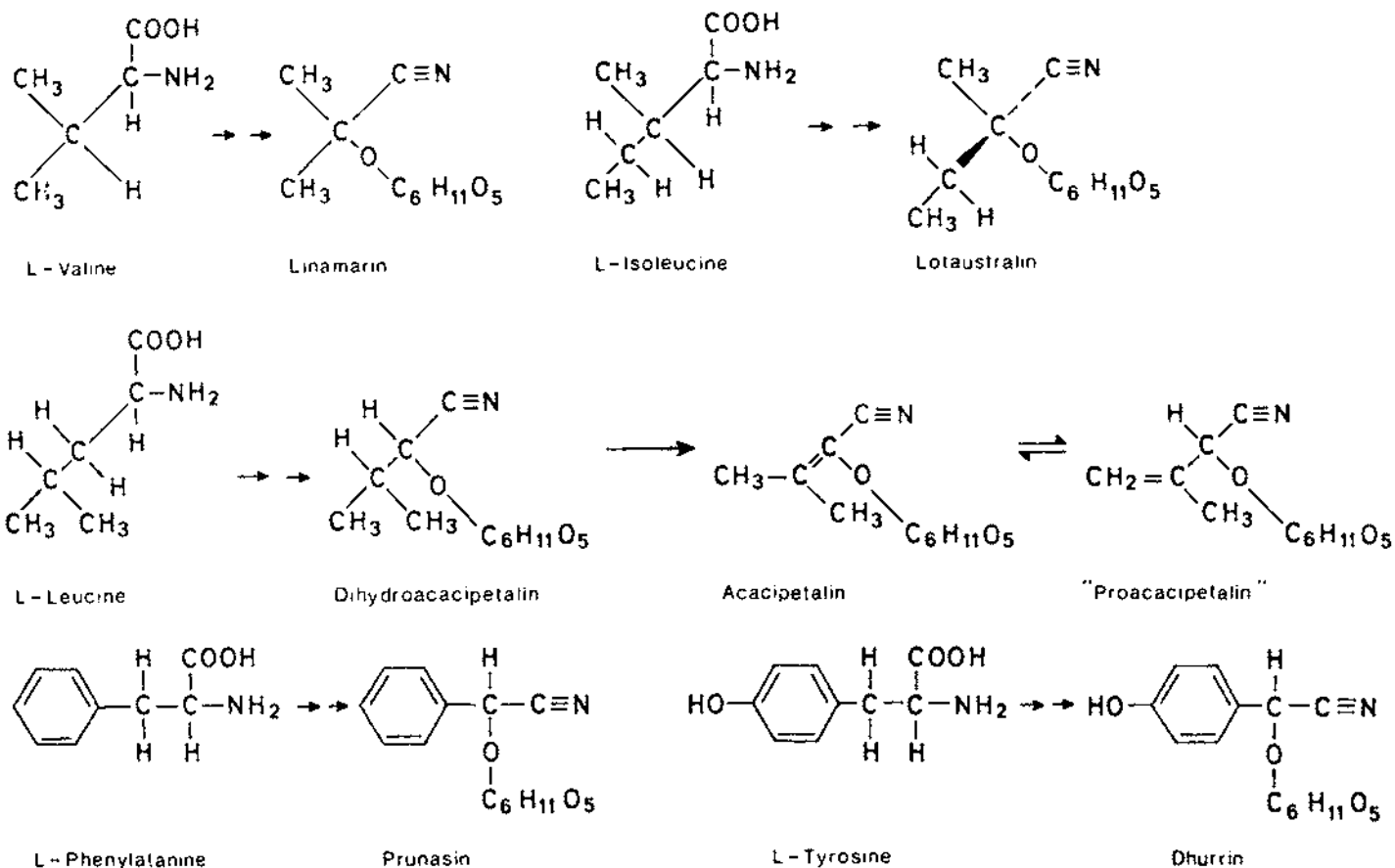


Figure 17. The structural relationships between some cyanogenic glucosides and their precursor amino acids.

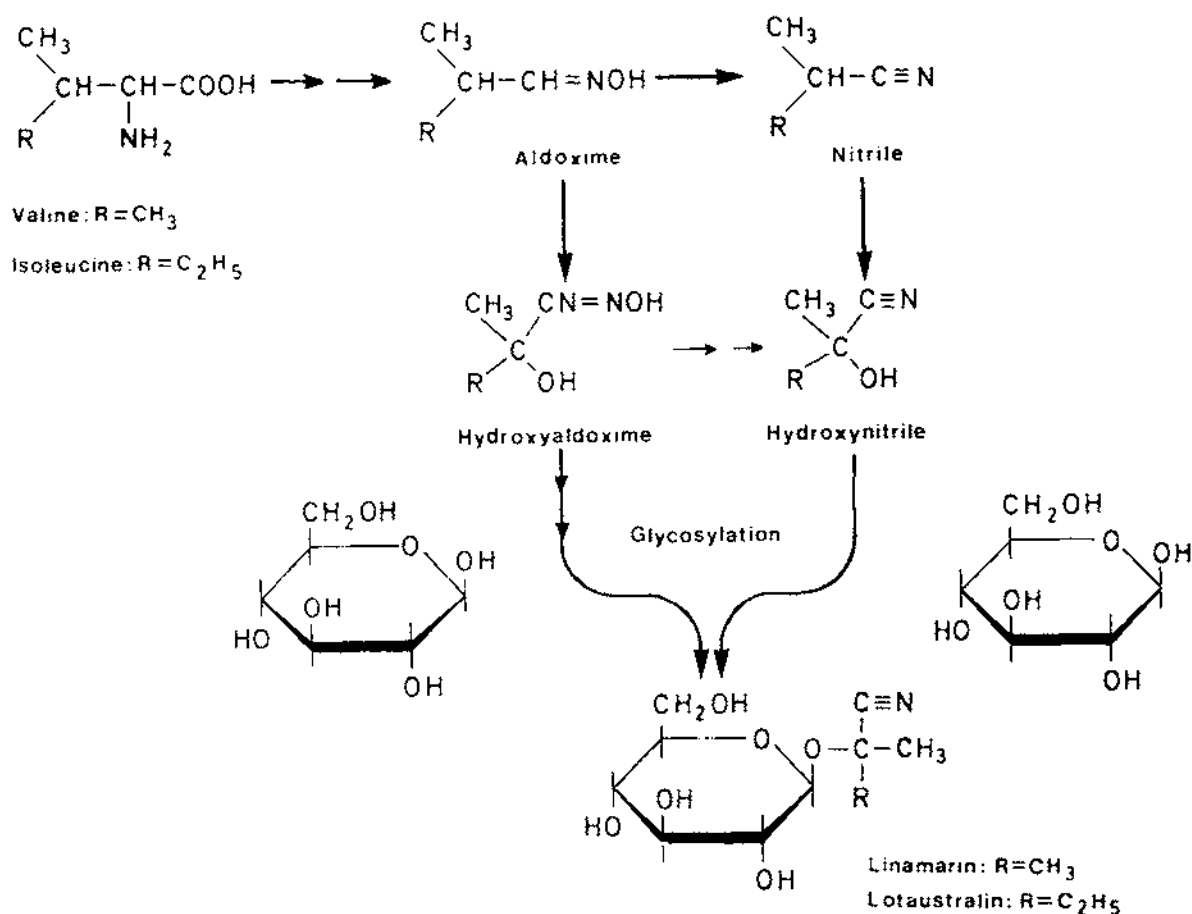


Figure 18. The biosynthesis of linamarin and lotaustralin in cassava plants.

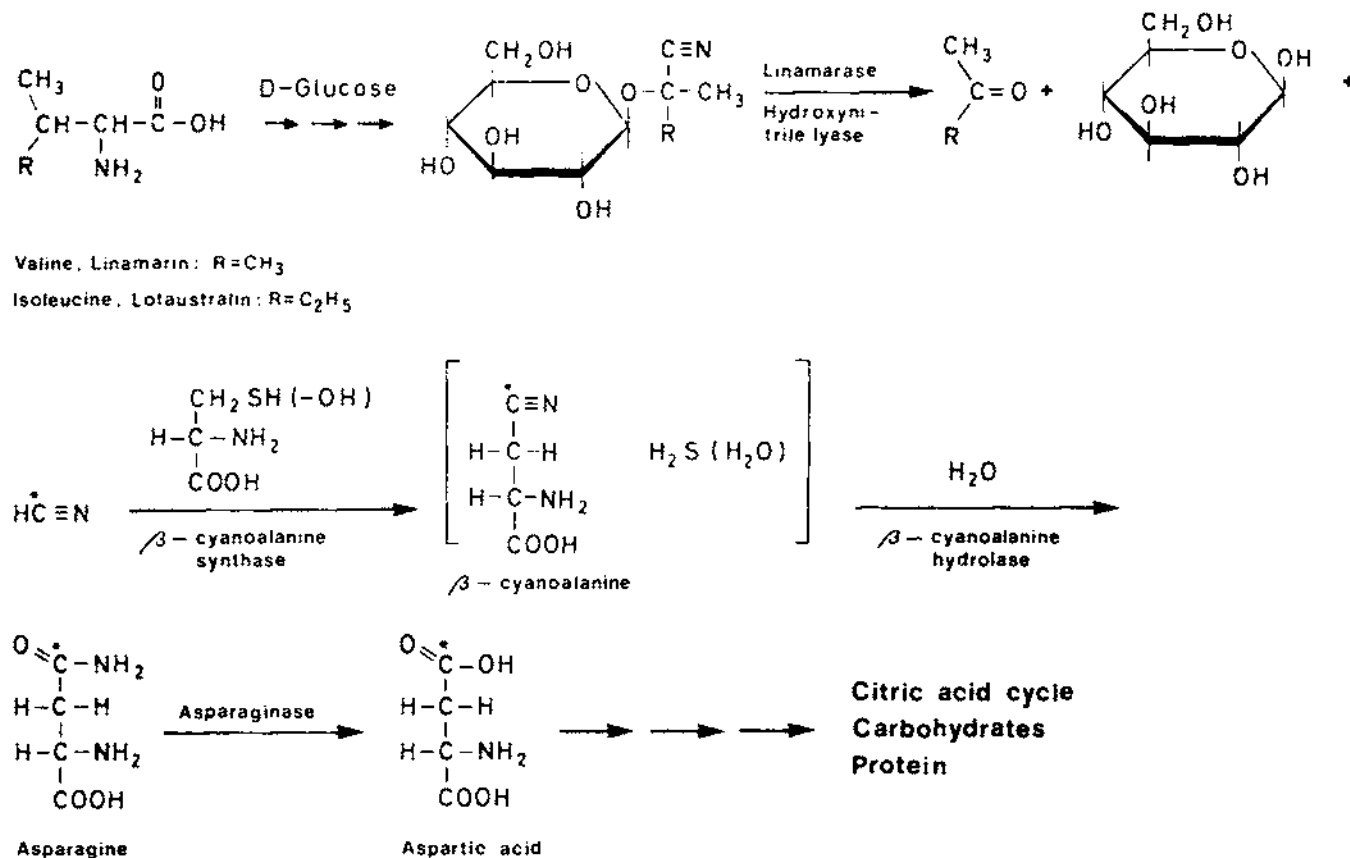


Figure 19. The biosynthesis and degradation of linamarin and lotaustralin, and the detoxication and assimilation of hydrogen cyanide by cassava plants.

tions of radioactivity from $^{14}\text{CO}_2$ and ^{14}C -acetate are found in the free amino acid pools, large amounts of radioactivity from H^{14}CN are incorporated in the free amino acid pools. A most striking feature of the labelling patterns is that although 49% of the total radioactivity from H^{14}CN is located in the free amino acid fraction of seedling extracts, over 95% of the total radioactivity in this fraction is located in asparagine, aspartic acid, glutamine and glutamic acid. Table 6 shows that asparagine is the major labelled product of cyanide metabolism in cassava. Furthermore, well over 97% of the total radioactivity in asparagine is located in its amide-carbon¹⁴. This mechanism for cyanide detoxification operates in a variety of cyanophoric plant species^{2,15}, and involves the enzyme catalyzed reaction of cyanide with serine or cysteine, with the resultant formation of α -cyanoalanine as the primary reaction product^{7,14,11}.

Quantitative data from in vivo and in vitro studies on cyanide metabolism by cassava seedlings and seedling extracts show that the natural acceptor of cyanide in cassava is serine¹⁴. α -cyanoalanine is not accumulated in cassava tissues, which contain highly active α -cyanoalanine synthase, α -cyanoalanine hydrolase and asparaginase¹⁶. The collective operation of these enzyme systems ensures that HCN evolved from cassava cyanogens by the action of linamarase and 2-hydroxynitrile lyase (or by non-enzyme catalysed dissociation of the hydroxynitrile moieties) is rapidly converted to amino acids, proteins, carbohydrates, lipids and other cellular materials. Figure 19 illustrates the detoxification and assimilation of hydrogen cyanide by cassava plants¹⁴.

Cassava plants possess also rhodanase activity. Rhodanase catalyses the reaction of cyanide with inorganic and organic sulphur compounds with the resultant formation of thiocyanate^{4,6,16}. Cassava rhodanase activity is inhibited by cysteine, while α -cyanoalanine synthase activity is inhibited by thiosulphate. Thus only one cyanide detoxification system in cassava may operate at any particular time. Both enzyme systems are localized in the mitochondria, and their functions may well be the reduction of high intracellular concentrations of cyanide for the preservation of electron transport and oxidative phosphorylation in cassava plants¹⁶.

ACKNOWLEDGEMENTS

This investigation was supported by DANIDA, The Danish Foreign Ministry.
The Danish Natural Science Research Council provided travel funds to the author.

REFERENCES

1. Beevers, H. (1961) Metabolic production of sucrose from fat. *Nature* 191, 384-6.
2. Blumenthal-Goldschmidt, S. et al. (1965) Incorporation of hydrocyanic acid labelled with carbon-14 into asparagine in seedlings. *Phytochem.* 4, 127-31.
3. Butt, V.S. et al. (1966) The plant lipids. In: *Plant Physiology, a treatise*. (Ed. F.C. Steward) 1VB, 226-414. Academic Press, New York.
4. Chew, M.Y. et al. (1972) Rhodanase in tapioca leaf. *Phytochem.* 11, 127-31.
5. ——— (1973) Rhodanase in higher plants *Phytochem.* 12, 2365-7.
6. Conn, E.E. (1973) Cyanogenic glycosides: their occurrence, biosynthesis, and function. In *Chronic cassava toxicity: proceeding of an interdisciplinary workshop*. pp. 55-63. Int. Develop. Res. Centre Monogr. IDRC-010e.
7. Conn, E.E. et al. (1969) The biosynthesis of cyanogenic glycosides and other simple nitrogen compounds. In *Perspectives in Phytochemistry*. p. 47-74. J.B. Harbourne and T. Swain (Ed). Academic Press, London.
8. Cooper, T.G. et al. (1969) Mitochondria and glyoxysomes from castor bean endosperm. *J. Biol. Chem.* 244, 3507-13.
9. ——— (1969) Oxidation in glyoxysomes from castor bean endosperm. *J. Biol. Chem.* 244, 3514-20.
10. Corkill, L. (1940) Cyanogenesis in white clover (*Trifolium repens* L.). 1. Cyanogenesis in single plants. *N.Z.J. Sci.* 22B, 65-7.
11. Fowden, L. et al. (1965) Cyanide metabolism by seedlings. *Nature* 206, 110-12.
12. Hitchcock, C. et al. (1971) *Plant Lipid Biochemistry*. Academic Press, London.
13. Nartey, F. (1968) Studies on cassava, *Manihot utilissima* Pohl. 1. Cyanogenesis: the biosynthesis of linamarin and lotaustralin in etiolated seedlings. *Phytochem.* 7, 1307-12.
14. Nartey, F. (1969) Studies on cassava, *Manihot utilissima*. 11. Biosynthesis of asparagine ^{14}C from ^{14}C -labelled hydrogen cyanide and its relations with cyanogenesis. *Physiol. Plant* 22, 1085-96.

15. — — — — (1970) Cyanide metabolism in higher plants. *Z. f. Pflanzenphysiol.* 62, 398—400.
16. — — — — (1973) Biosynthesis of cyanogenic glucosides in cassava (*Manihot* spp.). In *Chronic cassava toxicity; proceedings of an interdisciplinary workshop*. pp. 73—87. IDRC-010e.
17. — — — — *et al.* (1973) The major constituents of cassava seeds. *Trop. Sci.* 15, 273—277.
18. — — — — (1974) Changes in the major constituents of *Manihot esculenta* Crantz. *Econ. Bot.* 28, 145—154.
19. — — — — (1976) Amino acid profiles of cassava seeds (*Manihot esculenta* Crantz). *Econ. Bot.* 30, 419—423.
20. — — — — (1973) Fatty acid profiles in germinating *Manihot esculenta*. *Phytochem.* 12, 2909—2911.
21. Nestel, B. (1973) Current utilization and future potential for cassava. In *Chronic cassava toxicity: Proceedings of an interdisciplinary workshop*. pp. 11—26. Int. Develop. Res. Centre Monogr. IDRC-010e.
22. Rogers, D.J. (1965) Some botanical and ethnological considerations of *Manihot esculenta*. *Econ. Bot.* 19(4), 369—77.
23. — — — — (1959) Cassava leaf protein. *Econ. Bot.* 13, 261—3.
24. Vigil, E.L. (1970) Cytochemical and developmental changes in microbodies (glyoxysomes) and related organelles of castor bean endosperm. *J. Cell Biol.* 46, 435—54.

TABLE 1

Fatty acid composition of total lipids and triglycerides of cassava seeds

Fatty acid	% Composition	
	Total lipids	Triglycerides
C _{14:0} (Myristate)	0.07	0.00
C _{16:0} (Palmitate)	10.34	9.90
C _{16:1} (Palmitoleate)	0.09	0.00
C _{18:0} (Stearate)	4.10	3.90
C _{18:1} (Oleate)	22.40	23.00
C _{18:2} (Linoleate)	61.60	62.00
C _{18:3} (Linolenate)	1.40	1.20
C _{20:0} (Arachidate)	0.00	0.00

TABLE 2

Amino acid profiles of cassava seeds, expressed as mg amino acid/100 g dry seed kernel, and as g amino acid/16 g N

<u>Amino acid</u>	<u>mg/g dry seed kernel</u>	<u>g/16g nitrogen</u>
Aspartic acid	3600	10.85
Threonine	1345	4.05
Serine	1340	4.03
Glutamic acid	5815	17.51
Proline	1595	4.80
Glycine	1405	4.24
Alanine	1460	4.40
Valine	2775	8.36
Isoleucine	1015	3.06
Leucine	2110	6.36
Tyrosine	1005	3.02
Phenylalanine	1415	4.26
Lysine	1040	3.13
Histidine	765	2.31
Ammonia	460	1.39
Arginine	4590	13.83
Methionine	570	1.71
Cystine	545	1.64
Tryptophan	540	1.62

TABLE 3

Concentration of cyanogenic glycosides in tissues of sweet and bitter cultivars of cassava

<u>Cultivar</u>	<u>Tissue</u>	<u>Cyanogenic glycosides</u> (mg HCN/kg fresh wt tissue)
Sweet (3 cvs)	Seeds	0.00
	Seedlings (10 day old)	285.00
	Leaves (mature)	468.00
	Roots	126.50
	Tubers	402.00
Bitter (3 cvs)	Seeds	7.50
	Seedlings (10 day old)	245.00
	Leaves (mature)	310.00
	Roots	185.00
	Tubers	395.00

TABLE 4

Net changes in the fatty acid composition of cassava seedlings as a function of growth condition and period

Fatty acid	Age (days)	% composition				
		3	9	13	13	17
		Dark	Dark	Dark	Light	Dark
		(49.2)	(43.8)	(41.0)	(35.7)	(37.2)
						Light
						(28.5)
C _{14:0} (Myristate)		0.04	0.10	trace	0.00	0.00
C _{16:0} (Palmitate)		10.20	11.60	11.80	10.20	11.00
C _{16:1} (Palmitoleate)		0.05	0.11	trace	trace	trace
C _{18:0} (Stearate)		4.10	5.10	4.60	3.40	4.10
C _{18:1} (Oleate)		21.80	22.70	23.00	21.60	21.60
C _{18:2} (Linoleate)		62.20	59.20	58.70	63.30	60.20
C _{18:3} (Linolenate)		1.60	1.30	2.00	1.60	3.00
C _{20:0} (Arachidate)		0.11	trace	0.00	0.00	0.00

TABLE 5

Incorporation of radioactivity from L-Valine¹⁴-C(U) and L-Isoleucine¹⁴-C(U) into the aglucone moieties of Linamarin and Lotaustralin, and into Asparagine, by cassava seedlings

Label administered	Incorporation (%) into		
	Linamarin, Lotaustralin, Asparagine		
L-Valine ¹⁴ -C(U)	13.20	-	1.10
L-Isoleucine ¹⁴ -C(U)	-	2.40	0.53

TABLE 6

Incorporation of radioactivity from H¹⁴CN into free amino acids by 10g cassava seedlings exposed to H¹⁴CN released from 2.3 mole Na¹⁴CN, 125 Ci. 8.38 x 10⁸ cpm. in a closed system for the periods specified

Period of feeding (min)	Radioactivity (cpm x 10 ⁻⁵) incorporated in			
	Asparagine	Aspartic acid	Glutamine	Glutamic acid
10	0.86	0.11	0.16	0.07
60	24.91	5.73	0.89	0.18
180	42.03	6.68	0.65	0.43

A CHANGE OF SUBSISTENCE STAPLE IN PREHISTORIC NEW GUINEA

W.C. Clarke*

SUMMARY

Replacement of taro by sweet potato which began from 300–500 years ago is continuing. Sweet potato is less demanding both for site and for labour and is able to support population expansion more readily. Taro continues to be the preferred crop and has religious and cultural associations not shared by sweet potato. Factors relating to the change of crop are described.

RESUME

Le remplacement du taro par la patate douce qui commença il y a 300–500 ans est toujours en cours. La patate douce est moins exigeante quant au terrain et aux travaux qu'elle impose et peut suivre l'évolution de l'accroissement de la population.

Le taro continue d'être préféré et reste lié aux traditions religieuses et culturelles, ce qui n'est pas le cas avec la patate douce. Les facteurs liés au changement de cette plante ont été exposés.

RESUMEN

El reemplazo de la malanga** por el camote***, iniciado hace unos 300–500 años, continúa. El camote es menos exigente en cuanto al sitio en que se cultiva y en cuanto a fuerza de trabajo y es capaz de soportar la expansión de la población más fácilmente. La malanga continúa siendo el cultivo preferido y tiene asociaciones religiosas y culturales no compartidas por el camote. Se describen los factores relacionados con el cambio de cultivo.

INTRODUCTION

Even a casual observer of subsistence agriculture in the highlands of New Guinea becomes aware of the importance of the sweet potato (*Ipomoea batatas* (L.) Lam.) as a food plant. The literature attests the preponderant importance of this crop. Barrau, writing of lands above 1500 m, refers to the sweet potato as "... the staple subsistence crop of mountain dwellers in New Guinea". Brookfield⁴ also noted the highlanders' heavy dependence on the sweet potato as a characteristic distinguishing these people from other closely settled populations at similar elevations elsewhere in the tropics. Pospisil writes¹⁷ that more than 90 percent of the area of gardens among the Kapauku of Irian Jaya was planted to sweet potatoes. Hundreds of miles to the east in Papua New Guinea among the Chimbu group that Hipsley and Kirk⁹ studied in 1962 or the Fore families observed by Reid and Gajdusek¹⁸ in 1957, sweet potatoes contributed at a minimum 70 percent of the people's total intake of calories.

Not only is the sweet potato the dominant crop over much of the central range of New Guinea, but it is grown under a variety of specialized local techniques, including the making of small mounds, the composting of large mounds, the making of grid-iron-ditched plots on dry land, the fertilization of swamp-garden plots with ditch spoil, quasi-terracing, the tillage of grassland soil, and the use of untilled forest soil under a system of long-fallow slash-and-burn cultivation.

However, even though the sweet potato is the commonest crop, the major source of calories, and is planted in regionally specialized ways, this crop has been considered only to have been introduced into montane New Guinea within the past 300–500 years^{13,23}. Before the sweet potato's introduction, it is assumed that ancient Asian crops, particularly taro (*Colocasia esculenta* (L.) Schott), provided the major source of food to montane New Guineans^{5,6}.

* Department of Human Geography, The Australian National University, Canberra, A.C.T., Australia.

** Nota del Traductor: *Colocasia* es conocida como Malanga en diversos países de habla hispana como Cuba y México. Especies de *Xanthosoma* son a veces mencionadas como Malanga. *Colocasia* se conoce como Taro en Hawái.

***Nota del Traductor: el camote (sweet potato) es conocido en diversos países de habla hispana como batata dulce, batata o boniato.

REGIONAL STATUS OF TARO

An ancient cultivated plant of Indian or Southeast Asian origin^{7,24}, taro is now widely diffused through the tropical and parts of the subtropical world¹. In production by weight taro is exceeded only by sweet potatoes and bananas²⁰. Barrau¹ states that taro is the invariable staple crop in the rainforest-covered areas of foothills and mountains below 1500 m. Although such is not in fact everywhere the case, the picture put forward by Barrau is not inaccurate as a general pattern. Taro is also commonly grown in both dry and swampy lowlands — even in places where wild sago is a more important food. Higher in the mountains where sweet potato is now the dominant crop, taro is nonetheless cultivated almost everywhere. Unlike the sweet potato, taro has ceremonial or prestigious attributes attached to it^{2,11,15,25} a characteristic often taken to indicate antiquity.

Several questions arise as to the past and present place of taro among highland crops and horticultural practices. Does taro occupy a niche significantly different from the sweet potato? Why did the sweet potato come to so surpass taro in quantitative importance? Could taro once have supported populations as dense as those now found in some places in montane New Guinea? What ecological significance did the shift in staple crop have? In an attempt to answer these and other questions, I have over the past few years made field observations on taro cultivation in several parts of New Guinea and have carried out a few yield trials in gardens planted by traditional methods.

TARO CULTIVATION IN NEW GUINEA SUBSISTENCE FARMING

Based on field observations, as well as on the literature, I can make the following statements about taro as it is grown in New Guinean subsistence systems.

1. Taro is planted at all elevations where cultivation is practiced although it is less common above 2100 m than below. At the highest elevations (2600–2700 m) it is slow to mature, taking in places as much as 18 months, whereas sweet potatoes may be mature in about a year. However, unlike yams or bananas (the other important, vegetatively reproduced, starchy staples from Southeast Asia), taro will produce a crop up to the elevational limit of horticulture in New Guinea. Moreover, to judge from the recovery of taro and sweet potato following the severe frosts of 1972, taro is just about as frost-resistant as the sweet potato. In both crops the leaves die back with heavy frosts, but then both resprout from underground parts and eventually bear — although, as would be expected, taro is slower to do so than the sweet potato. It would seem, therefore, that taro-dependent horticulturalists could have supported themselves at elevations as high as any utilized by present-day sweet potato gardeners; but the yield per unit area per unit time would have been less with taro than with sweet potato.
2. More often than not, taro is absent from sites prepared with special techniques for the long-continued cultivation of sweet potatoes. That is to say that where the gardeners mound, or mound and compost, or ditch, sweet potatoes are always the dominant crop planted in the specially prepared gardens. Where taro is planted in intensively worked gardens — as in the Enga composted mounds or the swamp gardens of the Baliem Valley — it is always of infrequent occurrence compared with sweet potatoes.
3. On the other hand, in some areas the people establish gardens planted almost entirely to taro or dominantly to taro with a few associated crops other than sweet potatoes. In the choice of sites for planting taro there is considerable selectivity based on small variation in soils and topography. Taro is often planted in gullies while the adjacent rises are planted to sweet potatoes, not so much because of ideas regarding differences in moisture tolerance or requirements between the two crops as because of the belief that the gullies contain better soil. Old house sites, whose soils are rich in organic debris, are also favoured spots for small taro gardens or mixed gardens that include taro but not sweet potatoes. If taro and sweet potatoes are planted inside the same fence, taro is always planted in what is considered the best soil — on observation, dark, rich in organic matter, friable — whereas sweet potatoes are planted in any type of soil present. If a new garden site was fallowed, partly under trees and partly under grass, it is likely that the tree-fallowed soil will be planted to taro while sweet potatoes will predominate in the grass-fallowed soils. This widespread selectivity is based on the empirical knowledge that poor soils give exceedingly poor returns of taro corms but at least economic returns of sweet potato tubers. Table 1 serves to give some numerical definition to the differences in yields between the two crops in different sorts of soils. Within the small number of samples measured, sweet potatoes in 'poor' soil yielded more than taro in 'good' soil. Taro on 'good' soils yielded enough to be worth planting — especially as taro is a favoured food, in places a prestige food; but on 'poor' soils such as the long-gardened soil of Site 4, taro was considered to be a hopeless crop and was only planted because of my request.
4. Where crop rotation is practised, taro is always planted in newly cleared soil, whereas sweet potatoes occupy the later phases of rotation. Taro is scarcely ever planted twice in immediate succession, whereas sweet potatoes are often planted several times without a fallow period.

5. Observation suggests that collecting and preparing planting material takes longer with taro than with sweet potatoes. Measurement shows that planting a taro sett takes about 3 times longer than planting a single cluster of sweet potato stem cuttings, which will yield more and sooner than the taro sett. For the taro sett a sizeable hole must be dibbled; with sweet potatoes the soil is loosened by one slanting insertion of the dibble and the stem cuttings (2, 3 or 4 in number, 40 — 55 cm long) slipped in. During the cropping period taro requires more work too as the earth is piled up around the upward-growing corm.

OTHER CROPS ASSOCIATED WITH TARO CULTIVATION

Other crops (all Asian or Pacific in origin) grown in association with the taro are *Saccharum edule*, the greens *Rungia klossii* and *Oenanthe javanica*, cucumber, bananas, and sugarcane. Nearby are many *Castanopsis acuminatissima*, whose edible nuts are collected. At higher elevations are planted groves of *Pandanus julianettii*, whose seasonally maturing nuts are also an important source of food.

Several recently introduced crops further fill in blanks in a mixed garden's total period of yield. Maize provides substantial food before any of the tubers are available, onions and tomatoes provide early supplementary vegetables, and *Xanthosoma* and manioc offer a sturdy supply of carbohydrate after *Colocasia* has been harvested. At higher elevations the relatively quick maturing solanum potato is now growing in importance.

REASON FOR REPLACEMENT OF TARO BY SWEET POTATO

Several inferences can be drawn from these observations of taro and its associated crops. Although taro and sweet potatoes may both thrive growing together in an identical site (as is common in the forest-fallow soils planted by slash-and-burn cultivation), taro, if it is to be productive, has a more limited range of tolerance than sweet potatoes with regard to soil conditions. Planted in poor soil, taro may survive as a plant but not give a worthwhile harvest, whereas sweet potatoes planted in the same soil provide an adequate return. This means that with a shift in staple from taro to sweet potatoes there could have been a spatial expansion of the area suitable for gardening, although not necessarily an altitudinal extension of gardening. This situation is well exemplified by the present-day cultivation practices at Tifalmin in Papua New Guinea, where the word for food is the same as the word for taro, and taro remains a relatively important crop. At Tifalmin the people have recently begun to occupy a grassland shelf at an elevation of 1525 m, where they now make gardens largely planted to sweet potatoes. But they also make gardens at traditional sites at 1685 m and above on forested slopes; here the dominant crop is taro planted beneath girdled trees that have been left unfelled.

The coming of the sweet potato would have allowed a temporal as well as a spatial expansion in the food production of a system previously dominated by taro. Such an expansion is immediately clear where crop rotation is practised, as by the Kapauku¹⁷ on their valley-floor gardens or by the Karam of Papua New Guinea, whose taro gardens planted on *Casuarina*-fallow soils are followed by one or more croppings of sweet potatoes. Under a system of single croppings of mixed gardens the temporal expansion associated with adding sweet potatoes to the crop inventory is less striking but still important. For example, in the Jimi Valley of Papua New Guinea, where taro, sweet potatoes, and a number of other crops are planted mixed together under a system of slash-and-burn cultivation, the sweet potato vines begin to bear before the taro corms are ripe and continue their staggered production for several months after the temporally concentrated taro harvest is completed. Some gardeners further expand the period of yield of sweet potatoes by putting in new cuttings at the time taro is reaching maturity. Earlier in the garden's life, too many sweet potato vines are believed to inhibit the growth of the taro. If *Colocasia* is the single staple crop, planting must be spread widely throughout the year so that corms are always ripening.

The implication of a spatial and temporal expansion of garden production such as what I have suggested is that the coming of the sweet potato could have had a mildly revolutionary effect on highland agriculture. But the pre-Ipomoean agriculture would not have been 'intermittent' or 'casual', as has been suggested by Watson^{21, 22}. Instead, an agriculture based on taro would have required more careful site selection and more methodically regulated periods of planting than would seem to be necessary with sweet potatoes. That an elaborated agriculture did exist long before the presumed introduction of the sweet potato is now supported by the archeological evidence of ditching in the Wahgi Valley in 350 B.C. plus or minus 120 years⁸. I would postulate that at elevations between 1400 and 2000 m, where perhaps four-fifths of the highland population now live⁴ and where the wide-valley topography is often gentle enough to make ditching practicable, there could have been a relatively intensive agriculture based on taro that could have supported large and necessarily sedentary populations. With the coming of the sweet potato there could have been a dispersion of cultivation on to less favoured soils, a more careless approach to the timing of planting, and perhaps a relative lessening of labour input, as suggested by Brookfield *et al.*⁵. The intensive, swamp-ditching system

of taro cultivation^{3,17} could have been abandoned. Later, because of population growth or degradation of fallow vegetation or both, in the lands newly used for sweet potato cultivation, an intensification of cultivation may have developed. The new methods would have been sufficiently different from those of the earlier intensive taro cultivation to prove inadequate to support permanent cropping of taro. This would explain why, in areas of high population density, taro became a remnant crop relegated to sites of high natural fertility.

In less densely settled highland regions, taro remains an important crop. Looking at these areas today, it is easy to postulate a pre-Ipomoean horticulture based entirely on traditional crops supplemented by collected foods — that is, gardens something like those described for Tifalmin. Such gardens would have provided a quite adequate diet, but yields in relation to labour input would probably have been lower than in gardens where sweet potato is dominant. At present, even in the montane areas where taro remains important, sweet potato is planted; and generally the local people understand that taro is the more labour-demanding crop.

In several places in montane New Guinea — as in many other parts of the Pacific — there is record of a new shift from taro toward sweet potato. For instance, Waddell¹⁹ writes of this taking place in the densely settled Enga region. Reasons given by the Enga for the shift include disease and beetle (*Papuana* spp.) problems and declining soil fertility. Recognition of taro's higher labour input and an increasing use of land for cash cropping of coffee are other possible factors. Whatever the cause, it seems likely that the trend toward increasing dominance by sweet potato that began in prehistoric times will continue throughout New Guinea, perhaps to be followed in the future by a move toward still other crops found to be even more suitable or productive.

REFERENCES

1. Barrau, J. (1958) *Subsistence Agriculture in Melanesia*. Bishop Museum Press.
2. Best, E. (1925) Maori agriculture. *Dom. Mus. Bull.* 9.
3. Brass, L.J. (1941) Stone age agriculture in New Guinea. *Geogr. Rev.* 31, 555–59.
4. Brookfield, H.C. (1964) The ecology of highland settlement: some suggestions. *Am. Anthrop.* 66, (4) 11, 20–38.
5. Brookfield, H.C. et al. (1968) Revolution or evolution in the prehistory of the New Guinea highlands: a seminar report. *Ethnol.* 7, 43–52.
6. Bulmer, S. et al. (1964) The prehistory of the Australian New Guinea highlands. *Am. Anthrop.* 66 (4) 11, 39–78.
7. Burkill, I.H. (1935) *A Dictionary of the Economic Products of the Malay Peninsula*. Crown Agents for the Colonies, 1, 639.
8. Golson, J. et al. (1967) A note on carbon dates for horticulture in the New Guinea highlands. *J. Polynes. Soc.* 76, 369–71.
9. Hipsley, E.H. et al. (1963) Studies of the dietary intake and the expenditure of energy by New Guineans. Tech. Pap. S. Pacif. Commn. 147.
10. Kimber, A.J. (1972) The sweet potato in subsistence agriculture. *Papua New Guin. agric. J.* 3, 80–102.
11. McKnight, R.K. et al. (1980) Taro cultivation in Palau. *Anthropological working papers*. 6, 1–47. (Office of the Staff Anthropologist, Trust Territory of the Pacific Islands, Guam.)
12. Meggitt, M. (1958) The Enga of the New Guinean highlands: some preliminary observations. *Oceania* 28, 253–330.
13. Nishiyama, J. (1963) The origin of the sweet potato plant. In: Barrau, J. (ed.), *Plants and Migrations of Pacific Peoples*. Bishop Museum Press.
14. Oliver, D. (1955) *A Solomon Island Society: Kinship and Leadership among the Siuai of Bougainville*. Harvard University Press.
15. Panoff, F. (1969) Some facets of Maenge horticulture. *Oceania* 40, 20–31.
16. Plucknett, D.L., de la Pena, R.F. and Obrero, F. (1970) Taro (*Colocasia esculenta*). *Fld. Crop Abstr.* 23, 413–26.
17. Pospisil, L. (1963) *Kapauku Papuan Economy*. Yale University. (Yale Univ. Publ. Anthrop. No. 67)
18. Reid, L.H. et al. (1969) Nutrition in the Kuru Region. II. A nutritional evaluation of traditional Fore diet in Moke village in 1957. *Acta Trop.* 26, 331–45.

19. Waddell, E. (1972) *The Mound Builders: Agricultural Practices, Environment and Society in the Central Highlands of New Guinea*. Univ. of Washington Press, 198.
20. Walters, C.L. (1963) *Survey of Indigenous Agriculture and Ancillary Surveys 1961/1962*. Papua New Guinea Bureau of Statistics.
21. Watson, J.B. (1965) From hunting to horticulture in the New Guinea highlands. *Ethnol.* 4, 295-309.
22. — — — — (1965) The significance of a recent ecological change in the central highlands of New Guinea. *J. Polynes. Soc.* 74, 438-50.
23. Yen, D. (1963) Sweet potato variation and its relation to human migration in the Pacific. In: Barrau, J. (ed.) *Plants and Migrations of Pacific Peoples*. Bishop Museum Press.
24. Yen, D., et al. (1968) Introduction of taro into the Pacific: the indications of chromosome numbers. *Ethol.* 7, 259-67.

TABLE 1

Yields of taro and sweet potato from subsistence gardens

	Crop	El.(m)	Soil	Maturation period (months)	Yield (kg/ha)
Site 1 (Jimi Valley)	taro	1200	'good', A fallowed 10 yrs + under forest	6	7837 ^B
Site 2 (Jimi Valley)	taro	1650	'good', fallowed 10 yrs under forest	8	3944
Site 3 (Jimi Valley)	taro	1850	'poor', fallowed 1 yr	9	3104
Site 4 (Mount Hagen)	taro sweet potato	1650	'poor', culti- vation for past 10-15 yrs	13 8	750 ^C 9271
Site 5 (Mount Hagen)	taro sweet potato	1650	'good', fallowed 8 yrs + under <i>Miscanthus</i>	12 8	4390 ^C 18447 ^D

- A 'Good' and 'poor' indicate soil quality according to indigenous gardeners. Soil analyses will be available at a later date.
- B Return by weight of edible portion to planted material was 3.5 to 1 for Site 1; 2 to 1 for Site 2; 1.6 to 1 for Site 3.
- C Weighed yield would have been 15-20% greater but for damage by the beetle *Papuana biroi* Endrodi. At Site 4 only 42% of taro setts survived as plants to maturity; at Site 5 46% survived.
- D Compare with Kimber's¹⁰ estimate of about 14000 kg/ha as the average yield of sweet potato tubers for highland

THE COMPARATIVE ETHNOBOTANY OF AFRICAN AND ASIAN YAM CULTURES

D.G. Coursey

SUMMARY

Yam cultivation is postulated to have its origin in mesolithic times when a cultural continuum existed from New Guinea to Africa, before the development of the countries of origin of grain crops further north during the neolithic period. That the greatest subsequent development of yam-based cultivars occurred at the extremes of this continuum is attributed to later inter-actions with the respective grain-based civilizations of the Far and Near East. Man himself is conceived as being domesticated by his crops, and yam-based cultures are more in harmony with their ecosystems whereas grain-based cultures are more interventionist.

RESUME

On situe l'origine de la culture d'igname aux temps mésolithiques quand un continuum culturel s'était établi entre la Nouvelle Guinée et l'Afrique avant le développement des pays où les plantes à graine avaient leur origine en allant plus au Nord pendant la période néolithique. Le fait que des cultivars ayant pour base l'igname se soient par la suite développés à grande échelle aux extrêmes de ce continuum est attribué aux interactions ultérieures avec les civilisations de l'Etrême et du Proche Orient qui ont pour base la culture des plantes à graine. On considère que l'homme lui-même est domestiqué par les plantes qu'il cultive et les cultures basées sur l'igname sont plus en harmonie avec leurs écosystèmes alors que les cultures basées sur les graines sont plus interventionnistes.

BESUMEN

Se postula que el cultivo del ñame tiene sus orígenes en la época mesolítica cuando existía un medio cultural ininterrumpido desde Nueva Guinea a África, antes del desarrollo de los países donde se originaron los cultivos de grano — más al norte — durante el período neolítico. Se atribuye a posteriores interacciones con las respectivas civilizaciones del Lejano y Medio Este basadas en los cereales, que el grandioso desarrollo subsecuente de cultivares basados en el ñame haya ocurrido en los extremos de ese medio continuo. El hombre mismo se concibe como domesticado por sus cultivos y las culturas basadas en el ñame están más en armonía con sus ecosistemas; en tanto que las culturas basadas en los cereales, son más intervencionistas.

INTRODUCTION

If there is to be concern with the present status of root crop production in the world, and with the development of such production in the future. It is appropriate also to try to understand something of the past. Agricultural science developed in Western Europe and hence has been influenced by European modes of thought: these in turn were influenced by cultural concepts ultimately derived from the so-called 'Neolithic Revolution' of South-Western Asia of 7 to 10 millenia ago, where propagated grain crops and a number of animal species, but not vegetatively propagated root crops, were domesticated. Various authors^{7, 16, 30} have drawn attention to the interpenetration that has occurred between scientific thought and the folk ethnocentrism of Western Europe, and to the confusion generated by this that arises when tropical food production systems are being considered.

One outcome of this interpenetration of ideas is the frequent supposition that a non-grain-using, or a pre-grain-using culture is at a low order of evolution. Nevertheless, in connection with the cultivation of yams there are two major areas in the world to which, quite independently, the term "la civilisation de l'igname" has been applied. The first of these is that part of West Africa between central Ivory Coast and the Cameroun where root crops, especially yams, are the dominant staples^{14, 18, 31}. The other is that part of the Indo-Pacific, mainly Melanesia, but extending also into Micronesia and Polynesia, where yams and other vegetatively propagated crops are important²². Yam cultivation in the Pacific area has been considered in detail by Burkill^{8, 9} and by Barrau^{4, 5, 6, 7}.

*Tropical Products Institute, 58/62 Gray's Inn Road, London

The African and Asiatic species of *Dioscorea* have long been isolated genetically from each other: probably since the Miocene and in any case since before man's appearance in the world. The differences between Asiatic and African species are, however, far less than between Old World and New World *Dioscorea*, where divergence occurred much earlier in geological history. There are close morphological parallels between many African and Asiatic species, even in the wild state¹⁴.

Man has thus domesticated different species of yam in the two continents (see Table 1), but in each continent yam utilization tends to be dominated by a single cultigen. In Asia the cultigen *D. alata* is of the greatest importance, though *D. esculenta* (a species which has no parallel in Africa) and some others are also widely grown. In Africa the extremely similar cultigen *D. rotundata* is the commonest in cultivation, even though several other species are cultivated, and in the earlier times a greater number may have been utilized.

It is remarkable that both *D. alata* and *D. rotundata* are considered as cultigens, i.e. artifacts of domestication by man, which are known in the 'wild' state only as escapes from cultivation. The Asiatic species is believed to have originated from spontaneous hybrids between *D. hamiltonii* Hook and *D. persimilis* Prain et Burk., which are regarded as being two closely related species whose natural ranges overlap in Northern Burma and Thailand^{8,9}. The ancestry of the African species is less clearly understood but it may have originated^{3,15} from *D. cayenensis* and a savanna species, perhaps *D. praehensilis*, with a possibility of a second savanna species *D. abyssinica* Hochst also contributing to its ancestry.

Both cultigens belong to the section Enantiophyllum of the genus *Dioscorea* whose members are characterized by the formation of a single large tuber with only limited formation of subsidiary tubers. Both have probably been in predominantly vegetative propagation while under domestication since fertile seed is only very rarely formed.

ASIAN YAM CULTURES

In his early work on the origins of cultivated Asiatic yams, Burkill⁸ assumed that the emergence of cultivated forms was comparatively recent; that domestication occurred subsequently to the introduction of grain-based agriculture into both India and China; and that the pressures generated between these two grain-based cultures on the aboriginal peoples of the S.E. Asian peninsula provided the initial stimulus for yam domestication, at a date only about 2000 to 3000 BP. Although there is evidence supporting the hybrid origin of *D. alata*, also one can well agree that it is in tropical, as opposed to equatorial, regions that large-tubered forms of plants are most likely to have a selective advantage (as the fluctuation in seasonality between wet and dry makes a large, and more esculent, organ of dormancy necessary). The dates suggested for domestication are now considered far too recent.

The original concept of a separate origin of agriculture in the S.E. Asian region can be attributed to Haudricourt and Hedin²⁴, and after being popularized by Sauer³⁵ was developed substantially further by Barrau^{5,6,7}. These writers postulate that vegetatively propagated crops were brought into symbiotic association with man in S.E. Asia area independently of the S.W. Asian "Neolithic Revolution" and perhaps at a much earlier date. The aroid *Colocasia esculenta* (L.) Schott was probably the first plant to be domesticated in this area and was brought into cultivation by littoral or riverain people dependent on fishing as their major nutritional base; this crop was subsequently developed in cultivation particularly in the moister areas⁶. The yams, essentially plants of somewhat drier conditions than those in which *Colocasia* is best adapted are associated with regions of higher seasonality of rainfall, i.e. the savannas rather than the forests, and were suggested as somewhat later, but still exceedingly early, domesticates. Cipriani has also suggested¹³ that they may have been the first plants ever to be cultivated. These ideas are now beginning to receive some firm archaeological support. Though recognizable fragments of neither aroid nor yam material have so far been isolated in excavations, both artifacts and findings of other plant material indicate an association between plants and man at dates around 10,000 BP in various parts of S.E. Asia. Evidence which has recently been reviewed^{12,37} suggests a separate and earlier agricultural revolution, independent of the 'Neolithic Revolution' of S.W. Asia.

On most of the S.E. Asian mainland and many of the neighbouring islands the cultivation of aroids and yams is now of secondary importance although these crops are still known and used. Displacement was initially by rice (which may have been originally¹² a weed in flooded *Colocasia* fields); by dry land grain crops of more recent introduction; and, in the last few decades, by cassava. But before this displacement occurred these crops were carried by the Polynesian migrations, archaeologically dated between 4000 and 3000 BP, to the furthest reaches of the inhabited Pacific Ocean, and in many parts of this area they are still of very great importance.

It is in Melanesia, the area based on New Guinea and extending through the Solomons, New Caledonia and Fiji, that the cultivation of root crops, and particularly yams, has survived to the present day as the core of the agricultural complex. Parts of this area were designated by Haudricourt as "la civilisation de l'igname". Within this large and climatically diverse region, there are variations, depending basically

upon ecological factors, as to whether yam or *Colocasia* is favoured, and the whole production system of the area has also been modified within recent centuries by the introduction of the sweet potato (*Ipomoea batatas* (L.) Lamk.) which made possible extensive colonization of the New Guinea highlands where the climate is too cold for either yam or *Colocasia* to grow well. Throughout the area, the yam more than any crop is not only the major food but is also the focus of the socio-cultural system. In most of Melanesia there is a complex of ritual and socio-religious beliefs associated with almost every phase of the cultivation, storage and handling of yams. Although other species are also respected for their value as food, these cultural associations relate mainly to *D. alata*. For example, a practice has been described of growing giant tubers of *D. alata*, (frequently more than 2 m long and weighing more than 50 kg) under very carefully ritually controlled conditions^{25,28}, and there exists a highly complex system of ritual exchanges of yams between individuals and groups and sexual taboos associated with yam cultivation by which total celibacy is insisted upon during the entire growing season^{28,29,33}. Of ritual as an aid to history Campbell¹¹ has written "Ritual is... the DNA of society, the encoded informational basis of culture... the memory core of human achievement."

Recently evidence has been produced for the existence of horticultural systems closely similar to those of the present day, at dates around 5000 BP in New Guinea³³. These dates would be consistent with the origin of the yam and *Colocasia*-based agricultural systems in New Guinea being derived from earlier cultures of mainland S.E. Asia.

In addition, there exist in several parts of Asia, small, isolated groups of people who are culturally and ethnically distinct from their neighbours, and who utilize yams as their major staple. Notable amongst these are various Indian hill tribes such as the Kadar; the Veddas of Sri Lanka; the Andaman Islanders; the Semang and Malaya and various aboriginal groups in the Philippines¹⁶. These people are at an early level of cultural evolution and have often been described by ethnographers as being completely non-agricultural. However, as pointed out by Burkill¹⁰ referring specifically to the Andamans "They make *D. glabra* a crop plant to the small extent that the elders issue a taboo on the digging of the yams in the season of new growth" and, as has been pointed out elsewhere^{7,16,18}, ritual practices associated with this "protection" of the wild yam may be regarded as an incipient stage of horticulture.

The food plants of the Australian Aborigines, at least in the Northern part of the continent, are similar to those of tropical Asia, New Guinea etc.²⁰, and even amongst these people, there are what might be termed proto-agricultural rituals and concepts, similar to those of some of the relict Asian groups.

AFRICAN YAM CULTURE

Though yams are cultivated and utilized to some extent through most parts of Africa which are ecologically suitable for their growth, the main concentration occurs in the West African "Yam Zone". Here *D. rotundata* is the principal species although various other species are also grown. It is, however, with *D. rotundata* that the greater part of the human cultural aspect of yam growing is associated. In fact in more than one West African language, the name applied to this species signifies some such concept as "proper yam"³.

A major ethnobotanical difference between the African and S.E. Asian areas is that in old Africa no aroid crop, adapted to swamp or at least high moisture conditions was domesticated to any substantial degree, comparable to the domestication of *Colocasia* in Asia. Today however *Colocasia* is widely known in Africa (together with the recently introduced *Xanthosoma* of American origin), but it is an introduction of only the last millenium or two. Some wild African aroids (*Amorphophallus* and *Anchomanes* spp.) are occasionally eaten but they have never been developed to any extent as cultivated plants. In contrast therefore to the Asian situation where aroid cultivation developed in the more humid areas and yam cultivation in the areas of seasonal humidity, in Africa one must look for the origins of root crop agriculture mainly in the savanna areas and in association with the yam.

Against this however must be considered the biological origin of *D. rotundata*. One of its parents, *D. cayenensis*, is itself a forest species and other parent or parents savanna species. *D. rotundata* may have arisen initially at the forest/savanna ecotone, as we have discussed elsewhere.

Today an enormous range of cultivated forms exists which shade imperceptibly from pure *D. cayenensis* on the one hand to something very close to an improved form of *D. praeheensis* at the other end. Although a considerable number of these cultivated forms have been studied⁴⁰ and others have been recently collected and established in Puerto Rico, the cultivated material in existence in West Africa, has never been exhaustively studied. Serious erosion of the genetic resources is taking place both through the displacement of yam cultivation by rice and cassava and also by the spread of the particularly favoured cultivars of yam. In Ghana, for example, it is believed that some 80 percent of yam production is accounted for by two particular cultivars. High priority should be given to fully collecting and cataloguing the existing West African cultivars to prevent them from being lost forever^{14,17}.

In West Africa, yams are not only a major nutritional source but, at least until recently, a focus of human culture. Comments on the importance of yams and their social and even religious significance have been made spasmodically by visitors to West Africa since the 16th Century, but little attention has been

devoted to the subject by ethnographers or anthropologists, and little reliable information appears in the literature.

In the yam growing areas, before the impact of Western education and influence, the farming cycle concerning the yam was also the basis of the human social calendar, dominated by the annual ceremony held to open the yam harvest^{18,32}. Other events in the farming year were also associated with social, cultural or religious festivities, few of which have been well documented. Yam was an essential constituent of sacrifices or other offering in the traditional religious systems; in at least parts of the Yam Zone of West Africa the yam is associated with particular deities in the traditional religious systems^{2,32}. A man's social position may be related to his competency as a yam farmer; theft of yams may be regarded as a more heinous crime than theft of other goods, even of greater value.

These and other philosophical concepts related to African yam cultivation have been discussed elsewhere^{14,18} but, just as there is a need physically to collect the African yam cultivars before they are lost, there is a need for ethnological study of traditional concepts and practices relating to yam cultivation before these too finally disappear. Many traditional customs are now confined to the older generation. Such a study should be of value in understanding the historical development of production systems, and be a guide towards the future development.

Traditions strongly suggest yam cultivation antedates the introduction of the use of iron, which occurred approximately 2000 BP. Many writers have assumed that agriculture of any sort in Africa can only have arisen since the trans-Saharan Neolithic contacts with the middle east: while there is little doubt that such factors would have influenced and accelerated the development of any existing agricultural system¹, the beginning of the agricultural evolution may well be considerably older and of purely African origin. The collection of wild yam has been related¹⁹ to African artifacts dated ca. 50,000 BP, while an analysis based on both climatic changes, and changes in the human population that are archaeologically recorded by appearance of microlithic industries in West Africa suggests a major cultural change approximately 10000 BP. We have suggested that this coincides with the appearance of organized production of yams based on the selection and protection of natural hybrid yams at the rain forest/savanna ecotone^{3,16}.

ORIGINS OF THE YAM CULTURES

Current views on plant domestication²¹ suggest that, whereas grain crops were domesticated in the sub-tropical areas of S.W. Asia and middle China, in closely circumscribed areas that can be regarded as Centres of Origin in the Vavilovian sense, the tropical and equatorial crops were domesticated over wide, diffuse areas or "non-centres" in sub-Saharan Africa and in South-East Asia. These broad areas were originally culturally separated from the more northerly centres, although as history proceeded, cultural interaction took place between each centre and its equivalent "non-centre". Yams in both Africa and Asia can be regarded as domesticates of the "non-centres".

Although different yam species were domesticated in the two areas, a parallelism of evolution can be found not only in the morphology of the plants themselves, but also in the cultural complexes built up around them. In particular, the protocultural phase of evolution which we have postulated elsewhere¹⁸ for the African yam cultivation is a parallel with that in the less advanced Negrito and similar relict peoples of Asia. That these relict groups, whose cultures, though primitive, can be considered to be of much higher antiquity than those of major civilizations (Indian and Chinese) of Southern Asia, have similar practices despite their isolation suggests that the first steps towards yam domestication (in Asia) may have been taken by the remote ancestors of these people, when they were much more widely spread through tropical Asia than they are today. The presence of similar customs amongst the Australian aborigines, who first reached that continent 30,000 BP and whose stone tools resemble very early African and pre-Aryan Indian artifacts²⁷ also suggests extreme antiquity for at least the beginnings of the man/yam symbiotic relationship. Davies¹⁸ and I¹⁶ have already suggested similar extreme antiquity for the initiation of similar man/yam symbiosis in the African "non-centre". Indeed it appears that some form of cultural continuum may have existed in extremely early times right across the tropical Old World from West Africa at one extreme to New Guinea at the other. If so, then the development of the man/yam relationship into a true agriculture at the two extremities of such a continuum, could have occurred under the later influence in each extreme area of cultural contact with a grain-based civilization.

One could term this early phase of proto-agriculture the "Mesolithic Revolution", based on the "protection" or partial domestication of vegetatively-propagated plants.

The hypothesis of such a cultural continuum is supported from an unexpected direction, by ethnomusicology. Sophisticated, computer-based statistical taximetric techniques have been used to analyse the traditional music patterns of a great number of different ethnic groups and classify them according to their degree of similarity. In this study, it was found that higher orders of correlation exist between the music of Africa, Melanesia and the relict Indian groups, all within this postulated cultural root crop using continuum, than would be expected without very early contact between such widely separated groups. This hypothesis for the origins of yam-based agriculture conforms with the views of Lomax and Berkowitz³⁰ "that a con-

tinuous ring of gardening cultures once linked Oceania to Africa" of which "only traces of this ancient human distribution seem to have survived the incursion of higher cultures."

DOMESTICATION OF MAN

It could be said that domestication is a reciprocal process, and that man has been domesticated by his crops just as he has domesticated them. The consequences for man of the evolution of various food production systems have not been explored except in general terms, and it would be interesting to study the cognitive and conceptual aspects of these on human culture³⁶. Attention has already been drawn to differences in cultural behaviour between societies with grain-based agricultural systems derived from the S.W. Asian "Neolithic Revolution", and those with vegetocultural systems based on root and tuber crops of the S.E. Asian area²⁴ which we now regard as being derived from a "Mesolithic Revolution". The former require a direct, active and selective approach by man to his crops and lead to an "interventionist" type of mentality, a concept which was anticipated in the 18th Century by Rousseau³⁴. In contrast, the less active relationships between man and vegetatively propagated crop plants such as the yam lead to a "non-interventionist" attitude of mind and a closer integration of man into the overall ecosystem rather than as a modifier or exploiter of it.

REFERENCES

1. Alexander, J. and Coursey, D.G. (1969) The origins of yam cultivation. *The Domestication and Exploitation of Plants and Animals*. P.J. Ucko and G.W. Dimbleby (ed). Gerald Duckworth, London.
2. Arinze, F.A. (1970) *Sacrifice in Ibo religion*. Ibadan University Press.
3. Ayensu, E.S. and Coursey, D.G. (1972) Guinea yams. *Econ. Bot.* 26, 301-18.
4. Barrau, J. (1963) *Plants and the Migrations of Man in the Pacific*. B.P. Bishop Museum, Hawaii.
5. Barrau, J. (1965) L'humide et le sec. *J. Polynesian Soc.* 74, 328-46.
6. ——— (1965) Histoire et préhistoire de l'Océanie Tropicale. *J. Soc. Oceanistes*. 21, 55-78.
7. ——— (1970) La région indo-pacifique comme centre de mise en culture et de domestication des végétaux. *J. Agric. Trop. Bot. appl.* 17, 482-503.
8. Burkill, I.H. (1924) A list of oriental vernacular names of the genus *Dioscorea*, Gdms. *Bull. Straits Settl.* 3, 121-244.
9. ——— (1951) The rise and decline of the Greater Yam in the service of Man. *Advmt. Sci. Lond.* 7, 443-8.
10. ——— (1953) Habits of man and the history of cultivated plants in the Old World. *Proc. Linn. Soc. Lond.* 164, 12-42.
11. Campbell, B.G. (1966) *Human Evolution*. Aldine, Chicago.
12. Chang, K.C. (1970) The beginnings of agriculture in the Far East. *Antiquity*, 44, 175-85.
13. Cipriani, L. (1966) *The Andaman Islanders*. Weidenfeld and Nicholson, London.
14. Coursey, D.G. (1967) *Yams*. Longmans, London.
15. ——— (1972) The origins and domestication of yams in Africa. Wenner Gren Foundation for Anthropological Research, Burg Wartenstein Symp. No. 56. *The Origin of African Plant Domesticates*.
16. ——— (1972) The civilizations of the yam: Inter-relationships of man and yams in Africa and the Indo-pacific region. *Archaeol. Phys. Anthropol. Oceania*. 7, 215-33.
17. ——— (1973) Genetic erosion of yams in West Africa. *Crop Genetic Resources in their Centres of Diversity*. O.H. Frankel (ed). FAO/IBP Rome, pp. 67-9.
18. ——— and Coursey, C.K. (1971) The new yam festivals of West Africa. *Anthropos*. 66, 444-8.
19. Davies, O. (1968) The origins of agriculture in West Africa. *Curr. Anthropol.* 9, 479-82.
20. Golson, J. (1971) Australian Aboriginal food plants: some ecological and culture historical implications. *Aboriginal Man and Environment in Australia*. D.J. Mulvaney and J. Golson (eds). Australian National Univ. Press, Canberra. pp. 196-238.
21. Harlan, J.R. (1971) Agricultural Origin: centres and noncentres. *Science*. 174, 468-74.

22. Haudricourt, A.G. (1964) Nature et culture dans la civilisation de l'igname: l'origine des clones et des clans. *L'Homme* 4, 93-104.
23. — — — — (1964) Aspects qualitatifs des civilisations agricoles de la société de communauté primitive. Cong. of Anthropological and Ethnological Sciences, Moscow. 5, 506-7.
24. — — — — and Hedin, L. (1943) *L'Homme et les Plantes Cultivées*. Librairie Ballimead, Paris.
25. Haynes, P.H. and Coursey, D.G. (1969) Gigantism in the yam. *Trop. Sci.* 11, 93-6.
26. Igbozurike, M.V. (1971) Ecological balance in tropical agriculture. *Geogr. Rev.* 61, 519-29.
27. Jones, R. (1968) The geographical background to the arrival of man in Australia and Tasmania, *Archeol. Phys. Anthropol. Oceania*. 3, 186-215.
28. Lea, D.A.M. (1966) Yam growing in the Maprik area. *Papua New Guinea J. Agric.* 18, 5-15.
29. — — — — (1969) Some non-nutritive functions of food in New Guinea. *Settlement and Encounter*. F. Gale and G.H. Lawton (eds). Oxford University Press.
30. Lomax, A. and Berkowitz, N. (1972) The evolutionary taxonomy of culture. *Science* 177, 228-39.
31. Miegé, J. (1954) Les cultures vivrières en Afrique Occidentale. *Cah. d'Outre-Mer*. 7, 25-50.
32. Opolu, A.A. (1970) *Festivals of Ghana*. Ghana Publishing Corporation, Accra.
33. Powell, J.M. (1970) The history of agriculture in the New Guinea highlands. *Search* 1, 199-200.
34. Rousseau, J. —J. (1755) *Discours sur l'origine et les fondements de l'inégalité parmi les hommes*. Paris.
35. Sauer, C.O. (1952) *Agricultural origins and dispersals*. The American Geographic Society, New York.
36. Smith, P.E.L. (1972) *The consequences of food production*, Addison-Wesley Modular Publications. Module 31, 1-38.
37. Solheim, W.G. (1972) An earlier Agricultural Revolution. *Scientific American* 228, 34-41.
38. Tuzin, W.F. (1972) Yam symbolism in the Sepik: an interpretive account. *Southwestern J. Anthropol.* 28, 230-54.
39. Uchendu, V.C. (1970) Cultural and economic factors influencing habit patterns in sub-Saharan Africa. Proc. 3rd Int. Cong. Fd. Sci. Technol. 160-8.
40. Walitt, A.W. (1965) A key to some Nigerian variations of yam (*Dioscorea* spp.). Memorandum No. 80, Federal Department of Agricultural Research.

TABLE 1

Principal African and Asian yams utilized as food

<u>African</u>	<u>Asian</u>
<i>D. rotundata</i> Poir.	<i>D. alata</i> L.
<i>D. cayenensis</i> Lamk.	<i>D. esculenta</i> (Lour.) Burk.
<i>D. praehensilis</i> Benth.	<i>D. nummularia</i> Lamk.
<i>D. bulbifera</i> L.	<i>D. bulbifera</i> L.
<i>D. dumetorum</i> (Kunth) Pax.	<i>D. hispida</i> Dennst.
	<i>D. pentaphylla</i> L.

THE SAGO PALM: A POTENTIAL COMPETITOR TO ROOT CROPS

M. Flach*

SUMMARY

Cultivated sago palms in West Malaysia are estimated to produce 24 t/ha/year of dry starch from the harvesting of 130 palm trunks per hectare. Semi-wild palms on peat soils in Sarawak probably produce about half of this (60 trunks per hectare). Such yields from an unimproved crop suggests that the sago palm deserves more attention than it has received in the past. Speculations are made by comparison with the recorded growth of oil palms, suggesting that the production of 270 tons of de-barked pith equivalent to 54 tons of dry starch per hectare might be possible to obtain through research and its application.

RESUME

On estime que les sagoutiers cultivés en Malaisie Occidentale produiront 24 tonnes d'amidon sec par an à partir de la récolte de 130 troncs de sagoutiers à l'hectare. Les sagoutiers semi-sauvages cultivés en sols organiques au Sarawak pourraient en produire la moitié (60 troncs à l'hectare). De tels rendements obtenus de plante non améliorée indiquent que le sagoutier mérite plus d'attention que par le passé. Considérant la croissance connue des palmiers à huile, on pense qu'il n'est pas impossible d'obtenir, grâce à la recherche et à ses applications, une production de 270 tonnes de cervelle de la plante.

RESUMEN

Se estima que las palmas sagú, cultivadas en Malasia Occidental producen 24 t/ha/año de almidón deshidratado como producto de la cosecha de 130 troncos de palma por hectarea. Las palmas semi-silvestres de Sarawak, producen cerca de la mitad de esa cantidad (60 troncos por hectarea). Tales rendimientos, a partir de un cultivo no mejorado, sugieren que la palma sagú requiere mas atención que la que se la ha dado en el pasado. Se especula por comparación con el crecimiento registrado de palmas de aceite, sugiriéndose que mediante investigación y aplicación de la misma, sería posible obtener 270 ton, de medula, descor-tezada, equivalente a 54 ton. de almidón deshidratado por hectarea.

INTRODUCTION

Sago is the starch which the sago palm accumulates in its trunk. The pith of a sago trunk has the composition as given in Table 1, the dry matter composition closely resembles that of cassava roots and sago can be used for the same purposes, i.e. for human food, for preparation of industrial starches and also as an animal feed.

Rasped and dried sago pith has been used for a long time as a feed for pigs and poultry and refuse from sago starch factories is used as a feed for pigs and cattle. It is likely that rasped, dried and pelletized sago pith will be completely acceptable for the animal feed industry.

BOTANY AND CULTIVATION OF THE SAGO PALM

The palm genus *Metroxylon* consists of some six species. The name is derived from Greek, *metra* meaning pith and *xylon* meaning xylem. The genus is indigenous in the lowlands of a southeast Asia and Melanesia. It occurs between 10°N and S up to a height of 700 m. Most species are found on and around New Guinea which probably is the gene centre. The economically most important species are *M. sagu* Rottbol and *M. rumphii* (Wild.) Martius. The latter name was given in honour of Rumphius (1755) who, in his 'Amboinsch Kryd-boek' gave the first description of the palm accompanied by a drawing. The main difference between the two species is that *M. sagu* has no thorns, whereas in *M. rumphii* the leaf sheath and petiole are covered by sharp thorns up to 8 cm long. Barrau¹ considers that the two taxa should be conspecific as they appear to cross readily. This was proven in our department: the offspring of two unthorned palms in the Singapore Botanical Gardens also gave a few thorned palms.

Under natural conditions the palm occurs in fresh water swamps in the tropical rain forest zone. Isolated palms occur outside this natural habitat and appear to do well, provided they are tended properly. Probably

*M. Flach, University of Agriculture, Wageningen, Holland.

in its natural habitat the palm possesses a competitive advantage. The best natural stands occur in clayish fresh water swamps, high in organic matter; peat soils are less suitable. Although sago occurs in swamps, permanent inundation appears to be disadvantageous.

Each shoot of the sago palm flowers only once but the plant is a tillering perennial. Carbohydrates in the form of starch accumulate during the vegetative phase in the trunk and are used up for flowering and fruiting if this is allowed to occur, after which the trunk dies. Usually in the first year of growth the palm forms a number of buds in the axils of lower leaves which subsequently develop into shoots or tillers. (Photograph 1).

The crown of the palm consists of some 6–15 feathered leaves each composed of leaf sheath, petiole and approximately 20 pairs of leaflets of 60–180 cm². The rachis is concave on the upper side and convex on the underside. On the trunk the leaf sheath may be as wide as 30 cm. The senescent leaves break off from the leaf sheaths; later the leaf sheath abscises from the stem, and an annular leaf scar remains on the stem.

The appearance of the inflorescence is preceded by that of a number of smaller leaves. The terminal inflorescence, resembling an enormous antler, consists of a primary axis dividing into secondary and tertiary axes. The tertiary axis bear the small flowers in pairs, a male and an apparently complete flower together (Photograph 4). Male flowers open and shed their pollen before the complete flowers open; in the latter the stamens probably are not functional. The palm is therefore probably an obligatory cross pollinator. In male and shed their pollen before the complete flowers open; in the latter the stamens probably are not functional. The palm is therefore probably an obligatory cross pollinator. In male and in complete flowers the six stamens are fused into a tube. In the complete flowers the half inferior ovary contains three ovules out of which only one develops. This results in a beautiful scaled fruit with only one seed (Photograph 3).

The palm possesses a large number of mostly superficial primary roots from which pneumathodes often grow above ground level. Also the trunk may be covered with roots. Each tiller develops its own root system, provided it does not arise too far above the soil. After the first trunk has disappeared, the connection between its tillers may be severed. Tillers may produce their trunks at considerable distances, sometimes even a few meters from the original trunk (Photograph 1). The height of a flowering trunk without its inflorescence may vary from 10–15 m. Usually at its base the mature stem has a girth of 35–50 cm, slowly increasing up to 50–60 cm at mid-height, and tapering off again towards its distal end to a girth similar to that at its base. At harvesting on average the trunk weighs over 1000 kg.

The palm may be propagated from seeds (Photograph 3). In harvested wild stands however, the palm as a rule is not permitted to produce ripe seeds, because this uses up the stem starch which is the required product. Only thin stemmed, low-producing palms would normally be allowed to set seeds. This would result in negative mass selection if only sexual propagation were practised. In cultivation, however, the palm is usually clonally propagated, by means of tillers or suckers, from selected mother trees.

YIELDS OF WILD STANDS

In the wild condition, as in New Guinea and in the Moluccas, palms are harvested as their first young fruits are formed. It is very difficult to obtain data on production per unit area, and time under such conditions. Wild stands show large variations in numbers of stools per hectare of which also the age may vary. Moreover, the age of harvested trunks is only vaguely known. Best estimates on possible yields of very nearly pure wild stands are 40–60 stems per hectare per year¹⁴. At 1000 kg pith per trunk and a starch content of 15.5% this would result in 7–11 tons of dry starch or 28–44 x 10⁶ kcal per hectare per year.

PROBLEMS IN DEVELOPING SAGO

It is amazing that such an apparently high potential, even compared to modern methods of cultivation for other crops have not been fully developed, especially if one considers that Indonesia possesses several hundreds of thousands hectares of nearly pure stands. All reports indicate that the transport of the harvested stems to a factory was the main difficulty. In a highly productive wild stand transport of 40–60 tons of raw material per hectare per year would be required to a central point if central processing is to be adopted. This raw material, containing 80% moisture, would have to be transported from a swampy area lacking roads and mostly without navigable waterways. The indigenous population however has a very simple solution to this problem. The trunks are harvested and processed in the swamp. Only the wet starch is taken out of the swamp.

Only in 1957 was systematic research on the processing of sago started by a Dutch company in New Guinea. Trunks were cut and rasped in the wild stands. Rasped pith, with its contents of starch, was mixed with clear water and pumped through a pipe line towards a floating factory and refined there. In 1962 results appeared to be promising, but the experiments were then ended.

YIELDS UNDER SEMI WILD CONDITIONS

The situation in the semi-wild cultivation in Sarawak differs in several aspects from the situation in Indonesia. In Sarawak most sago areas are on peat rather than mineral soils. On peat the palms have less leaves; the leaves show deficiency symptoms and growth is slower. Whereas a palm on mineral soil may reach maturity after 8–10 years, a palm on peat soil is said to reach maturity only after 15–17 years³. Production from good sago land is said to be about 60 stems per hectare per year.

In Sarawak the sago area is crossed by a fairly dense network of small rivers and creeks. Although transport, even of one-meter logs from the site of felling to the river, is difficult, transport of logs once in the water is easy. This has resulted in the establishment of a number of sago starch factories. These factories produce poor quality starch because in the processing they only have available water coloured by peat. Refuse of the starch production is not utilized but is washed into the river.

YIELDS UNDER CULTIVATION

Ridley⁷ mentions sago plantings around Batu Pahat in Johor, West Malaysia. Nicholson⁵ described the cultivation in this area and, as I could see for myself in 1971, what he described is still true. Similar cultivation also existed on the island Benkalis and in the Lingga archipelago, east of Sumatra in Indonesia^{8,9}. Whether cultivation is still practised I do not know, but the cultivation still continues near Batu Pahat. Official estimates amount to 2000 hectares while in the last few years at least 100 hectares have been planted.

In the Batu Pahat area the palm is planted in clayish soils in coastal areas, under tidal influence but above the salt water line. This results in twice daily flooding of the plantings with fresh water. The palm is planted using carefully selected well-sized suckers at 6 x 6 m (277 suckers per hectare). Around the palms the soil is kept clean weeded; the plants are regularly and carefully pruned in order to ensure an even spread over the surface.

After eight years of growth the first trunks may be harvested (Photograph 2). Each stool of palms, derived from one planted sucker, produces one trunk per two years. So an estimate of 130 trunks per hectare per year is obtained. This would lead to a production of 24 tons of waterfree starch per hectare per year, of 96 x 106 kcal. The trunks are harvested before the inflorescence develops in the growing point. This is probably the time with the highest production per unit of surface and time. Trunks are cut as low above ground level as possible and transported to the processing plant as rafts made up from one meter logs.

The continuous flooding and draining of the sago area probably provides all the nutrients required for the sago palm and no additional fertilizer is used. Data of Woodman *et al.*¹³ shows that pith had the analysis given in Table 2. These figures have also been applied to data from Batu Pahat. All nutrients in other plant parts are assumed to be returned to the soil, approximately *in situ*.

In an area flooded and drained twice daily one may assume that nutrient contents of the soil are in equilibrium with the nutrient contents of the fresh water that floods the soil. Data on the nutrients in the river running through the area is not however available, but there is data for the nearby Malacca river¹⁰. A comparison of these data with the nutrient contents of sago pith is given in Table 2. In calculating the nutrient economy it is assumed that the area is flooded twice daily with a layer of 10 cm water above ground level.

If the nutrient balances of sago cultivation are as postulated, it could be considered to be a kind of water culture. This would explain the continuous high yields maintained without the addition of fertilizer. As application of fertilizer in such a situation would be very difficult, it might be a limiting factor to further increase yield.

It is extraordinary that this remarkably interesting and high yielding crop has hardly received any research attention. This level of production reported had been reached by the farmers themselves without any outside influence. It is therefore of interest to speculate on whether yields still could be higher, and what research might be worth-while.

POTENTIAL PRODUCTION

If all other conditions are optimal the potential dry matter production of a crop is determined by photosynthesis, and thus by sunlight. In the tropics one can grow a sago crop the year round. In the region between 10°N and S gross potential photosynthesis amounts to about 400 kg of carbohydrates per hectare per day on a cloudless day. On a clouded day, however, potential photosynthesis might reach only 220 kg carbohydrates¹². Roughly 30 percent of the carbohydrates produced by the plant are used for respiration. Assuming that in the humid tropics the sky will be half clouded on the average, the potential production of carbohydrates by a crop with a closed canopy making use of all the available light, can be roughly estimated at 200 kg/ha/day. Depending on the cloudiness, potential production could be higher or lower than this figure. A comparison of potential production of rice, cassava and the hypothetical production of sago palm

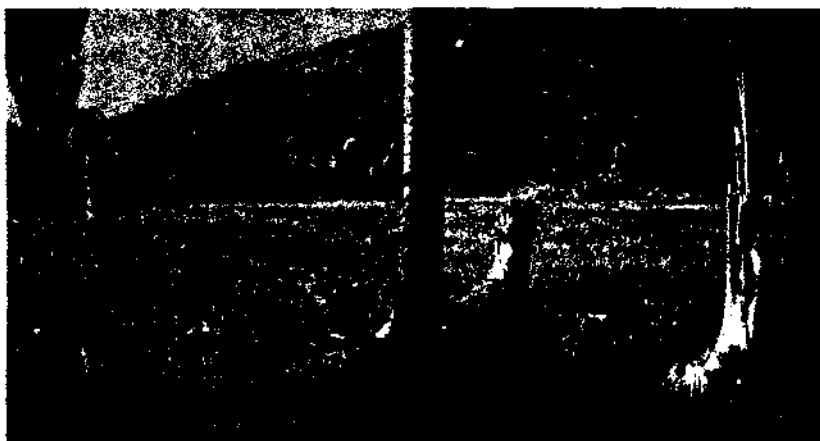


PHOTO 1 FREE GROWING SAGO PALM STOOL IN WET RICE
FIELD (SARAWAK)



PHOTO 2 WELL MAINTAINED SAGO PLANTING CLOSE TO
BATU PAHAT (W.MAL.)

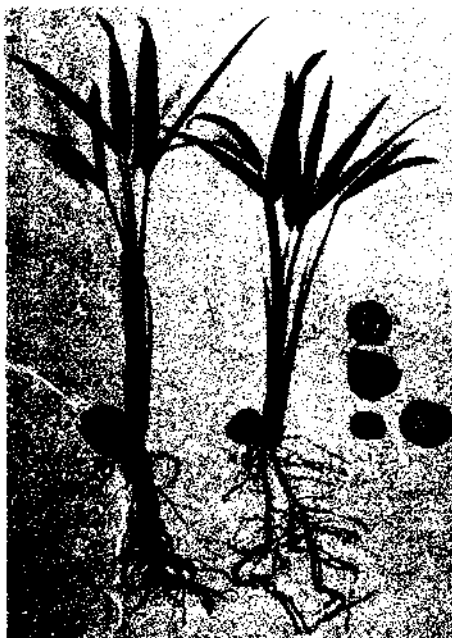


PHOTO 3
FRUIT, SEED AND SEEDLINGS OF THE SAGO PALM



PHOTO 4
FLOWERS OF THE SAGOPALM; ABOVE COMPLETE
FLOWER; UNDER MALE FLOWER

under the circumstances mentioned is presented in Table 3. In this table the percentage of useful dry matter in rice and cassava is based on data provided by de Vries¹¹. Useful dry matter production of the sago palm was estimated by means of comparison with recorded data for the oil palm². A sago palm is estimated to consist of crown and roots 50 kg, bark of trunk 200 kg, pith 1000 kg. Its 20 percent dry matter contains starch at 18.5 percent of the 1000 kg fresh pith, i.e. 74 percent of the total dry matter of the palm comprises the useful product.

It appears from the comparison that the sago palm has clear advantages over both cassava and rice. Two factors contribute to this; a more favourable dry matter distribution than in rice, which it shares with cassava, and a greater proportion of time in which there is a closed canopy than in either rice or cassava. In this sago closely resembles the climax vegetation in the humid tropical lowlands of which in fact it is a part. Perhaps, on this hypothetical analysis, the present yields of the sago palm may be doubled.

MAIN ADVANTAGES AND DISADVANTAGES OF THE CROP

There are a few distinct advantages of this crop over all other starchy crops.

1. It is perennial, fitting into the climax vegetation.
2. It is especially suited for swampy areas which at the moment cannot be used for most other crops without expensive measures for water control.
3. It is a relatively simple crop in maintenance and care.
4. Harvesting of the crop is not confined to any particular season: neither is harvesting limited to a strict physiological growth phase.
5. Harvested stems can be kept in water during some weeks without great losses.

One problem presents a clear disadvantage for any new plantations in the eight year period from planting to first harvest. This period might be shortened by means of fertilization.

If earlier harvesting proves impossible, other means are available to reduce the economic disadvantage of the long juvenile period. In the first four years after planting, much unused space is available between the suckers. If the final stand is to be at 6 x 6 m, one might initially plant one additional sucker in the centre of each square. These could be left to grow into one or maybe two trunks each. In the first few years one could then harvest approximately double the usual number of trunks, in this way partially compensating the losses of the eight years juvenile period.

The sago palm is a hitherto neglected starch crop with a high yield potential and suited for marginal swampy soils. Due to its unique characteristics it is suggested that this crop be included within the interests of the International Society for Tropical Root Crops, despite its not being a root crop.

REFERENCES

1. Barrau, J. (1959) The sago palm and other food plants of marsh dwellers on the South Pacific Islands. *Econ. Bot.* 13, 151-62.
2. Ferwerda, J.D. (1962) Die Oelpalme. *Tropische und subtrop. ische Weltwirtschaftspflanzen* II, 344 Enke; Stuttgart.
3. Johnson, R.M. and Raymond, W.D. (1956) Sources of starch in colonial territories. I. The sago palm. *Col. Plant and Animal Prod.* 6, 20-32.
4. Lim, H.K. (1967) Animal feeding stuffs. *Mal. Agric. J.* 46, 63-79.
5. Nicholson, G.P. (1921) Le sagoutier en terrains maracageux (Malacca). *Bull. Econ. Indoch.* 24, 159-200.
6. Oijen, L.A.T.J.F. (1909) Sagoe en sagoepalmen. *Bull. Kol. Mus. Haarlem* 44, 12-69.
7. Ridley, H.N. (1895) Sago. *Agric. Bull. Malay Penins.* 4, 62.
8. Reep, C. (1907) Sagocultuur op Benkalis. *Tijdschr. Binnenl. Best.* 32, 393-4.
9. Scheffer, R.H.C.C. and Holle, K.F. (1873) Een sagoboom op Java. *Tijdschr. Ind. Mij Nijverh. & Landb.* 18, 397.
10. Tan, Y.T. and Prowse, G.A. (1972) A chemical survey of the Malacca river. *Mal. Agric. J.* 48, 185/221.
11. Vries, C.A. de, Ferwerda, J.D. and Flach, M. (1967) Choice of food crops in relation to actual and potential production in the tropics. *Neth. J. Agric. Sci.* 15, 241-8.
12. Wit, C.T. de (1965) Photosynthesis of leaf canopies. *Agric. Res. Rep.* 663. Centre Agric. Publ. & Doc: Wageningen.
13. Woodman, H.E., Menzies, A.W., Kitchin, A.W.M. and Evans, R.E. (1931) The value of tapioca flour and sago pith meal in the nutrition of swine. *J. Agric. Sci.* 21, 526-46.
14. Zwollo, M. (1955) Rapport sago onderzoek Inanwatan. Report available in the archives of the former Directorate Netherlands New Guinea, the Hague.

TABLE 1

Composition of cassava roots and sago pith

	tapioca root		sago pith	
	fresh(%)	dry matter(%)	fresh(%)	dry matter(%)
Moisture	62.4	-	80.0	-
Soluble carbo- hydrates	35.5	94.4	18.5	92.5
Protein	0.4	1.1	0.3	1.5
Fat	0.2	0.5	0.1	0.5
Fibre	0.8	2.1	0.3	1.5
Ash	0.7	1.9	0.8	4.0
Convertible to chips (at 14% moisture)	43%		22.8%	

TABLE 2

A comparison of nutrient contents of harvested sago pith and nutrient contents of flooding river water
nutrient contents of flooding river water

Nutrients	Nutrient contents of pith of 130 trunks/ha/year	Total of nutrients flowing over the soil in aqueous solution in kg/ha/ year	Percentage that would need to be withdrawn from the aqueous sol. to maintain yields
N	80 kg	763 - 903	10.5 - 8.9
P ₂ O ₅	30 kg	161 - 301	18.6 - 10.8
K ₂ O	160 kg	1,883 - 2,772	8.5 - 5.8
CaO	100 kg	1,834 - 2,030	5.5 - 4.9
MgO	40 kg	1,295 - 2,296	3.1 - 1.7

TABLE 3

A comparison of the potential production of rice, cassava and sago palm

	<u>Rice</u>	<u>Cassava</u>	<u>Sago Palm</u>
Assumed duration of growth	120 days	270 days	30 years
Estimated period before closed canopy is reached	50 days	90 days	4 years
Estimated dry matter production			
a) before closed canopy	50 x 200kg. 2	90 x 200kg. 2	4 x 365 x 200kg. 2
b) after closed canopy	70 x 200kg.	180 x 200kg.	26 x 365 x 200 kg
Estimated dry matter production per day of vegetation	158 kg	166 kg	186 kg
Percentage useful dry matter	40 %	80 %	74%
Useful dry matter per day of vegetation in kcal.	252 x 10 ³	531 x 10 ³	550 x 10 ³
Production per day in % of rice production	100%	210%	218%
Part of increase over rice due to			
a) longer period of closed canopy	-	5%	18%
b) more favourable dry matter distribution	-	105%	100%
Potential crop yield in practical terms	8.500 kg polished rice per harvest	97 tons of fresh roots per harvest	270 tons of debarked pith per year of full production

ROLE OF ROOTS AND TUBERS IN NIGERIAN NUTRITION AND AGRICULTURAL DEVELOPMENT

E.O. Idusogie and S.O. Olayide*

SUMMARY

Production and consumption of root and tuber staples such as cassava, yams, cocoyams and sweet potatoes can furnish large quantities of food energy per unit area of land under climatic conditions that do not favour dry land cereals production. It is now being increasingly realized that inadequacy of food calories in diets, as well as protein deficiency, contributes to malnutrition in Nigeria. Root and tuber crops are in demand in trade between Nigeria and neighbouring West African countries and also overseas, and they therefore contribute to foreign exchange earnings.

There is therefore a strong case for giving greater prominence to root and tuber crops development in the national agricultural planning in Nigeria to meet both nutritional and economic needs.

RESUME

La production et la consommation de denrées à base de racine et de tubercule telles que le manioc, l'igname, le tarot et la patate douce peuvent fournir une grande quantité d'énergie alimentaire par unité de parcelle de terrain en conditions climatique qui ne favorisent pas la production de céréales en terrain sec. On se rend de plus en plus compte que l'insuffisance de calories dans les régimes alimentaires, de même que le manque de protéine contribuent à la malnutrition au Nigéria. Il y a une demande commerciale des plantes à racine et à tubercule entre le Nigéria et les pays voisins de l'Afrique Occidentale, et aussi d'Outre-mer, et elles constituent par conséquent des sources de devises.

Il est donc d'une nécessité impérieuse d'accorder une part importante au développement des plantes à racine et à tubercule dans la planification agricole au plan national pour que le Nigéria puisse satisfaire ses besoins aussi bien dans le domaine de la nutrition que de l'économie.

RESUMEN

La producción y el consumo de raíces y tubérculos básicos como la yuca, ñame y el camote** pueden proveer grandes cantidades de energía alimenticia por unidad de superficie bajo condiciones climáticas que no favorecen la producción de cereales de tierras mas secas. Se ha incrementado ahora la atención, en cuanto a que la dieta calórica de los alimentos, así como la deficiencia de proteínas, contribuyen a la malnutrición en Nigeria. Se observa una demanda en el comercio de cultivos para raíces y tubérculos entre Nigeria y los países vecinos de Africa Occidental y también con ultramar, lo cual por lo tanto, contribuye a la obtención de ganancias por intercambio con el extranjero. Es cuestión portanto de dar mayor importancia al desarrollo de raíces y tubérculos en la planeación agrícola nacional en Nigeria para subsanar necesidades, tanto nutricionales como económicas.

INTRODUCTION

Seasonal food shortages causing hunger and malnutrition and important health and social problems impede economic progress in Nigeria and many other developing countries. It is increasingly being recognized that an inadequate quantity of food, with an insufficiency of calorie or energy intake, and not merely protein deficiency, is the cause of widespread protein-calorie malnutrition, since, with insufficient food calories protein is used to supply energy instead of fulfilling its body-building role. Calculations show that cassava or manioc (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), yam (*Dioscorea* spp.) and cocoyam

*E.O. Idusogie, Regional Nutrition Officer, FAO Regional Office for Africa, Accra, Ghana.

S.O. Olayide, Professor and Head of the Department of Agricultural Economics and Extension, University of Ibadan.

**Nota del Traductor: el camote (sweet potato) es conocido en diversos países de habla hispana como batat dulce, batata o boniato.

(*Colocasia* spp.) are all good and cheap sources of energy, and produce high amounts of food calories per acre of land⁹.

Root and tuber crops have a long history of consumption in many Nigerian communities^{3,10} which we shall review.

History of root and tuber crop cultivation and consumption in Nigeria

Root crops in West African culture:

In general, the people living in the Southern Province of Nigeria are 'root eaters', and it can be taken for granted that the traditional inhabitants of Benin in Mid-Western Nigeria and the people of Ifesha in Western State of Nigeria eat 'fufu' made from yam three times in a day.

The harvesting of wild roots and tubers was probably one of the earliest methods of food procurement in ancient Africa. Root and tubers feature prominently in Nigerian folklore and traditional ceremonies, and this is considered to provide evidence that roots and tubers have been eaten in the respective communities since the earliest times.

Today the cultivated edible roots and tubers in Nigeria include cassava, yam, cocoyam, sweet potato and Irish potato, of which however only the yam is probably indigenous and traditional. Cassava originated in South America and was perhaps introduced into Nigeria late in the 19th century. Many old people still alive in Nigeria remember times when cassava was not eaten in their home areas. Now, however, both sweet and bitter cassava are extensively grown and consumed in many parts of Nigeria.

Indigenous and introduced yam species:

About 70 percent of the world's yams are produced in Africa⁴ and about half of the world's yams are produced in Nigeria. According to Phillips¹⁶ some yams are indigenous to West Africa and some are introduced. Coursey³ and Irvine¹² both agree that the white yam (*Dioscorea rotundata*) and the yellow yam (*Dioscorea cayenensis*) are indigenous to West Africa. A wild form of the yellow yam occurs in West Africa². The writers support these, but also consider that the water yam (*D. alata*) the bitter yam (*D. dumetorum*) and the potato yam, or air potato (*D. bulbifera*) are indigenous. We have ourselves seen wild forms of these species in Nigeria, and there are local names for both the cultivated and edible yams and for their wild forms. The Chinese yam however, also known as the 'lesser yam' (*D. esculenta*) is an alien in Africa and is believed to have originated in the Indo-Chinese region. The Chinese yam is now grown and eaten, particularly in the Western State of Nigeria.

According to Irvine¹¹ who has reviewed evidence for the origin and distribution of cocoyams, the wild ancestor of cultivated cocoyams has never been traced, and cocoyams are considered to be one of man's earliest food crops. Evidence suggests that cocoyams originated in Asia, were grown in India for centuries, taken to Egypt at the time of Christ, then to Europe, and then back to North Africa and reached West Africa across the desert¹². Two species of cocoyam (*Colocasia esculenta* and *Xanthosoma sagittifolia*) are now grown in Nigeria and many other parts of tropical Africa.

The Spaniards found the Indians of Central and South America already growing sweet potatoes in the fifteenth and sixteenth centuries. They are now an important crop in Northern Nigeria. Three recognized market categories are 'white', 'red', and 'yellow'.

Irish potatoes originated in the Andean highlands. They were first introduced into Nigeria during World War II. Their cultivation is increasing in small-scale farms, particularly in areas of Northern Nigeria.

Coleus potatoes are thought to have originated in the Ethiopian region. There are two species, the 'Hausa potato' (*Solenostemon rotundifolius*) and the 'Rizga' (*Coleus dazo*). Both are grown and consumed in Mali and the Upper Niger Basin and are likely to diffuse into Nigeria and other parts of Africa. Average yields of root and tuber crops are given in Table 1. Estimated acreages and production of staple root and tuber crops in Nigeria from 1959 to 1970 are given in Tables 2 and 3.

CURRENT CULTIVATION METHODS FOR ROOTS AND TUBERS IN NIGERIA

Cassava is grown from stem cuttings and cultivated both as a sole crop and mixed with other crops. It has become ubiquitous and a popular staple crop in many parts of the country because of its hardiness. Cassava may mature for harvesting from 6 months to 2 years under the range of possible growing conditions. Sweet cassava yields are generally lower than those of bitter cassava. Low yields, which are general, are partly due to poor agricultural extension services. Cassava products include gari, sun-dried cassava flour and starch.

Yam production is expensive in terms of planting materials and labour. The crop is propagated by yam

⁹But at much higher moisture content than cereals. (Ed.)

setts which are mainly the tops of yam tubers which, if not used for propagation, could have been eaten. About 1,680 lbs per acre of planting setts are required. Average time of maturity is 8 months and during the whole growing period the yam vines have to be supported above ground by wooden poles. Soil fertility, the amount and distribution of rainfall, the size of the setts used, crop management, the cultivar of yam and whether it is grown as a sole crop or in mixed stands all affect yields. Recently yam yields have tended to decrease mainly due to indiscriminate use of poor soils to grow yam and poor management practices.

Sweet potato receives systematic planting and proper crop management in the North, but not in the Southern parts of the country. In the South the crop is found growing on refuse heaps around dwellings and not in well-ordered plots.

Both *Colocasia* and *Xanthosoma* cocoyams are widely grown in Southern Nigeria either as sole crops or mixed with others. Substantial cocoyam production is from roadside plots, and from palm oil and cocoa plantations since they can thrive without proper crop management. Yields are generally low.

Irish potatoes are grown mainly in Benue-Plateau State and Kano and North-Central State.

CONTRIBUTION OF ROOTS AND TUBERS TO THE DAILY PER CAPUT AVAILABILITY OF ENERGY AND PROTEIN

The diet of the 'average Nigerian' is composed of cereals, starchy roots tubers and fruits, oils and fats, legumes, fish and livestock products, oilseeds and nuts, sugars, beverages, vegetables and fruits.

The contribution of roots and tubers to the total per capita supply of 2,083 kilocalories (8713 kJ) and 53.83 g of protein in Nigeria for the 1968/69 agricultural year, is shown in Table 4. Roots, tubers and plantain together provide 24.1 percent of calcium and 51.4 percent of ascorbic acid of the total daily per capita supplies¹⁴ and these figures do not include the nutrients available from the leaves of cassava, cocoyams and sweet potatoes, all of which are used as green vegetables.

For the Southern States of Nigeria data in Tables 5,6,7,8 show that starchy roots, tubers and fruits taken together can provide between 50 to 90 percent of the daily per capita energy intake and from 20–28 percent of the daily protein intakes^{5,6,13,18}. Although the Southerners' consumption patterns of predominantly starchy roots, tubers and fruits are not ideal and indeed are inconsistent with national nutritional targets, nevertheless, the data provide evidence that roots and tubers are at present indispensable in the Nigerian diet and this emphasizes the need to give greater prominence to their production in the national agricultural development plan.

ROOT AND TUBER CROPS IN INTERNATIONAL TRADE

Dried cassava roots are being exported to Europe for making starch and the roots have been suggested as raw materials for manufacturing glucose or power alcohol. Cassava chips are also used for animal feeds.

In recent years there has been increased exportation of gari, yams and sweet potatoes to England and other overseas countries for sale to immigrant populations. As well as becoming a useful source of foreign exchange earnings, the growth of international trade in roots and tubers increases effective demand for farm food produce and this needs to be matched by an increase in production if it is not to effect adversely the availability of produce for internal consumption.

SUPPLY AND DEMAND FOR ROOTS AND TUBERS IN NIGERIA

Data from a recent study (Table 9) indicate that substantial marketable surpluses in rural areas which have sometimes been considered by planners to exist are in fact not produced. Policy makers, believing in the existence of surpluses, gave no prominence to programmes for increasing the production of staple food crops in the national development plans. However, both the Federal and the State Governments have now come to realize that the first obligation of the national agriculture is to provide adequate food for the people. Current thinking is that food production and general agricultural development must be considered as one of the topmost priorities in the national development plans¹. However, mere plans and project proposals do not themselves constitute solutions to the existing gap between food supply and demand. Realistic strategies for implementing the expansion of production and consumption of root, tuber and other food crops in the country must include the following measures.

Reinforcement of research to improve root and tuber crops

Because the traditional species of roots and tubers are generally low in yields and protein value, they have been largely neglected in research and development programmes. There are promising indications now that protein content and possibly yields of root and tuber crops could be increased significantly over present low levels by the selection of better planting materials and the improvement of cultural practices. For example, recent findings by Martin and Thompson in Puerto Rico show that the protein content of 40 collections of yams varied between 6.3 and 13.4 percent. These protein levels compare favourably with the

1–6 percent protein in cassava, 4–6 percent in sweet potato, and the 3–5 percent protein in taro¹⁵. If the protein content of root and tuber crops could be increased by over 50 percent then their production and consumption would certainly eliminate both calorie and protein shortages, and the incidence of protein-calorie malnutrition in those parts of Nigeria and other tropical and subtropical countries where millions of people depend almost entirely on these staple foods. Already, selection for protein content in root and tuber crops is in progress in a number of national and international institutions including the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, the International Potato Centre (CIP – in Peru) and the Federal Experimental Station, Mayaguez, Puerto Rico.

Intensification of agricultural extension services

Agricultural extension services in Nigeria are not at present effective. Peasant farmers tend to use land of poor soil fertility for crop production and this limits yields. Also, they tend to plant their crops without any regard to optimum cropping patterns and seasons, so that poor harvests and crop failures are usual in many Nigerian farming communities. There is a need for general education of Nigerian farmers in improved crop cultivation.

Incentives to farmers

Realistic and aggressive agricultural food production programmes would necessitate a transformation of the existing traditional production practices. Farmers would need fertilizers, new crop cultivars, crop protection chemicals, machinery, etc. Farmers must be able to get credit to buy these inputs, and hence they need extra returns to be able to undertake the repayment of credits. This implies in turn the need for effective markets for at least some of their produce.

Elevation of food crops into cash economy

Major progress in food crop production cannot be achieved and perennial food shortages in the communities will persist as long as a large part of the national food crop production is produced only for subsistence and does not pass through organized market economy and hence contribute to the farmers' cash economy. There is therefore a need to elevate root, tuber and other food crops into the cash or market economy, a position currently enjoyed only by traditional export crops. This would confer a prestige which food crops at present lack as well as justifying the use of the inputs required to raise production.

Technological measures

Root and tuber crops are very perishable. Current wastage for root and tuber crops in Nigeria seem to range from about 15–25 percent of production and this represents a value of several million Naira¹¹.

Bitter cassava contains glucosides which forms poisonous hydrocyanic acid on hydrolysis. The two genera of cocoyam, (*Colocasia* and *Xanthosoma*) both contain poisonous saponins. Bitter yam contains dioscorine which is also a poisonous substance. These poisonous substances could be removed by suitable food processing techniques. The tendency however is to grow and consume sweet cassava whose edible portion of the root is free from hydrocyanic acid, while the bitter yam is usually only eaten during the hungry season when other foods are scarce and expensive.

ROOT CROP PROCESSING

The establishment of food processing plants that can use root and tubers as raw materials at strategic areas in the country would overcome some of the major obstacles to increased root and tuber crop production. It would reduce food waste, make foods of better quality available, and hence would permit fuller and better utilization of root and tuber crops in the national dietaries. Improved food processing facilities should aim to produce foods of high quality which would meet international standards. Such a development could increase the incomes of farmers and therefore create incentives for increased food production which could lead to higher nutritional standards and general national socio-economic development.

REFERENCE

1. Anon. (1973) Perspective Plan for Agricultural Development in Nigeria, 1973–1985. Federal Department of Agriculture, Lagos.
2. Chevallier, A. (1945) Cited in Coursey, D.G. 3.
3. Coursey, D.G. (1967) *Yams. An account of the nature, origins, cultivation and utilization of the useful members of the Dioscoreaceae*. Longmans. 230 pp.

4. Coursey, D.G. and Haynes, P.H. (1970) Root crops and their potential as food in the tropics. *World Crops* 22, 260-5.
5. Dema, I.S. (1965) In *Nutrition in relation to agricultural production*. FAO, Rome. 123 pp.
6. Dema, I.S. and Osamo, N.O. (1966) In: Stamp, D. and Cox, I.H. (Eds.) *Uboma Report, World Land Use Survey, Occasional Paper No. 6*.
7. FAO (1973) *Energy and Protein Requirements*. Report of a Joint FAO/WHO ad hoc expert committee, Rome, 22nd-March-2 April 1971. FAO Nutrition Meetings Report Series No. 52, FAO, Rome.
8. Gopalan, C. (1968) In: McCance, R.A. and Widdowson, E.M. (Eds.) *Calorie deficiencies and protein deficiencies*. Churchill, London.
9. Idusogie, E.O. (1971) The nutritive value per acre of selected food crops in Nigeria. *Journal of W. African Science Assoc.* 16(1), 17-24.
10. — — — — (1973) Centuries of changing food consumption patterns in African communities. Nutrition Bulletin No. 12, Food and Nutrition in Africa. Publ. of Joint FAO/WHO/OAU Regional Food and Nutrition Commission for Africa, Accra, Ghana. 5-45.
11. — — — — , Olayide, S.O. and Olatunbosun, D. (1973) Implications of agricultural wastes on Nigerian nutrition and economy. In Press.
12. Irvine, F.R. (1969) *West African Agriculture (3rd edition) II. West African Crops*. Oxford University Press, 272 pp.
13. Martin, A. (1956) *The oil palm economy of the Ibibio farmer*. Ibadan University Press. 53 pp.
14. Olayide, S.O., Olatunbosun, D., Idusogie, E.C. and Abiagom, J.D. (1972) *A quantitative analysis of food requirements, supplies and demands in Nigeria, 1968-1985*.
15. PAG (1972) A study on protein contents of yams. PAG Bulletin 13(2), 40.
16. Phillips, J. (1959) *Agriculture and ecology in Africa. A study of actual and potential development south of the Sahara*. Faber & Faber. 423pp.
17. UNICEF Fellows (1966) Report of nutritional studies in Mid-Western Nigeria, London/Ibadan Nutrition Course. Ibadan, 1966.

TABLE 1

Yield of root and tuber crops per acre by States, 1968/69 (1,000 lbs)

<u>States</u>	<u>Cassava</u>	<u>Potato</u> <u>(Irish)</u>	<u>Potato</u> <u>(sweet)</u>	<u>Yams</u>	<u>Cocoyams</u>
Benue-Plateau	8.985	6.720	6.720	7.215	1.617
East-Central	8.420	-	-	5.824	5.154
Kano	5.444	6.720	+	+	+
Kwara	5.160	-	+	7.051	1.344
Lagos	9.166	-	+	4.305	2.298
Mid-West	14.819	-	+	6.143	3.394
North Central	3.632	6.720	+	2.005	1.537
North-Eastern	21.573	+	+	5.311	4.260
North Western	3.302	+	+	3.345	+
Rivers	8.420	-	+	3.149	5.040
South-Eastern	8.420	-	+	5.824	7.459
Western	8.179	-	+	8.115	2.977
Potential: yield of best cv. (fresh)	35.840 (bitter cassava)	10,480	10,480	14,400	10,460
+ = positive unknown yield - = no information as to whether the crop is cultivated or not.					
Source: Olayide, S.O., Olatunbosun, D., Idusogie, E.O. and Abiagom, J.D. (1972); Idusogie, E.O. (1971).					

TABLE 2

Estimated acreages of roots and tubers in Nigeria, 1959/60–1969/70 (Million acres)¹³

	<u>Cassava</u>	<u>Potato</u> <u>(Irish)</u>	<u>Potato</u> <u>(Sweet)</u>	<u>Yams</u>	<u>Cocoyams</u>
1959/60	1.802	0.005	0.032	2.164	0.410
1960/61	1.861	0.005	0.032	3.132	0.421
1961/62	1.925	0.005	0.032	3.486	0.446
1962/63	2.137	0.005	0.032	3.208	0.726
1963/64	1.979	0.005	0.032	3.855	0.633
1964/65	2.149	0.005	0.034	4.006	0.699
1965/66	2.048	0.005	0.034	3.777	0.694
1966/67	2.248	0.005	0.037	3.319	0.608
1967/68	2.366	0.005	0.037	3.388	0.712
1968/69	2.226	0.005	0.037	4.195	0.601
1969/70	2.238	0.005	0.039	3.191	0.700

TABLE 3

Estimated production of roots and tubers in Nigeria, 1959/60–1969/70 (Million metric tons)¹³

	<u>Cassava</u>	<u>Potato</u> <u>(Irish)</u>	<u>Potato</u> <u>(Sweet)</u>	<u>Yams</u>	<u>Cocoyams</u>
1959/60	6.882	0.018	0.149	8.910	0.643
1960/61	6.682	0.018	0.149	12.109	0.652
1961/62	7.400	0.018	0.150	13.474	1.150
1962/63	7.600	0.019	0.155	13.102	1.549
1963/64	7.800	0.020	0.160	15.885	1.555
1964/65	8.000	0.021	0.165	14.563	1.625
1965/66	8.200	0.022	0.170	14.736	1.606
1966/67	8.400	0.025	0.175	11.963	1.437
1967/68	8.600	0.023	0.180	10.670	1.625
1968/69	8.820	0.024	0.185	12.392	1.308
1969/70	9.040	0.025	0.190	15.155	1.793

TABLE 4

Contribution of Nigerian foods to the daily per capita supplies of calories and protein¹³

Food	Contribution to total	
	Calories	Protein
Cereals	42.1	48.7
Starch roots, tubers and fruits	34.4	19.6
Oils and fats	10.9	0.0
Legumes	4.9	11.7
Fish and livestock	4.1	15.5
Oil seeds and nuts	1.4	1.8
Sugars	0.8	0.0
Beverages	0.7	0.3
Vegetables and fruits	0.6	2.3

TABLE 5

Mean calorie and protein intakes in Western State of Nigeria

Calorie sources %	ILESHA, Western State	
	Igun Village	Abebeyun Village
Starchy roots	53.8	59.1
Cereals	15.5	10.4
Pulses and other seeds	8.0	5.4
Fruits and vegetables	1.9	3.6
Oils and fats	8.9	12.6
Animal products	6.6	6.8
Others	5.3	2.1
	<u>100.0</u>	<u>100.0</u>
Calorie intake/head/day	1,947.0	2,111.0
Crude protein intake g/head/day	49.0	51.0

Condensed from Dema, I.S. (1965)⁴

TABLE 6

Mean calorie and protein intakes in four villages of Eastern Nigeria⁴

Calorie sources %	Adiasim 1962	Maku 1962	Idembia 1962	Uboma 1963-64
Starchy roots (yams, cocoyams, cassava)	78.0	64.5	81.2	48.7
Cereals	0.8	0.8	0.2	5.5
Pulses and other seeds	2.2	5.6	6.1	10.8
Fruits and vegetables	3.8	4.4	1.5	0.8
Oils and fats	7.2	18.4	5.3	19.7
Animal products	3.0	2.9	4.3	5.8
Others	5.0	3.4	1.4	8.7
	100.0	100.0	100.0	100.0
Calorie intake/head/day	1,686	1,651	1,587	2,881
Protein intake g/head/day	33	34	31	60

TABLE 7

Calorie and protein sources in three Mid-Western Nigeria dietaries¹⁷

	Ewu village		Unoghovo village		Ibusa village	
	Calorie % total	Protein % total	Calorie % total	Protein % total	Calorie % total	Protein % total
Cereals	20	20	3	4	7	7
Roots and tubers	37	20	62	23	69	28
Sugars	1	-	-	-	-	-
Pulses, nuts, seeds	17	36	2	5	5	10
Fruits and vegetables	2	-	1	4	1	4
Meat	1	4	4	32	2	13
Fish	3	20	3	32	5	38
Oils and fats	19	-	23	-	11	-
Others	-	-	2	-	-	-
	100	100	100	100	100	100
Calorie intake/head/day	1,344		1,489		2,210	
Crude protein intake g/head/day	33		27		42	

TABLE 8

Energy (kilocalories) per caput per day contributed by major foodstuffs in the Ibibio, South-Eastern State of Nigeria.¹²

Foodstuffs	House- hold 2	House- hold 3	House- hold 5	House- hold 7	House- hold 9	House- hold 14
Cassava and cassava	1,823	795	1,198	867	716	1,303
Yams	410	485	280	307	641	510
Bananas and plantains	34	15	57	12	26	40
Meat	22	27	4	-	6	12
Local fish	164	152	94	87	167	222
Imported fish	66	35	12	-	26	10
Total calories contributed by the six foodstuffs	2,469	1,509	1,646	1,273	1,682	2,092
% calories contributed by starchy roots, tubers and fruits	92	86	93	93	82	89

TABLE 9

Projected supply and demand of roots and tubers, 1968/69 — 1985 in Nigeria. (1,000 metric tons)

	Cassava	Potato (Sweet)	Potato (Irish)	Yam	Cocoyam
1968/69 Base year supplies	7,521.667	136.141	13,939	7,239.028	802.173
% trend growth of supplies	2.5E	2.5A	2.5A	-0.2SL	2.5A
1975 Projected demand	8,439.310	152.750	15.640	8,122.189	900.038
Projected supply	8,940.899	161.829	15.622	7,138.288	953.532
Surplus	+ 501.589	+ 9.079	-0.018	- 983.901	+53.494
1980 Projected demand	9,183.955	166.228	17.020	8,838.853	979.453
Projected supply	10,115.806	183.095	17.675	7,067.189	1,078.833
Surplus	+ 931,851	+16.867	+0.655	-1,771.664	+99.380
1985 Projected demand	10,191.859	184.471	18.887	9,808.883	1,086.944
Projected supply	11,445.106	207.156	19.998	6,996.799	1,220.601
Surplus	+1,253.247	+22.685	+1.111	-2,812.084	+133.657

Suggest compound annual

rate of growth of supplies(%) 3.50 4.50 4.50 4.50 3.50

+ = positive surpluses that could enter the African and/or international market

- = negative surpluses that would have to be imported unless there is increased production

L = log function; E = Exponential function; SL = Semi-log function;

A = Assumed growth rate.

COMPARATIVE PERFORMANCE: LARGE-SCALE PRODUCTION vs. SMALL-SCALE PRODUCTION OF YAMS AND SWEET POTATOES IN THE CARIBBEAN

C.B. Rankine*

SUMMARY

Sample surveys in the islands of Barbados, St. Vincent, St. Kitts-Nevis and Jamaica have shown that yam and sweet potato production are financially very unattractive. At the present time small farm production achieves higher productivity to land than that on large farms. Improved technology is not adopted and yields are far below those achieved in experiments. Analyses are provided for each island of the costs and returns for each crop under different farming systems.

RESUME

Des résultats d'enquêtes menées dans les îles de Barbados, de St. Vincent, de St. Kitts-Nevis et de la Jamaïque indiquent que la production d'igname et de la patate douce n'a pas d'attrait du point de vue financier. Actuellement la production obtenue dans les petites fermes ont une productivité plus élevée que celle des grandes fermes. Les techniques améliorées ne sont pas adoptées et les rendements sont de loin en dessous de ceux qu'on obtient sur les parcelles expérimentales. Les coûts et les bénéfices pour chaque culture selon des systèmes adoptés ont été analysés par île.

RESUMEN

La producción de ñame y camote es muy poco atractiva desde el punto de vista financiero según nuestras encuestas en las Islas de Barbados, St. Vincent, St. Kitts-Nevis y Jamaica. Actualmente la producción en las fincas pequeñas alcanza una mayor productividad de la tierra que en las fincas grandes. La tecnología mejorada no se adopta y los rendimientos se encuentran muy por debajo de los que se alcanzan en los experimentos. Se proveen análisis de costos y utilidades para cada cultivo bajo diferentes sistemas agrícolas.

INTRODUCTION

Root crop investigations using satisfactory experimental techniques in the English-speaking Caribbean countries have included agronomic, physiological and bio-chemical studies. Little attention however has been paid to economic and social aspects of root crop production although these crops are staples in the diet of most of the population and contribute to an important extent to the growth and development of their economies. Domestic consumption of root crops is estimated at about 80 percent of production with 20 percent being exported to the growing markets in North America and Europe. Domestic consumption has increased rapidly because of recent shortages of other foods in many of the Caribbean countries. Many people preferred other foods to root crops because of their high starch content and the form of their presentation in the market. Today the situation is gradually changing, not only because of the apparent food shortage but also because of the tight monetary situation.

A recent review of agricultural policies by Edwards and Cropper¹ of many Caribbean countries has shown heavy emphasis on programmes to stimulate the production of food crops and programmes designed to encourage the consumption of more locally produced foods in order to reduce the national food import bill. However, production is not keeping pace with demand. This has resulted in price increases for these commodities.

Two major reasons for the failure of supply to keep up with demand is the lack of knowledge or application of the techniques appropriate for large-scale commercial production. These crops are still considered as 'peasant crops' despite efforts to stimulate their production on large farms. Large-scale farmers have not yet shown much interest in root crops, some because they are preoccupied with other crops, and others who resent the fact that they are required by law to change their pattern of land utilization to accommodate these crops. Other farmers are enthusiastic but lack sufficient knowledge to make a success of the crop. Because of the numerous problems which have reduced the effectiveness of the Food Crop Laws, at least one country is contemplating repeal of the laws.

*Agricultural Economist, Faculty of Agriculture, University of the West Indies, Mona, Kingston, Jamaica.

That the small farms carry the bulk of root crop production has origins dating back to the days of slavery. Small farm lands are usually situated on the fringes of the large sugar estates or in inaccessible, often steep areas of the country. However, they have managed to continue their production from year to year. Very little assessment has previously been made of their performance in relation to that of the large producers now being required to grow root crops. Should development be aimed at large-scale producers or small-scale producers? Should a strategy be adopted which would lead to the development of specialized producers along the lines of the more traditional crops such as sugarcane, coffee, citrus and bananas? We have lacked statistics necessary even to begin to be able to answer these questions. In this paper I shall try to present some data relevant to the development of an appropriate strategy for root crop production in the Caribbean.

INDICES OF PRODUCTION

In this paper yam and sweet potato production on large farms is compared with their production on small farms, using four indices: labour utilization, productivity to land, productivity to labour and relative profitability.

By labour utilization is meant the number of hours or man-day equivalents required to produce one crop. Total labour used is converted to man-day equivalents by simply dividing the total number of hours by 8 (the standard working day) to get the required coefficient.* Productivity is measured as the average saleable yields per acre per crop and as the number of pounds of the crop produced per hour of labour used. It was not possible to derive marginal productivities because the data are at present too incomplete. Profitability is measured as net return per pound of produce.

SAMPLING METHOD FOR THE SURVEY

Between 1969 and 1971 some 700 farms, both large and small, were visited for collection of data. These comprised 116 farms in Barbados, 88 farms in St. Kitts-Nevis, 261 farms in St. Vincent and 241 farms in Jamaica. Farm size ranged from under one acre to several hundred acres. The primary concern was with root crops rather than on the entire farm even though some information on other farm activities was registered. This survey was later supplemented with smaller selected observations on the crops during the same period.

Few sophisticated sampling techniques were adopted. Other surveying consisted of marshalling the forces of the Ministries of Agriculture, informed individuals, other University personnel, marketing boards and other relevant bodies to ensure that the farms covered were representative of the area in which they were located. The structural features of the countries' agriculture were a significant factor in the selection of the farms. The four countries of the survey are the major ones producing root crops in the English-speaking Caribbean both in terms of acreage devoted to the crop and quantity produced.

The data collected from the survey and subsequent additional studies have been analyzed. Several conclusions resulting from this survey are currently being used as the basis for more advanced studies on the root crop industry.

RESULTS

Systems of production – general

In the Caribbean, yams are generally planted between May and June, just before the onset of the rains. Very little attention is given to which species or cultivar to plant, except where special clones are known to be best suited to the specific areas e.g. of *Dioscorea rotundata* in parts of Jamaica and of *D. alata* in parts of Barbados. Lands are usually forked or ploughed where possible, mechanically or otherwise, then rows, hills or banks are formed at varying distances from 3 – 5.5 ft. Two pieces of yam heads or setts, varying in size from 4 gunces to 4 pounds, are inserted in holes dug on the hills or banks. The crop is weeded two or three times between planting and harvesting which takes place some 8–9 months later, depending on the variety. Very few producers apply fertilizer.

The technology adopted on sugar plantations or estates is similar to that described above for the small farm except that planting distances are standardized to meet the requirements of the coming sugarcane crop, and a little fertilizer is applied. Yams may be staked, as in Jamaica and some parts of St. Vincent, or left to run along the ground, as in Barbados and St. Kitts-Nevis.

For sweet potatoes, the land is prepared in a similar manner. Row spacing may differ depending on the amount of planting materials available or whether they are being produced on estates or small farms – dis-

*A full working day (agric. or industrial) is now however considered to be 5–6 hours in many parts of the Caribbean.

tances vary between 2'6" – 4'. Vines used in planting vary between 6–9 inches in length. Generally two to four vines are planted in each hole. Fertilizer application is rare. Two weedings are generally carried out for the 3–4 month crop.

It is clear from the variety of methods used that no scientifically determined system of production has been developed and passed on to farmers for use in the production of these crops. What has been described briefly above are largely the habits that have been formed and evolved by the farmer himself over the years. As a result there is a very wide difference between the yields reported from experiments and those obtained in the field. It is largely because of this that efforts have begun in the Faculty of Agriculture of the University of the West Indies to try and extend, or at least to test, experimental findings under commercial conditions in several of the Caribbean countries.

Labour utilization, productivity and relative profitability

This section contains data on labour use, productivity, profitability and costs for various farming situations in the four countries of the survey. Yam and sweet potato production in Barbados and St. Kitts-Nevis are largely on sugar plantations or estates but also on small farms while in St. Vincent and Jamaica they are produced largely in the small farm sector.

Barbados:

Data in Table 1 shows an acre of yams produced on small Farms in Barbados required approximately 430 hours or 54 man days for the duration of the crop – divided almost equally between help from within the family and outside help. A 3–4 month sweet potato crop requires about 300 hours of labour or 27 man-days. On the other hand, production of these crops on estates or plantations demands less labour, only 233 hours or 29 man-day equivalents for yams and 159 hours or 20 man-days for sweet potatoes. The reason for this difference is that small farmers depend heavily on hand labour to carry out most of the cultural practices while on estates several of these operations are done mechanically. These include land preparations, transporting of planting materials and haulage of produce at harvest.

Table 2 presents productivity to land and labour for yams and sweet potatoes in Barbados.

As shown in the Table, yield per acre, the crude indicator of land productivity was significantly higher on small farms than on productivity was significantly higher on small farms than on plantations/estates both for yams and sweet potatoes. Small farms produced over 3,000 pounds more yams and about 2,500 pounds more sweet potatoes on the average than their counterparts on the estates. Yield per hour of labour used showed the reverse trend. Plantations/estates produced 50 percent more yams and over 100 percent more sweet potatoes per hour of labour used than small farmers. Small farmers produced only between 28 and 30 pounds of produce per hour of labour used while plantations averaged between 46 and 62 pounds of produce.

Table 3 presents data on relative profitability as measured by net returns per pound. With few exceptions, yam production appears profitable but margins were extremely low on both small farms and estates. Sweet potatoes were much more profitable particularly when produced by small farmers. On the other hand, small farmers tended to have higher production costs for both crops than those on plantations. It costs between 5–13 cents to produce a pound of yams on small farms and between 5–7 cents per pound on the estates. Sweet potatoes cost 3–6 cents to produce on small farms and 2–5 cents per pound on plantations/estates.

The structure of the production costs as indicated by percentage of total cost is presented in Table 4. Costs are broken down into variable and fixed components. For yams, expenditure on labour ranged between 55–85 percent of total costs on the small farms but only 46–47 percent on plantations/estates. Expenditures on materials and equipment varied from 30–39 percent on small farms and 35–47 percent on plantations. Marketing costs were relatively small in both circumstances, and in neither case exceeded 10 percent, but they were higher on plantations. Fixed costs – mainly land tax and rent – were relatively small on both small and large farms.

St. Kitts-Nevis:

Data on labour used (family and hired labour) in producing yams and sweet potatoes in St. Kitts-Nevis are presented in Table 5.

Data on yield per acre and yield per hour of labour used are presented in Table 6. The yam yields obtained on small farms were more than twice the yields obtained on plantations/estates, while sweet potato yields were more than three times the average quantities produced on estates.

Yam yields per hour of labour were similar on both small farms and estates.

Data presented in Table 7 show positive net returns to yams on small farms and on estates in St. Kitts-Nevis. Both yam and sweet potato production were more costly on plantations/estates than on small farms in St. Kitts-Nevis.

Distribution of the costs among production inputs again showed a high proportion for labour in relation to other inputs (Table 8). For yams, the labour component of cost was considerably higher on small farms than on estates.

St. Vincent:

The data for St. Vincent is tabulated according to areas in which the sampled farms were located, different agricultural districts having different rainfall patterns. Those in the Windward part of the island usually receive more rainfall than those on the Leeward side.

Table 9 present information on the number of hours used in producing an acre of yams and sweet potatoes in St. Vincent on small farms.

Farms in the Windward section of the island use approximately 193 man-days to produce one acre of yams, while those on the Leeward side use 139 man-days. Sweet potato production requires about 68 man-days on the Windward, but only 45 man-days on the Leeward side of the island. There is heavy dependence on hired labour.

Table 10 presents data on yield per acre and yield per labour hour. Productivity to land for yams appears from our sampled farms to be higher on the Leeward side than it is on the Windward side, while the reverse is true for sweet potatoes. Yield per hour of labour used for yams was about 6 pounds for all farms, but there was an apparent difference of about 1 pound per hour in favour of the Leeward side of the island for production of sweet potatoes.

Table 11 presents returns on yams and sweet potatoes produced in St. Vincent. Both crops appear to be unprofitable in the Leeward areas but sweet potatoes showed profits in the Windward areas.

The distribution of costs is presented in Table 12.

Labour costs were much higher than costs of materials used in producing sweet potatoes, while marketing costs amounted to 11 and 10 percent in each producing area. Fixed costs were low.

Jamaica:

Data are stratified according to land authorities. Agriculture is administered 'independently' in each authority.

Labour used for yams and sweet potatoes is presented in Table 13. Considerably less labour was used in producing sweet potatoes than yams.

Yield per acre per hour of labour are presented in Table 14.

Net returns to yam are presented in Table 15. It is apparent that there are very few instances of profit.

Labour costs (Table 16) represented between 68 and 85 percent of total costs for sweet potatoes and 33-60% for yams. Expenditure on materials varied between 11 and 20 percent, while fixed charges were only between 1 and 2 percent of total costs.

DISCUSSION

The high and costly labour inputs are noteworthy, especially on the small farms. Small farms would be unable to take advantage of many mechanical devices because of the steep slopes on which the majority of the farms were located especially in Jamaica and St. Vincent. Labour costs were also high, partly because small farms had to compete in the same labour market as the large farms and plantations. The situation is aggravated by the present shortage of labour and the unwillingness of labour to work on eight hour days. Family labour provided a higher proportion of work in Barbados, St. Kitts and Jamaica, whereas farmers in St. Vincent used more hired labour.

Small farms achieved higher production per unit of land, but lower production per hour of labour than large farms in Barbados. In St. Kitts small farmers produced more both per unit of land area and per unit of labour. Small farmers in Jamaica achieved high land productivity, but their labour productivity was significantly lower than in Barbados.

Land and labour are relatively unproductive in St. Vincent.

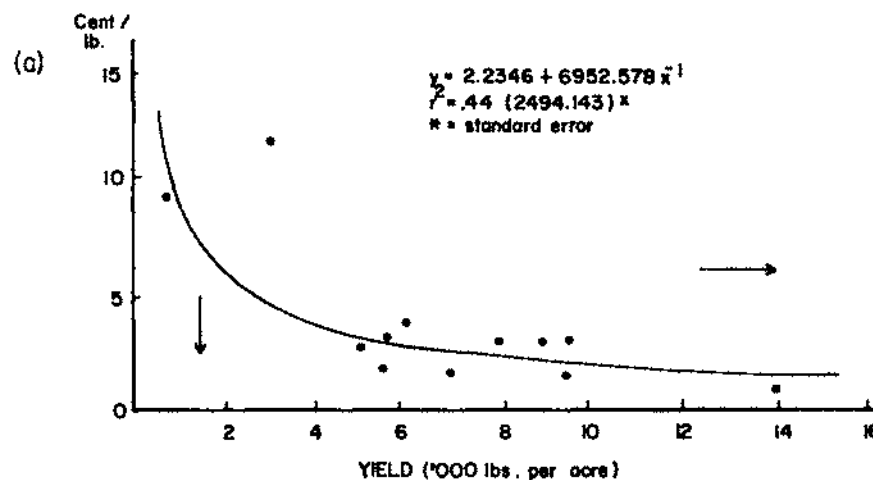
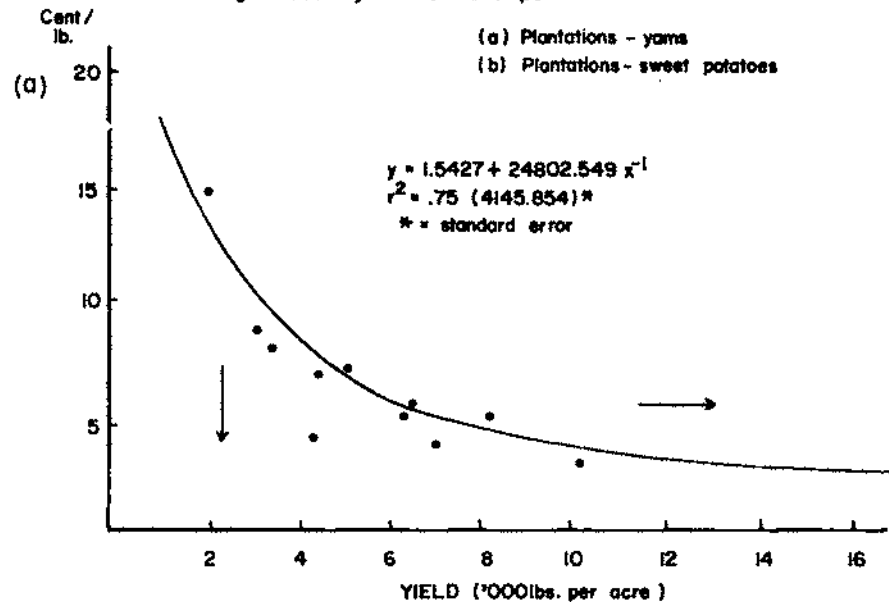
It is clear that neither yam nor sweet potato production in the four countries studied were very profitable operations. Production costs were much higher in Jamaica and St. Vincent than in Barbados and St. Kitts-Nevis because of the labour component necessitated by the steep terrain.

Expenditure on marketing was higher on plantations than on small farms in both Barbados and St. Kitts-Nevis. This was associated with the use of 'well-defined' marketing channels.

However, there are indications that the situation for production and marketing of root crops can be improved. The first problem that should be tackled concerns efforts to increase yield per acre to a level more nearly approaching those achieved in experimental stations, since this has a direct bearing on the overall returns from production. The present relationship between yield and costs is remarkable in that farms with higher yields also had much lower production costs (Figs. 1, 2). A shift in the production functions should be possible to achieve.

But how can this be done? From these preliminary findings it would be obvious to suggest paying greater attention to small farmers; but how long will these farmers remain with us? Will they be able to

Fig 1. Cost - yield relationships



make the most effective use of new technology required to bring about the required overall shift in the production function? The production function *must* be shifted if supply is to be able to satisfy demand and in order in the future to keep 'processing plants' operating at full capacity.

REFERENCES

1. Edwards, D.T. and Cropper, J. (Undated) An economic view of the development of new production systems: with particular reference to root crops in the West Indies. Department of Agricultural Economic and Farm Management, University of the West Indies, St. Augustine, Trinidad.
2. Rankine, L.B. (1972) Comparative economics of root crop production in selected countries of the Commonwealth Caribbean. 1. Cost and returns for specified root crops. Occasional Series No. 8, Department of Agricultural Economics and Farm Management, Univ. of the W. Indies, St. Augustine, Trinidad.
3. ———— McConnie, H., Daniel, G. and Stewart, H. (1972) Economic evaluation of food crops produced on selected farms in St. Vincent 1970-71. Occasional Series No. 7, Dept. of Agric. Econ. & Farm Management, Univ. of the W. Indies, St. Augustine, Trinidad.

Fig 2. Cost - yield relationships

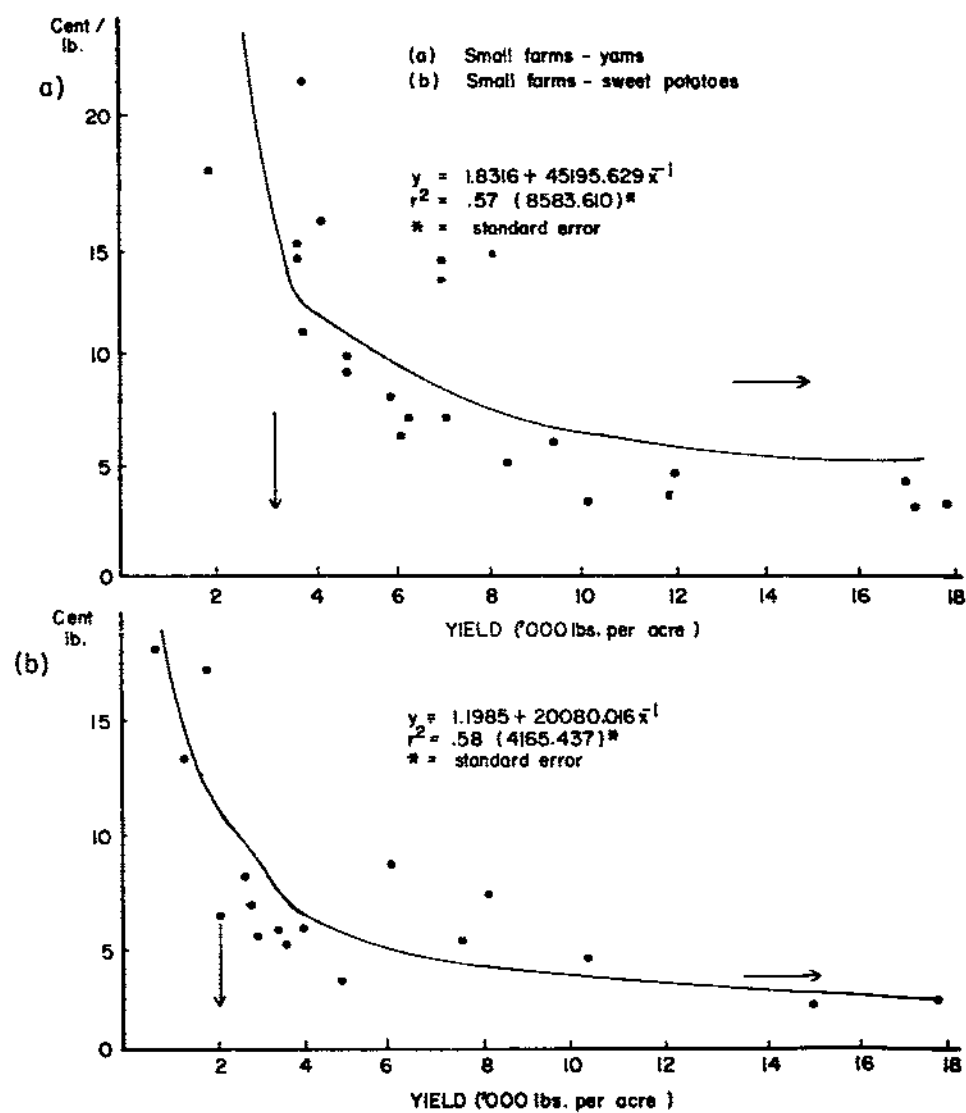


TABLE 1

Number of hours used for acre: yams and sweet potatoes, Barbados

SMALL FARMS (less than 2 acres)			
<u>Yams</u>		<u>Sweet potatoes</u>	
Hired labour	Family labour	Hired labour	Family labour
hrs	hrs	hrs	hrs
315	80	122	80
266	157	127	123
89	380	102	232
Av. 224	206	154	145
Man-day equiv.28	26	19	18
PLANTATIONS/ESTATES (more than 10 acres)			
188	-	134	-
237	-	139	-
274	-	203	-
Av. 233		159	
Man-day equiv.29		20	

N.B. The three entries in each column in this and all tables for Barbados indicate data for each rainfall zone - low, intermediate and high respectively.

Source: Rankine (1972)

TABLE 2

Land and labour productivity on farms producing yams and sweet potatoes in Barbados

		Yield per acre	
		Small farms	Plantations/estates
Yams lbs.	Sweet potatoes lbs.	Yams lbs.	Sweet potatoes lbs.
5,331	7,073	4,181	6,154
15,378	9,877	6,862	9,782
10,441	13,091	7,574	7,053
Av. 10,383	10,014	6,216	7,663
Yield per man hour of labour used			
17	27	38	46
43	30	30	86
23	34	80	53
Av. 28	30	46	62

Notes: Figures are rounded off for computation ease.

Reported yields are saleable yields.

Source: Rankine(1972)

TABLE 3

Relative profitability — net returns and costs of production for yams and sweet potatoes in Barbados

Farm types	Yams		Sweet potatoes	
	NR	CP	NR	CP
Small farms	-5.3	13.0	3.3	6.3
	0.7	6.3	3.3	3.3
	5.6	5.3	5.0	5.0
Plantations/ estates	0.3	6.3	1.6	2.3
	1.6	5.0	0.6	2.6
	-0.6	7.0	-	4.6

NR = net returns per pound (cents)

CP = cost of production per pound (cents)

Source: Rankine(1972)

TABLE 4

Structure of production costs — yams and sweet potatoes Barbados

Cost factors	Small farms						Plantations/estates					
	<u>Yams</u>			<u>Sweet potatoes</u>			<u>Yams</u>			<u>Sweet potatoes</u>		
<u>Variable cost</u>	(percentage of total costs)											
Labour	63	55	65	86	65	65	46	47	55	54	45	55
Materials and equipment use	30	39	32	13	32	29	47	44	35	42	45	38
Marketing	1	2	2	-	2	4	5	8	8	5	9	6
<u>Fixed costs</u>												
Rent,tax and sundries	6	4	1	1	1	2	2	1	2	1	1	1

The data in the columns reading from left to right in each section represent low, intermediate and high rainfall zones respectively.

Source: Rankine (1972)

TABLE 5

Number of hours used per acre in producing yams and sweet potatoes in St. Kitts-Nevis

	SMALL FARMS (under 1-5 acres)			
	Yams		Sweet potatoes	
	Hired labour	Family labour	Hired labour	Family labour
	hrs	hrs	hrs	hrs
St. Kitts	255	189	178	88
Man-day equivalents	32	24	22	11
Nevis	501	97	339	190
Man-day equivalents	63	12	42	24
PLANTATIONS/ESTATES				
St. Kitts	217	-	84	-
Man-day equivalents	27	-	10.5	-

Source: Rankine (1972)

TABLE 6

Land and labour productivity of farms producing yams and sweet potatoes in St. Kitts-Nevis

Productivity	Small farms		Plantations/estates	
	Yams	Sweet potatoes	Yams	Sweet potatoes
	lbs.	lbs.	lbs.	lbs.
Yield per acre				
St. Kitts	6,576	2,741	2,538	839
Nevis	5,237	2,046	-	-
Yield per hour of labour used				
St. Kitts	15	10	12	10
Nevis	9	4	-	-

Source: Rankine(1972)

TABLE 7

Relative profitability — net returns and cost of production for yams and sweet potatoes in St. Kitts-Nevis

	YAMS		SWEET POTATOES	
	NR	CP	NR	CP
Small farms				
St Kitts	4.0	6.0	2.0	6.0
Nevis	6.0	8.0	-7.0	17.0
Plantations/estates				
St Kitts	2.0	9.0	-*	9.0

* Breakeven point

NR = net returns per pound (cents)

CP = cost of production per pound (cents)

Source: Rankine (1972)

TABLE 8

Structure of production costs — yams and sweet potatoes — St. Kitts-Nevis

<u>Cost factor</u>		<u>Small farms</u>				<u>Plantations/ estate</u>	
<u>Variable</u>		<u>Yams</u>		<u>Sweet potatoes</u>		<u>Yams</u>	<u>Sweet potatoes</u>
Labour		71	67*	82	85*	53	61
Materials and equipment use		23	24	13	10	36	30
Marketing		4	6	3	3	6	7
<u>Fixed</u>							
Rent, tax and sundries		2	3	2	2	5	2

* Data in these columns refer to Nevis, others are for
St. Kitts.

Source: Rankine (1972)

TABLE 9

Number of hours used per acre in producing yams and sweet potatoes in St. Vincent

<u>Agricultural districts</u>	<u>YAMS</u>		<u>SWEET POTATOES</u>	
<u>Windward section</u>	Hired labour hrs.	Family labour hrs.	Hired labour hrs.	Family labour hrs.
No. of hours	1,254	294	452	94
Man-day equiv.*	157	36	56	12
<u>Leeward section</u>				
No. of hours	863	248	278	72
Man-day equiv.	108	31	36	9

* Man-day equivalents: 8 hours day
Source: Rankine (1972)

TABLE 10

Land and labour productivity — yams and sweet potatoes — St. Vincent

Productivity	YAMS	SWEET POTATOES
<u>Windward section</u>	lbs	lbs
Yield/acre	4,424	3,983
Yield/hour of labour used	6	8
<u>Leeward section</u>		
Yield /acre	5,554	3,096
Yield/hour of labour used	6	9

Note: Figures are rounded off for computational ease.
Indicated yields are saleable yields.

Source: Rankine (1972)

TABLE 11

Relative profitability — net returns and cost of production — yams and sweet potatoes — St. Vincent

Agricultural districts	YAMS		SWEET POTATOES	
	NR	CP	NR	CP
Windward areas	-6.0	18.5	1.0	5.0
Leeward areas	-4.0	14.5	-1.5	6.5

NR = net returns per pound (cents)

CP = cost of production per pound (cents)

Source: Rankine (1972)

TABLE 12

Structure of production costs — yams and sweet potatoes — St. Vincent

<u>Cost factors</u>		YAMS		SWEET POTATOES	
<u>Variable</u>		Windward	Leeward (% of total cost)	Windward	Leeward
Labour		50	48	76	73
Materials		43	45	11	16
Marketing		6	6	11	10
<u>Fixed</u>					
Rent, tax, sundries.		1	1	2	1

Source: Rankine (1972)

TABLE 13

Number of hours used per acre — yams and sweet potatoes — Jamaica

Land Authorities	YAMS		SWEET POTATOES	
	Hired hrs	Family hrs	Hired hrs	Family hrs
Santa Cruz	-	-	232(29)	162(20)
Grange Hill	801(100)*	416(52)	-	-
Cambridge	705(88)	298(37)	-	-
Falmouth	482(60)	597(74)	241(30)	527(66)
Claremont	507(43)	226(28)	230(29)	118(15)
Linstead	669(83)	341(43)	-	-
May Pen	596(73)	237(29)	-	-
Mandeville	548(68)	287(36)	276(24)	115(14)
Christiana	325(41)	503(63)	-	-

* Refers to man-day equivalents

TABLE 14

Land and labour productivity — yams and sweet potatoes — Jamaica

Agricultural districts	YAMS		SWEET POTATOES	
	Land	Labour	Land	Labour
Grange Hill	7,123	6	-	-
Cambridge	12,254	12	-	-
Falmouth	5,409	5	1,886	2
Claremont	6,997	10	2,440	7
Mandeville	9,616	11	3,782	10
Christiana	5,623	7	-	-
Linstead	6,157	6	-	-
May Pen	10,314	12	-	-
Santa Cruz	-	-	4,898	12

Note: Land productivity lbs./acre
Labour productivity lbs/hour

Source: Rankine

TABLE 15

Relative profitability — net returns and cost of production — yams and sweet potatoes — Jamaica

Agricultural districts	YAMS		SWEET POTATOES	
	NR	CP	NR	CP
Grange Hill	-9.0	14.0	-	-
Cambridge	2.0	4.0	-	-
Falmouth	-3.0	9.0	-10.0	13.0
Claremont	-1.0	7.0	- 2.0	4.0
Mandeville	-1.0	6.0	- 1.0	5.0
Christiana	-2.0	6.0	-	-
Linstead	-2.0	7.0	-	-
May Pen	1.0	4.0	-	-
Santa Cruz	-	-	1.0	3.0

Note: NR = Net returns per pound (cents)
CP = Cost of production per pound (cents)

Source: Rankine (1972)

TABLE 16

*Structure of production costs — yams and sweet potatoes — Jamaica

Cost factors		YAMS								SWEET POTATOES			
		GR	Ca	F	C1	L	MP	M	C	F	C1	M	S
Variable													
	Labour	33	51	42	38	54	43	40	60	85	72	80	68
	Materials	64	42	51	54	43	50	58	37	11	20	16	20
	Marketing	2	6	6	6	1	6	1	1	3	6	2	1
Fixed													
	Rent, tax sundries	1	1	1	2	2	1	1	1	1	2	2	1

Note: Gr = Grange Hill C1 = Claremont M = Mandeville
 Ca = Cambridge L = Linstead C = Christiana
 F = Falmouth MP = May Pen S = Santa Cruz

Source: Rankine (1972) * Percentage of total costs.

THE INFORMATION CENTER AT CIAT

F. Monge *

SUMMARY

1500 articles from the widely scattered literature on cassava have been assembled and processed as abstracts and keywords. The summary cards are linked to a retrieval system on the TERMATREX principle. Complete sets of abstract cards can be obtained or a selected set of references to cover particular topics can be ordered.

RESUME

1500 articles d'ouvrages sur le manioc dispersés ca et là ont été rassemblés sous forme de documents classés. Les fiches ont un système de récupération basé sur la méthode TERMATREX. On peut obtenir des collections de ces fiches au complet ou commander des collections couvrant un sujet précis.

RESUMEN

1500 artículos provenientes de literatura sobre yuca ampliamente dispersa se han concatenado y procesado como compendios y palabras clave. Las tarjetas-resumen se eslabonan a un sistema de recuperación sobre el principio TERMATREX. Se pueden obtener juegos completos de tarjetas compendio o se pueden ordenar juegos seleccionados de referencias para cubrir un tema determinado.

INTRODUCTION

The Centro Internacional de Agricultura Tropical, CIAT, is directed toward the agricultural and economic development of the lowland tropics. CIAT seeks to assist such development through research and training, and the stimulation and strengthening of national capacities in both these areas. The specific action targets of CIAT programmes are:

1. Agricultural Development, as indexed by *increased productivity per person and per unit of area, as well as increased output* of the basic food commodities of the area served.
2. Institutional Development, as evidenced by increased willingness, technical competence, and organizational ability of national institutions to cope with continuing problems related to agricultural and economic development in the lowland tropics.

CIAT concentrates efforts and resources on six agricultural commodities for lowland farming systems — beef, cassava, beans, swine, rice and corn. In addition, CIAT is also concerned with overall agricultural production systems for tropical areas.

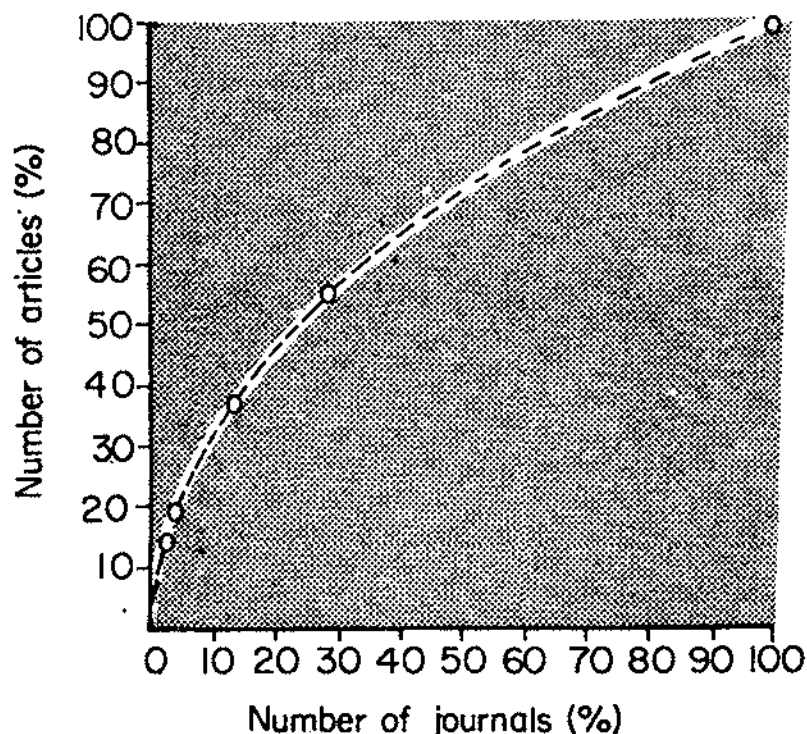
CIAT's systems approach to solving problems calls for a specialization in terms of problems rather than disciplines. If a library is to be an effective tool with such an organization, it must also mirror the organizational nature of the institution and its philosophy. Thus the CIAT library and information service is crop oriented.

THE CASSAVA LITERATURE

Since cassava is one of the commodities receiving major emphasis at CIAT, our information activities on this crop are similarly strong. However, the literature on cassava is sparse as traditionally it has been considered a 'backyard crop' and only sporadically has systematic research been done on it. Consequently, cassava literature is scattered through a wide range of publications from many countries.

In 1971, a preliminary analysis of the scope of the cassava literature was performed¹. A sample of 162 articles published in the last four years was obtained from a search done at the National Agricultural Library, Beltsville, Maryland. Figure 1 illustrates the results of plotting the number of articles against the cumulative number of journals ordered from those with the greatest to those with the least number of articles on cassava.

* Associate Communication Scientist and Librarian, Centro Internacional de Agricultura Tropical, CIAT, P.O. Box 6713, Cali, Colombia.



This curve shows that approximately 50 percent of the articles published on cassava appear in a core group of 28 percent of the journals, and therefore, covering the remaining 50 percent of the articles requires subscription to a great number of marginal journals. Elaborating these data further, a reference-scatter coefficient can be calculated, which is a numerical indicator of the diversity of journals in which information on a particular area appears. While the reference-scatter coefficient for all tropical and sub-tropical agriculture literature as calculated by Lawani² is 0.61, the coefficient for cassava (on the basis of the above-mentioned sample) is 0.93. For comparison, in a more specialized field, the petroleum literature, has a reference-scatter coefficient of 0.43³.

The wide scatter of the cassava literature and the need for centralizing all cassava literature as well as being able to provide rapid access to information on any specialized aspect of cassava research and practice, made CIAT adopt a document-by-document approach in conjunction with a simple mechanized system of information handling.

THE CIAT CASSAVA DOCUMENTATION SYSTEM

With the partial support of the International Development Research Centre, IDRC, of Canada, the Cassava Information Center was established as a special project under the Library and Documentation Services Program of CIAT. Since the total production of cassava documents in the world is rather small (estimated around 4,000) the Cassava Information Center aims at collecting all the literature produced on this crop. In order to accomplish this, the CIAT Librarian travelled to several institutions in the world that were likely to have at least significant portions of the cassava literature in their holdings. Some of the institutions visited were the Royal Tropical Institute (Holland), the Tropical Products Institute (England), the Institut pour la Recherche Agronomique Tropicale, IRAT (France), and others, where copies of all their cassava references were made for future ordering of photocopies of documents. Additional contacts were made by mail and specific searches were requested from institutions such as the National Agricultural Library, Beltsville, Maryland, USA, the Instituto Brasileiro de Bibliotecologia e Documentacao, IDDB, Rio de Janeiro, Brazil, etc.

The final result of this initial effort to collect references was represented by 20 separate lists each containing from approximately 200 to 2,000 cassava references, on the basis of which, acquisition activities began. Of the estimated 4,000 documents existing in the world on this crop, approximately 3,500 have been identified and ordered by CIAT, and nearly 3,000 have already arrived.

Processing the documents after arrival is a time-consuming operation. An accession number is given to each document regardless of topic. This number will identify the document throughout its 'life' in the Center. Once the complete literature citation is obtained and written according to the rules adopted by the Center, a search for an already existing abstract in any of the standard Abstract Journals is performed. If this search proves to be unsuccessful, an abstract is drawn up by our cassava specialist in the Library who is an M.S. agronomist. In some specific instances, however, a paper may require more specialized treatment,

so our team of cassava specialists collaborates in making abstracts or giving technical assistance to our information science personnel.

Perhaps the most critical step in the processing of documents is that of assigning key-words or descriptors to the document, since these constitute the handles, so to speak, through which documents will be located afterwards when searches on specific topics, or individual interest profiles are performed. Although key-words are obtained from the document title and text itself, many complex problems may arise in the actual use of particular words for descriptors. As an example, the word *Nitrogen* is most likely linked with the field of *Fertilizers*. However, after performing one of our first searches on this topic, we realized that *Nitrogen* is also quite frequent in the context of *Foliar analysis* and, consequently, provisions have to be made in the system to correct for this and other types of problems.

Key-words, therefore, are not included in the system without careful consideration of their possible meanings and relations to other key-words. With the help of a thesaurus specialist, Mr. Donald Leatherdale from IDRC, a specialized cassava thesaurus was produced, which constitutes the 'official register' of terms used by the Center. In addition, this thesaurus is an invaluable tool for searching, since it includes broader terms (BT), narrower terms (NT), related terms (RT), and scope use, and use of notes (SN, USE, UF) which help to determine the specific meanings or usage of a certain term. The following example of thesauri terms may be helpful in illustrating this point.

PRICE MAINTENANCE

BT PRICES

PRICES

SN: Use for cassava products and comparative data only

BT ECONOMICS

NT PRICE MAINTENANCE

RT CASSAVA PRODUCTS

PROCESSED PRODUCTS

BT CASSAVA PRODUCTS

NT CASSAREEP

CASSAVA BEER

CASSAVA MEAL

DRIED TUBERS

PULP

TAPIOCA FLOUR

RT FERMENTED PRODUCTS

PROCESSING

SN: Processing of tubers to the manufacture (but not use) of cassava products

NT BOILING

CENTRIFUGING

DRYING

FERMENTATION

GELATINIZATION

GRINDING

PEELING

PRESSING

PULPING

RASPING

SCREENING

SILTING

STEEPING

WASHING

RT MECHANIZATION

NUTRIENT LOSS

WATER REQUIREMENTS (PROCESSING)

Product applications

USE USES

PRODUCTION
 RT ECONOMICS
 FACTORIES
 FORESTRY
 MARKETING

Product costs
 USE COSTS

PRODUCTIVITY
 UF LOSS OF YIELD
 YIELDS
 NT ENERGY PRODUCTIVITY
 STARCH PRODUCTIVITY
 TUBER PRODUCTIVITY
 RT WASTES

The output of the system is a card containing the bibliographic citation, the key-words and an abstract of the document. Figure 2 shows a typical abstract card.

CIAT, Apartado aéreo 6713, Cali, Colombia

1766 SILVA, W.J. DA Plano de melhoramento da mandioca (*Manihot esculenta* Crantz). (Cassava a breeding program). Agrônômico 23:100-116, 1971. Port., 7 Rel., Illus.

Cassava. *Manihot esculenta*. *Manihot melanobasis*. *Manihot saxicola*. Cassava programs. Plant breeding. Brazil.

Work done on cassava breeding in Madagascar, Tanzania, Indonesia, India and Brazil is discussed in order to establish a parallel to the following program, which should be carried out in chronological order: (1) collection of material to form a germplasm bank. Progeny of *Manihot melanobasis* and *M. saxicola* should be included because of the favorable characters they can contribute toward improving *M. esculenta*; (2) screening of promising material in yield trials; and (3) crossing of selected clones. Steps taken to incorporate genetic variability through hybridization include dialled crosses, self-pollination and individual crosses of self-pollinated plants. (Summary by S.S. de S. Trans. by T.M.) G01

Figure 2. A typical abstract card.

INFORMATION RETRIEVAL SYSTEM

The system used for retrieval is based on the principle of optical coincidence of interior-punched cards. As described by the REMAC International Corp., manufacturers of the equipment used in our Center, "TERMATREX is a system for storing and retrieving information. The system, like all data and information systems, consists of items such as a research report, personnel records, correspondence etc., which are indexed for the system, and characteristics, which are the terms used to describe these items. TERMATREX, however, is an inverted retrieval system. Where conventional systems employ a card for each item and indicate characteristics on this card, TERMATREX uses a card for each characteristic and indicates on the card every item having this characteristic.

Each TERMATREX card represents one characteristic, key word, or term. On every card there are 10,000 distinct positions. One item is assigned to each of these positions. A hole is drilled in the position assigned to an item to indicate 'yes', this item has the characteristic represented by the card. The absence of a hole in the card means, 'no' this item does not have this characteristic. The information in the TERMATREX system is searched by posing a question, selecting the card or cards representing the characteristics encompassed by the question, and superimposing these cards over a light source. The holes drilled to indicate 'yes' will allow light to pass through, indicating that the items represented by these positions contain material relevant to the question asked. The accession numbers of the items desired are easily determined using scale devices. The number of holes showing are rapidly counted using an automatic counting device.'

SERVICES PROVIDED BY THE CENTER

The Cassava Information Center at CIAT provides two types of services. One is a *current awareness service* by which all abstract cards are regularly distributed to subscribers.* Although the capacity for selective dissemination of information according to specific interest profiles exists within the system, this is not being done at present since it is considered that information on cassava is very scanty anyhow, and thus, cards dealing with topics not falling within the specific interest of a particular scientist may be passed on to other colleagues or institutions that would welcome this type of information.

The other service provided by the Center is *retrospective searches* performed on specific topics upon request. These are charged at the rate of US\$5.00 per search and always cover the entire data base at a given point in time. The user receives a set of those abstract cards dealing with the topic or combination of topics requested.

PROJECTIONS FOR 1974

The Center has processed to date approximately 1,500 articles. It is expected that during 1974, an additional 2,000 to 2,500 articles will be fully processed, thus completing the major portion of past literature. Efforts, however, will not be concentrated only on past literature but the Center will continue its present policy of giving first priority to processing current articles appearing in the literature.

Our plans for 1974 also include the publication of a bibliography in book-form of all the citations and abstracts of articles in the Cassava Information Center. Presently, all abstract cards produced at the Center are sent to IDRC in Ottawa where they are sorted by main topic in order to produce the text of the bibliography by computer. It is thought that a book-form bibliography will constitute a permanent record for cassava workers, without duplicating the flexibility of specific multi-topic searches attained by means of abstract cards.

A Directory of Cassava Workers is also being compiled. This publication will be useful in increasing communication among scientists working on this crop and, at the same time, it may be the basis for an author citation analysis to be started in the near future.

Finally, although the initiative in centralizing all cassava information and providing a rapid and versatile service to cassava scientists has been taken by IDRC and CIAT, the success of any information project depends heavily on the direct participation of those people who are the final users of the service. Consequently, we ask your personal collaboration in letting us know about new information appearing in the field in whatever form it may be. Our policy is not to be restricted only to the better established forms of publication. Internal reports, and even memoranda, frequently carry very useful and recent information that could and should be included in our service. We hope to extend and organize as far as possible, the informal network of information — sometimes called an 'invisible college' of cassava scientists so that benefits may be derived from the sharing of information by a greater number of people.

REFERENCES

1. CIAT Annual Report 1971, p. 114.
2. Lawani, S.M. Periodical literature of tropical and sub-tropical agriculture. UNESCO Bulletin for Libraries 26(2), 88-93. March-April, 1972.
3. Cole, P.F. A new look at reference scattering. Journal of documentation. 18(2), 58-64. June, 1962.
4. REMAC International Corp. How TERMATREX works. Descriptive pamphlet.

*Current price of subscription US\$3.00 includes initial set of approximately 1,200 abstract cards.

CURRENT TRENDS IN CASSAVA RESEARCH

B.L. Nestel*

SUMMARY

Cassava, for long a crop neglected by research workers is now receiving attention at both national and international research centres with the largest ever research programme for this commodity being provided by the International Centre for Tropical Agriculture (CIAT) in Colombia. The significance of the crop in tropical agriculture and its growth potential, especially as an animal feed, have recently been widely recognized. The recent literature, and a substantial volume of unpublished ongoing work, are reviewed under the following headings: cassava as human and animal food; enrichment and fortification; toxicity; industrial use; economics of production; genetic improvement; diseases and pests; factors affecting yield; and improved information systems. A multi-disciplinary approach to cassava research and a greater research input are recommended.

RESUME

Le manioc, une culture oublié pendant des années par les investigateurs, recoit actuellement une attention particulière de la part des centres de recherches nationaux et internationaux; jusqu'à présent, le plus grand programme d'investigation sur le manioc se fait au Centre International pour l'Agriculture Tropical (CIAT) en Colombie. Il n'a été que tout récemment qu'on a reconnue la valeur de cette culture dans les pays tropicaux et sa capacité de production, comme nourriture pour animaux spécialement. Des publications récentes et de nombreux travaux actuellement en procès et qui n'ont pas encore été publiés ont été décrit sous le titre: "Le manioc comme nourriture humaine et animal, sone enrichissement et renforcement, toxicité, utilisation industrielle, economie de sa production, progrès génétique, maladies, pestes, facteurs qu'affectent son rendement et des méthodes meilleurs d'information". On recommande l'utilisation d'un plus grand effort investigatif et un aperçu multidisciplinaire dans l'investigation sur le manioc.

RESUMEN

La mandioca, un cultivo olvidado durante mucho tiempo por los investigadores, ha despertado ultimamente el interés de los centros de investigación tanto a nivel nacional como internacional; hasta ahora el mayor de los programas de investigación sobre este cultivo se está llevando a cabo en el Centro Internacional de Agricultura Tropical (CIAT) en Colombia. Solo recientemente ha sido reconocido el valor de su cultivo en los trópicos y su capacidad de producción, especialmente como alimento para animales. Un recuento de las publicaciones recientes y de una cantidad apreciable de trabajo actualmente en desarrollo que no ha sido publicado, aparece bajo el título: "La mandioca como alimento para humanos y animales, su enriquecimiento y fortalecimiento, toxicidad, utilización en la industria, economía de su producción, mejoramiento genético, enfermedades y pestes, factores que afectan su rendimiento y sistemas mejorados de información." Se recomienda un mayor esfuerzo investigativo y un enfoque multi-disciplinario en la investigación sobre mandioca.

INTRODUCTION

One of the most thoughtful and perceptive contributions to the Second International Symposium on Tropical Root Crops in Hawaii was presented by Frank Martin¹¹⁵ in his paper entitled 'Cassava in the World of Tomorrow'. Martin postulated that cassava represented an untapped resource in tropical agriculture and indicated what he felt was the type of research programme required before the potential of this commodity could be properly assessed and exploited. In some senses Martin's paper turned out to be prophetic in that within a year of its presentation, the International Centres for Tropical Agriculture in Colombia (CIAT) and Nigeria (IITA) both decided to give priority to cassava in their research programmes.

Prior to 1971 the global resources available for cassava research were extremely limited and, with the exception of Kerala in India, the work was being carried out by individual scientists, usually with limited financial support, rather than by multidisciplinary teams. In the last two years this picture has changed

*International Development Research Centre, Latin American Regional Office, Apartado Aereo 53016, Bogota, Colombia.

dramatically. CIAT now has a team of scientists from nine different disciplines backed up by basic research in Canada, and dealing with eight specific problems. The total annual budget of this joint programme exceeds one million dollars. The new multimillion dollar research and training centre at CIAT is already receiving scientists for training, especially in methodology, not only from Latin America but also from Asia and Africa. Thus, the framework has been established for constructing an international network of cassava researchers somewhat analogous to that which already exists for wheat and rice.

CIAT is fortunate in that Latin America is free from the problem of mosaic disease which causes serious losses in Africa. IITA's cassava programme is designed to work specifically on this problem through the disciplines of breeding, entomology and pathology with subsidiary support from other scientists and network links into other African countries. Like CIAT, with which it has close links, this institution has superb research and training facilities and is able to devote more resources to cassava than have hitherto been available in Africa.

However, while the resources of international centres can do much in the way of basic and applied research and training, their impact on farm productivity ultimately has to be transmitted via national institutions, which have traditionally paid very little attention to cassava except in India, where for the last decade there has been a strong Central Root and Tuber Crop Research Station, albeit with a rather small budget. Fortunately other good new national programmes are beginning to emerge. One of the newest and largest is in North East Brazil where there is a particularly broad-based and dynamic multidisciplinary team at the University of Bahia⁵ funded by the private sector and counselled by Normanha. Stronger (and in most cases new) national programmes are also under discussion in Peru, Malaysia and Thailand and in some African countries. Additionally, the private sector (Brascan in Brazil, Uniroyal in Indonesia and Nusbaum Associates) are beginning to look at the potential of this crop.

To a group such as this, it is not necessary to detail the reasons for this upsurge of interest in cassava. Probably the most important factor is the development of the export market for chips and pellets which is now worth about \$80 m a year. However, the potential for growth in this market and the likely increase in the use of cassava for food¹⁴⁶, coupled with the general lack of knowledge about the crop in spite of its phenomenal energy producing potential³⁶ in a hungry world, appear to have led to some rethinking regarding the role of cassava.

During the last two years, I have been associated with the management of research funds specially allocated for cassava, and it has been my fortune to travel extensively throughout the tropical world and to visit many of the relatively small groups of researchers interested in this crop. In my paper today I have attempted to present an overall assessment of the research situation as it is today. The rather ambitious title of this paper is not meant to signify that it is a definitive description of the 'status quo' — there are a number of cassava research workers whom I have yet to meet and I had not seen all of the papers presented at this Symposium when I prepared this paper. The objective of the paper is to provoke discussion on priorities and to stimulate the provision of information on unpublished and current research activities.

I have deliberately biased my presentation towards the utilization side for two reasons. Firstly, because almost all the papers at this Symposium dealing with cassava are production-oriented and, from the formal and informal discussions this week, many of you will already be well-briefed on the agricultural aspects of the commodity. My second reason for stressing utilization is that I have the distinct impression that we are going to see the possibility of higher yields being demonstrated within a relatively short time. However, unless these yields can be produced, stored, dried, marketed and effectively utilized at competitive prices, we may find ourselves, because of the very perishable nature of cassava, with even greater problems than occurred when the 'green revolution' passed its 'take-off' stage.

CASSAVA AS A HUMAN FOOD

Traditional products

The most important use of cassava is for human food. Whilst data on this are notoriously unreliable their quality does appear to be steadily improving. Current FAO estimates indicate that about 55 million tons out of annual global production of 98 million tons are consumed by humans. Phillips¹⁴⁵ has projected that by 1980 consumption will rise to about 71 million tons.

Table 1 indicates those countries in which human cassava intakes appeared to be highest in the mid 1970's. These national data do disguise regional differences within countries. For example Nicol¹³⁴ found that 25–56% of dietary calories in Southern Nigeria came from cassava (as opposed to a national figure of 15% in Table 1). Likewise, as opposed to the Indonesia figure of 15% in Table 1, Bailey's¹² surveys in Java indicated areas where the calorie intake from cassava exceed 63 percent. Normanha¹³⁵ recorded urban intakes of 42 kg/caput and rural ones of 200 kg/caput to give a national average intake of 124 kg in Brazil in the early 1960's.

The form in which cassava is consumed is very varied and traditional processing procedures may be very complex³⁶. They are also frequently labour intensive, and recently a process has been developed for

mechanizing the processing of gari, one of the most popular forms in which fermented cassava is consumed in West Africa³. A preliminary report from Ghana⁴⁹ indicates that the mechanized gari has high consumer acceptability. Gari production is, however, an important source of employment and a study is presently underway at the University of Ife to examine the socio-economic implications of mechanizing this traditional process.

At the Food Research Institute in Ghana an 'instant' fufu powder has been developed and is being commercially produced⁴⁹. Miche¹¹⁸ has pointed out that the industrial manufacture of traditional African dishes will not only encounter all the classic difficulties met by the development of agro-industry in the tropics but will also have to build on a raw material which has not yet been the subject of extensive research. He suggested that it will be necessary to develop roots of uniform, simple shape with a thin skin, high dry matter content, high degree of consumer acceptability and good storage potential. A number of these characteristics have been identified in the CIAT cultivar collection (and this issue is also discussed in the paper by Onochie and Makanjuola¹⁴⁰), but much still remains to be done to incorporate them into a high yielding ideotype.

Some promising progress has been made in storage, for which the literature has recently been reviewed by Ingram and Humphries⁹⁰. They refer to both early experiences, and to more recent work carried out in India and Venezuela using low temperature storage. Reference is also made to preservation by waxing, a technique which has recently received some publicity in Colombia⁸ where it is claimed to have considerably extended shelf life.

More recently, Booth¹⁷ has reported on a technique which extends both post-harvest on-farm storage and shelf-life. In another paper¹⁸, Booth has stressed the importance of mechanical damage in post-harvest losses, thus confirming the observation of Averre⁹ that vascular streaking of cassava roots commenced at cut surfaces. Averre's claims^{9,10} that vascular streaking is enzymatic in nature received some support from the identification by Czyhrnciw³⁸ of peroxidase and catalase in fresh cassava. Montaldo¹²², suggested that factors other than enzymes might be associated with vascular streaking, and noted some varietal resistance to this condition. Further work on this subject appears warranted.

Enriched and fortified cassava products

Because of its low protein content the nutritional enrichment of cassava has received a great deal of attention. Some work has been carried out on enriching traditional products such as gari² and cassava soups and porridges¹²⁴; however, the main attention has been given to fortification of cassava flour with soy protein isolates or soya grits. This work has been the subject of extensive research in Brazil⁶ where cassava flour is widely used in the production of composite flours as substitutes for wheat flours. USAID are also supporting studies on fortified cassava in Nigeria and Zaire. At present the problem of using fortified cassava flour appears to be more of economics than of technology in that the protein deficient sector of the population seldom has the cash to purchase flour of any type.

The subject of composite flours has received attention from the Institute for Cereals, Flour and Bread (TNO) at Wageningen in Holland, the Central Food Technological Research Institute at Mysore in India, the Instituto de Tecnologia Agrícola e Alimentar in Rio de Janeiro and the Instituto de Investigaciones Tecnológicas in Bogotá. The subject was exhaustively reviewed at a meeting sponsored by the Study Group on Composite Flours of the International Association for Cereal Chemistry in Bogotá in October 1972. During the last decade remarkable progress appears to have been made in the use of non-wheat flours and starches (particularly cassava) as total or partial substitutes for wheat flour in bread making^{97,147,145,45}.

This process not only dilutes the gluten but also changes the concentration and characteristics of other components which affect the bread making properties of the mixture. The role of non-wheat starches and their effect on dough quality has recently been reported on by Hosney *et al.*⁸³ and the role of gluten substitutes has been examined by Legendijk and Pennings¹⁰¹ and by Rasper, Mak and de Man¹⁵³ who have studied the structural development of dough and its visco-elastic properties in cassava fortified mixes. Research in progress in Manitoba by Bushuk²² is showing promising progress towards the development of a simple process of mechanical mixing which both simplified and improves the quality of the flour containing cassava. Technical and economic issues still remain to be resolved, but present and projected demands and the relative prices for wheat and cassava suggest that cassava-fortified flours may play an increasingly significant role in commercial baking in the future.

Using cassava as a substrate for the production of fungal protein was discussed by Gray and Abou-El-Seoud⁷³, and later expanded upon by Stanton and Wallbridge¹⁷⁴. More recently Strasser, Abbott and Battey¹⁷⁵ described a pilot plant process for which they prepared preliminary cost estimates for a 10 ton/day plant. Gregory and Reade⁷⁴ have developed a process using an *Aspergillus* sp. which grows on a liquid cassava substrate at a temperature of 50°C and at a pH of 3.5. This process appears to have a potential for producing animal feed of 15% protein content from cassava at a relatively low cost under conditions which may be practical at a field scale in cassava producing areas. Related work is being undertaken by Hutagalung and Stanton in Malaysia using a solid cassava substrate.

CASSAVA AS AN ANIMAL FEED

Although early work on fungal enrichment of cassava was related to the need to improve human protein intakes, current activities in this field tend to be more oriented towards livestock feed. The work of Gregory and Reade is particularly related to the use of residues from cassava (tapioca) starch factories⁷⁴. These residues are already used extensively as pig feed. The magnitude of this practice is difficult to estimate in the absence of data on cassava starch production, although Mahendranathan¹¹¹ calculated that the production of starch factory residues in Malaysia totalled about 300,000 tons per annum. Obviously a means of raising the protein level of this residue from 2 to 15 percent could have important implications for the pig industry.

The main thrust of work on livestock feeding with cassava is, however, based on the use of raw or dried roots. Preliminary work on this was carried out in the 1930's in Malaya although the modern literature appears to originate from the paper by Oyenuga and Opeke¹⁴² and more recently the work has been spearheaded by Maner and his associates at CIAT¹¹⁴, by a group of workers at the University of Malaya and by Müller in Singapore^{126, 127}.

Much of this research is being done in countries that are not major cassava producers in world terms. Furthermore, the major current users of cassava in animal feeds are feed compounders in the EEC who import much of their cassava from Thailand where it is seldom fed to either man or livestock. European use of cassava in animal feeds has resulted from its favourable price, compared with that of feed grains, in countries deficient in feed energy. At present cassava seldom comprises more than 10 percent of compounded feeds, although on occasion it has been used at levels as high as 40%, and in some of the tropical trials its level has reached 60 percent. The real potential for using cassava for animal feed appears to lie in cassava producing countries especially those in which the pressure of demand is leading to increasing prices for animal products and where a market for quality meat is developing.

Müller, Chou and Choo¹²⁶ found that cassava meal substituted satisfactorily for corn up to levels of 60 percent in broiler rations, provided that the diet was balanced, and that at higher levels of substitution, the cassava was pelletized. Nutritional problems arose if the fibre content of the cassava meal exceeded 3.5 percent and economic difficulties occurred if the cassava meal price exceeded 67 percent of the price of corn. Somewhat similar findings were reported in Mexico by Tejada de Hernández and Brambila¹⁷⁸ who were able to use up to 50 percent cassava meal in rations for young chicks. These had similar growth but lower feed efficiency than chicks on corn starch. The authors commented on the wide range of cyanide levels present in their rations and their uncertainty regarding the nutritional significance of cyanide. A similar finding of satisfactory growth but low conversion efficiency was reported by Jalaludin and Oh⁹³ who fed very high levels of cyanide to laying hens without producing obviously toxic effects.

Hamid and Jalaludin⁷⁸ used cassava successfully to replace corn at levels of up to 60 percent for layers. At higher levels they had difficulty in maintaining the protein content of the ration. Yolk colour became progressively whiter as cassava levels increased, so that a rich source of carotene needed to be added to the ration. There was also some evidence that methionine became a limiting nutritional factor on high cassava rations. The carotene level might, however, be of less significance in areas where yellow cassava is produced⁷⁶.

The use of cassava root meal in both grower and layer diets has been reported from Hawaii⁵⁴ where egg production, feed conversion, egg weight and shell thickness have been related to levels of cassava intake.

In swine, the most comprehensive work has been carried out by the CIAT workers¹¹² who have used up to 60 percent cassava in their rations. However, at this level, gain and efficiency declined although these could be improved by methionine supplementation which compensated for the low methionine level of the cassava and also provided a sulphur donor for cyanide detoxification. Hew and Hutagalung⁸¹ found that feed intake in swine decreased as the cassava level of the ration was increased. Performance improved significantly following the addition of 0.2 percent methionine to a 50 percent cassava diet, but did not improve with higher methionine levels. The further addition of palm oil (which also enabled the pigs to better utilize higher methionine levels) and glucose (which may have reduced cyanide levels by forming glyconohydrin and improving palatability) improved both daily gain and food conversion. From the economic standpoint, the fully supplemented 50 percent cassava ration gave 10 percent lower daily gains at a cost per kg. of gain that was 3 percent less than a corn-based ration.

Müller, Chou, Nah and Tan¹²⁶ recommended the use of cassava meal in pig rations when the price of a 85 percent cassava, 15 percent soya meal was significantly cheaper than that of corn. They stressed the importance of pelleting the cassava to avoid bulk and dust problems, and the need to balance fibre, mineral, vitamin B and amino-acid levels. Suggested maximum levels of cassava meal for starter, grower and finisher rations of different ash and fibre contents were tabulated. These ranged from 0 percent in starter rations with 5 percent fibre, to 75 percent in finisher rations of 2.8 percent fibre and containing only cassava, soya-bean meal and minerals.

Further recent reports using cassava for swine feeding originate from Fiji¹⁷⁹ and Venezuela²⁹. A 40 percent cassava, 29 percent rice bran ration was shown to require the addition of zinc before it would give gains equivalent to a ration in which corn was the primary energy source, although evidence was not pro-

vided to indicate whether the cassava or the rice bran was responsible for the reduced availability of zinc¹¹⁷.

The literature on cassava as a ruminant feed appears to be very sparse, although Chicco *et al.*²⁸, Shultz *et al.*¹⁶⁷ and Shultz and Chicco^{168,169} have carried out extensive studies on the use of cassava in conjunction with urea in both bovines and sheep. In Malagasy, Serres¹⁶⁴ described the use of both cassava roots and leaves as components or rations for intensive finishing of cattle. Serres and Tillon¹⁶⁵ described the production of cassava root silage for pigs (fed at 3 kg/day) and cattle (fed at 5 kg/day). Extensive trials on the use of cassava root silage as a component of swine rations have been conducted by Maner at CIAT¹¹². Low protein levels presented a problem, and attempts to raise this by microbial action have not so far been successful⁷⁴.

Serre's work on using cassava leaves as cattle feed followed Echandi⁵¹ who sought a substitute for alfalfa meal in Costa Rica. This work has been followed up in chickens and quails by Ross and Enriquez¹⁵⁹ and in pigs by Lee¹⁰⁴ and Lee and Hutagalung¹⁰⁵. It appears that in both pigs and poultry, 20 percent cassava leaf depressed both liveweight gain and feed conversion, but the addition of sodium thiosulphate, methionine and molasses and/or vegetable oil can partially correct these depressions. Further studies on cyanide content²⁷ and water soluble protein⁶⁶ of cassava leaf have been carried out to help elucidate its nutritional value. Additional work on this seems to be necessary since Juarez⁸⁴ reported an annual leaf yield of up to 27,000 kg from two leaf pickings in Peru and preliminary data from more frequent picking in Brazil (Bahia) and Colombia (CIAT) suggest that with appropriate management even higher leaf yields may be feasible. Since leaf protein values are reported to be between 20 and 30 percent on a dry matter basis¹⁵⁶, the possible role of cassava leaves as food or feed may need re-examining. Eggum⁵² has already shown that the digestibility of cassava leaf protein in rats was 70–80 percent, although the biological value of the protein was only 44–57 percent. However the addition of methionine to the diet raised the B.V. of the cassava leaf protein to 80 percent. A similar result was obtained by Adrian and Peyrot¹ when adding cassava leaf protein to cereal diets.

CASSAVA TOXICITY

Cyanogenic glucosides and cyanide toxicity

In discussing the use of cassava in animal feeding frequent reference has been made to the subject of toxicity. The cyanogenic glucosides of cassava have been known for some time to be responsible for both acute and chronic toxicity in humans, although the importance of chronic toxicity has been studied extensively only in the last decade. Recent work has indicated not only that high cassava intakes are associated with the incidence of tropical ataxic neuropathy in Africa¹⁴¹, but that in the presence of marginal iodine and low protein intakes, high cassava diets may potentiate the development of goitre and cretinism^{53,61}. Domestic livestock are seldom fed high levels of cassava for prolonged periods, but nevertheless there is evidence to indicate that impaired growth occurs in pigs and poultry on high cassava diets unless these are supplemented with methionine¹¹³.

A recent workshop reviewed the subject of chronic cassava toxicity. This covered the biosynthesis of the cyanogenic glucosides^{23,34,130}, the agronomic and physiological aspects of cassava toxicity⁴², and detoxification mechanisms^{35,138}. The workshop proceedings¹³³ contain 18 papers and recommendations for future research. Amongst these was the need to ensure that breeding for low cyanide cultivars would not consequentially increase susceptibility to pathogens and pests. The techniques and problems of adequate assay also received considerable attention. Cyanide in cassava results from the breakdown of the relatively stable glucosides linamarin and lotaustralin, whose own toxicity is unknown. There have been several recent papers^{62,161,191} dealing with cyanogen assay in cassava roots and leaves. The relevance of rapid assay techniques to the problem of toxicity requires further clarification, especially since both CIAT and IITA are selecting for low cyanogen levels.

Aflatoxicity

Cassava has also been incriminated in problems of aflatoxicity since it appears to be an excellent growth medium for *Aspergillus flavus*. Samples of cassava flour from Brazil were found to have relatively high levels of aflatoxins and at one time it was thought that this might be associated with the high incidence of black fever in children on the upper Amazon¹⁹. More extensive studies with cassava starch in Thailand and Hong Kong¹⁶⁶ and in fermented cassava from Dahomey¹⁸⁰ have also shown the presence of aflatoxins and an aflatoxin-like factor has been recorded in India¹²⁸. In a field study in Uganda¹⁶³ there was circumstantial evidence that a highly contaminated cassava sample may have been involved in a documented poisoning episode. However, by and large, particularly in view of the varied ways in which cassava is handled after harvest, there appears to be little evidence that aflatoxins present a significant problem.

THE INDUSTRIAL USE OF CASSAVA

Apart from its use as direct food and feed, cassava is used in the food industry, principally in the form of starch. The low-amylase high-amylopectin content of cassava starch give it unusual viscosity characteristics and great dimensional strength, these find a number of specialized uses¹¹. The characteristics and behaviour of this starch have been studied in great detail by Rasper^{150,152,152}, Banks *et al.*¹³, Srivasta and Patel¹⁷³, Velikaya and Nguen¹⁸², and by a number of Brazilian workers^{123,158}.

Cassava can be hydrolized to produce glucose¹⁴³ and a feasibility study for a cassava based glucose industry has been carried out in Nigeria⁴⁷. It can also be converted to alcohol¹⁷⁷, although this process does not appear to be used industrially.

Dextrins made from cassava flour can be used to make adhesives which are superior to starch-based adhesives in a number of characteristics⁶³. Cassava stalks have also been used to make particle board⁶⁶.

The technology for processing cassava has been described in some details by Grace⁷¹. Usually the processing procedures used are very traditional, although some modernization of the cassava starch industry has taken place recently. The last two years have also seen an interest in improving the drying of cassava chips. A simple solar heat drier suitable for cassava was described by Williams, Beeny and Webb¹⁸⁸ and a pilot solar drier of another type is currently undergoing tests in Trinidad¹⁷². The drying characteristics of cassava are also being studied by Roa¹⁶⁶ who has developed machinery for producing cassavabars (1 x 1 x 0.5 cm) directly from roots. However, none of these new techniques appear to have been evaluated economically in comparison with current drying practices in which sun drying in concrete yards are normal. A variety of chip sizes and shapes are produced and there appears to be an urgent need for further research on the optimum size and shape of chips and perhaps on a simple technology to reduce radiation losses in drying yards.

This need for improvement in current drying and pressing techniques was stressed in a study by Mathot¹¹⁶ which pointed out that these procedures could lead to substantial improvements in both quality and cost price of pellets exported from Thailand (which supplies the bulk of world trade in this item).

THE ECONOMICS OF CASSAVA PRODUCTION

In order to exploit the markets for cassava, it has to be sold at a price that is competitive. To some degree this depends on the use to which the crop is put. Thus the Thai farmer, who grows most of the cassava which reaches the world market, obtains U.S. \$11–12 for the farm-dried chips produced from a ton of fresh cassava, whereas for fresh cassava for human use, the Jamaican farmer obtains 2–4 times this price¹⁴⁷ and, at certain times of the year, the Colombian farmer may obtain 6–10 times the price obtained by his Thai counterpart. However, generally speaking the farm price seems to lie in the range of U.S. \$10–15/ton of fresh root equivalent.

It is difficult to cost cassava production since the main inputs are family labour and land, and in subsistence farming areas, the land is often communally owned. Brannen²⁰ reviewed some of the literature on production costs and found that the usual cost of producing cassava was about U.S. \$6/ton. The major production cost was labour. For a variety of reasons, it is difficult to compare the various labour costings available, but in various surveys the man-hours used to produce a ton of cassava appeared to range from 30–200 and to average about 100^{4,147,20,48}. Obviously the return to labour from cassava production is very low, notwithstanding the fact that Raeburn *et al.* found the yield per man-day from cassava production exceeded that of other tropical staples. Clarke and Haswell³¹ reported a similar finding when comparing both the output value and the labour productivity of various tropical crops in terms of FAO standard wheat equivalents.

The low return to labour relates to the fact that the opportunity costs of labour in many subsistence areas is often regarded as being close to zero, otherwise a production cost per ton of U.S. \$6 would not be possible. However, we may anticipate that some mechanization may be necessary in the future since, as economies develop, labour generally tends to demand a higher return, especially for an unpleasant job such as harvesting cassava (which commonly accounts for 25–30 percent of the total labour costs). For this reason production costs may be expected to rise. Against this it must be taken into account that subsistence yields are often only about 10 percent of the production potential of the crop, so that there is a great deal of scope for reducing the costs of production by raising yields. This is especially true if high-yielding cultivars can be produced that are more easily harvested (by either man or machine) but still retain adequate drought and disease tolerance.

In view of the limited past resources devoted to both the breeding and the mechanization of cassava, compared with those now available, it is difficult to make any forecasts of the likely future pattern of production costs. What does appear probable is that these costs will be strongly influenced by the results of plant breeding work in terms of the achievements that are made with respect to yield and morphology.

Andersen and Diaz⁴ have examined this situation from the standpoint of public policy and have drawn particular attention to a possible conflict arising between the social objective of employment-creation and

the profit-maximizing objective of introducing new technology. They point out the labour-intensive nature of cassava production and the adverse effects on employment which could arise from both extensive mechanization of land preparation and the widespread use of chemical herbicides. The impact of mechanization on the labour requirements for planting and harvesting has also been examined by Krochmal⁹⁹ and the economics of mechanization by Dulong⁵⁰ who claimed that very high yield levels would be required for mechanization to become economic in the Malagasy Republic.

Andersen and Diaz's paper⁴ highlights the need for more information on the total economic structure of the cassava industry. The global market for animal feed has been looked at by the International Trade Centre⁹² and by Phillips¹⁴⁶ and the processing sector in general by Grace⁷¹ and more specifically in West Malaysia by Wahby and Eriksen¹⁸⁴ and in the Malaysian State of Perak by Chye and Loh³⁰. However, integrated studies dealing with production, processing and marketing are harder to come by. The Ministry of Agriculture in Thailand completed such a study in 1973 but to date, I believe, it is only available in Thai. A similar type of study is being pursued in Brazil by the Comissao Nacional de Mandioca and by Dantas³⁹ in the Brazilian State of Bahia. Probably the most complete study of the cassava industry at the national level is a recent Ph.D. Thesis by Tan¹⁷⁶ in Malaysia.

At the farm level, Diaz⁴⁶ has published a preliminary report on a 300 farm survey in 5 zones of Colombia. This survey is attempting to provide very detailed information on production practices and to relate these to the CIAT research programme. Some farm costing studies involving cassava are also being carried out at IITA and by the team at the University of Bahia. However, the absence of adequate economic data would appear to be a constraint from the standpoint both of identifying growth opportunities and attracting new investments. In this context it is relevant to observe that cassava does appear to offer opportunities for labour-intensive production on small farms and since small farms and rural employment are important issues in many tropical countries, the need for more research on the structure of production and the relationship of this to public policy cannot be overstressed.

THE GENETIC IMPROVEMENT OF CASSAVA

Even in the absence of detailed agro-economic studies, the cassava breeder does have some guidelines. Foremost amongst these is the need to evaluate the genetic material which is currently available. To date very limited attention has been paid to the study of fundamental aspects of the genetics, cytology and breeding of the crop. Little has been added to the literature in these fields recently, the current state of knowledge has been covered in the review of Dempsey⁴⁴ and in the reports to the previous and current Tropical Root Crop Symposia by Magoon^{107,108} and Magoon and Krishnan¹¹⁰.

The main efforts in plant breeding are devoted to increasing yield, although both CIAT and IITA are screening for cyanogen level and for disease and insect resistance. Plant breeders working with cassava are known to be operational in Brazil, Colombia, Costa Rica, India, the Malagasy Republic and Nigeria, although the number of trained geneticists involved with the crop is still very small. The use of radiation or mutagenic agents has been practiced in Turrialba (Costa Rica), and Malagasy Republic⁵⁰ and India, where it has been associated with efforts to enhance the protein level of the crop⁸⁴. Colchicine has also been used to induce polyploidy by Magoon *et al.*¹⁰⁹ and later by Imam⁸⁶, but significant yield increases do not appear to have followed this treatment.

The recent publication by Rogers and Appan¹⁵⁷ of a monograph on the genus *Manihot* is useful for both agronomists and plant breeders interested in cassava improvement. Their bio-systematic work has identified some particularly interesting opportunities for further research in interspecific hybridization which has already been used successfully to produce disease resistance in cassava. In Java, grafts of *M. glaziovii* on *M. esculenta* stock have been found to lead to the production of enormous roots (up to 100 kg in 24 months) on individual plants, but whether or not this technique has a potential beyond 'backyard' production remains to be determined⁴³. Similar but less spectacular increases in yield have been reported from grafting *M. flabellifolia* onto *M. esculenta*, although, according to Rogers and Appan¹⁵⁷, *M. flabellifolia* is the same species as *M. esculenta*.

A recent upsurge of interest in the ethnobotany of cassava may also be of interest to the plant breeder. The role of cassava in the development of civilization in lowland South America was discussed at a Symposium of the American Anthropological Society in November 1971 at which it was postulated that the use of manioc (cassava) may pre-date that of corn. Other evidence concerning the area of origin of *M. esculenta* as a crop plant has been reviewed by Renvoize¹⁵⁴.

A major problem associated with efforts to select and improve cassava is the difficulty that is faced in moving material around the world because of disease problems. The normal method of propagation by vegetative means accentuates this problem, as does the outbreeding nature of the plant (due to protogyny) and the frequency with which pollen sterility occurs. Efforts to overcome this situation are being made by propagation studies^{99,185}.

Wholey and Cock have developed a field multiplication procedure which enables them to produce 1800 stem cuttings from one plant in one year. Under mist propagation in a greenhouse, they have in-

creased this number to 18000 cuttings from one mature plant. Another possible approach to rapid propagation is through tissue or cell culture. This is being developed primarily to produce mosaic-free plants^{16,95}, but may also offer possibilities for rapid propagation (and perhaps for the production and dissemination of mosaic-free material) provided that the genetic stability of culture material can be assured.

DISEASES AND PESTS OF CASSAVA

Mosaic disease in cassava has been the subject of a number of recent studies and the state of current knowledge was reviewed at a Workshop held at IITA in December 1972⁹¹. This meeting categorized cassava 'mosaics' into:

- a) a mechanically transmitted disease found in Brazil whose causal agent is a virus of the potato virus X group.
- b) a white-fly transmitted disease found in Africa and India whose causal agent is unknown.
- c) mycoplasma-induced diseases, of which at least three occur in Brazil and one in the Ivory coast.

The meeting was not attended by anyone familiar with mosaic disease in India and the relationship of this to the African and Brazilian mosaics does not appear to have been studied although Peterson in Canada¹⁴⁴ has recently established a programme which will enable him to study cassava mosaic diseases from all three geographic sources.

A report on Indian mosaic is being presented at this meeting by Narasimhan and Arjunan¹²⁹ and Kitajima and Costa⁹⁸ are reporting on their EM studies with cassava virus and mycoplasmas in Brazil. The IITA report contains a review of most of the African literature but excludes reference to a paper by Golato⁷⁰ in Ghana and to the most recent contribution by Chant, Bateman and Bates²⁵. It also excludes mention of a paper by Ganguly, Raychaudhuri and Sharma⁶⁸ describing a serodiagnostic method for detecting mosaic infected plants in the field. This is a subject which may justify further study in view of the difficulty of ensuring that vegetative material is mosaic-free.

No work on the 'brown streak' virus disease of East Africa appears to have been published recently. However, the literature on the major bacterial, viral and fungal diseases of cassava has recently been reviewed by Lozano and Booth¹⁰⁶. Their review in fact covers most of the work reported on at this meeting in addition to many observations from recent research at CIAT. They draw attention to the large number of diseases, many of them poorly understood, which can attack cassava both prior and subsequent to harvesting. Little information is available on control measures except for bacterial blight.

Cultivars which are resistant to some diseases are noted, and the need for more information on host-parasite relations in other better to understand the nature of this resistance is pointed out. A similar plea is put forward by Rosseto *et al.*, and it appears to be relevant to resistance to insects since van Schoonhoven¹⁸¹ has noted varietal differences in tolerance to attack by thrips and mites. The possibility of relating disease and pest resistance to a chemotaxonomic classification of the CIAT and other cultivar collections is being examined by Grant⁷².

The literature on parasitic nematodes associated with cassava appears rather sparse. In his bibliography, Montaldo¹²¹ lists only two species recorded as parasites of cassava. There is, however, a recent reference on this subject from Trinidad²¹. An up-to-date review of insect and mite pests of cassava also appears to be lacking although Montaldo lists about ninety species of insect pests as having been found on cassava. Currently detailed work on thrips and spider mites is under way at CIAT. In Uganda the accidental introduction of a neotropical mite, *Mononychellus tanajoa* (Bondar) is causing considerable devastation¹⁵ and the mite is being studied by Nyirira¹³⁶.

Research on weed control in cassava also appears to be relatively new. Doll and Piedrahita⁴⁸ at CIAT have a fairly comprehensive programme which is of particular interest from the standpoint of the relationships between morphology, yield and weed control. Their programme is linked to the cost studies of Andersen and Diaz referred to previously. Doll's work highlights the need for a multidisciplinary approach to cassava research, in which the definition of the ideotype which the plant breeder must seek may be dependent not only on yield but on factors such as disease and insect resistance, weeding costs, ease of harvesting, drought tolerance, fertilizer response, cyanide level, starch composition, etc. The complexities of these interrelationships may imply the necessity for some model-building inputs, once more information is available on the basic production parameters.

FACTORS AFFECTING YIELD

It is in these production parameters, particularly 'yield' that the major research thrust is taking place at present. This is hardly surprising since yields under farm conditions are frequently reported as averaging only 5-15 tons/ha whereas experimentally it has been claimed that this range can be far surpassed. Dulong⁵⁰ reports 70 tons/ha in the Malagasy Republic, Cock³³ 47 tons in Colombia, and Schmidt and Pereira¹⁶² 34 tons in Brazil. These yields are well in excess of those encountered under commercial conditions, although on a recent visit to Malaysia I witnessed the harvesting of a crop on virgin land which was

estimated as yielding over 50 tons/ha, and I understand from Chan that this is not unusual. At this meeting we have reports on yield responses to various fertilizers from Sierra Leone⁷⁵, Kenya⁷⁷, Peru⁸², Nigeria^{137, 139} and Colombia¹⁸⁵, and recent papers on this theme also originate from the Seychelles¹⁷¹, Mozambique¹²⁵ and Malaysia²⁴.

Amongst the factors influencing yield, one that has been relatively neglected in past research efforts is that of the onset and rate of tuber root bulking. Wholey and Cock found that differences in yield after seven months were associated with variations in the rate rather than in the time of onset of bulking. However, seven months may be too early to make decisions on yield maximization. Chan found that a number of his cultivars yielded significantly higher at 12 months (but not at 14) than they did at 8 months. There appear to be very great differences in local practices in relation to harvesting age. This factor must obviously be an important component of any systematic study on yield.

Chan and Okigbo have both studied the effects of planting stick orientation, length, and polarity at planting time on subsequent yield and performance. This is a subject on which the early cassava literature is very rich. There seems to be little consensus on the issue of orientation although most authors seem to get better growth from longer cuttings and to have a fairly high mortality in cuttings planted upside down. Enyi⁵⁶ has also shown that there was a positive linear relationship between root yield and age of planted cutting (this is a subject that may justify re-examination within the context of the rapid propagation technique of Wholey and Cock.)

Enyi^{56, 57, 58} has also examined the effects of spacing on growth development and yield of single and multiple shoot plants. He found that bulking rate was positively related to net assimilation rate and that both net assimilation and tuber yield were higher in single shoot plants. Maximum yields were obtained from a planting density of 12,600 plants/ha. (A further report on this is contained in a more recent paper⁵⁹ which has not yet come to hand).

The relationship between spacing, yield, assimilation and dry matter distribution has also been examined by Sinha and Nair¹⁷⁰ and Williams^{186, 187, 188} and in papers presented by Cock³², Cuervo³⁷, Natarajan and Rengasamy¹³¹ and Natarajan and Vijayakumar¹³². It appears that leaf area index is sub-optimal after six months due to leaf fall although in one cultivar Cock found that he could compensate for this by raising the plant population as high as 20,000/ha and that the improved LAI was associated with increase in yield. However, the application of modern techniques and ideas in plant physiology to cassava research is very new, and there is obviously scope for more research on factors affecting dry matter production especially leaf area index, leaf inclination and photosynthesis.

Research on the responses of cassava to fertilizer has given conflicting and generally unsatisfactory results. It has been suggested that high levels of nitrogen may increase leaf production at the expense of roots¹⁰⁰, and in one experiment⁴⁰ P and K applied before planting depressed survival. On the other hand various authors (Chan²⁴, Chew²⁶, Cock³², de Silva and Freire⁴¹, Vijayan and Aiyer¹⁸³ and Young¹⁹⁰) suggest a positive response to fertilizer, especially nitrogen, although this response is not always significant. Research on fertilizer use is currently underway in a number of stations and is also reported on at this symposium by Godfrey-Sam-Aggrey and Gurnah.

More basic studies on the mineral nutrition of cassava have been carried out by Forno, Asher and Edwards⁶⁷ in Queensland and by Bates¹⁴ in Canada who is preparing a series of colour slides on macro and minor element deficiency and toxicity symptoms. This work is being carried out at the University of Guelph on behalf of CIAT. A related programme⁹⁵ in the growth rooms at Guelph is examining: a) photosynthesis and b) growth and tuberization in *M. esculenta* and some other *Manihot* species. Growth and tuberization are also being studied in the field in Colombia³², India^{87, 88}, New Guinea⁶⁰ and Trinidad⁶⁴. Ketiku and Oyenuga⁹⁶ have traced the changes in the carbohydrate constituents of cassava roots during growth. The starch level peaked (81 percent of the carbohydrates) at 8 months and sugars reached their peak concentration of 5.7 percent (of which 69 percent was sucrose) 9 months after planting.

The water requirements of cassava have received little study although it is known to be very drought tolerant. The only paper that I am aware of on this subject is that by Garcia and Montaldo⁶⁹ although the group at the University of Bahia are studying the responses of cassava to irrigation.

IMPROVED INFORMATION SYSTEMS

Until recently it has been difficult to track down the literature dealing with cassava, although in the past few years there have been several special bibliographies^{121, 79, 89, 7}, in addition to some reports with lengthy lists of references^{71, 80}. However, none of these bibliographies appears to include more than about half of the world literature which is currently believed to exceed 3500 references. An effort is being made to fill this void by preparing a comprehensive bibliography with a key word index and abstract of each item referenced¹¹⁹. A cassava thesaurus has been prepared¹⁰³ and an interim bibliography with about 1500 abstracts is expected to be published at the end of 1973. When the final document is prepared, hopefully in 1974, CIAT will institute a cassava information centre which will be linked into the AGRIS network and will be able to provide abstracts and photocopies of the world literature to interested workers.

In recent years the literature on cassava has grown by about 50 documents each year. The last two years have seen a remarkable upsurge in these numbers, particularly in 1973, due especially to this meeting (48 papers mention cassava in their title) and to the meeting on cyanide toxicity in cassava (18 papers). In this paper I have mentioned the names of nearly 100 scientists who are actively engaged in research on cassava at the present time.

This is a big change from the situation only three years ago. However, if the world really produces almost one hundred million tons of cassava a year, and if this has a farm value which is normally at least US\$10/ton, as my figures suggest, we are talking of a commodity whose annual production value exceeds one thousand million dollars and may reach \$1.5 billion. As far as I can judge, the research expenditure devoted to the production side of this industry lies between 2 and 3 million dollars a year, or perhaps 0.25% of the value of production with perhaps 40% of the research funding going to CIAT and related programmes.

Concerning human resources, there appear to be less than ten trained geneticists working full-time on this crop, the number of physiologists and economists may be even smaller. The state of knowledge described in this paper and some of the questions raised suggest that the current research input may still be too low, especially in terms of the value of the crop and its apparent growth potential. Areas requiring more research are numerous but perhaps most important of all is to ensure that more work is performed on an interdisciplinary basis. One has only to study the literature to recognize how limited has been the breadth of past research on cassava and how irrelevant are many of its findings. Hopefully, with the network of cassava researchers and the information services that are developing, we will not see these past mistakes repeated.

REFERENCES

1. Adrian, J. and Peyrot, F. (1971) *Plt. Fds. Hum. Nutr.*, 2, 61.
2. Akinrele, I.A. (1967) *W. Afr. J. Biol. and Appl. Chem.*, 10, 19.
3. Akinrele, I.A., Ero, M.I.O. and Olatunji, F.O. (1971) Fed. Inst. Indust. Res. Tech. Mem 26. Fed. Min. Indust., Lagos, Nigeria.
4. Andersen, P.P. and Diaz, R.O. (1973) Mimeo.*
5. Anon. (1972a) *Proyecto Mandioca, Relatório Semestral de Andamento e Avaliação de Pesquisas*, Fed. Univ. Bahia, Salvador, Brazil.
6. Anon. (1972b) Mimeo Rep. 3rd meeting on fortification of mandioca products, Rio de Janeiro 13--16 March 1972, Min. Agric. Rio de Janeiro, Brazil.
7. Anon. (1972c) *Bol. Tec. do Centro de Tec. Agric. e Alimen*, No. 1, Min. Agric., Rio de Janeiro, Brazil.
8. Anon. (1973). 'La República', 8 Nov. 1973, Bogotá, Colombia.
9. Averre, C.W. (1967) *Proc. Int. Symp. Trop. Root Crops*, 2, 31. Univ. W. Indies, Trinidad.
10. — — — — (1970) Mimeo. Reunion Lat.-Amer. Fitotecnía, Bogotá, Colombia.
11. Ayres, J.C. (1972) In 'Hendershott et al.' Chap. VIII (see ref. 80).
12. Bailey, K.V. (1961) *Trop. Geogr. Med.* 13, 234.
13. Banks, W., Geddes, R., Greenwood, C.T. and Jones, I.G. (1972) *Stärke* 24, 245.
14. Bates, T. (1973) Personal communication to IDRC, (Soil Sci, Dept., Univ. Guelph, Canada).
15. Bennett, F.D. (1973) Personal communication, (Comm. Inst. Biol. Control, W. Indies Station, Curepe, Trinidad).
16. Berbee, F.M., Berbee, J.G. and Hildebrandt, A.C. (1973) *In Vitro* 8, 421.
17. Booth, R.H. (1973a) Mimeo.*
18. — — — — (1973b) *Proc. 2nd Int. Cong. Plt. Path.*
19. Boshell, J. (1968) *Belem Virus Lab. Ann. Rep. (Appendix)*, Belem, Brazil.
20. Brannen, S.J. (1972) In 'Hendershott et al.' Chap. X (see ref. 80)

*Paper presented to 3rd Int. Symp. on Trop. Root Crops. Dec. 2--9, 1973, IITA, Ibadan, Nigeria.

21. Brathwaite, C.W.D. (1972) *Plant. Dis. Rep.* 56.
22. Bushuk, U. (1973) Personal communication to IDRC, (Food Sci. Dept. Univ. Manitoba, Canada).
23. Butler, G.W., Reay, P.R. and Tapper, B.A. (1973) In 'Nestel and MacIntyre', p. 65 (see ref. 133).
24. Chan, S.K. (1969) Mimeo. Rep. 'Taploca Invest. at the Fed. Expt. Sta. Serdang, Min. Agric. Kuala Lumpur, Malaysia.
25. Chant, S.R., Bateman, J.G. and Bates, D.C. (1973) *Trop. Agric.* 48, 263.
26. Chew, M.Y. (1970) *Malay. Agric. J.* 47, 483.
27. ——— (1973) *Malay. Agric. J.* 48, 354.
28. Chicco, C.F., Carnevali, A.A., Shultz, E. and Ammerman, C.B. (1971) *Asoc. Lat-Amer. de Prod. Anim, Memoria*
29. Chicco, C.F., Garbati, S.T., Muller-Hayes, B. and Vecchionacce, H. (1972) *Agron. Trop. (Maracay)* 22, 599.
30. Chye, K.O. and Loh, W.Y. (1971) *Agric. Econ. Bull.* 1, 1 Fed. Agric. Mktng. Authority, Kuala Lumpur, Malaysia.
31. Clarke, C. and Haswell, M.R. (1964) *The Economics of Subsistence Agriculture*. Macmillan, London.
32. Cock, J.H. (1972a) Mimeo.*
33. ——— (1973b) Personal communication to IDRC (CIAT, Colombia).
34. Conn, E.E. (1973) In 'Nestel and MacIntyre', p. 55 (see ref. 133).
35. Coursey, D.G. (1973) In 'Nestel and MacIntyre', p. 27.
36. Coursey, D.G. and Haynes, P.H. (1970) *World Crops* 22, 260-5.
37. Cuervo Gomez, P.L. (1973) Mimeo.*
38. Czyhrinciw, N.W. (1969) *Rev. Fac. Agron. (Maracay)* 5, 108.
39. Dantas, W. (1973) Personal communication to IDRC, (Econ. Dept., Univ. Bahia, Salvador, Brazil.)
40. da Silva, J.R. and Freire, E.S. (1968a) *Bragantia* 27, 291.
41. ——— (1968b) *Bragantia* 27, 357.
42. de Bruijn, G.H. (1973a) In 'Nestel and MacIntyre' p. 43. (see ref. 133).
43. ——— (1973b) Personal communication to IDRC, (Agron. Fac., Univ. Brawijaya, Malang, Java).
44. Dempsey, A.H. (1971) In 'Hendershott et al.' Chapter II. (see ref. 80).
45. Dendy, D.A.V., Clarke, P.A. and James, A.W. (1970). *Trop. Sci.* 12, 131.
46. Diaz, R.O. (1973) Mimeo. Descripción agro-económica del proceso de cultivar yuca en Colombia, CIAT, Colombia.
47. Dina, J.A. and Akinrele, I.A. (1970) Econ. Feas. Study for the Establishment of a glucose industry in Nigeria, Fed. Inst. Indust. Res., Lagos, Nigeria.
48. Doll, J. and Pledrahita, W. (1973) Mimeo*.
49. Dovlo, F.E. (1972) Mimeo. Cassava and cassava prod. Conf. 24/25 March, 1972. Univ. Ghana, Legon, Ghana.
50. Dulong, R. (1971) *Agron. Trop* 26, 791.
51. Echandi, M.O. (1972) *Turrialba* 12, 166.
52. Eggum, B.O. (1970). *Brit. J. Nutr.* 24, 761.
53. Ekpechi, O.L. (1973) In 'Nestel and MacIntyre', p. 39. (see ref. 133).
54. Enriquez, F.Q. and Ross, E. (1972) *Poult. Sci.* 51, 228.
55. Enyi, B.A.C. (1970) *Beitr. trop. and sub trop. Landwirt. and Tropenvet-Med.* 8, 71.
56. ——— (1972a) *East Af. Agric. for. J.* 38, 23.
57. ——— (1972b) *East. Af. agric. for. J.* 38, 27.

58. ——— (1972c) *J. Hort. Sci.* 47, 457.
59. ——— (1973a) *J. Agric. Sci.* 81, 15.
60. ——— (1973b) Mimeo.*
61. Ermans, A.M., van der Velden, M., Kinthaert, J. and Delange, F. (1973) In 'Nestel and MacIntyre' p. 153. (see ref. 133).
62. Esquivel, T.F. and Maravalhas, N. (1973) *J. Agr. Fd. Chem.* 21, 321.
63. Evans, R.B. and Wurzburg, O.B. (1967) In 'Starch Chem. and Tech.' Vol. 2, p. 253. Ed. Whistler, R.L. Academy Press, New York.
64. Ferguson, T.H. (1973) Personal communication to IDRC. (Dept. Soil Sci., Univ. West Indies, Trinidad)
65. Flaws, L.J. and Palmer, E.R. (1968) Report G34, Trop. Prod. Inst., London.
66. Foo, L.C. and Chew M.Y. (1973) *Malay. Agric. J.* 48, 347.
67. Forno, D.A., Asher, C.J. and Edwards, D.G. (1973) Mimeo.*
68. Ganguly, G., Raychaudhuri, S.P. and Sharma, B.C. (1970). *Curr. Sci.* 39, 191
69. Garcia, B.J. and Montaldo, A. (1971) *Agron. Trop. (Maracay)* 21, 25.
70. Golato, C. (1971) *Riv. Agric. Subtrop. Trop.*
71. Grace, M. (1971) *Processing of cassava*, Agric. Serv. Bull. 8, FAO, Rome.
72. Grant, W.F. (1973) Personal communication to IDRC (Dept. Genetics, McGill Univ. Canada.)
73. Gray, W.D. and Abou-el-Seoud, M.O. (1966) *Econ. Bot.* 20, 251.
74. Gregory, K.R. and Reade, A.E. (1973) Personal communication to IDRC (Microbiol. Dept. Univ. Guelph, Canada.)
75. Godfrey-Sam-Aggrey, W. (1973) Mimeo*.
76. Guimaraes, M.L. and Cresta de Barros, M.S. (1972) *Bol. Tec. Div. Tecnol. Agr. Aliment. (Brazil)* 4, 4.
77. Gurnah, A.M. (1973) Mimeo*.
78. Hamid, K. and Jalaludin, S. (1972). *Malay. Agric. Res.* 1, 48.
79. Henain, A.E. and Cenoz, H.M. (1969) Bibliography on cassava, Fac. Agron. and Vet., Univ. Nac. Nordeste, Corrientes, Argentina.
80. Hendershott, C.H. et al. (1972) Literature Rev. and Res. Recommendations on Cassava. AID Contract csd/2497, Univ. Georgia, Thens, Ga. USA.
81. Hew, V.F. and Hutagalung, R.I. (1972) *Malay. Agric. Res.* 1, 124.
82. Hoffman, A.S. (1973) Mimeo.*
83. Hosene, R.C., Finney, K.F., Pomeranz, Y. and Shogren, M.D. (1971) *Cer. Chem.* 48, 191.
84. Hrisshi, N. and Jos, J.S. (1973) Mimeo.*
85. Hunt, A. (1973) Personal communication to IDRC (Crop Sci. Dept. Univ. Guelph, Canada).
86. Imam, M.M. (1972) *Ghana, J.Sci.* 12, 19.
87. Indira, P. and Jurlan, T. (1973) Mimeo*.
88. Indira, P. and Sinha, S.K. (1970) *Ind. J. Pl. Phys.* 13, 24.
89. Ingram, F.S. (1969) Rep. G51, Trop. Prod. Inst., London.
90. Ingram, J.S. and Humphries, J.R.O. (1972) *Trop. Sci.* 14, 131.
91. International Institute for Tropical Agriculture, (IITA) (1972) Proc. IDRO/IITA Cassava Mosaic Workshop, Dec. 1972, IITA, Ibadan, Nigeria.
92. International Trade Centre, (1968) The markets for manioc as a raw material for compound animal feed, UNCTAD/GATT., Geneva.

93. Jalaludin, S. and Oh, S.Y. (1972) *Malay. Agric. Res.* 1, 77.
94. Juarez, G. (1955) Bull. 58, Est. Exp. Agric. La Molina, Lima, Peru.
95. Kartha, K.K., Gamborg, O.L., Constabel, F. and Shyluk, J.P. (1974). Nat. Res. Counc. Saskatoon, Canada.
96. Ketiku, A.O. and Oyenuga, V.A. (1972) *J. Sci. Fd. Agric.* 23, 1451.
97. Kim, J.C. and de Rulter, D. (1968) *Food Technol.* 22, 867.
98. Kitajima, E.W. and Costa, A.S. (1976) Mimeo.*
99. Krochmal, A. (1973) Mimeo.*
100. Krochmal, A. and Samuels, G. (1970) *Ceiba* 16, 35.
101. Legendijk, J. and Pennings, J. (1970) *Cer. Sci. Td.* 15, 354.
102. Lathrap, D.W. (1973) Mimeo.*
103. Leatherdale, D. (1973) *Cassava Thesaurus*, CIAT, Cali, Colombia.
104. Lee, T.K.C. (1972) Thesis Fac. Agric., Univ. Malaysia.
105. Lee, T.K.C. and Hutagalung, R.I. (1972) *Malay Agric. Res.* 1, 38.
106. Lozano, J.C. and Booth, R.H. (1974) *PANS*, London, 20, 30-54.
107. Magoon, M.L. (1967) Proc. Int. Symp. Trop. Root Crops 1, 100 Univ. W. Indies.
108. — — — — (1970) Proc. 2nd Int. Symp. Trop. Root Crops 1, 68. Univ. Hawaii.
109. Magoon, M.L., Jos, J.S., Vasudevan, K.N. and Nair, S.G. (1969) *Genetica Iberica* 21, 27.
110. Magoon, M.L. and Krishnan, R. (1973) Mimeo.*
111. Mehendranathan, T. (1971) *Malay. Agric. J.* 48, 77.
112. Maner, J.H. (1972) Mimeo. Seminar on swine production in Latin America, Sept. 1972. CIAT, Cali. Colombia.
113. Maner, J.H. (1973) Mimeo.*
114. Maner, J.H. and Gomez, G. (1973) In 'Nestel and MacIntyre' P. 113. (see ref. 113).
115. Martin, F.M. (1970) Proc. 2nd Int. Symp. Trop. Root Crops 1, 53. Univ. Hawaii.
116. Mathot, P.J. (1972) Production and export control in Thailand and marketing in Europe of tapioca pellets. Thai Tapioca Traders Assn., Bangkok.
117. Maust, L.E., Pond, W.G. and Scott, M.L. (1972). *J. Anim. Sci.* 35, 953.
118. Miche, C. (1971) Mimeo. Root and tuber crops in W. Africa, Seminar 22-28 Feb. 1971, IITA, Ibadan, Nigeria.
119. Monge, F. (1973) Mimeo.*
120. Mogliner, I., Portuguese, A.J.D., Botuzzo, A.D. and Acosta, J.A. (1967) *Bonplandia* 2, 137.
121. Montaldo, A. (1967) Bibliografia de Raices y Tuberculos Trop., Univ. Cetr. de Venezuela, Maracay.
122. — — — — (1973) *Trop. Sci.* 15, 39.
123. Mors, W.B. (1972) *Bol. Tec. Cent. Tecnol. Agr. Aliment. Rio de Janeiro.* 1, 12.
124. Mosha, A.C. (1972) Mimeo. Mandioca Fort. Conf. 13-15 March 1972, Rio de Janeiro.
125. Mota, T.P. (1970) *Agron. Mocamb.* 4, 21.
126. Müller, Z., Chou, K.C., Nah, K.C. and Tan, T.K. (1972) Mimeo. Rep. NUT. (Plgs) R672, FAO, Singapore.
128. Nagarajan, V., Bhat, R.V. and Tupule, P.G. (1973) *Environ. Phys. Biochem.*, 3, 13.
129. Narasimhan, V. and Arjunan, G. (1973) Mimeo.*
130. Nartey, F. (1973) In 'Nestel and MacIntyre' p. 73. (see ref. 133).

131. Natarajan, R. and Rengasamy, P. (1973) Mimeo.*
132. Natarajan, R. and Vijayakumar, G. (1973) Mimeo.*
133. Nestel, B.L. and MacIntyre, R. (Eds.) (1973) *Chronic Cassava Toxicity*. Proc. Interdisciplinary Workshop, IDRC, Ottawa.
134. Nicol, B.M. (1962) *Brit. J. Nut.* 6, 1.
135. Normanha, E.S. (1970) Proc. 2nd Int. Symp. Trop Root Crops 1, 61. Univ. Hawaii.
136. Nyilira, Z.N. (1973) Mimeo. Rep. on studies on Min. of Ag., Kampala, Uganda.
137. Obigbesan, G.O. and Agboola, A.A. (1973) Mimeo.*
138. Oke, O.L. (1973) In 'Nestel and MacIntyre' p. 97. (see ref. 133)
139. Okigbo, B.N. (1973) Mimeo.*
140. Onochie, B.E. and Makajuola, G.A. and Schulte, E.E. Mimeo.*
141. Osuntokin, B.O. (1973) In 'Nestel and MacIntyre' p. 127. (see ref. 133)
142. Oyenuga, V.A. and Opeke, L.K. (1957) *W. Afr. J. Biol. Chem.* 1, 3.
143. Park, Y.K. and Lima, D.C. (1973) *J. Food Sci.* 33, 356.
144. Peterson, J.L. (1973) Personal communication to IDRC. (Dept. Plant Path. McGill Univ. Canada).
145. Perten, H. (1970) Composite Flour Program, Doc. Package No. 1, FAO, Rome.
146. Phillips, T.P. (1973) *Cassava, a study of its utilization and potential markets*. IDRC Ottawa.
147. Pringle, W., Williams, A. and Hulse, J.H. (1969) *Cer. Sc. Td.* 14, 114.
148. Raeburn, J.R., Kerkham, R.K. and Higgs, J.W.Y. (1950) Rep. on a survey on problems of mechanization of native agriculture in tropical African colonies, H.M.S.O. London.
149. Rankine, L.B. and Houn, M.H. (1971) Dep. Agric. Econ. Occ. Series 6 Univ. W. Indies, Trinidad.
150. Rasper, V. (1969a) *J. Sci. Fd. Agric.* 20, 165.
151. — — — — — (1969b) *J. Sci. Fd. Agric.* 20, 642.
152. Rapwer, V. (1971) *J. Sci. Fd. Agric.* 22, 572.
153. Rasper, V., Mak, H.M. and de Man, J.M. (1972) Mimeo. Prodn. and Mkting of composite flours meeting, 23—27 Oct. 1972, Bogota, Colombia.
154. Renvoize, B.S. (1972) *Econ. Bot.* 26, 352.
155. Roa, G. (1973) Personal communication (CIAT, Colombia).
156. Rogers, D.J. (1959) *Econ. Bot.* 13, 261.
158. Rosenthal, F.R.T., Barbosa, C.M., Mello, A.P. and Silva, S.M.O. (1972) *An. Acad. Bras. Cienc.* 44, 55.
159. Ross, E. and Enríquez, F.Q. (1969) *Poult. Sci.* 47, 846.
160. Rosseto, C.J., Veiga Leao, A.F.S., Pereira, A.S. and Normanha, A. (1973) Mimeo.*
161. Sadi, S. (1973) Mimeo.*
162. Schmidt, N.C. and Pereira, A.S. (1968) *Bragantia* 27, 249.
163. Serck-Hansen. (1970) *Arch. Environ. Health* 20, 729.
164. Serres, H. (1969) *Rev. Elev. Vet. Pays. Trop.* 22, 529.
165. Serres, H. and Tillon, J.P. (1972) *Rev. Elev. Vet. Pays. Trop.* 25, 455.
166. Shank, R.C., Wogan, G.N., Gibson, J.B. and Nondasuta, A. (1972) *Fd. Cosmet. Toxicol.* 10, 61.
167. Shultz, T.A., Chicco, C.F., Sjuiltz, E. and Carnevali, A.A. (1970) *Agron. Trop. (Macaracay)* 20, 185.

168. Shultz, E., Shultz, T.A. and Chicco, C.F. (1970) *Agron. Trop. (Macaracay)* 20, 421.
169. Shultz, T.A., Shultz, E. and Chicco, C.F. (1972) *J. Anim. Sci.* 35, 865.
170. Sinha, S.K. and Nair, T.V.R. (1971) *Ind. J. Gen. and Plat. Brdg.* 31, 16.
171. Smith, B.C.G. (1970) *E. Afr. Agric. For. J.* 35, 319.
172. Springer, B. (1972) Personal communication to IDRC (Dept. Biometrics, Univ. W. Indies, Trinidad.)
173. Srivasta, H.C. and Patel, M.M. (1973) *Die Starke* 25, 17.
174. Stanton, W.R. and Wallbridge, A. (1969) *Process Biochem.* 6.
175. Strassner, J., Abbott, J.A. and Battey, R.F. (1970) *Food Eng. (May)* 112.
176. Tan, K. (1973) The Tapioca Indust. in Malaysia. Ph D. Thesis. Univ. Malaysia, Kuala Lumpur, Malaysia.
177. Teixeira, C.G. (1950) *Bragantia* 10, 277.
178. Tejada de Hernandez, I. and Bramolla, S. (1969) *Technica Pecuaría en Mexico*, 12-13, 5-11.
179. Teleni, E. (1972) *Fiji Agric. J.* 34, 81.
180. Toury, J. and Giorgi, R. (1966) *Ann. Nut. et Alimentation.* 20, 111.
181. van Schoonhoven, A. (1973) Personal communication. (CIAT, Colombia.)
182. Vellkaya, E.I. and Nguen Din Thyong (1971) *Izv. Vyssh. Uchebn. Zaved Pishch. Teknol.* 3, 57.
183. Vijaya, M.R. and Aiyer, R.S. (1969) *Agric. Res. J. Kerala* 7, 84.
184. Wahby, O. and Eriksen, S.G. (1969) Tapioca Ind. in W. Malaysia, Food Technol. and Res. Centre, Serdang Malaysia.
185. Wholey, D.W. and Cock, J.H. (1973) Mimeo.*
186. Williams, C.N. (1971) *Expl. Agric.* 7, 49.
187. Williams, C.N. (1972) *Expl. Agric.* 8, 15.
188. Williams, C.N., Beeny, J. and Webb, B.H. (1969) *Trop. Agric. (Trin.)* 46, 47.
189. Williams, C.N. and Ghazali, S.M. (1969) *Expl. Agric.* 5, 183.
190. Yong, C.W. (1970) *Malay. Agric. J.* 47, 483.

TABLE 1

Human intake of cassava in 14 countries 1964-66

(Source: FAO Food Balance Sheets 1974-66)

	Human population (million)	Cassava as % total calories	Calories per day from cassava	Cassava consumed per year (kg/head)
Congo(Brazzaville)	0.84	54.8	1184	470
Zaire	15.63	58.5	1193	437
Central African Rep.	1.33	48.7	1057	354
Gabon	0.46	47.0	1027	342
Mozambique	6.96	42.6	908	304
Angola	5.15	34.5	659	220
Liberia	1.08	26.2	600	201
Togo	1.64	26.5	590	197
Dahomey	2.36	20.1	438	148
Paraguay	2.03	19.7	540	181
Ghana	8.14	18.2	380	130
Brazil	80.77	10.8	274	107
Nigeria	58.48	14.1	306	103
Indonesia	105.74	15.3	269	92
Total:	304.15	-	-	-
Weighted average (14 countries)	-	19.4	374	124

DEVELOPMENT-ORIENTED INTEGRATED CASSAVA PROJECTS

Simon J. Nusbaum*

SUMMARY

The development of specific integrated projects for cassava production and processing requires a clear policy backed with sufficient funding. It also requires commercial activities of a local firm or organization with sufficient entrepreneurial competence. This can often usefully be backed up on a temporary basis by employing the services of public or private consultants with appropriate knowledge and experience. It is suggested that the first processing development can most easily be directed towards the production of stock feeds with the production of human food following as a second stage of development.

RESUME

Le développement de projets spécifiques intégrés pour la production et la transformation du manioc exige une politique bien définie et un financement adéquat. Il faut également la mise en place d'une société locale ayant l'expertise pour organiser efficacement les structures et les activités de commercialisation. Pour commencer, il faut envisager une période transitoire en recourant aux services d'experts compétents du secteur public ou privé. L'entreprise peut se faire en deux phases: la première, facilement réalisable pourrait être orientée vers la production d'aliments de bétail et la seconde vers la production alimentaire destinée à l'homme.

RESUMEN

El desarrollo de proyectos integrales específicos para la producción procesamiento de yuca, requiere una clara política apoyada con fondos suficientes. También requiere de las actividades comerciales de una empresa u organización local suficientemente competente. Esto se obtiene a menudo, sobre una base temporal, con el empleo de los servicios de los consultores públicos o privados con conocimientos apropiados y experiencia. Se sugiere que el primer proceso para el desarrollo puede lograrse mas fácilmente si se dirige hacia la producción de alimentos para ganado continuando con la alimentación humana en una segunda etapa de desarrollo.

INTRODUCTION

Cassava (manioc, mandioca, yuca) is a well-known root crop, grown and consumed all over the tropical and subtropical world. Estimated world production is 90,000,000 tons. Its main use in nearly all countries where it is grown is as a staple food, and it is usually cultivated as a subsistence crop. However, its use in industrialized countries, especially in the U.S.A., is well established in the form of processed cassava starch ('tapioca') employed both as food and for industry for innumerable derivatives such as glucose. Recently cassava has found a substantial market in the compounded animal feeds industry in Western Europe. This market reached 1,500,000 tons in 1971. Thailand provides nearly all the cassava traded for animal feed, and this country itself consumes no cassava at all, and until World War II, grew none.

This monopolistic position, coupled with the recent renewal of interest in cassava in scientific and development-aid circles, has generated several inquiries from governments and private organizations in developing countries. Some of these inquiries have led to projects intended to introduce new producers into the promising European animal feeds market. However, each attempt has revealed considerable difficulties at practically every operational level — agricultural marketing, quality, cost of production — as well as the complications of coordinating all the components into a workable enterprise or 'system'. As a result, Thailand still (1973) maintains its dominant position in the markets, and no substantial alternative source of supply has yet been developed.

The challenges presented by the formulation and implementation of new 'integrated cassava projects' several years ago involved organizing applied research, analyzing the economics and developing trading contacts required by such an undertaking. Several projects are now on the verge of becoming realities, so it is possible to outline them here in general terms.

*International Development Consultant. 301 East 47th St., New York, N.Y. 10017

GENERAL ORIENTATION OF FUTURE CASSAVA PROJECTS

Cassava has three main uses: as human food, as an industrial item, and as animal feed.

Our analysis of past inquiries from many developing countries over a twenty-year period suggests that industrialization of cassava production for purposes of entering international markets will not generally support a project. The main reason is probably the competition from other starches, particularly corn starch in the U.S., which is being recently matched by similar developments in Europe.

Similarly, attempts at industrialization of the traditional human food uses for cassava in developing countries have so far had limited success. For example, neither improved or better-packaged 'gari' in Nigeria, nor projects for cassava-containing bread or pastry in some South American countries, have yet produced a substantial commercial cassava project. However, current research now holds promise in these directions.

Finally, while cassava has sometimes been fed to animals (hogs and cattle particularly) by farmers in many developing countries, the intensive and recent importation and use of it in Western Europe has drawn attention to the obvious possibility of applying this new technology to the animal industries in developing countries themselves. Such development could go far in solving the meat production and dairy production problems, hence meeting the protein needs, of many developing countries. This use of a locally produced cassava feed, together with the use of sugarcane by-products should have an important effect on the structuring of future cattle projects.

OUTLINE OF POSSIBILITIES FOR COMPREHENSIVE CASSAVA PROJECTS

A careful analysis of the potential and of the limitations of cassava operations have led us to the conclusion that a development-oriented and business-oriented cassava project should be constructed as follows:

1. At the start there is need for solidly organized production of a steady supply of roots of consistent quality and in sufficient quantity to initiate, within one year or two at the most, the export of a reasonable quantity of semi-processed products (i.e. chips or pellets) to Europe. The problems in achieving this basic foundation are numerous, but with proper coordination of applied research, continuing experimentation, management, production, processing, transportation, handling, and marketing, solutions should be found, and at a cost of production competitive with Thailand.
2. Simultaneously, the project should include a development component (based on applied research, experimentation and gradual implementation) towards the feeding of local livestock for meat and dairy production.
3. Also simultaneously, or shortly thereafter, the project should revive or initiate attempts to apply new technologies aimed at the production and commercialization of improved human food products through protein enrichment and flour substitution. Bread, pastry, crackers, sausage, meat products, macaroni, noodles, beer, fermentation-enriched concentrates may all be developed on a basis of cassava starch.
4. The starch uses for industry involve much more limited quantities and thus should be developed for local industry in the producing country (textile, wood, paper, etc.) and only as a secondary objective for export to surrounding or even more distant countries.

CONCLUSIONS AND RECOMMENDATIONS

Much applied research has now been done; the information is readily available, and study of failed projects and of their difficulties can provide guides to the pitfalls to be avoided.

Studying such projects leads us to the conclusion that a successful cassava project in almost every developing country also requires:

1. A clear policy by each government with much higher priority and greater means than allotted so far towards agricultural development projects.
2. Competent but concentrated local entrepreneurship, if necessary supported by fairly small specialized consulting teams, able to provide guidelines, on an essentially temporary basis. Consultants may be from public or private institution.

PRESENT AND POTENTIAL LABOUR USE IN CASSAVA PRODUCTION IN COLOMBIA

Per Pinstруп-Andersen and Rafael O. Diaz*

SUMMARY

Present labour use in cassava production in Colombia was estimated at about 60,000 man-years, or 2.4 percent of the total agricultural labour force. Weeding was the most labour-consuming activity. Potential labour use was analyzed as a function of increasing cassava area and of the adoption of mechanical, chemical and biological technology. Increases in cassava area at the present rate, with present methods, were estimated to require an additional 1,584 workers annually. Mechanization of land preparation and chemical weed control might reduce labour use by 2.5 man days/ha/year. Yield-increasing biological technology would be expected to increase labour demand among adopters slightly (1.8 man-days/ton/ha). However, if prices fall because of production expansions, the net impact on producer sector employment may be negative. The price flexibility for cassava for direct human consumption which could bring this about will no longer be a relevant criterion for estimating changes in employment if new markets, e.g. for livestock feeds, can be developed.

RESUME

La main-d'œuvre actuelle utilisée pour la production du manioc en Colombie occupe environ 60,000 personnes annuellement soit 2.4 percent de la force totale de travail destinée à l'agriculture. Une part importante de cette force est consacrée aux travaux de désherbage. L'utilisation de la main-d'œuvre potentielle est considérée comme un facteur d'accroissement des terres consacrées à la culture du manioc et de l'adoption des techniques de mécanisation, de l'emploi de produits chimiques et de l'application de la biologie. Si on considère le rythme actuel d'accroissement des terres consacrées à la culture du manioc et les méthodes de son exploitation, il faut 1,584 ouvriers supplémentaires par an pour satisfaire la demande en main-d'œuvre. La mécanisation du labour et l'utilisation de produits chimiques pour lutter contre les adventices pourraient réduire la main d'œuvre d'environ 2.5 ouvriers par hour et à l'hectare en un an. Les techniques de biologie pour l'accroissement du rendement pourrait légèrement augmenter la demande en main-d'œuvre là où elles sont adoptées (1.8 d'ouvriers/jour/tonne/ha). Toutefois, s'il y a chute des prix en raison de l'extension de la production, l'impact sur l'emploi dans le secteur producteur peut être négatif. La flexibilité des prix du manioc directement consommé par l'homme qui peut en être la cause ne sera plus un facteur valable pour estimer les changements dans l'emploi si de nouveaux marchés, comme les aliments de bétail, peuvent être développés.

RESUMEN

El uso actual de la fuerza de trabajo en la producción de yuca en Colombia se estimó en alrededor de 60,000 hombres-año, o 2.4% del total de la fuerza de trabajo agrícola. El deshierbe fué la actividad que consumió más mano de obra. El uso potencial de la fuerza de trabajo se analizó como una función del incremento del área destinada a yuca, y de la adopción de tecnología mecánica, química y biológica. Se estimó que el incremento del área para yuca en la producción actual, con los métodos actuales, requiere de 1,584 trabajadores adicionales anualmente. La mecanización en la preparación de la tierra y el control químico de malas hierbas podrían reducir el uso de la mano de obra en unos 2.5 hombres/ha/año. Se podría esperar que el incremento de rendimiento por el empleo de tecnología incrementara ligeramente la demanda de fuerza de trabajo entre los que la adopten (1.8 hombres/día/ton/ha). Sin embargo, si los precios bajan debido a expansión de la producción, el impacto neto sobre el empleo, en el sector productivo, podría ser negativo. La variabilidad de los precios de yuca para consumo humano directo, que podría ocasionar aquella situación ya no constituiría un criterio relevante para estimar los cambios en cuanto empleo, si se pudiesen desarrollar nuevos mercados, pro ejemplo: el de alimento para ganado.

*Centro Internacional de Agricultura Tropical, CIAT, Apartado Aereo 67-13, Cali, Colombia.

INTRODUCTION

High and increasing rates of unemployment, resulting in severe poverty among large segments of the population, is a common problem in most developing countries. The problem is generally associated with rapid population growth and inability of the economy to absorb the expanding labour force. A strong rural-to-urban migration trend accelerates urban unemployment. It is not uncommon to find urban areas with an annual population growth rate of 7–8 percent, with about half of this growth resulting from rural-to-urban migration, while the annual growth in urban employment opportunities may be only 3–4 percent.

Creation of more productive jobs at a greater rate than exists at present is essential to reduce poverty. Even to avoid worse poverty the rate of employment generation must be accelerated considerably.

Additional jobs may be created in the rural as well as the urban sector. More jobs in the rural sector tend to reduce rural-to-urban migration provided that earnings and working conditions in the rural sector are sufficient to satisfy the aspirations of the potential migrant. But, there have been few instances of rapid expansion of rural employment in recent years.

Governments of developing countries frequently consider a rapid reduction of the rural labour force necessary to accelerate economic growth. Furthermore, individual farmers tend to replace labour by machinery to increase labour efficiency and to reduce the problems associated with maintaining a large labour force. Farm machinery is frequently imported and hence domestic agricultural labour is replaced by foreign labour services, and the kind of mechanization adopted fails even to create additional jobs in local industry and commerce to absorb the displaced farm workers.

Recently, a number of developing countries have become concerned about the equity issues of economic growth. Equitable income distribution and possibilities for productive employment have been added to the goal of efficiency in establishing new social objectives in politics. In this new political trend, governments seek ways to increase employment in agriculture while gaining time to expand urban employment.

This paper deals only with a small fraction of the complex problems of employment in agriculture. The paper attempts to analyze present and potential labour use in the production of cassava in Colombia. The specific objectives of the paper are:

1. To estimate present labour use in cassava production in Colombia.
2. To compare labour use in cassava production with that of other major agricultural products.
3. To estimate how certain new technology applied in cassava production may influence employment.

The analysis is limited to the production process. No attempt is made to estimate labour use in processing and marketing of cassava.

THE EMPLOYMENT PROBLEM IN COLOMBIA

The total population of Colombia was estimated at 22.6 million for 1970. Twenty-nine percent of the population was considered economically active. Of the economically active, 2.5 million, or 38 percent were engaged in agriculture. Past population growth of 3.2 percent per year and massive rural-to-urban migration resulted in an urban population increase of 5.4 percent annually during 1951–64, while the rural population increased, in spite of migration to towns, at a rate of 1.3 percent. During the same period, the three largest cities grew at 7 percent per year⁽⁸⁾. New employment has been insufficient to meet the increase in the labour force, and unemployment is increasing.

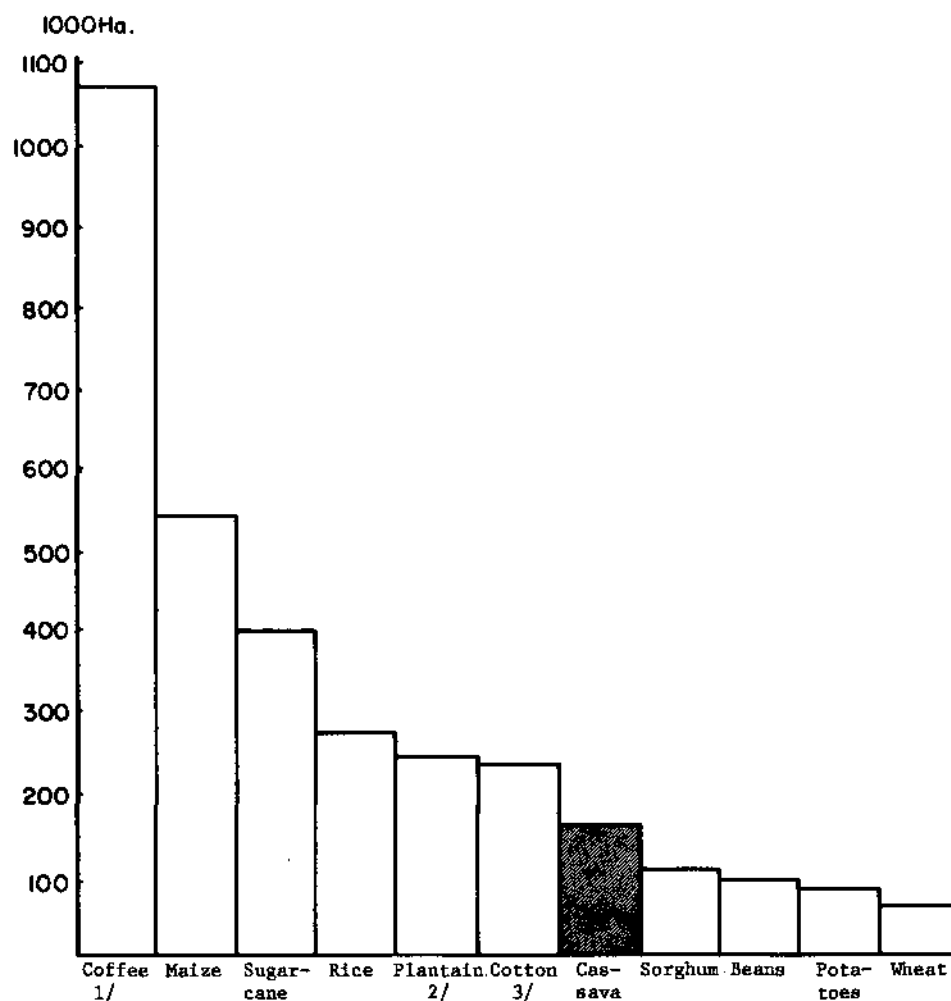
Despite the rapid outmigration, it is estimated that only 70 percent of the present potential agricultural labour force is employed. This figure takes into account unemployment as well as under-employment.

The Colombian labour force is projected to grow at a rate of 3.5 percent annually for a period of at least fifteen years, while employment during the last two decades rose only by 2.2 percent. It is estimated that agriculture will need to provide employment for 50,000 additional persons annually during the period 1970–85⁽⁹⁾. How can cassava production help meet this need?

CASSAVA IN COLOMBIA

Although cassava occupies a considerable area in Colombia (Figures 1 and 2), the crop has received minimal attention from research workers and public agencies engaged in agricultural development. Yields are low, and little improvement has occurred in the last ten years (Figure 2). Production increases have resulted almost exclusively from expanded area. A linear trend shows an annual increase of 3,760 ha. (Figure 2).

Cassava, typically, is grown on small farms. As the producer and his family consume a considerable amount of the production, the amount going to market is considerably less than that produced. Because of the past lack of interest in the crop on the part of decision-makers in research and public policy, and because of its utilization as a subsistence crop, reliable statistical information on cassava is scarce. Hence the information presented in Figure 2 should be considered as a general indication rather than as an exact representation.



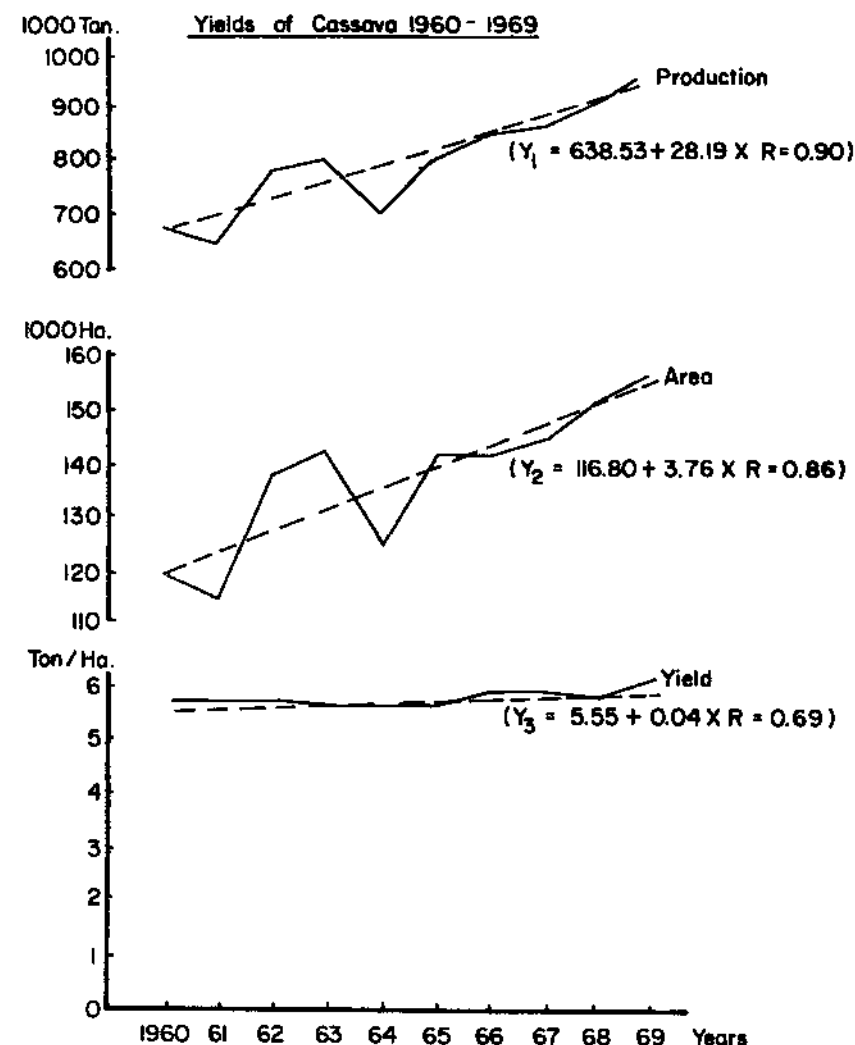
1/ Data from 1970

2/ Data from 1970

3/ Data from second semester of 1971 and first semester of 1972.

Source: Programas Agrícolas del Ministerio de Agricultura. Oficina de Planeamiento del Sector Agropecuario, Bogotá, Colombia. January and December 1972.

Fig 1. Area grown with 11 major crops in Colombia 1972.



Sources: Programas Agrícolas del Ministerio de Agricultura. Oficina de Planeamiento del Sector Agropecuario, Bogotá, Colombia. December 1972. P. 204.

L. Jay Atkinson, Changes in Agricultural Production and Technology in Colombia. U.S. Department of Agricultural, Economic Research Service in Cooperation with the Ministry of Agriculture and The Central Planning Agency of Colombia. P. 25.

Fig 2 The trend in production, area and yields of Cassava 1960-1969.

To obtain more information on the cassava production process, data was collected from 300 producers in 19 departments of Colombia. Obtaining reliable information on production costs and the use of inputs was emphasized. This paper reports the major findings with respect to labour use.

About 30 percent of the sampled farms used machinery to prepare land. No other activities were mechanized. In order to assess the impact of mechanized land preparation on labour use and cost of production, the sample farms were classified in two groups according to whether land preparation was mechanized.

Estimated labour use in cassava production

Table 1 shows the estimated labour use by production activity. Total annual labour use per hectare was estimated at 87.7 man-days using mechanized land preparation and 110.6 man-days when land was prepared manually. Weeding was the major labour-using activity. Manual land preparation and harvesting were other important labour activities.

To assess the general applicability of the results reported in Table 1, comparisons are made with results from similar studies undertaken in other regions. Total labour use per hectare in cassava production in the coffee zones of Colombia was estimated to be similar to that estimated for producers preparing land manually (Table 2), but the distribution of labour between production activities was quite different. In the coffee zone⁽²⁾, more labour was spent on harvesting, but less on weeding. Estimates from North East Brazil⁽³⁾ show a considerable variation between regions. However, the average labour requirements are similar to those estimated for Colombia. Labour requirements in the production of cassava in Jamaica⁽⁴⁾ have been estimated to be considerably larger than those estimated for Colombia and Brazil.

The labour needed to produce a ton of cassava was estimated to be 7.5 man-days if machines were used for land preparation and 10.2 man-days if the land was prepared manually. Labour needs per ton of cassava produced appear to be similar for Colombia and North East Brazil while they are somewhat larger for Jamaica (Table 2).

Table 3 compares the labour use per hectare for 10 major crops in Colombia. Among the 10 crops, cassava occupies fifth place in terms of labour use per unit of land, being exceeded by sugar-cane, coffee, plantain and potatoes. Cassava provides about twice as many jobs as corn per unit of land per crop, and three times as many as wheat. In some regions, two crops of corn are grown per year, but only one of cassava, hence the labour use per year in these regions will be approximately the same for the two crops.

Assuming that the labour use per hectare reported in Table 3 is representative of the total national production, then the total annual labour use in cassava production is estimated to be approximately 2.4 percent of the total agricultural labour force. There will be some surprise with the finding that cassava uses more labour than cotton, since the latter is traditionally considered a major labour-consuming crop.

POTENTIAL LABOUR USE BY DEVELOPING CASSAVA PRODUCTION

Assumption of the analyses

On the future role of cassava production as a labour-absorbing activity, the analysis is divided into two parts. First, we will estimate the demand for labour as a function of the adoption of new technology, assuming constant cassava prices. Then we will remove this assumption so as to include the effect of product-market relationships (elasticities of supply and demand). Throughout the analysis, we assume an unlimited potential supply of labour, i.e. we assume that increasing demand for labour will have no impact on wages. This assumption appears valid for the relatively small demand changes to be dealt with in this analysis and in view of the present employment situation in Colombian agriculture, as previously discussed. (In regions with large seasonal fluctuations in labour demands for crops other than cassava, the assumption may not be valid during peak seasons. Labour demand in cassava production itself shows little seasonal variation.)

Labour demand and new technology assuming constant cassava prices

Almost no technological change has occurred in cassava production in Colombia other than some mechanization of land preparation. Hence, the analysis attempts to predict changes in labour demand that might follow if new technology were to be adopted (*ex ante*) rather than to evaluate what has happened in the past (*ex post*).

Four levels of technological development are considered:

1. No new technology will be adopted. Area and yields will continue along past trends.
2. Mechanical technology will be adopted for land preparation. Area and yields will continue along past trends.
3. Chemical technology will be adopted for weed control. Area will continue along past trends but yields may increase.

4. Improved biological technology will be adopted. Area will continue along past trends, but yields will increase.

No new technology.

Past trends in cassava area show an annual increase of 3,760 ha. (Figure 2). Assuming constant factor and factor-product proportions, each additional hectare would require an additional 96 man-days per year (Table 3). Hence, taking 250 man-days as a man-year, the demand for labour would increase by 1,444 workers annually⁽⁷⁾. This amounts to 2.9 percent of the estimated additional needs for employment in agriculture (50,000 workers) as previously discussed. Present employment in cassava is only 2.4 percent of the total agricultural employment. Hence an expansion of the cassava area along past trends would provide more than its share of employment for the additional expected labour force. To the extent that the new cassava area originates from substitution to cassava from other crops, labour requirements for the production of other crops would however decrease. For example, substituting cassava for single-crop maize will increase labour demands for cassava by 96 man-days/ha. However, if two maize crops are, or can be, produced annually, the above substitution would reduce total labour use by 16 man-days/ha.

Mechanical technology

A large portion of the cassava area is found on slopes where mechanization would not be feasible. There is a considerable area though where mechanical means could replace present manual land preparation. Such replacement would displace (save) approximately 25 man-days per hectare (Table 1). Figure 3 shows the relationship between increasing mechanization of land preparation and the displacement of labour. We may speculate that about 10 percent of the total cassava area presently prepared manually is suitable for mechanical land preparation. A change from manual to mechanical means on this area would displace about 1,550 workers.

Chemical technology

Application of herbicides using a back-pack sprayer utilizes about three man-days per hectare. Hence, assuming an average labour use for manual weed control of 45 man-days/ha (Table 1), substitution of chemical for manual weed control would displace labour by about 42 man-days/ha. Figure 4 shows the relationship between the use of herbicides and labour displacement. If, for example, herbicides were used on 10 percent of the cassava area, labour employment would be reduced by 2,604 man-years. If used on one-half of the area, the labour displacement would be 13,020 or 21.7 percent of the total labour presently employed in cassava production.

Fig 3. The effect of mechanization of land preparation on labor use in cassava production in Colombia.

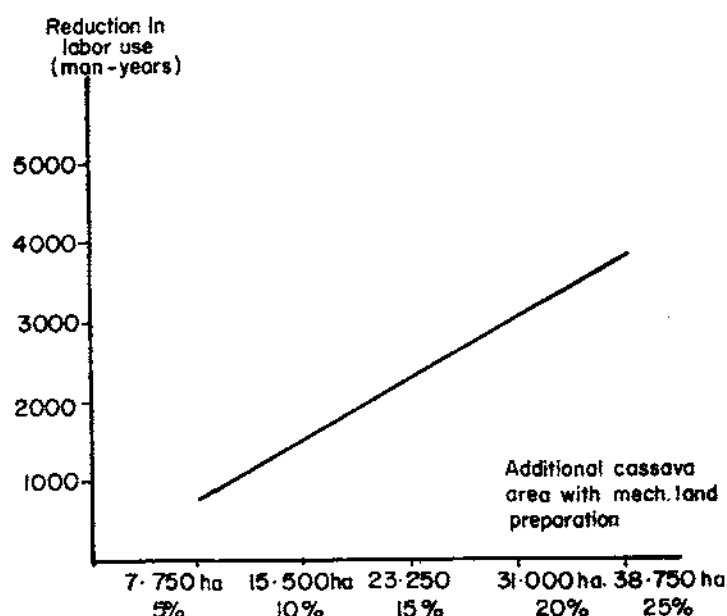
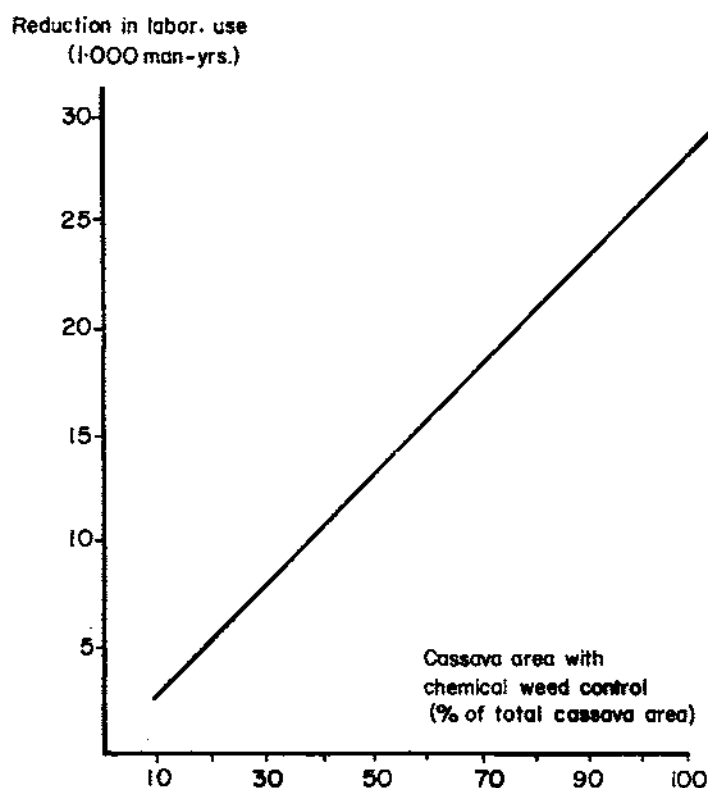


Fig 4. The effect of chemical weed control on labor use in cassava production in Colombia



Although application of herbicides might increase yields and thus increase labour needed for harvesting and packing, it is unlikely that a change from adequate manual weed control to chemical control would have an impact on yield. Present use of herbicides for cassava in Colombia is limited. However, an increase in the wage-herbicide price ratio could result in a considerable adoption of herbicide use.

Biological technology

Assuming that a new biological technology adopted by the farmers (high yielding cultivars, resistance to certain diseases etc.) results in increased yields, its impact on labour employment per unit of land will occur through increased harvesting and packing demand. If the adoption of new cultivars must be accompanied by increased fertilizer use or other improved cultural practices, then labour requirements for these activities may increase as well. But insect-resistant cultivars may reduce labour employment for insecticide application. This analysis is limited to the impact on labour for harvesting and packing. Changes in labour for other activities would probably be relatively small and would depend on the specific characteristics of the biological technology. They cannot be estimated in this general analysis.

Labour requirements for harvesting and packing as a function of yield were estimated for the farmers included in the sample previously mentioned using simple linear regressions. The results were as follows:

$$L = 5.7214 + 1.8066Y, R^2 = 0.7352$$

Where L = labour requirement for harvesting and packing (man-days/ha.). Y = yield (tons/ha).

i.e. Each unit increase in yield (ton/ha) requires an additional 1.81 man-days/ha. for harvesting and packing.*

Based on this estimate, we then proceeded to estimate the change in labour requirements as a function of the level of yield increase among adopters of new biological technology and adoption rates. The following equation was developed:

$$\Delta L = \frac{(\% \Delta Y_a)}{100} \times (\% A_a) \times \frac{Y_n}{100} \times \frac{(b)}{k} \times A_n$$

where:

- ΔL = change in total labour requirements (man-years)
- $(\% \Delta Y_a)$ = percentage change in yields on farms adopting new technology**
- $(\% A_a)$ = percentage of total cassava area where new technology was adopted
- Y_n = average national yields before adoption (ton/ha)
- b = coefficient of the above regression equation
- A_n = total cassava area (ha)
- K = number of work days per year (assumed to be 250)

By substituting 1969 average national yields and cassava area for Y_n and A_n and using the estimated values of the b coefficient, the equation becomes:

$$\Delta L = 0.6747 (\% \Delta Y_a) (\% A_a)$$

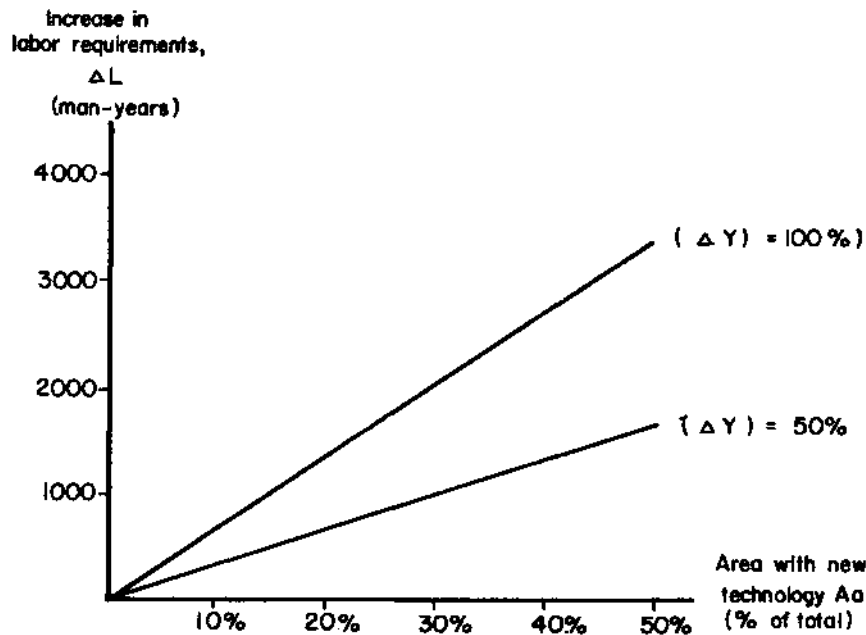
The impact of the adoption of new biological technology on labour requirements can be estimated directly from the equation on the basis of yield increasing effects and rate adoption. Figure 5 shows the relationship between rate of adoption and labour requirements for selected levels of yield increases. If, for example, the adoption of a certain new biological technology increases yields on adopting farms by 100 percent and the technology is being adopted on 10 percent of the cassava area, the estimated increase in labour requirements is 675 man-years. If the technology is adopted on 50 percent of the area, labour requirements increase by 3.374 man-years.

A certain increase in labour absorption may be brought about by a number of combinations of yield increases (ΔY) and adoption rates (A_a). Figure 6 shows this relationship for selected levels of labour absorption. As an illustration of the use of the curves presented in Figure 6, assume that the desired level of increase in employment in cassava production is 1,000 man-years. This level may be reached by any combination of yield increase and adoption rate shown by the curve labelled $L = 1000$ man-years, for example, a yield increase of 100 percent on 15 percent of the area.

* The elasticity of employment, defined as the percentage change in labour requirements for each one percent change in cassava yields, was estimated to be 0.2. This implies that total labour requirements per hectare increase by 0.2 percent for each one percent increase in yields/ha.

**Percentage change based on national average yields not individual farm yield.

Fig 5. The effect of adoption of new biological technology on labor requirements.



Labour demand and new technology considering market impact

In the previous section we estimated the impact of new technology on labour demand assuming constant cassava prices. How realistic is this assumption? As yield-increasing technology is adopted and area is expanded, more cassava will be produced. If the increase in the quantity produced exceeds the increase in the quantity demanded at the current price, a downward pressure on the price will result.

The demand for cassava in Colombia is projected to increase by about 36 percent, at constant prices, during the period 1970–80.⁽⁴⁾ If past area and yield trends continue, production will increase by 31 percent (estimated from regression equations shown in Figure 2). Hence, national yields can increase five percent more than indicated by past trends, or a total of 11.5 percent, during the period without a price-depressing effect. In this case, labour demands will increase by 1,443 man-years annually because of area expansions and 138 man-years annually because of yield increases*, or a total of 1,581 man-years annually.

The price decrease likely to result from supply expansion beyond those estimated above can be estimated from the price elasticity of demand.** The majority of the cassava grown in Colombia is directly consumed by people. The price elasticity for cassava for direct human consumption is such that supply expansions beyond normal demand increases will result in price declines proportionally larger than the supply expansions. Thus total revenues to the producer sector will decrease as production increases. This analysis would imply that traditional resources (land and labour) must move out of cassava production as new technology is adopted. If the cassava producers were to depend exclusively on the demand for direct human consumption, supply expansions beyond those needed to fulfill demand increases at current prices would result in a reduction in labour demand. While the farmers adopting the new technology would expand labour demands, at least initially, the expansion would be insufficient to counteract the reduction in labour demands among non-adopting farmers, a proportion of whom would not be able to recover costs at the lower prices. The adopters, however, can stand a considerable price fall. The additional production brought about by the new technology adds little to total costs per hectare*, but the cost per ton is severely reduced.

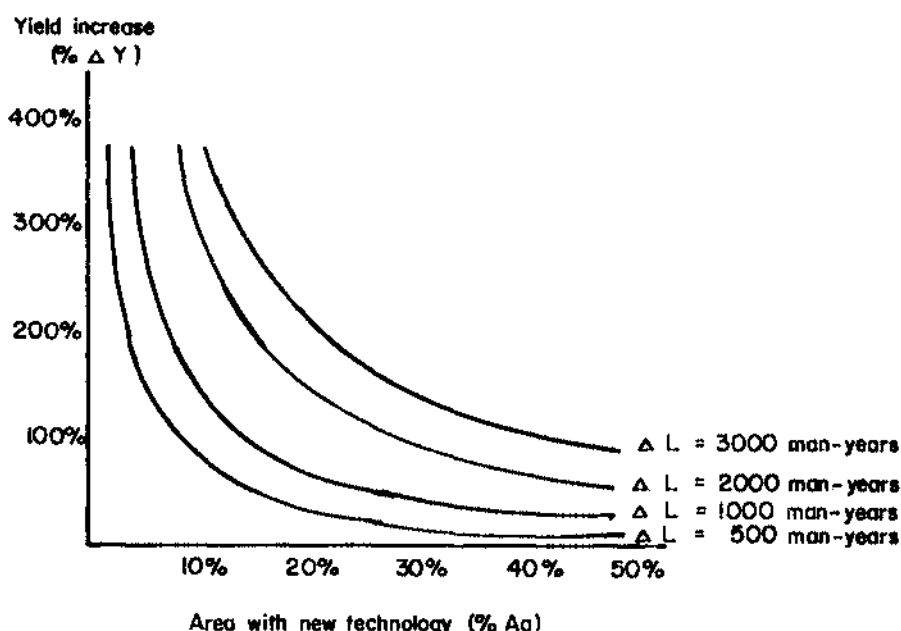
There are a number of reasons why cassava prices may not fall as drastically as indicated above as envisaged for large production expansions. The government may, for example, establish support prices to protect the producer. Furthermore, if prices are allowed to fall, new markets, such as cassava for livestock feed, should appear. This will slow down the rate of price decrease. The price elasticity for the direct human consumption market would thus no longer be a valid criterion for estimating changes in labour employment. Further production expansions may well increase returns to the producer sector and also allow for a net increase in labour demands.

* The elasticity of employment (0.2) multiplied by the percentage increase in yields (11.5) provides an estimate for the increase in employment between 1970 and 1980 (1,380). Assuming a linear increase in yields during the period, the annual increase in labour demand will be 138 man-years.

**The price elasticity of demand is defined as the percentage change in the price of a commodity for each one percent change in the supply of the commodity in order that the market may be cleared.

*Each additional ton/ha. is expected to add the cost of 1.8 man-day, while the average current labour use, was estimated at 9.5 man-days/ton.

Fig 6. Alternative combinations of yield increase and adoption rate resulting in selected levels of increase in labor requirements.



CONCLUSIONS

By examining the present and potential labour absorption in cassava production in Colombia we have estimated present labour employment at about 60,000 man-years, or 2.4 percent of the total agricultural labour force. Weeding accounts for 40–50 percent of the total labour requirements, being the most labour-consuming activity in cassava production, followed by harvesting and packing.

If past trends continue, additional cassava production will require an annual increase of 1,581 workers or 3.2 percent of the expected annual increase in the agricultural labour force. Mechanized land preparation and chemical weed control reduce labour requirements per hectare by about 22 and 40–50 percent respectively. Extensive mechanization and/or herbicide use could have a significant negative impact on labour demand.

While new biological technology is expected to increase labour demand among adopters, the increase is relatively small (1.8 man-day/additional ton produced) and may well be offset by labour reductions among non-adopters if cassava prices are permitted to adjust to large supply expansions resulting from the new technology. The marginal cost associated with adoption of yield increasing biological technology is extremely low. The adopters will be able to absorb a considerable price fall and still maintain a reasonable net return. As prices fall, the non-adopters will find their net returns reduced, and losses may occur. This will result in a reduction in labour and land dedicated to cassava among non-adopters. New uses for cassava, such as livestock feed and industrial processing, are likely to become economically sound as prices fall. When this occurs, the price may stabilize as production expands. This would result in increased revenues to the producer and allow for additional employment.

Based on this study, we conclude the following:

1. Cassava production contributes significantly to agricultural employment in Colombia.
2. Increasing the cassava area and yields along past trends to meet increasing demand may be expected to employ a considerable number of agricultural workers.
3. Adoption of yield-expanding biological technology will be neutral if cassava prices remain constant, and negative if prices fall.
4. The impact on labour demand among non-adopters will be neutral if cassava prices remain constant, and negative if prices fall.
5. The net effect of yield-increasing biological technology on labour use in the producer sector could be positive, neutral or negative, depending on the extent to which cassava prices decrease.
6. As the cassava production is expanded and prices decrease, production of new markets for cassava are likely to be economically feasible. Prices will not fall in these markets to the extent indicated by the price elasticity of demand for direct human consumption.
7. Extensive mechanization of land preparation and/or extensive use of herbicides would have a considerable adverse impact on employment.
8. The social objective of creating employment may conflict with private objectives of maximizing profits.

It is clear from this analysis that while biological research may have a considerable positive impact on productivity and hence increase consumer real income through reduced food prices and/or increase producer real income through higher net returns, it may at the same time have an adverse impact on employment. Furthermore, while increasing mechanization and chemical weed control may increase net returns to the producer, the impact on the social objective of expanding employment will be negative. The extent to which labour will be replaced by mechanical and chemical technology depends, at least in part, on the relative factor prices, which in turn may be influenced by public policy. It is important that these trade-offs among goals be fully understood by government policy makers so that corrective measures may be introduced, if needed to meet overall development objectives.

REFERENCES

1. Daines, S.R. et al. (1972) Summary results of employment, income distribution and small farm analysis. Analytical working document No. 2, Colombia Agriculture Sector Analysis, AID, Bogota.
2. Fondo de Desarrollo y Diversificación de Zonas Cafeteras, (1968) Cultivos y empresas de sustitución para zonas cafeteras marginales.
3. Ministerio de Agrícola, Programas Agrícolas. (1972) Oficina de planeamiento del sector agropecuario.
4. Phillips, T.P. (1973) Cassava: a study of utilization and potential markets. School of Agricultural Economics and Extension Education, University of Guelph, Canada. (Preliminary report.)
5. Rankine, L.B. & Houn, M.H. (1971) A preliminary view of cassava production in Jamaica. Occasional Series No. 8. Department of Agricultural Economics, University of the West Indies, Trinidad.
6. University of Georgia, (1971) Feasibility of manioc production in Northeast Brazil.
7. U.S. Department of Agriculture, Economic Research Service in cooperation with the Ministry of Agriculture and the Central Planning Agency of Colombia. Changes in agricultural production and technology in Colombia.
8. World Bank Country Economic Report (1972) *Economic Growth of Colombia. Problems and Prospects*. Johns Hopkins University Press, Baltimore.

ACKNOWLEDGEMENT

Acknowledgement is due to James Cock, Alberto Valdes and Grant Scobie for valuable suggestions on an earlier draft of this paper, and to Patricia Zuffiga for preparing the figures.

TABLE 1

Estimated labour use in the production of cassava in Colombia by activity

Activity	Mechanical land preparation		Manual land preparation	
	Man-days per ha/yr	%	Man-days per ha/yr	%
Land preparation	-	-	25.0	22.6
Planting	9.1	10.4	10.8	9.8
Re-planting	0.3	0.3	0.6	0.6
Weeding	46.8	53.4	43.2	39.0
Fertilizer application	0.5	0.6	0.3	0.3
Insecticide application	0.3	0.3	0.7	0.6
Harvesting and packing	30.7	35.0	30.0	27.1
TOTAL	87.7	100.0	110.6	100.0

TABLE 2

Labour use per hectare and per ton of cassava produced in Colombia, Brazil and Jamaica

	Man-days per ha/yr	Yield (ton/ha)	Man-days per ton
<u>Colombia^{1*}</u>			
Mechanized land preparation	87.7	11.7	7.5
Manual land preparation	110.6	10.8	10.2
 <u>Colombia^{2*}</u>			
Coffee zones	105.0	-	-
 <u>Northeast Brazil^{3*}</u>			
Alagoas	96.0	10.7	9.0
Maranhao	69.0	10.0	6.9
Sergipe	165.4	13.9	11.9
Average	110.0	11.5	9.6
 <u>Jamaica^{4*}</u>			
Mandeville	191.5	15.9	12.0
Santa Cruz	186.0	6.3	29.5

1* Data estimated in this study

2* From: Fondo de Desarrollo y Diversificacion de Zonas Cafeteras. Cultivos y Empresas de Sustitucion para Zonas Cafeteras Marginales, 1968.

3* From: Feasibility of Manioc Production in Northeast Brazil. University of Georgia, 1971, p.45.

4* From: Rankine, L.B. & Hounig, M.H. A Preliminary View of Cassava Production in Jamaica. Occasional Series No.6. Department of Agricultural Economics, University of West Indies, Trinidad. December, 1971.

TABLE 3

Estimated labour absorption in the production of various crops in Colombia

Crop	Area (1,000ha)	Labour use per ha/yr (man-days)*	Total labour absorption	
			Man-years (1,000)**	Percent of total agr. labour for. ***
Coffee	1,069	134	572.8	22.9
Sugarcane	398	145	230.8	9.2
Corn	542	56	121.6	4.9
Plantain (cooking bananas)	240	120	115.2	4.6
Rice	273	68	74.4	3.0
<u>Cassava</u>	155	96	59.6	2.4
Cotton	238	62	59.2	2.4
Potatoes	80	115	36.8	1.5
Beans	92	68	25.2	1.0
Sorghum	104	15	6.4	0.3
Wheat	61	31	7.6	0.3

* Daines, S.R. et al. Summary results of employment, income distribution and small farm analysis. Analytical Working Document No.2, Colombia Agriculture Sector Analysis, AID, Bogota, 1972.

** Assuming that a man-year is equal to 250 man-days.

*** Total agricultural labour force in Colombia 1970 was estimated to be approximately 2.5 million (Economic Growth of Colombia, Problems and Prospects, World Bank Country Economic Report, Washington, 1972.)

POTENTIAL SUPPLY OF AND DEMAND FOR CASSAVA IN THE '70's AND '80's

Truman P. Phillips*

SUMMARY

Three markets for cassava can be identified: the human food, the industrial starch, and the animal feed markets. The first and third are the most important and receive consideration. Supply of and demand for cassava are projected to 1980. The resulting figures are compared. If all residual production in producing countries was directed towards Europe, supply might well exceed demand. Nevertheless, there is scope for cassava as a diversification crop. Its import-saving ability has important implications for freeing LDC resources for other uses.

RESUME

Les marchés du manioc peuvent être répartis en trois secteurs: l'alimentation de la population, l'amidon industriel et l'alimentation de bétail. Le premier et le troisième secteur sont les plus importants et dignes d'intérêt. Une estimation de l'offre et de la demande en manioc pour l'an 1980 a été présentée, et les chiffres qui en ont résulté ont été comparés. Si toute la production en reste dans les pays producteurs était dirigée vers l'Europe, l'offre pourrait dépasser la demande. Toutefois, le manioc est une culture dont les produits peuvent être diversifiés. Le fait qu'on peut en produire suffisamment pour ne pas avoir à en importer a des implications importantes dans les pays moins développés puisque cela permet de dégager des ressources en faveur d'autres secteurs.

RESUMEN

Se pueden identificar tres mercados para yuca: el de la alimentación humana, el de almidón industrial y el de alimentos para ganado. El primero y el tercero son los más importantes y reciben consideración. Se proyectan la oferta y la demanda de yuca hasta 1980. Se comparan los cálculos resultantes. Si toda la producción residual en los países productores, se dirigiera hacia Europa, la oferta bien podría superar a la demanda. No obstante, existe un panorama para yuca como un cultivo para la diversificación. Su habilidad para evitar importaciones tiene importantes implicaciones para liberar recursos LDC para otros usos.

INTRODUCTION

Cassava, manioc, tapioca, manidoca and yuca are common regional names of the shrubby perennial tropical root crop *Manihot esculenta* Crantz. Cassava is thought to have originated in tropical Brazil, from where it spread to other parts of Latin America (archeologists have found traces of cassava dating as early as 800 BC on the Colombia-Venezuela border¹²) and in post-Columbian times, to other regions of the tropics.

Today cassava is successfully grown between latitudes 30° north and south and at elevations of up to 2,000 metres (6,500 ft); it is tolerant of temperatures of 18°C (65°F) to 35°C (85°F), precipitation of 50 to 500 millimetres (20–200 ins)⁸ and soils with pH from 5–9¹¹.

This ecological zone or 'cassava belt' coincides roughly with FAO Economic Class 2, or less developed countries (LDCs). This belt accounts for 46% of world arable land, 47% of world population, but provides only 13% of world Gross Domestic Product^{2,6}.

Cassava production amounts to 57% of tropical root and tuber production while utilizing only 54% of tropical root and tuber acreage⁶. The crop's pre-eminence in less developed tropical countries is explained by its ecological adaptability and its appropriateness to the agricultural conditions of the Cassava Belt. The main attributes which favour the production of cassava are:

1. It is easily propagated — seeds or roots are not required, propagation being a simple matter of planting stalk cuttings.
2. It is relatively high yielding.
3. It is relatively inexpensive to produce since it is easily planted and harvested and requires little or no weeding because of its leafy canopy; it does not have a critical planting or harvesting time, and hence, is not season bound.

*University of Guelph, School of Agricultural Economics and Extension Education, Guelph, Ontario, Canada.

4. It is a good risk aversion crop. Its cyanide content makes it subject to minimal animal and pest attacks; it is capable of growing on soils often considered too poor for other crops.
5. It is a reliable staple and an excellent producer of carbohydrates.*

The economic implications of these attributes are many. The farmer can plant and harvest cassava at times when the opportunity cost of his labour is very low (or zero), and, given that labour is the major input, the production of cassava enables the farmer to increase his income. The plant's tolerance to drought and pests makes it a very suitable risk and famine aversion crop. As a human food, cassava has been criticized for its low protein content; on the other hand, cassava produces more carbohydrate per unit area than any other widely cultivated crop, and since it has been projected that by 1980 there may be a carbohydrate rather than a protein shortage in many tropical regions¹, the importance of cassava in the human diet in LDCs cannot be overlooked. Thus, cassava is an attractive staple for subsistence farmers, and given favourable market conditions could have potential as a diversification crop. In most regions of the tropics the major proportion of cassava produced is domestically consumed (Africa 73.8%, Latin America 48.5%; the Far East 81.6%)* in the past decade, however, an increasing share of cassava production has been traded internationally. The future of cassava as a crop for economic diversification depends greatly upon whether or not this trade will increase.

This study takes as its point of departure the present very interesting situation in which conventional wisdoms regarding cassava are confronted by emerging markets, new contexts and reassessments. The situation is economically and politically interesting because it, of necessity, invokes (hopefully accurate) speculation on future trends of cassava production and marketing. Most important, the situation is humanly interesting because it involves the food source and livelihood of many millions of people living within the Cassava Belt.

Three distinct markets for cassava can conveniently be identified: the human food market; the industrial starch market, and the animal feed market. It is the future of the first and last markets which are considered in this brief paper.**

CASSAVA IN THE HUMAN FOOD MARKET

Cassava is well known as an important dietary staple in many parts of the tropics, with Zaire reported to be the country with the highest per capita consumption rate (1193 calories/day, or 58.5% of calorie requirements³). At the more aggregative level, cassava is found to provide 38% of the calories required in Africa; 12% in Latin America, and 7% in the Far East. Thus cassava may provide 146 million people in the tropics with half of their calorie requirements.

Future demand for cassava will be determined by future population, income and prices. Of these factors, the first two are considered to be the most important (as well as being relatively more easy to predict). The functional relationship between demand, population and income is expressed in equation 1.

$$D_{cjt} = [d_{cjo} + n_j (\Delta Y/Y_{jo})] P_{jt} \quad (1)$$

where

- D_{cjt} = demand for cassava at time t ;
- d_{cjo} = per capita consumption at the initial time period;
- n_j = income demand elasticity* for cassava;
- ΔY = change in per capita income between time t and o ;
- Y_{jo} = per capita income at the original time period;
- P_{jt} = population at time t
- j = signifies data referring to the j th country
- c = signifies cassava.

Substituting 1980 projections of population and income into this model produces the following estimates of 1980 human demand for cassava (Table 1).

These projections represent at least a 25% increase in demand in the seventies. If the projected demand levels are realized, cassava could provide 37% of the calorie requirements of Africa; 11% in Latin America; and 6% in the Far East; thus cassava may provide more than 500 million people in the tropics with more

*Coursey and Haynes⁴ p. 265 have calculated the production of kilo-calories/hectare/day (khd) of some major crops to be: cassava, 250 khd; maize, 200 khd; rice, 176 khd; sorghum, 114 khd; and wheat, 110 khd.

* Correspondences with the Commodity and Trade Divisions of the Food and Agriculture Organization, Rome, 1972.

**Presently the industrial starch market, located primarily in Canada, Japan, and the United States, accounts for less than 1% of total demand for cassava and cassava products; and whilst this market will probably grow, there is little evidence that its relative importance will increase¹⁰.

¹⁰Of the 78 tropical countries for which income demand elasticities are available, 57% are positive, implying that as income increases so will demand for cassava.

than half their daily calorie requirements. Clearly the future of the human market in volume terms is promising.

CASSAVA IN THE ANIMAL FEED MARKET

The growth of this market coincides with the development of the EEC's Common Agricultural Policy (CAP) which altered the relativity of livestock feed energy and protein prices, making it attractive to use large quantities of relatively cheap protein and energy sources (*viz.* soybean meal and cassava respectively) rather than cereals in the production of compound feeds, — in short, 'fabricating' from an appropriate mix of soyabean and cassava a product superior in quality to maize. The increased demand for livestock products which led to increased demand for compound feeds, increased dependence on mixed feeds in livestock rearing, and increased livestock production. Only small quantities of cassava were traded prior to the initiation of the CAP in the early 'sixties. Prior to 1969, the bulk of cassava exports was in the form of meal and chips, but within a matter of two years cassava pellets captured 90% of the market. The bulk of cassava imported into Europe comes from Thailand, which increased exports from 280,000 tons in 1962 to approximately 1,480,000 tons in 1973³. Obviously, other exporting countries have not experienced such large absolute increases, but their potential to increase exports has evidently always existed.

An important factor in the growth of Thai exports is the fact that cassava is an insignificant component in the Thai diet, and thus is considered by Thai growers to be a cash crop with realizable cash returns. Thai exports have also benefited from foreign investment, initially in the form of two German pelleting plants, followed by the establishment of other large commercial plants (at present 7). In most other producing countries (especially in Africa and South America) human consumption of cassava is of primary importance, with the price of domestic products often yielding greater returns than produce for export markets (*viz.*, in Brazil, farinha de mandioca, consumed at table, costs approximately \$100.00/ton, while cassava pellets for export sell at best at \$60.00/ton f.o.b. Brazil. Despite these pressures from domestic demand the export market is now worth approximately \$75,000,000 to cassava exporting countries.

As in the past, future demand for cassava in the EEC is a function of demand for livestock products, the total demand for concentrate feeds, and price. Recent studies^(6,7) predict that demand for livestock products will increase, and that higher percentages of compound feeds will be used in livestock production. The two studies cited indicate that higher incomes, greater demand for livestock products, and increased dependency of compound feeds will lead to a substantial increase in the demand for compound feeds (Table 3). Largest expansion in the use of concentrate feeds is expected to occur in France and Italy, since these two countries use relatively low levels of compound feeds at present.

Projections of the share of this expanded compound feed market which will be captured by cassava imports have been estimated by the evaluation of least-cost feed rations. This analysis entailed collecting data on feed ingredient prices and compound feed specifications (*i.e.*, starch equivalent, metabolizable energy, crude protein, lysine, methionine, etc. requirements for various categories of feed) in EEC countries. The least-cost feed rations were estimated by means of linear programming. From these formulations it was possible to determine the percentage of cassava in each ration, given various price relativities. For simple projection purposes, it is possible to multiply cassava percentages by the appropriate demand level for compound feed, and then to sum the results to arrive at an estimate of the total demand for cassava in 1980. Symbolically the calculation is as follows:

$$D_{c,80} = \sum_{i=1}^9 \sum_{j=1}^{n\sum} X_{i,j} C_{i,j} \quad (2)$$

where

- $D_{c,80}$ = demand for cassava in 1980;
- X = demand for compound feed;
- $C_{i,j}$ = percentage of cassava in the ration;
- i = the *i*th country in the EEC;
- j = the *j*th type of feed.

However, for the projections presented in this paper, Equation 2 was modified to comply with the following country-specific constraints:

1. Only feed compounded in the Northern part of Germany will use cassava (approximately 60% of total compound production.)
2. Belgium and Luxembourg are assumed to behave similarly and thus are treated as one country.
3. Only very small quantities of cassava will be used in Ireland; therefore this demand has not been included in the final estimations.

These constraints, applied to Equation 2, produced the projection of the demand for cassava in 1980

contained in Table 4. The demand projections for Germany, Belgium-Luxembourg and Holland appear to be a continuation of trends begun in 1963, while the French, Italian, Danish and British demands reflect a break with past trends. The latter two countries, being still relatively free to purchase feed grains at world prices, will probably not use cassava before 1974/75. Hitherto Italy has used only small quantities of cassava, primarily because of a concessionary levy on maize which made it more attractive to use maize than cassava and other energy feeds in feed compounding. This concession is being dismantled. France was not an earlier user of cassava because of the relatively low price of domestic grains. However, in 1972, several large French compounders began using cassava in their rations at about the 15% level. For projection purposes, it has been assumed that this trend will not be reversed.

The accuracy of projected demand for cassava in 1980 (Table 4) hinges on three further assumptions: 1) that the EEC will not introduce barriers to cassava trade; 2) that EEC grain prices are maintained at their present level and 3) that protein prices do not increase too sharply*. (Recall the complementarity between cassava and soybean meal and other protein sources). The first assumption, while speculative, is deduced from several considerations. First, the importation of 8,900,000 tons of cassava is but a small part of total feed imports, and, as such will probably be allowed to enter the EEC at existing levies. Second, cassava comes from developing countries, whom the EEC has declared that they will assist. What better way than to import animal feed? Third, in order to promote the production of livestock, the EEC would like to keep feed prices as low as possible. A complete banning of cassava would increase the per ton cost of feed. The second and third assumptions, also speculative, are based upon best possible information.

Whilst future political exigencies may invalidate these arguments, they presently have currency. Thus, our attention is turned to a brief examination of the projected availability of supply.

SOURCES OF SUPPLY

It was noted in the introduction that a large percentage of cassava production is domestically consumed. In fact, for almost all exporting countries (with the notable exception of Thailand) exports appear to be residual supplies. Therefore, a first approximation of the availability of cassava for export can be derived from a comparison of projected domestic demand for cassava and projected production of cassava (Table 5). The production projections are based upon regression growth models.* The difference between projected demand for and production of cassava is taken as a first approximation of the amount of cassava which will be available for export if export promotion policies are not introduced. The implications of Table 4 are that Africa as a region will have much smaller quantities of cassava for export than the Far East and South America, which can have more than 24,000,000 metric tons of fresh root equivalents to export. Converting the minimum difference between production and demand to animal feed ingredient units (2.5 tons of roots = 1 ton of pellets), suggests that if all residual production is converted to chips and pellets, the supply of cassava for export, 10,287,000 metric tons, is greater than the projected demand for cassava in Europe.

This first approximation, therefore, must temper the emerging awareness on the part of producing countries of the potential for cassava as a diversification crop. In Thailand, the country with the largest realized export capacity, the Ministry of Agriculture is now concluding a lengthy survey of the production and processing conditions for cassava, while the Department of Trade and Business is studying marketing and transporting arrangements. In Brazil and Malaysia studies and programmes providing substantial technical and financial assistance are under way to promote production and export of the crop. Without doubt such efforts will greatly influence the global competition of cassava exports.

CASSAVA AS A DIVERSIFICATION CROP

From the above analysis it can be concluded that there will be a growing demand for cassava products, and that global supply, given past trends, will meet future demand. Therefore, *prima facie*, any producing country which is attracted to cassava as a diversification crop must be prepared to provide cassava products at competitive prices and at suitable quality and quantities. The potential exporter of cassava should realize:

1. That the price of cassava products must be competitive. In the EEC this means a cif Rotterdam price of approximately \$75.00/ton.
2. That supplies of cassava must be readily available throughout the year — consumers do not wish to stockpile large quantities of cassava products.

*Even with a 60% increase in the cost of all high protein ingredients it appears that the low projection could be exceeded¹⁰.

The production equations are:

$$\ln P_j = a_j + b_j t$$
 where P_j = production of cassava; t = time; j = the j th country.

3. That Thailand may continue to expand exports, and thereby capture an even larger proportion of the European market.
4. That if Brazil can either increase production by a few percentage points or divert a small percentage of production to export markets,* Brazil and Thailand could meet total export demand.

Notwithstanding these reservations, it appears that there is scope for a number of developing countries to now consider cassava as a diversification crop**. Furthermore, the current interest in cassava trade may also highlight the possibilities of promoting cassava because of its potential import-saving ability. The use of cassava as an input to industry and animal rearing instead of other starches or grains, especially those which must be imported, could free LDC resources for more productive uses. Cassava may soon cease to be criticized for what it is not, and become valued for what it is.

REFERENCES

1. Abbott, J.C. (1972) Efficient use of world protein supplies. *Monthly Bulletin of Agricultural Economics and Statistics*, 21, 1-8.
2. Bangkok Bank Monthly Review, Vol. 14, No. 4, April, 1973.
3. Coursey, D.G. & Haynes, P.H. (1970) Root crops and their potential as food in the tropics. *World Crops*, July/August 1970, 261-5.
4. Esselmann, W. (1972) Development of future mixed-feed consumption in the common market. Paper presented at the Eighth European Mixed-Feed Congress, Rotterdam, 19th May, 1972.
5. FAO (1971) *Agricultural Commodity Projections 1970-1980*. Food and Agriculture Organization, Rome.
6. FAO (1972) *Production Year Book 1971*. Food and Agriculture Organization, Rome.
7. Ferris, J., Josling, T., Davey, B., Weightman, P., Denis, L., O'Callaghan, L. & Sorenson, V. *The impact on U.S. agricultural trade of the accession of the United Kingdom, Ireland, Denmark and Norway to the European Economic Community*. Research Report No. 11, Institute of International Agriculture, Michigan State University, 1971.
8. Jones, W.O. (1959) *Manioc in Africa*. Stanford University Press.
9. Nestel, G. & MacIntyre, R. (Eds.) *Chronic cassava toxicity*. IDRC-010e, International Development Research Centre, Ottawa, 1973.
10. Phillips, T.P. (1974) *Cassava. Utilization and Potential markets*. International Development Research Centre, 020e, Ottawa.
11. Rogers, D.J. & Appon, S.B. (1972) *Cassava (Manihot esculenta Crantz). The plant, world production and its importance in world supply. A literature review and research recommendations on cassava*. University of Georgia, pp. 1-14.
12. Smith, C.E. Jr. (1968) The new world centres of origin of cultivated plants and the archaeological evidence. *Economic Botany* 22(3), 253-66.

* Note that Brazil produces 30,000,000 tons of cassava a year (25% of world production). Therefore, a 10% increase in output or a similar diversion of production to exports would produce an additional 1,200,000 tons of pellets (35% of the low EEC projection, Table 3).

**The demand for cassava as a feed ingredient may increase dramatically if Japan becomes a user of cassava. Present estimates are that Japan could easily consume 1 million tons of pellets a year once cassava is used in compound animal feeds.

TABLE 1

Projected human demand for cassava;* 1980
(1000 metric tons)

Region	Low	High**
Latin America	26,353	29,036
Africa	34,727	35,444
Far East	21,154	21,318
TOTAL	82,234	85,798

Source: Truman P. Phillips¹⁰

* Much of this work was kindly provided by the Commodity and Trade Division of the FAO, Rome, 1972.

** Low projections were derived from the FAO's Second Development Decade growth model, while the high projections reflect a continuation of past trends.

TABLE 2

Imports of cassava products into the European Economic Community
(1962-1970) (1000 metric tons)

	1962	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73
W. Germany	366	387	462	520	702	533	481	548	591	479	387	420
France	23	20	18	17	16	na	na	na	35	79	na	na
Italy	0	0	0	1	0	na	na	na	14	na	na	na
Netherlands	1	5	17	76	96	159	237	444	502	599	650	700
Belgium	23	72	105	100	70	113	127	212	268	278	na	na
TOTAL	413	484	602	714	884	(805)	(845)	(1204)	1410	1750	1850	na

Source: 1962-66 *The markets for manioc as a raw material for compound feedingstuffs*. International Trade Centre, UNCTAD/GATT, Geneva, 1968.

1967-70 *The EEC tapioca market - possibilities and limits*. Food and Agricultural Organisation of the United Nations (unpublished) 1972.

1971-73. Unpublished country information.

TABLE 3

Projected EEC demand for commercially compounded feeds: 1980
(1000 metric tons)

	Cattle + calves	Hogs	Poultry	TOTAL
W.Germany	3,550	6,200	4,180	13,930
France	4,250	5,250	4,195	13,695
Italy	2,200	1,300	4,530	8,030
Netherlands	2,550	4,560	2,180	9,290
Belgium/ Luxembourg	1,100	2,475	1,305	4,880
United Kingdom	3,033	3,171	3,965	10,169
Denmark	753	4,461	437	5,651
EEC TOTAL	17,436	27,417	20,792	65,645

Source: 1. W.Esselmann⁴ 2. Truman P. Phillips¹⁰

TABLE 4

Projected EEC demand for cassava: 1980
(1000 metric tons)

	Low	High
Netherlands	1,020	2,380
France	157	1,950
Denmark	558	1,227
Germany	677	1,161
United Kingdom	472	947
Belgium	472	725
Italy	117	577
TOTAL	3,473	8,967

Source: Truman P. Phillips¹⁰

TABLE 5

Projected human demand for and production of cassava: 1980
(1000 metric tons)

	1980 demand	1980 production	Difference between production and demand
<u>Minimum Difference</u>			
Africa	35,444	37,107	1,663
Latin America	29,036	48,052	19,016
Far East	20,318	26,357	5,039
World	85,798	111,516	25,718
<u>Maximum Difference</u>			
Africa	34,727	37,207	2,480
Latin America	26,353	60,491	34,138
Far East	21,154	29,592	8,438
World	82,234	127,290	45,056

Source: Truman P. Phillips

THE USE OF NURSERY TRANSPLANTS IN TARO (*COLOCASIA ESCULENTA*) CULTURE*

H.C. Ezumah and D.L. Plucknett**

SUMMARY

In Hawaii and other Pacific Islands, taro (*Colocasia esculenta*) is propagated by setts consisting of the uppermost top of the corms plus 12-20 cm of the lower petioles. These setts, called *huli* in Hawaii, are obtained at harvest and are perishable. In an effort to preserve planting materials, *hulis* were grown in closely spaced nurseries for 0, 2, 4 and 6 weeks before transplanting them to the field. Time in nursery had no effect on total corm yields. Plants held longer in nursery (6 weeks or more) were taller, produced more suckers, and produced corms with higher specific gravity. It was concluded that nursery transplants of taro may be used with no loss in yield: and, if higher specific gravity is an indication of greater corm maturity, crop duration in the field may be shortened by using rooted transplants.

RESUME

En Hawaï et dans les autres îles du Pacifique, le tarot (*Colocasia esculenta*) est propagé par boutures constituées par la partie supérieure de la tige bulbeuse et des premiers 12-20 cm de la partie inférieure des pétioles. Ces boutures, appelées *huli* en Hawaï, sont obtenues au moment de la récolte et sont périssables. Pour pouvoir préserver le matériel de semis, les *hulis* sont cultivés en pépinières proches 1' une de 1' autre pendant 0,2,4 et 6 semaines avant qu'ils ne soient repiqués au champ. La durée des plantules en pépinière n'a aucun effet sur le rendement total des tiges bulbeuses. Les plantules qui restent plus longtemps en pépinière (6 semaines ou plus) sont plus longues, produisent plus de surgeons et les tiges souterraines bulbeuses ont une gravité spécifique plus élevée. La conclusion présentée est que les plants de pépinière pour le repiquage peuvent être utilisés sans perte de rendement dans le cas du tarot: et, si le fait d'avoir une gravité spécifique plus élevée indique une maturité de tige bulbeuse plus grande, la durée de culture au champ peut être réduite en utilisant des plants de repiquage à racine.

RESUMEN

En Hawaii y otras Islas del Pacífico la malanga (*Colocasia esculenta*) se propaga utilizando la parte superior de los cormos junto con 12-20 cm de la parte baja de los peciolos. Estas "estacas" llamadas *huli* en Hawaii, se obtienen en la cosecha y son de carácter perecedero. Tratando de preservar estos materiales para siembra, se hicieron crecer *hulis* en viveros con los materiales dispuestos estrechamente, por 0,2,4 y 6 semanas antes de transplantarlas al campo. El tiempo en el vivero no tuvo efecto en el rendimiento total de cormos. Las plantas que permanecieron más tiempo en el vivero (6 semanas o más) fueron más altas, produjeron más hijos y dieron cormos con gravedad específica más elevada. Se concluyó que los transplantes de vivero se pueden usar en malanga sin detrimento del rendimiento y que si bien la gravedad específica es un indicador de una mayor madurez del cormo, la duración del cultivo, en el campo, puede acortarse utilizando transplantes ya enraizados.

INTRODUCTION

To propagate taro (*Colocasia esculenta* (L.) Schott) several 'seed' types may be used. Among materials used are corm pieces or small sucker corms which are called cormels, oha, daughter corms, setts or cormlets in various taro producing areas. In Hawaii and a few other islands of the Pacific, taro is propagated by vegetative setts called *huli* (about 0.5 cm of the tip portion of corms plus 20 to 25 cm of lower petiole). These make mechanical planting possible¹². One problem is that the *hulis* do not store for long and therefore a farmer must carry out many operations — harvesting, plot preparation and planting within a week in order to be assured of availability of planting materials.

* Journal Series No. 1803 of the Hawaii Agricultural Experiment Station.

**University of Hawaii, Department of Agronomy and Soil Science, Honolulu, Hawaii 96822.

Human nutrition studies^{8,13,15} have caused taro to be recognised as a speciality food, and it is envisaged that higher demands for the crop may necessitate more extensive production.

Farmers have several alternatives in order to secure enough planting materials; these include:

1. The use of corm pieces, as practised in many parts of the world, e.g. Caribbean Islands, Africa and most of Asia. However, reductions in yield have been associated with the use of corm pieces^{10,11} in comparison with setts from apical portions, and more weed problems and a higher incidence of sett rot occur when corm pieces are used for propagation¹⁰.
2. The *huli* may be stored under controlled environment and used as necessary. The problem here is the large expenditure necessary to maintain equipment, and this approach will probably not be practical.
3. Alternatively, a small nursery may be maintained solely for preservation of the materials which can then be transplanted as needed.⁷ The advantage here will be the low cost of maintaining such nurseries, plus preservation of all planting material.

This study was conducted to determine the practicability of growing taro *huli* in small nurseries before transplanting them to the field. Factors investigated were general performance of *huli* in nurseries, optimum time in nursery before transplanting, and influence of the practice on corm quality.

METHODS AND MATERIALS

Huli of two commercial cultivars of taro, lehua and maui lehua, were grown in the nursery for 2, 4, and 6 weeks and then transplanted into the field. The experiment was laid out in randomized complete block design with three replications. The experiment was conducted on the island of Kauai, Hawaii, in an area having an average annual rainfall of over 100 cm. Plot size was 10 m x 4 m and plant spacing was 75 cm x 75 cm. Details of the experimental procedure have been reported elsewhere.⁸ The performance of freshly cut *hulis* was compared with that of nursery grown transplants. Data recorded were sucker number, plant height, total corm yield, sucker corm yield, main corm yield, individual main and sucker corm yields, and specific gravity of sucker and main corms at harvest.

RESULTS

Corm yield

Table 1 shows the corm yield at 12 months from time of planting. There were no within-cultivar differences in total corm yield due to length of time in nursery. Differences in total corm yield between cultivars were also not significant. Significant yield differences ($P = 0.05$) between types of planting material were observed for main corm yields and also sucker corm yields. While cultivar maui lehua gave higher main corm yields, it produced lower sucker corm yields than lehua. When the yields from these two components were combined, comparable total corm yields were obtained, resulting in no significant yield differences between the two cultivars.

Plant height and suckering capacity

The extent to which top growth and root or tuber development are interdependent has been discussed by several workers^{5,6,9,14}. In taro, a flush of vegetative growth is produced in the first 3 to 5 months of the crop. Later, top growth declines and plant height shortens as photosynthate is accumulated in corms. Table 2 shows heights and suckering of the two taro cultivars at 3, 5 and 10 months of age. Maui lehua was taller but suckering was greater in lehua at all ages. The effect of length of time in nursery on sucker number was inconsistent. However, there was an inverse relationship between sucker number and sucker weight. (Table 3)

Specific gravity

Specific gravity has been used successfully as an index of corm maturity of taro. Bowers *et al.*² found that the best range of specific gravity for the lehua cultivar was 1.05 to 1.15. Generally poi and flour yields increased with increasing specific gravity. Table 4 shows the ranges of specific gravity obtained from corms harvested at different dates and with planting materials of different ages. A specific gravity in the range of 1.11 to 1.16 was obtained within 6 months in the field when 6 weeks-old transplants were used. The specific gravity of sucker corms also tended to increase with increasing age of the transplants used and with increasing crop age.

The specific gravity of corms and corm dry weights were not correlated (Table 5). This supports previous observations of Ching³ and de la Pena⁴ for taro and Austin *et al.*¹ for sweet potatoes.

REFERENCES

1. Austin, M.E., Aung, L.H. and Graves, G. (1970) The use of carbohydrate contents as an index of sweet potato maturity. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops (Hawaii), Vol. 1, 42-4.
2. Bowers, F.A.I., Plucknett, D.L. and Youngs, O.R. (1964) Specific gravity evaluation of corm quality in taro. Hawaii Agr. Exp. St., Univ. Hawaii Cir. No. 61, 19 pp.
3. Ching, Ken Wai. (1970) Development of starch, protein leaf and corm in *Colocasia esculenta* (L.)Schott. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops (Hawaii), Vol. 1, 143-6.
4. de la Pena, R.S. (1967) Effects of different levels of N, P and K fertilization on the growth and yield of upland and lowland taro. Ph.D. Diss., Univ. Hawaii. 169 pp.
5. Enyi, B.A.C. (1967) Growth of cocoyam, *Xanthosoma sagittifolium*. *Indian J. Agric. Sci.* 38(4), 627-33.
6. Ezumah, H.C. (1972) The growth and development of taro, *Colocasia esculenta* (L.)Schott, in relation to selected cultural management practices. Ph.D. Diss., Univ. Hawaii. 197 pp.
7. Ezumah, H.C. and Plucknett, D.L. (1974) The use of nursery to enhance storage and crop performance of planting materials in taro production Haw. Agr. Exp. Sta. Prog. Rep. 214.
8. Glaser, J., Lawrence, R.A., Harrison, A. and Bell, M.R. (1967) Proc. Taro Conf. Co-op. Ext. Ser., Univ. Hawaii. Publ. 36, 39-68.
9. Milthorpe, F.L. (1967) Some physiological principles determining the yield of root crops. Proc. 1st Int. Symp. Trop. Root Crops (Trin). 1(2). 1-19.
10. Mohamoud, E.E. (1953) M.Sc. thesis. Alexandria Univ. Egypt. (see Moursi 1955).
11. Moursi, M.A. (1955) A comparative study of the effects of types of 'seed' on rate of emergence, establishment of plants and yield in different dasheens grown in Egypt. *Indian J. Agric. Sci.* 25(4), 265-70.
12. Plucknett, D.L., Ezumah, H.C. and de la Pena, R.S. (1973) Mechanization of taro (*Colocasia esculenta*) in Hawaii. Proc. 3rd Int. Symp. Trop. Root Crops, Nigeria. (This volume).
13. Roth, A.J., Moore, W. and Lichton, I. (1967) Research on poi (taro). Proc. Taro Conf. Co-op. Ext. Ser., Univ. Hawaii. Publ. 36, 27-32.
14. Spence, J.A. (1970) Growth and development of tannia, *Xanthosoma* sp. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops Hawaii. Vol. 2, 47-52.
15. Standal, B.R. (1970) The nature of poi carbohydrates. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops Hawaii. Vol. 8, 146-8.

TABLE I

The effect of time in nursery of rooted plants or huli on corm yield of lehua and maui lehua cultivars of taro grown for twelve months under paddy conditions

Time in nursery before transplanting. Weeks	TOTAL YIELD			MAIN CORM YIELD			SUCKER CORM YIELD		
	Cultivar			Cultivar			Cultivar		
	lehua	maui lehua t/ha*	2 cvs. average	lehua	maui lehua t/ha*	2 cvs. average	lehua	maui lehua t/ha*	2 cvs. average
0	63.95a	68.12a	66.05	26.70b	28.58b	27.64	37.27c	39.52c	38.41
2	64.86a	73.43a	69.16	19.46b	32.33b	25.91	46.78c	41.00c	43.94
4	66.94a	72.69a	69.80	22.50b	34.06b	28.28	44.44c	33.59c	41.55
6	71.73a	71.41a	71.58	21.71b	34.23b	27.99	50.02c	37.05c	43.60
Average	66.23a	71.41a		22.60a	32.31b		44.63a	39.03b	

*Means on the same column followed by the same letter are not significantly different ($P = 0.05$) by the Duncan's Multiple Range Test.

TABLE 2

Effects of time in nursery on suckering capacity and height of rooted plants and hulis of two cultivars of taro at different periods during crop growth.

A. NUMBER OF SUCKERS PER PLANT

Time in nursery before trans- plant- ing.	Crop ages, months						Averages	
	3		5		10			
	lehua	maui lehua	lehua	maui lehua	lehua	maui lehua	lehua	maui lehua
Weeks								
0	2.8	2.8	7.0	5.7	7.4	6.8	5.7	5.1
2	2.8	1.5	8.5	6.0	9.1	6.7	6.8	4.7
4	4.0	1.9	10.3	6.7	12.6	7.1	9.0	5.2
6	4.6	4.3	7.8	8.0	8.3	12.2	6.9	8.2
Average	3.6	2.4	8.4	6.6	9.4	8.2	7.1	5.8

B. PLANT HEIGHT* (cm)

Time in nursery before trans- plant- ing.	Crop ages, months						Averages	
	3		5		10			
	lehua	maui lehua	lehua	maui lehua	lehua	maui lehua	lehua	maui lehua
Weeks								
0	93.7	115.5	120.6	185.9	74.6	94.7	96.2	132.0
2	99.5	114.3	125.2	151.6	77.2	96.0	100.5	120.6
4	104.1	140.9	117.0	158.5	90.9	123.9	104.1	141.2
6	107.7	153.9	122.9	169.9	98.8	140.2	109.7	154.6
Average	101.3	131.3	121.4	166.6	85.3	113.7	102.6	154.6

*Plant height is equivalent to length of longest petiole at the time of measurement.

TABLE 3

Effects of time in nursery of rooted plants and hulis on main and sucker corm yields of lehua and maui lehua cultivars of taro harvested at twelve months.

Time in nursery	Total corm weight(kg) per hill*		Number of suckers/hill*		Weight per sucker corm* (gms)		Weight per main corm* (gms)	
	maui		maui		maui		maui	
	lehua	lehua	lehua	lehua	lehua	lehua	lehua	lehua
Weeks								
0	2.38	2.53	10.4	10.1	133	145	998	1064
2	2.46	2.73	12.9	7.7	135	199	725	1204
4	2.49	2.70	11.5	8.4	143	172	838	1268
6	2.67	2.66	12.4	8.3	150	166	808	1275
Average	2.50	2.66	11.8	8.6	140	171	842	1203

*Averages of 6 observations.

TABLE 4

The range of specific gravity of two cultivars of taro transplanted from nursery in which they were maintained for various periods. (Subscripts represent ages of transplant in nursery.)

Crop age (months)	Ranges of specific gravity				
	1.00-1.05	1.05-1.11	1.11-1.16	1.16-1.21	1.21
6	L ₀ , L ₂ , L ₄ M ₀ , M ₂	M ₄ , M ₆	L ₆ , L ₁₄ **		
9		L ₂ M ₄ , M ₀	L ₀ M ₂ , M ₆	L ₄ , L ₆ , L ₁₄ **	
12			L ₀	L ₂ , L ₄ , L ₆ M ₀ , M ₂ L ₀ , L ₂ , L ₄ , L ₆ * M ₀ , M ₂ , M ₄ , M ₆ *	L ₁₄ **

L = Lehua, M = Maui lehua.

* Specific gravity of main corms determined at 12 months.

**Lehua cultivar grown for 14 weeks in the nursery before transplanting. Since there was no maui lehua cultivar of corresponding age, this was not included in statistical analysis. All other notations are of sucker corms.

TABLE 5

Effect of time in nursery on the (a) specific gravity and (b) percent dry matter of two cultivars of taro at different ages.

(a) Specific gravity

Age of trans- plants	SUCKER CORMS						MAIN CORM*	
	Crop ages, months							
	6		9		12			
Weeks	lehua	maui lehua	lehua	maui lehua	lehua	maui lehua	lehua	maui lehua
0	1.008	1.003	1.112	1.103	1.134	1.160	1.124	1.111
2	1.013	1.016	1.098	1.122	1.190	1.136	1.155	1.153
4	1.011	1.101	1.175	1.164	1.182	1.211	1.136	1.155
6	1.121	1.098	1.163	1.147	1.164	1.163	1.135	1.133
Average	1.038	1.055	1.137	1.134	1.167	1.168	1.137	1.138

(b) Percentage dry matter

Weeks								
0	36.05	35.22	42.62	39.90	41.57	40.97	43.43	39.33
2	35.59	35.18	40.17	40.83	41.27	40.33	40.05	40.63
4	39.93	38.35	41.53	41.71	44.94	40.97	42.54	38.71
6	38.14	37.41	42.86	43.26	42.31	41.66	43.69	39.89
Average	37.43	36.54	41.94	41.43	42.53	40.98	42.43	39.64

*Main corm was sampled at 12 months only. For the 14 week old transplants, specific gravities were 1.134, 1.177 and 1.211 for sucker corms at 6, 9 and 12 months age, respectively, and 1.153 for 12 months old main corms.

Corresponding percentage dry matter contents were as follows: 36.54, 41.43, and 40.98 for suckers and 39.64 for main corms.

A RAPID METHOD FOR THE PROPAGATION OF CASSAVA

(*MANIHOT ESCULENTA* Crantz)

D.W. Wholey* and J.H. Cock

SUMMARY

A study of methods to propagate cassava rapidly is under way at CIAT. Results so far show that un-lignified shoot tips when planted under mist produce roots during the second week after planting. These rooted cuttings may be transplanted into the field after a ten day hardening off period.

Shoots are produced from stem cuttings planted in an environment of high humidity. More rapid production of shoots occurs in humid chambers than under mist. Propagation by this method is twenty times more rapid than by conventional methods.

RESUME

Des méthodes de propagation rapide du manioc sont en cours d'étude au CIAT. Les résultats déjà obtenus montrent que les boutures de pousse non aoutées produisent des racines en deux semaines lorsqu'elles sont plantées en condition brumeuse. Les boutures enracinées peuvent être repiquées au champ après une période fortification de 10 jours.

Les pousses sont obtenues à partir des boutures de tige plantées en milieu d'humidité élevée. On peut obtenir une production de pousses plus rapidement en chambre humide qu'en condition de brume. Cette méthode de propagation est vingt fois plus rapide que par les procédés conventionnels.

RESUMEN

Se lleva a cabo en el CIAT, un estudio sobre métodos rápidos de propagación de yuca. Hasta el momento, los resultados muestran que cuando se siembran brotes terminales, bajo nebulización, producen raíces durante la segunda semana después de la siembra. Estas estacas, ya enraizadas, se pueden transplantar al campo después de un período de acondicionamiento de diez días.

Los vástagos se producen a partir de estacas sembradas en un ambiente de elevada humedad. La producción de vástagos es más rápida en cámaras húmedas que bajo nebulización. La propagación por este método es veinte veces más rápida que por los métodos convencionales.

INTRODUCTION

Crop improvement programmes frequently encounter problems associated with the rate of multiplying planting material. A low multiplication rate impedes agronomic testing of a new variety, and the scarcity of planting material delays distribution to farmers.

This problem is more acute with vegetatively propagated crops. Table 1 compares the multiplication rate of cassava with that of some sexually propagated crops such as rice and maize.

It is important therefore that a cassava improvement programme should have an organized procedure for rapidly multiplying improved cultivars. A successful propagation programme must be able to multiply rapidly from an initial stock of a small number of plants. For example, the CIAT cassava germ plasm bank with more than 2,000 cultivars is maintained with four plants per cultivar because of the problems associated with growing large numbers of plants. In extreme cases, one plant may be the sole foundation stock.

*This work forms part of a thesis to be presented for a Ph.D. degree at the University of the West Indies. D.W. Wholey and J.H. Cock, Centro Internacional de Agricultura Tropical, CIAT Apartado Aereo 87-13, Cali, Colombia.

PROPAGATION METHODS

Stem cuttings, 15-30 cm in length, are used as planting material to establish commercial crops of cassava. These cuttings are selected from the leafless woody portion of the stem of plants normally older than nine months. Results from experiments comparing the size and origin of cuttings generally agree that longer cuttings from the basal portion of the stem germinate and establish better than apical cuttings.^{4,5,7,8,10} However, it has been shown that under optimum conditions for establishment and with the use of good quality planting material, the length of cutting has no effect on establishment.¹²

Single node, woody cuttings have been successfully used for rapid propagation in Venezuela and Brazil (Alvarez-Luna, personal communication). Where internodes are short, preventing the preparation of single node cuttings, eye cuttings (a bud together with a segment of stem split longitudinally) may be used. This method was developed initially in an attempt to produce plants free of cassava bacterial blight from infected stems¹¹.

Techniques have been developed using shoots produced from stem cuttings grown under conditions of high humidity. The first report recommended the use of shoots, excised together with a heel of lignified tissue². These shoots produced roots when placed in a propagating case.

It has recently been shown, however, that non-lignified shoots without the lignified heel also produce roots^{3,13}. These shoots have been used to prepare single node cuttings with the leaf attached which root under mist¹³. Leaves also have been rooted^{10,13}, but so far no technique has been found to stimulate shoot production from rooted leaves. A programme was initiated at CIAT in 1971 to develop simple, efficient methods for rapid propagation of cassava.

MATERIAL AND METHODS

Initially, a bamboo lathhouse was used for preliminary studies of double and single node stem cuttings. Later, a mist propagation unit was used to investigate the potential of shoots as propagules for rapid propagation. The system incorporated an electric leaf (1) that controlled the intermittent mist according to the evaporation rate of water. Subsequently, a propagating frame using a wood and polyethylene roof over a bed of sterile soil was constructed (Fig. 1). Hollow concrete blocks, forming the retaining wall of the soil bed, were cemented on one open side, placed hollow surface uppermost and filled with water. The roof of the frame partially covered the water which evaporated, thus increasing the humidity within the frame.

RESULTS

During the initial phase, observations of the rooting of single and double node cuttings in the lathhouse showed that roots were produced from three distinct sites:

1. Initially from discreet zones associated with the leaf scar and internode bud.
2. Later from the basal end of the cutting associated with callus produced from the cambium.
3. From the etiolated base of the new shoot that developed from the cuttings.

The ability of young shoots to produce roots under such conditions suggested that the excised shoot demonstrated a potential as the propagule upon which to base a rapid propagation system. The efficiency of this system depends upon the success of two phases, shoot production and the rooting and establishment of shoots.

Shoot production

Shoot production under mist was evaluated using 25 cm stem cuttings, planted horizontally immediately below the surface of the medium. Shoots were removed when they had attained a length of 8 cm. Woody stem cuttings produced more shoots after three months than non-lignified cuttings. Most of the latter, despite some rooting, were dead at the end of the experiment. An efficiency of two shoots per node was achieved from woody cuttings of cultivars M Col 75 and 1438 (Table 2).

It was observed on termination of the experiment that, despite a shoot production efficiency of two shoots per node in two cultivars, these shoots were produced from a comparatively small number of nodes, the majority of the nodal buds remaining dormant. This capability for multiple shoot production (Fig. 2) from one bud demonstrated a potentially efficient shoot production system.

A subsequent experiment showed that single and two node woody cuttings produce more shoots per node than longer cuttings, (Table 3). In these minimal size cuttings, all nodal buds were stimulated into shoot production.

To develop a system more adaptable to developing countries, the efficiency of shoot production under mist was compared with production in a propagation frame.

Cuttings grown in the propagation frame produced more shoots than the cuttings under mist (Table

3). The relative humidity under both regimes was similar, but large temperature differences were noted (Table 4), the air in propagation frames reaching 45° at midday. This high temperature had no adverse effects on growth and may be responsible for the increase in shoot production. Other experiments to investigate the effect of environment on shoot production are under way.

Observations were made on the rooting of excised shoots placed under intermittent mist. During the first two days under mist, the shoots wilted but regained turgor after the third or fourth day. Most expanded leaves fell during the first week. The formation of callus at the shoot base began ten days after planting, and roots developed from the callus region during the following ten days (Fig. 3). Twenty days after planting, the root system was sufficiently developed to enable transplanting.

There were no differences in rooting of shoots from woody or non-lignified stem cuttings of different cultivars. Root formation was excellent in both 2 mm gravel and perlite media.

CIAT propagation system

A routine system for the propagation of promising selections has been developed based on the above observations. Two node stem cuttings are planted horizontally in a propagation frame with sterile well-structured soil. Shoots are removed when they are 8 cm long using a sterile blade. A 5 mm section of stem is left from which new shoots are produced. Before planting, all leaves except the unopened leaves and the newly opened leaf are removed when they are 8 cm long using a sterile blade. A 5 mm section of stem is left from which new shoots are produced. Before planting, all leaves except the unopened leaves and the newly opened leaf are removed. The shoots are planted in 2 mm gravel under mist 5 cm apart and left to root for three weeks. After this period the rooted shoots are carefully removed from the medium and planted into peat pots with sterile soil. After a further ten days under reduced mist, during which time the roots break through the peat pot, the rooted shoots are transferred to the field. Fig. 4 shows a typical rooted shoot ready for transplanting. More than 95 percent survival of shoots is regularly achieved using this system.

Recent studies show that shoots can be rooted in propagating frames using IBA hormone. Further work is under way to refine this technique.

DISCUSSION

The rapid propagation programme is developing the entire system of shoot production and rooting using techniques applicable to the developing countries. Although mist propagation which maintains low tissue temperature under high light intensity⁶ offers more advantages than any other system of propagation, the success of an intermittent mist system depends on a reliable supply of both water and electricity. The water supply must be low in salt content; the accumulation of salt on the leaves through evaporation results in leaf loss. Water pressure greater than 2.5 kg/cm² is needed to form mist at the jets. In the tropics many experimental stations lack a reliable, low salt, high pressure water supply. As the salt concentration of the well-water at CIAT is too high for mist propagation, rain water is used.

An intermittent mist system entirely depends on a reliable electricity supply. Similarly, many water supplies rely on electricity as a source of energy for pumps. Unfortunately, electricity supplies in the developing nations of the tropics frequently fail. Therefore, a successful propagation system for cassava in the tropics should not depend upon mist propagation.

The rapid propagation system described above is capable of producing 18,000 stem cuttings after one year, starting with one mature plant (Fig. 5). The efficiency of this method is due to the exploitation of multiple shoot production. Chant and Marden's method², producing 500 stem cuttings from a seed after two years did not allow further shoot production from each node because of the removal of the lignified heel with each shoot.

Using a standard field multiplication procedure, starting from one plant with 15 cm stem cuttings as planting material, it is possible to produce thirty plants after one year. Each plant provides thirty more cuttings, a total production of 900 15 cm stem cuttings. By reducing the cutting size to two nodes which establish under good management³, this output can be increased to 1,800 stem cuttings. Therefore the above system is much more rapid than previously used methods.

REFERENCES

1. Bean, G., Trickett, E.S. & Wells, D.A. (1957) Automatic mist control equipment for the rooting of cuttings. *J. Agr. Eng. Res.* 2, 44-8.
2. Chant, S.R. & Marden, J.A. (1958) A method for the rapid propagation of cassava cuttings. *Trop. Agriculture, Trin.* 35(3), 105-99.

3. CIAT (1972) Propagation, cassava production systems. *Centro Internacional de Agricultura Tropical, (CIAT). Annual Report 1972*. Cali, Colombia. p. 57-60.
4. Enyi, B.A.C. (1970) The effect of age on the establishment and yield of cassava setts. *Beiträge zur tropischen und subtropischen Landwirtschaft und Tropenveterinärmedizin*. 8, 71-5.
5. Fernando, M & Jayasundera, E.S. (1942) Cultural experiments with cassava. *Trop. Agriculturalist (Ceylon)* 98(3), 3-8.
6. Hess, C.E. & Snyder, W.E. (1957) A physiological comparison of the use of mist with other propagation procedures. *Int. Hortic. Congress 14th Report Scheveringen*, 12, 1133-9.
7. Huertas, A.S. (1940) A study of the yield of cassava as affected by the age of cuttings. *Philippine Agriculturalist* 28(9), 762-70.
8. Jeyaseelan, K.N. (1951) Studies in growth and yield of cassava. 1. Yield in relation to size and type of sett. *Trop. Agriculturalist (Ceylon)* 107, 168-71.
9. Kloppenburg, T.G.A., Sibie, D. & de Bruijn, G.H. (1972) *Tropical root and tuber crops newsletter* No. 5, 38-9.
10. Loria, W (1962) Influencia del tamaño y posición de la estaca de yuca en el arraigamiento, rendimiento y producción de follaje. *Amer. Soc. Hort. Sc. (Caribbean region)*. 6, 20-3.
11. Lozano, J.C. (1962) Bacterial blight of cassava (*Manihot esculenta* Crantz) in Colombia, etiology, epidemiology, and control. *Ph.D. Thesis*. University of Wisconsin, Madison. 114 pp.
12. Roasa, C. (1969) Influencia de la modalidad de siembra y tamaño de la estaca de yuca (*Manihot esculenta*, Crantz). *Tesis de Ing. Agron.* Universidad Nacional Agraria, La Molina, Peru.
13. Sykes, J.T. & Harney, P.M. (1972) Rapid clonal multiplication of manioc from shoot and leaf bud cuttings. *J. Roy. Hort. Soc.* 97, 530-4.

TABLE 1

Comparison between sexually and asexually propagated crops.

	Rice	Maize	Cassava
Crops per year	2	2	1
Multiplication rate/year	160,000	640,000	30
certified seed production			
Breeders' seed production	25 million	1 million	90

TABLE 2

Shoot production from woody and non-lignified 25 cm stem cuttings of four cassava cultivars after three months.

Mean of twelve cuttings.

Cultivar	Type of cutting				mean	
	non-lignified		woody		Shoots/ cutting	Shoots/ node
	Shoots/ cutting	Shoots/ node	Shoots/ cutting	Shoots/ node		
M Col 22	4.3	0.46	13.7	1.07	9.0	0.77
M Col 75	6.7	0.95	11.6	1.99	9.2	1.46
M Col 76	3.2	0.32	7.9	0.89	5.6	0.61
M Col 1438	2.2	0.34	10.2	1.97	6.2	1.16
Mean	4.1	0.52	10.9	1.48	7.5	1.00
L.S.D. (P=0.05) no/cutting between ages = 1.13: between vars.=1.60						
no/node			"	"	= 0.12: between vars.=0.17	

TABLE 3

The effect of environment and size of cutting on shoot production after 40 days (M Col 1438)

Cutting size	Intermittent mist		Propagation frame		Mean of environments	
	Shoots/ cutting	Shoots/ node	Shoots/ cutting	Shoots/ node	Shoots/ cutting	Shoots/ node
1 node	0.9	0.9	1.1	1.1	0.9	1.1
2 node	1.4	0.7	2.9	1.4	2.2	1.1
10 cm	1.8	0.5	3.1	0.9	2.5	0.7
20 cm	3.0	0.5	4.2	0.9	3.6	0.7
Mean	1.8	0.6	2.8	1.1	2.3	0.9
L.S.D. (P=0.05) Between cutting size = 0.22.						
Shoots/node Between environment = 0.15						

TABLE 4

A comparison of air temperature and relative humidity under mist and in a propagation frame

	Air temp. °C		Relative Humidity(%)		
	Max.	Min.	Max.	Min.	Hours/day RH at 80%
Mist	32.3	20.2	96.0	42.5	14.0
Propn. frame	45.1	22.8	99.0	39.5	15.5



Figure 1. *Propagation frame showing simple inexpensive construction.*



Figure 2. *Multiple shoot production from one nodal bud of cassava.*



Figure 3. Shoots removed from stem cuttings (A),
and after three weeks under mist (B).

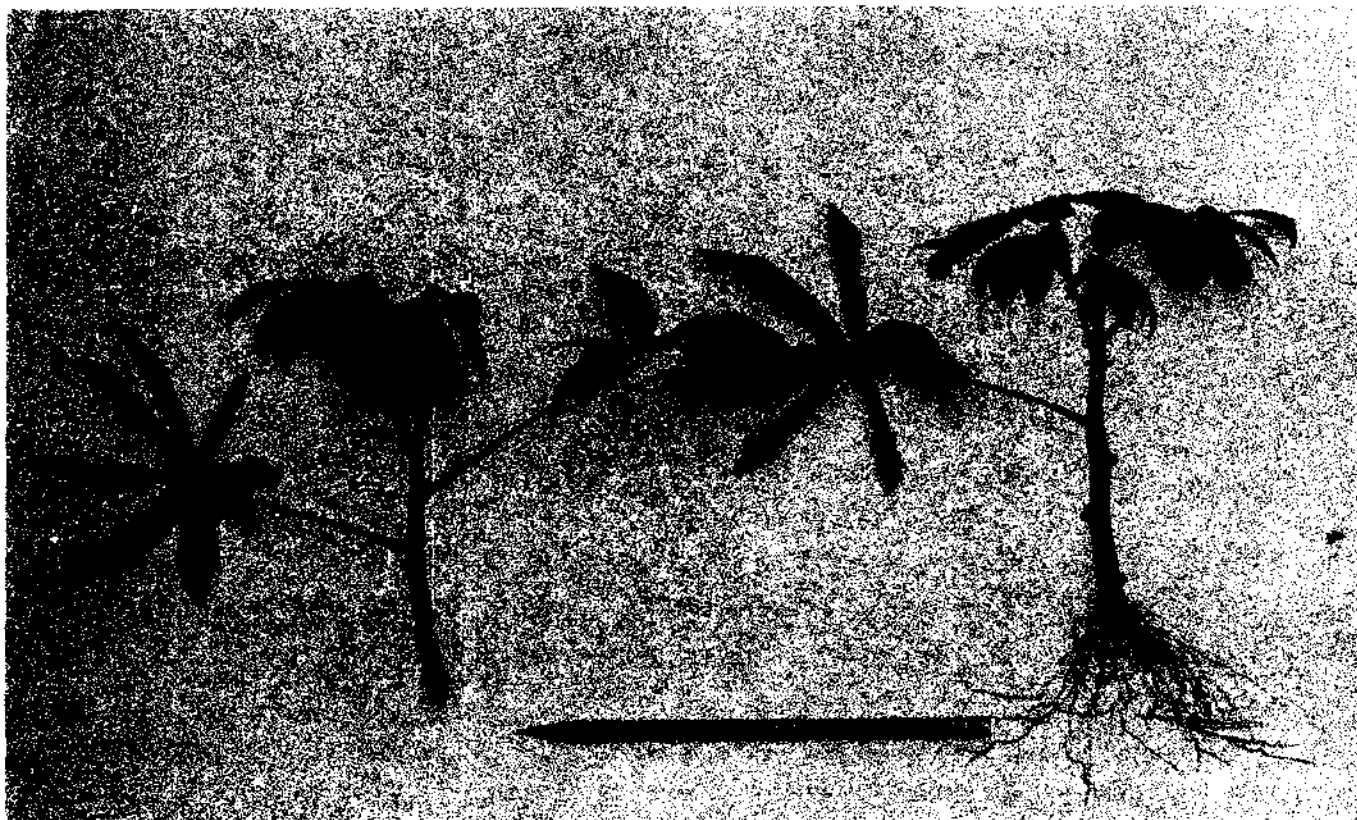
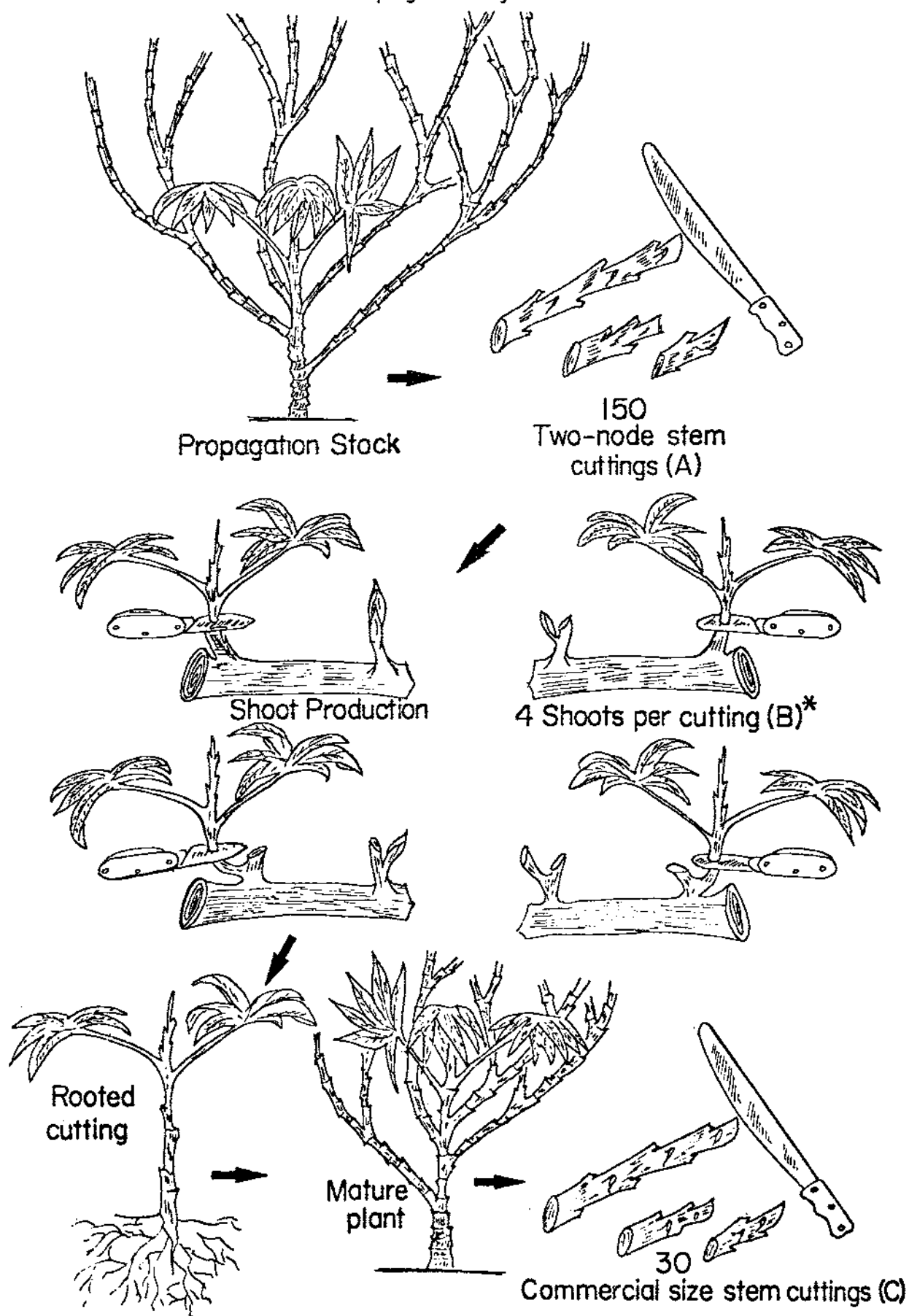


Figure 4. Rooted shoot of variety Llanera ready for planting out in the field.

Fig. 5 Diagram of CIAT'S Propagation System



Multiplication rate ; $A \times B \times C = 150 \times 4 \times 30 = 1800$

* Two shoots per node (data from current experiment)

A NEW METHOD OF YAM PROPAGATION

B.N. Okigbo and D.G. Ibe*

SUMMARY

A new method of yam propagation to establish two or three stands from a single sett is described. Preliminary experiments indicate that the yields of tubers from the milked setts often exceeded yields from control setts, especially in *Dioscorea rotundata* (cv. Abi and cv. Aga) and in *D. Alata*.

RESUME

Une nouvelle technique de propagation d'igname pour faire germer deux ou trois plants à partir d'une seule bouture a été exposée. Les premiers essais révèlent que les rendements en tubercules fournis par ces plants dépassent souvent les rendements des boutures-témoins, surtout avec *Dioscorea rotundata* (cv. Abi et cv. Aga) et *D. alata*.

RESUMEN

Se describe un nuevo método de propagación de ñame para establecer dos o tres lotes de producción a partir de una sola 'estaca' de propagación. La experiencia preliminar indica que el rendimiento de tuberculos de las 'estacas' de las que se obtuvo material de propagación continuamente, a menudo sobrepasó el de las 'estacas' testigo. Lo anterior se observó especialmente en *Dioscorea rotundata* (cv. Abi y cv. Aga) y en *D. alata*.

INTRODUCTION

Haynes *et al.*¹, reviewing the importance of physiological studies in the agronomy of yams, reported experiments carried out by Chapman which showed that yams respond better to nitrogen applied at 3 months after planting than either at planting or later than 3 months after planting. Ineffectiveness of early nitrogen application was explained as being due to the flush of mineralization of nitrogen at the onset of the rains. The possibility that the tubers themselves might supply all the nitrogen necessary for early growth was not considered. It has also been observed that sometimes tubers of *Dioscorea rotundata* develop fresh tubers directly from old yam setts which fail to develop shoots and also that yam vines with well developed roots often continue to grow, though at a reduced rate when tubers are accidentally or otherwise removed if there is little damage to the roots. Further, when tubers of mature yam plants, especially those of *Dioscorea alata* and *D. cayenensis* are topped or 'milked', new shoots may develop from the yam head at the base of the old mature vine.

All these observations indicate physiological inter-relationship between shoot and the tuber growth and that detaching shoot and parent tuber at any given stage of development of the yam plant may adversely, or perhaps with advantage, affect the subsequent development in either portion. Hence we postulated that perhaps fertilizers applied to young growing yams with shoots and tubers separated might be effective in promoting yield from the shoot-derived plant while at the same time the old sett could be used to establish another yam plant. Higher aggregate yield might result in this way from a given quantity of available setts. The experiments describe an attempt to test this idea.

MATERIALS AND METHODS

1972 preliminary and observational experiment

In 1972 in the Faculty of Agricultural Sciences farm, 20 yam tubers of almost the same size from each of three yam species, *D. alata*, *D. Rotundata*, and *D. cayenensis* were planted in March 1 metre apart on 1 metre ridge in each plot. Six weeks later 10 of the 20 setts of each yam species were detached carefully from the growing plants and replanted on ridges in another plot at the same spacing as at first planting. At the same time, 10 new setts of each of the above species were planted on an adjacent ridge in the same plot

*B.N. Okigbo, International Institute of Tropical Agriculture, Ibadan, Nigeria.
D.G. Ibe, University of Nigeria, Nsukka, Nigeria.

as the 'milked' setts. After another six weeks, the replanted setts which have by now developed a second shoot were again detached or 'milked' from these shoots and replanted on other ridges in a third plot adjacent to which another control of 10 new setts of the same species were also planted. These operations are illustrated in Figure 1. The whole experiment was replicated twice. Harvesting was carried out in November and fresh weights of the tubers were recorded.

1973 experiments

As a result of the observations made in the 1972 experiments, it was decided to repeat the experiment in 1973 on a larger scale. This time the experiment was laid down in a split split-plot design with the following treatments:

1. Main treatments: dates of planting of controls and replanting of 'milked' setts.
 - A. First date of planting of control and treatment setts (March 8th, 1973).
 - B. Second date (5 weeks after first planting date) of planting of second plot of control and first removal or 'milking' and replanting of treatment setts.
 - C. Third date (10 weeks after first planting date) of planting of third control plot and second milking and replanting of treatment setts.
2. Sub-treatments: movement of setts.
 - (a) Control setts planted and left in place.
 - (b) Treatment setts detached from vines and replanted in another location on dates specified above.
3. Sub-sub treatments: species or cultivars.
 - (i) *Dioscorea rotundata* (cv. Aga)
 - (ii) *Dioscorea alata*
 - (iii) *Dioscorea dumetorum*
 - (iv) *Dioscorea rotundata* (cv. Abi)
 - (v) *Dioscorea cayenensis*

The main treatments and the associated sub- and sub-sub-plot treatments were replicated three times. Randomization and allocation of treatment followed the usual procedures for the split plot design. Each sub-sub plot consisted of four 1 metre ridges 30 metres long separated by guard rows of two 1 metre ridges on either side and two metres at each end of the plot. The yam setts of approximately the same size were planted 1.2 metres apart on the ridges. The control setts were planted on two adjacent ridges of each sub-sub plot chosen at random and the treatment setts were planted on the remaining two ridges. The planting and milking of setts followed the procedure indicated in Figure 1. Although it was planned to move the milked setts five weeks after planting date (a), delay in the starting of the rainy season caused the dates of replanting and milking on dates (b) and (c) above to be carried out at seven week intervals. Fertilizers were applied one week prior to milking and replanting of setts for each planting date. Harvesting was carried out for dates A and B on 31/10/73 and for C on 12/11/73. Fresh weights of tubers, plant population and number of tubers were recorded.

A similar experiment was carried out involving whole tubers, heads, and bottoms of tubers of *D. alata* and *D. rotundata*. Only the relevant parts of the 1973 experiment are reported here, but are described more fully elsewhere^{1,3}

RESULTS

1972 preliminary and observational experiments

The preliminary experiments at Nsukka in 1972 not only confirmed the feasibility of the technique but showed that:

1. For the aggregate of all planting materials at each planting date, the control plots outyielded the 'milked' sett treatment plots.
2. For the first planting date for some planting materials, the controls outyielded the milked plants, while some 'milked' setts gave higher tuber yields.
3. At later planting dates (B and C) controls gave higher yields than milked setts, indeed some of which gave zero yields.

1973 experiments at Nsukka

The 1973 data are presented in Tables 1, 2 and 3. There were highly significant differences in tuber yield between planting dates, and among cultivars there were significant differences between controls and milked treatments.

Yields of both controls and milked setts decreased with lateness of planting. In *D. dumetorum* and

D. cayenensis many setts failed to sprout and all milked-setts decomposed at the third planting date.

Cumulative yields of milked setts (Table 2) at the second planting exceed the yields of controls at the first planting date for both *D. cayenensis* and *D. rotundata* (Abi). At the first planting date, yields of milked setts as percentage of controls ranged from 85.2 percent in *D. rotundata* (Aga) to 218.6 percent for *D. rotundata* (Abi). Yields lower than controls at the first planting date were more than made up (except in *D. cayenensis*) by yields from milked setts at the two later planting dates (B and C).

When the effects of milking are averaged over all replicates and cultivars (Table 3), the milked plants still yielded 93.9 percent of those of controls at first planting date (A), with additional yield being obtained from the replanting of the setts 44.5 percent at the second planting date (B) and 23.6 percent at the third planting date (C) of the relevant controls for those dates.

DISCUSSION AND CONCLUSIONS

This experiment, although still in its preliminary stages, demonstrated that leaving the sett attached to the vine until new tubers are developed may not be the best way to maximise yield. The great quantity of setts used in establishment of new yam plants which is a major contribution to yam production being uneconomical, could be made to provide a much greater population of plants and yield by this propagation technique. There is a possibility of further improvement of this technique by (1) pre-sprouting the yam in the barn before the first planting in the field so as to reduce time before the first milking; (2) treating the yam setts with fungicides and other chemicals to reduce the rotting (which in these trials made the third planting date or second milking uneconomical); (3) rooting (as well as sprouting) the yam vines in the nursery or barn in plastic bags or soil blocks prior to field planting; (4) partial severing of the yam heads before planting with the expectation of more rapid resprouting after milking.

There were marked differences in response to this method of propagation in different cultivars or species. It was easier to milk setts planted horizontally without damaging the roots. We think that there is little doubt that the economics of yam production can be significantly improved if the potentialities indicated by this method of propagation can be realized on a production scale.

REFERENCES

1. Haynes, P.H., Spence, J.A. and Walker, C.J. (1967) The use of physiological studies in the agronomy of root crops. Proc. Int. Symp. Trop. Root Crops. 1(3), 1-15. University of West Indies, St. Augustine, Trinidad.
2. Ibe, D.G. (1973) Final Research Training Report Root and Tuber Improvement Program, IITA, Ibadan.
3. Okigbo, B.N. and Ibe, D.G. (1973) An evaluation of a new method of yam propagation by sequential removal of setts and establishment of stands from the same sett. (In preparation).

TABLE 1

Mean yields* (kg per plot) fresh weight of tubers of five yam cultivars in relation to planting date and 'milking' of planted setts

Species or cultivars	First planting date		Second planting and milking date		Third planting and milking date		Cultivar means	
	a	b	a	b	a	b	a	b
<i>D. rotundata</i> (cv. Aga)	45.9	38.5	27.6	15.9	3.6	0.2	25.3	18.2
<i>D. alata</i>	47.5	40.8	22.1	19.0	3.1	1.8	24.3	20.5
<i>D. dumetorum</i>	22.0	20.3	20.9	3.7	0.4	0	14.4	8.0
<i>D. rotundata</i> (cv. Abi)	35.6	42.2	21.2	13.8	1.7	0.4	19.5	18.8
<i>D. cayenensis</i>	25.7	23.5	27.0	0.3	1.5	0	18.1	8.0
Planting date means	35.2	33.1	23.8	10.6	2.1	0.5	20.3	14.7

* Mean yields are based on individual plots of 20 plants each replicated three times.

a = control

b = sett milked

MECHANIZATION OF YAM CULTIVATION IN THE IVORY COAST

R. Vandevenne*

SUMMARY

Hand cultivation of yams in Ivory Coast requires 182-202 man-days of work per hectare. Mechanization of land preparation, planting and harvesting are all possible, using machinery specially developed by IRAT since 1968. The machines are described, figured and costed. Most of the machinery was made up by using components from other existing machines. The machines can all be matched to an MF165 or similar 60 h.p. tractor. Yams pose several special difficulties for all operations. An analysis of performance and the costs of yam production by both man power and machinery provide a basis on which decisions on the appropriateness of mechanization in any particular situation could be based.

RESUME

La culture manuelle d'igname en Côte-d'Ivoire nécessite 182-202 travailleurs par jour par hectare. L'utilisation d'engins appropriés mis au point par l'IRAT depuis 1968 rend possible la mécanisation de la préparation du sol, du semis et de la récolte. Les engins sont décrits, chiffrés et leurs coûts estimés. La plupart des engins ont été mis au point à partir des pièces tirées de machines déjà fabriquées. On peut adapter tous les engins à un tracteur MF165 ou analogue à 60 h. p. L'igname pose des problèmes spécifiques pour chaque opération. Une analyse de la performance et des coûts de la production manuelle et de la production mécanisée d'igname permet de déterminer l'utilité de la mécanisation selon les cas en présence.

RESUMEN

Las labores de cultivo manuales para el ñame en la Costa de Ivory, require de 182-202 día-hombre por hectárea. La preparación del terreno, mecanizadamente, la siembra y la cosecha son todas posibles desde 1968, utilizando maquinaria especialmente desarrollada por el IRAT. Se describen las máquinas, sus características y sus costos. La mayor parte de la maquinaria se desarrolló utilizando componentes de otras máquinas ya existentes. Todas estas máquinas pueden ser tiradas por un tractor MF 165 u otro similar de 60 h.p. El ñame posee dificultades especiales para todas las operaciones. Las decisiones sobre lo apropiado de la mecanización de ñame, en cualquier situación particular, podrán basarse en un análisis del comportamiento del cultivo y costos de producción tanto manual como mecanizadamente.

INTRODUCTION

Present status of yams in Ivory Coast

In Ivory Coast, yams are grown in the savanna that extends to the north of forested area and to the east of the Bandama River. During 1969, 209,000 hectares of yam were cultivated and produced 1,520,000 tons. Yields vary from about 7.5 to 9 t/ha. During 1965, the average consumption in Ivory Coast was 171.2 kg per person per year. Consumption for 1980 is projected at 149.3 kg per person per year. At present yams are grown with traditional methods in a shifting cultivation system and all the work is manual. Yam comes first in crop sequence on cleared savanna or forest. Cropping is on mounds and there are up to 1000 of these per hectare. Labour inputs are as follows: making of mounds, 50-60 days; preparation and sowing of setts, 12 days; weeding, 80 days; harvesting, 40-50 days. This makes a total of 182-202 days work per hectare.

Objectives for crop improvement

More and more of the main food crops in Ivory Coast are now produced in modern agricultural systems. These systems increasingly involve mechanization and yam has been excluded from these modern systems because it is grown entirely with hand labour.

*Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières, BP. 635, Bouaké, Ivory Coast.

Considering the importance of yams as food crop, it would be desirable to bring them into modernized farming, and for this to occur, a method for mechanizing its production must be developed. To achieve this involves solving three problems that IRAT in the Ivory Coast has been studying since 1968.

The first two will be only briefly discussed. These are: Adaptation of farming practices: in order to get maximum production in a modern farming system it is necessary to arrive at a crop rotation which takes into account the economic value of crops at particular times, and the capability for intensive use of the land available.

Adaptation of the crop itself: attempting to adapt yam to mechanization encounters several problems. Yams tend to produce roots of a wide variety of sizes and shapes and are reproduced from tubers which need to be retained from the previous harvest. The three major operations requiring a special mechanized solution are ridging, planting and harvesting. Other farming operations can be carried out using standard methods. Yam mechanization has previously been studied by I.G. Campbell¹, James (not consulted). Warren⁵ and IRAT in the West Indies.

RESEARCH ON THE MECHANIZATION OF YAMS

Choice of equipment

The selection of equipment for this study was obtained with a view to making ridges with a profile comparable to the traditional system, i.e. 45-60 cm high, being able to plant setts of irregular and large size, which might also be carrying a delicate bud or shoot, and being able to recover fragile tubers at harvest from deep underground.

Location and conditions of the study

The study has been carried out at IRAT-CI station in Bouake in cooperation with the Committee for Agricultural Machinery of Ivory Coast (COMACI) during the seasons of 1969-1970 and 1971³. A 60 H.P. Massey Ferguson 165 tractor was used for all trials. The trial plots were previously opened up by ploughing and harrowing.

METHODS

Mechanization of ridging

Two ridgers were tested. The first in 1969 and 1970, the other in 1971. A ridger with rigid stanchions was built using parts from various other pieces of machinery at the station. It comprises a double tool bar 2.45m wide and a set of disks 71 cm in diameter. (Figs 1 and 2) Adjustments can be made for the lateral displacement of disk-carrying stanchions to adjust the distance between disks and for the angle of presentation of the disks in one plane only. Satisfactory results were obtained with this first ridger, using the tractor in 3rd gear at 3.1 k/hr. and the space between the disks was adjusted to make ridges with a 1.25-1.30m base. The height then varied between 40-50cm.

There were some problems with this tool, including the irregular height and shape of the ridges, and especially that ridges produced with too sharp a profile tended to encourage erosion and rapid compaction. To remedy this it is desirable to be able to adjust leading edges of the disks in two planes instead of just one, and to be able to stabilize the ridger by preventing lateral movements. Thus we tried to obtain a ridger equipped with fully adjustable disks and circular coulters for stabilization. In 1971 we obtained such a ridger from Israel.

Description of the articulated stanchion ridger

The chassis comprised three tool bars, 2.55 wide, and two pairs of disks 71 cm in diameter (Fig. 1). The stanchions were composed of four articulating parts allowing for the adjustment of spacing, angle of presentation of the leading edge, deviation from the vertical plane and depth (Fig. 3). Two circular coulters mounted in front of the ridger disks provide the required stability. In performance the width of the work required (1.25m) did not allow the mounting of more than one pair of disks, and an attempt to use the ridging device with the concave side of the disks facing outside was unsatisfactory. The device for ridging finally adopted, taking advantage of the many possible adjustments, made it possible to get long parallel ridges with a rounded profile and having a 1.25m wide base and height of 45-50cm.

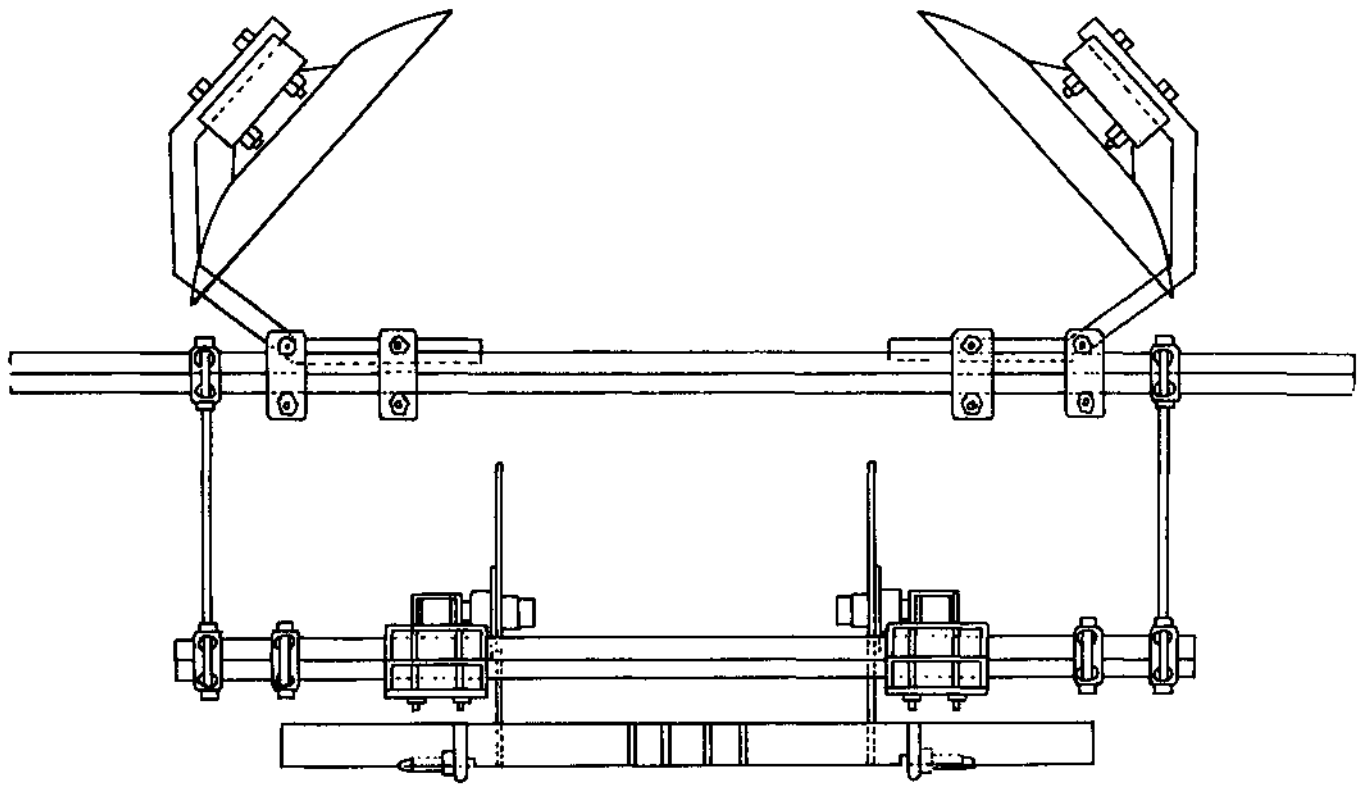


Figure 1. *Ridger, utilizing disks attached to a tool bar.*

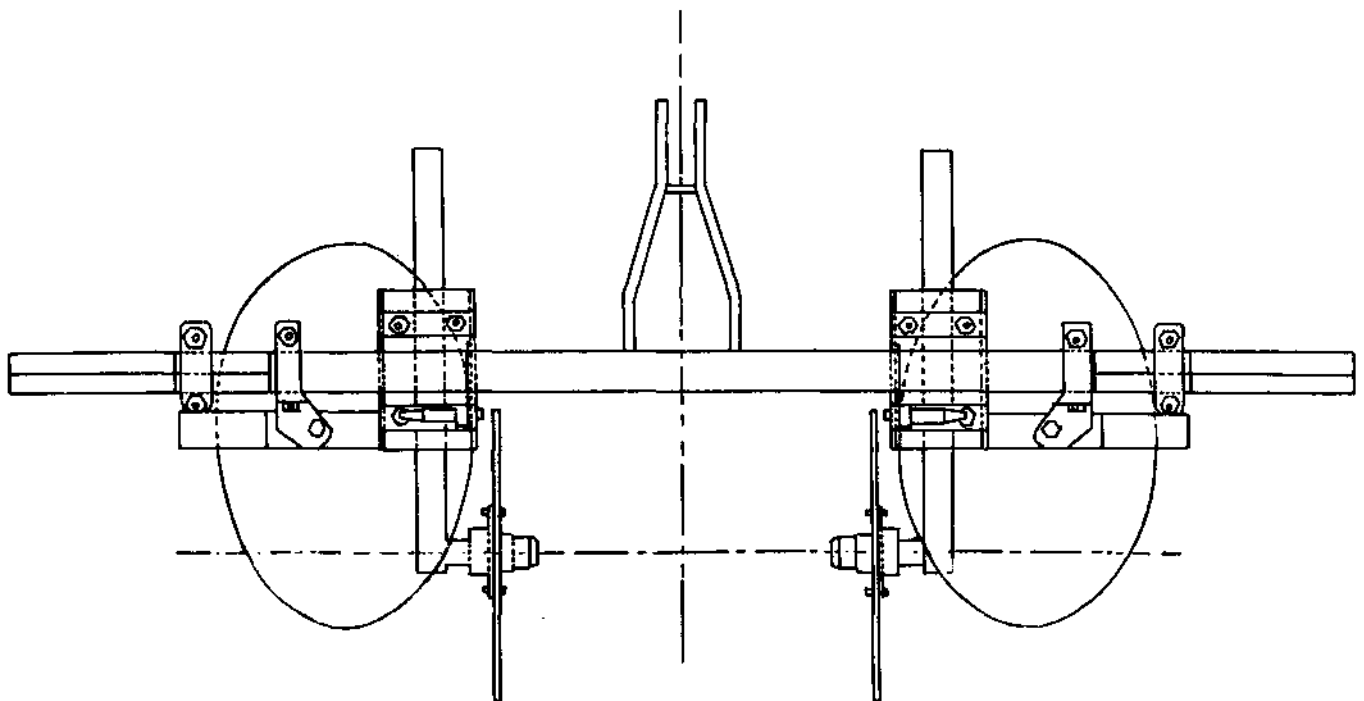
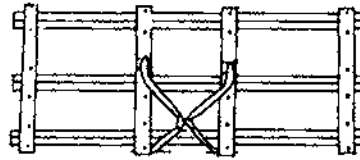


Figure 2. *Ridger, utilizing disks attached to a tool bar. Detail of attachment to the tool bar.*

CHASSIS



DISQUE ET ETANCON

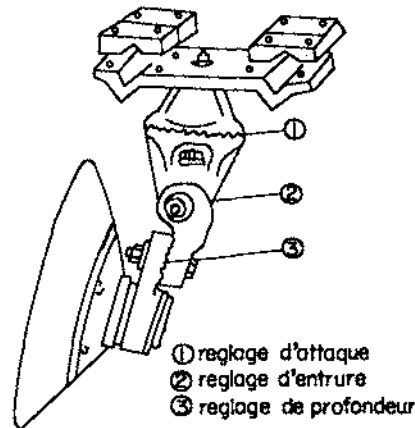


Figure 3. Stanchions with capability of being adjusted for spacing, angle of cutting edge, deviation from vertical and depth.

Economic aspects

Because the ridgers studies are no longer available commercially, the data are based on the costs of similar materials. The price can vary, according to the quality of the material, between 7,000-26,000 FF, from different manufacturers in France. In Ivory Coast a commercial firm has proposed to sell the ridger for 706,000 Francs CFA per unit. The rate of work for ridge forming ranged from 2¼-3½ hours per hectare, depending on the nature and the condition of the land.

Mechanization of the planting operation

The most convenient planter is one that uses a distribution system of bucket chains which are fed manually. A planter of this type selected in France, was greatly modified by the manufacturer at our request before being dispatched and met the following specifications: weight (after modifications), 360 kg; length, 1.55 m; width, 1.37 m. The metallic frame and wheels, mounted on extended stanchions, were able to straddle the ridges. Sett distribution was by a fourteen cup chain of 18 x 12 x 10 cm running over sprockets. The furrow was opened by a breasted share equipped with mould boards. The setts are covered over by the action of two sets of concave disks of 45 and 55 cm diameter respectively (Figures 4 and 5).

Adjustments can be made to the depth of planting by raising or lowering the wheel stanchions in the frame. The wheel base can be varied from 1m to 1.20m. The plant population can be adjusted by use of a set of five interchangeable sprockets so as to allow spacing from 58 to 101 cm. The disks for covering the setts can be adjusted by swivelling.

Performance of the planter

With the tractor track reduced to 1.32 m, a single ridge can be straddled without damaging adjacent ridges. A forward speed of operation of 2.62 km/h in the second lowest gear of the tractor was used. One tractor driver and three men operated the planter.

After initial trials some modifications appeared necessary to improve the efficiency of the machine. This was made and the planting operation was then performed well.

Economic aspects

The material cost from the manufacturer was 2,580 FF or 3,309 FF delivered Abidjan. The modifications cost a further 1,600 FF. The planter can operate at the rate of 5 hours 10 minutes per hectare (manual planting takes 10 man-days per hectare).

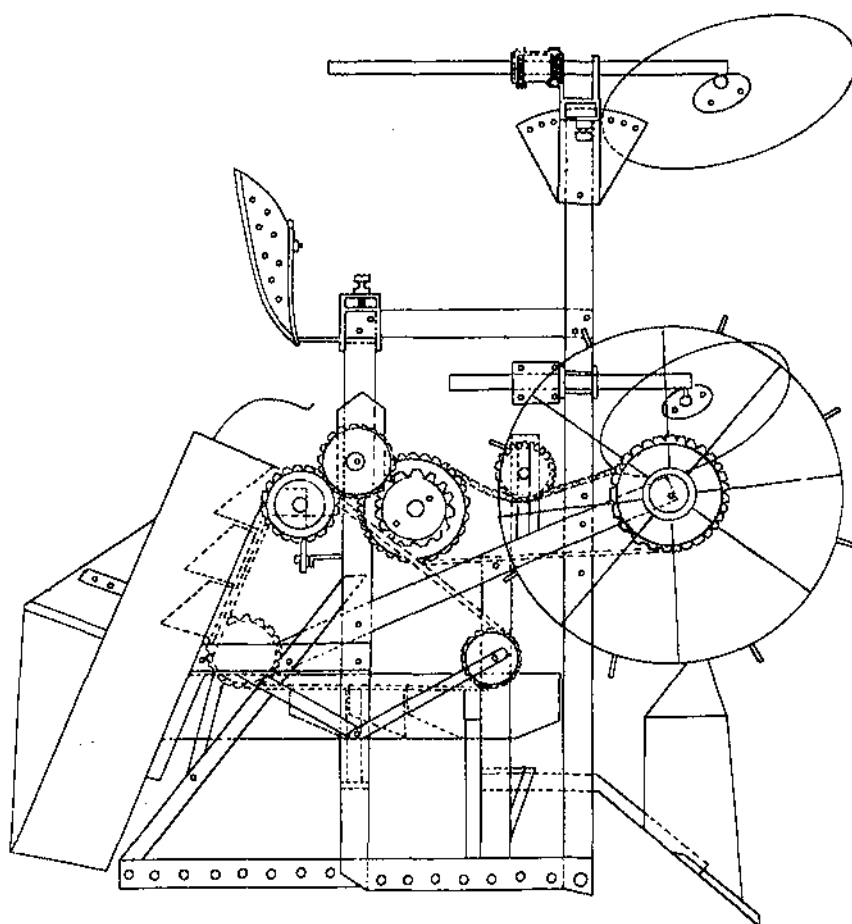


Figure 4. A modified planter for yams.

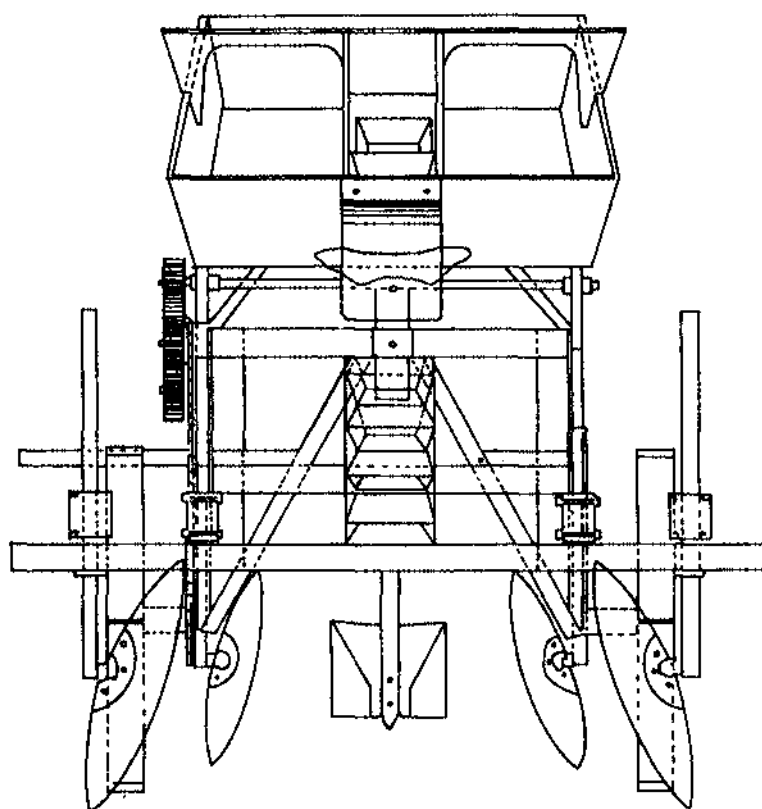


Figure 5. Overhead view of the planter.

Mechanization of harvesting

The harvester has to be strongly built but nevertheless should not subject the tubers to rough handling.

The manufacturer made no modification before delivery to the machine which we chose. The specification of the machine is: weight, 340 kg; length, 1.50 m; and width 1.40 m. The body is manufactured from steel tubing. The working parts comprise two U-shaped stanchions carrying the ploughshares and the frame for the shaking riddle. These parts oscillate around pivots. By means of a set of rod-drives the ploughshares and the riddle are caused to reciprocate by power supplied by the tractor's power take-off. (Figs. 6 and 7).

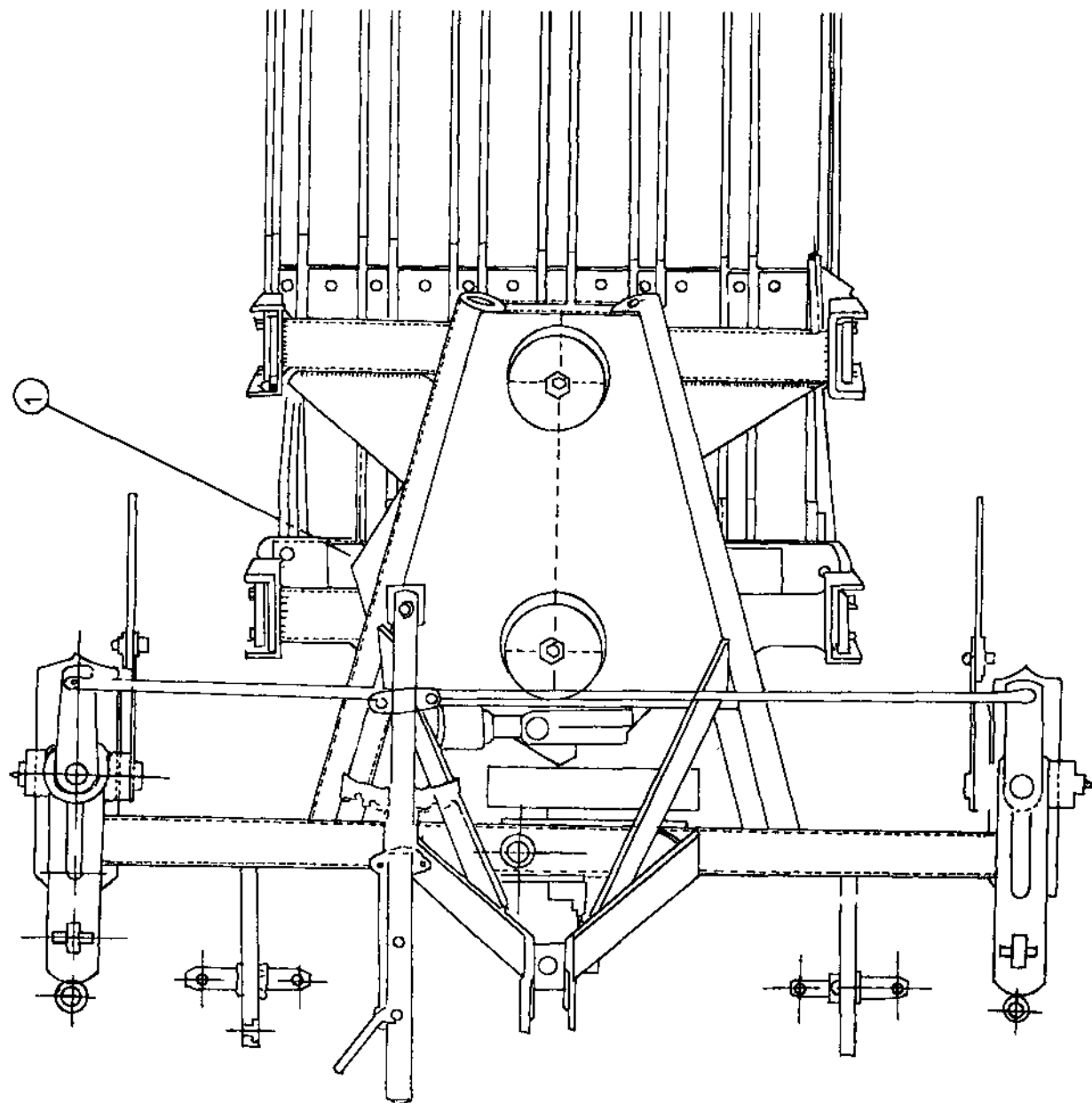
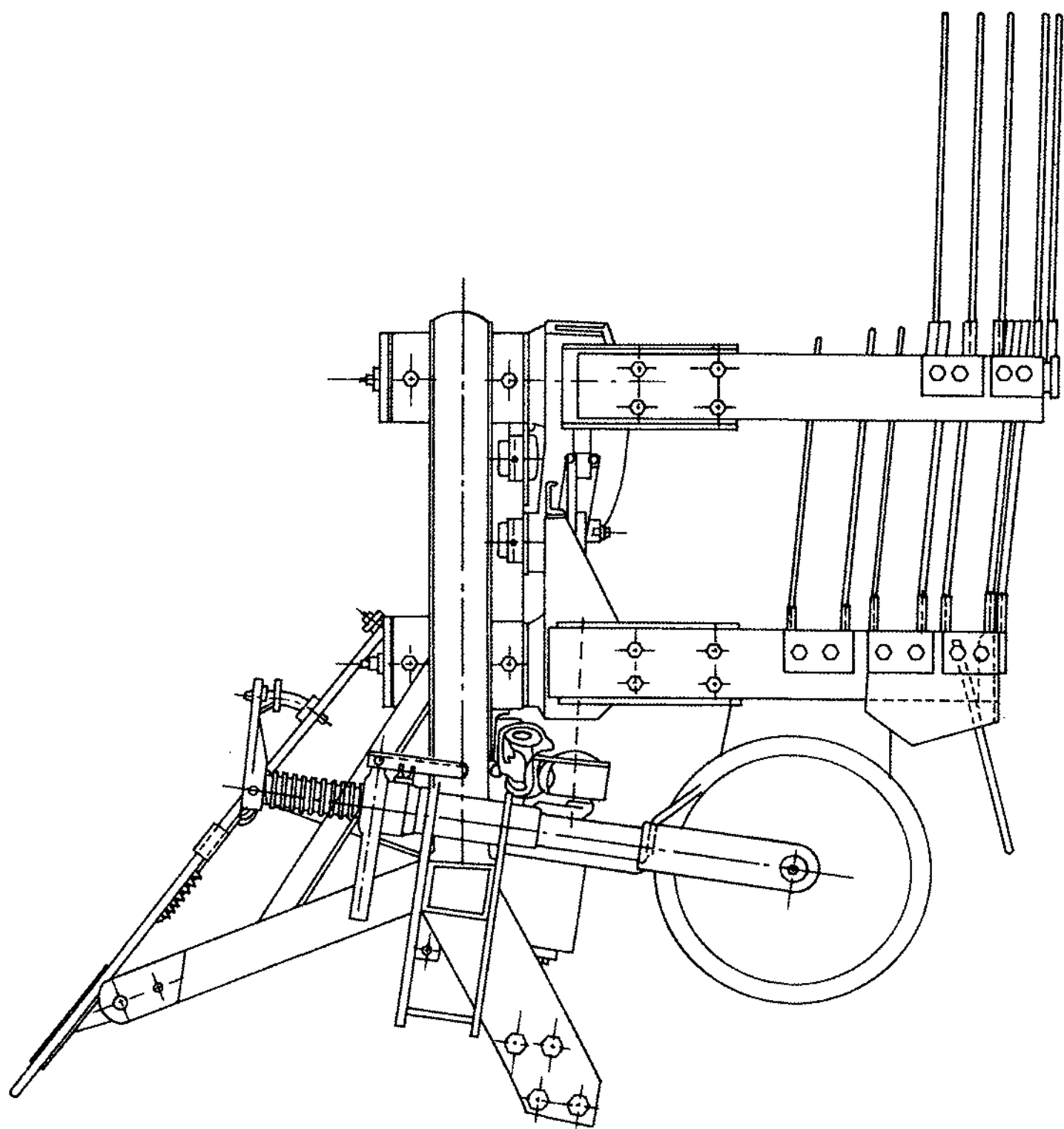


Figure 6. *Harvesting machine, overhead view.*



Adjustments and operation

Depth is adjustable to within a height of 25 cm., and the speed of shaking depends upon the r.p.m. of the power drive. The lifter is operated in the 2nd lowest gear with 1,500 r.p.m. as a minimum and requires 1 tractor driver, 1 man controlling the lifter (optional) and 4 men collecting and moving tubers aside before the tractor returns on its next round.

Performance of the lifter

The first trials were carried out under heavy and dry soil and it was apparent that the stanchions and original ploughshares were not strong enough. Modifications made included replacing of the stanchions and shares by stronger components, reducing the width of work from 1.30 m to 0.80 m, increasing the length of the stanchion to 0.60 m, and reducing the number of riddling rods to hasten separation.

Even after modifications to the lifter tubers were sometimes damaged by sifters and broke when harvested from heavy and dry ridges. It has become apparent that for use of the machine harvester the ridges must be quite straight, too deep planting must be avoided and the tops of the yam must be cut and removed before harvesting. Results of harvesting trials are presented in Table 1.

Economics of yam harvesting

The cost price of the unmodified machines from the manufacturer was 3,548 FF and the cost price delivered in Abidjan was 4,376 FF. The work rate of the lifter primarily depends very much on the condition of the land at harvest time, and varies between 5-7½ hours per hectare. In contrast, hand harvesting requires from 2-3 man days per hectare.

AN ECONOMIC STUDY OF A MECHANIZED CULTIVATION

Costs

The cost for a mechanized yam cultivation (Table 2) was determined first on one hectare of land with the cultivar N'za Seguella of *Dioscorea alata*. Data for depreciation of material, with the exception of tractors, are based on a study published by the Ministry of Agriculture in Ivory Coast² on identical material or on material of reasonably similar type and value. These have been used in calculating the operating cost of the machines. Land preparation was done with equipment usually used in mechanized cultivation. Data are provided for full costs in Table 2.

Profitability

For cultivar N'za Seguella yielding 12 tons per hectare the expected profit is as follows: estimated sale price, 10 F/kg; gross return, 120,000 francs C.F.A.; variable costs, 100,000 francs C.F.A.; gross margin, 20,000 francs C.F.A.; percent profit (in terms of gross return), 16.6%.

CONCLUSIONS

At the end of four years of experimentation with equipment designed to introduce mechanization of yam cropping, it appears that the solutions proposed would allow integration of this crop into modernized systems of land management.

The solutions proposed certainly are not the only possible ones and the machinery worked out can be further improved. However, using the equipment described, hand labour could be reduced by 70%.

REFERENCES

1. Campbell, L.G. (1967) Prospects for mechanization of yam growing. In *Yams*. Coursey, D.G. (Ed.). pp. 100-105.
2. Ministry of Agriculture, Ivory Coast (1969) Project for rural modernization of Brobo, Diabo.
3. Minagri -- Comaci, Ministry of Agriculture, Ivory Coast. Annual Reports on Trials at Minagri, Comaci 1969-1970-1971.
4. Soitout, M. (1970) IRAT/West Indies (Guyana (1970) Mechanization of yam harvesting).
5. Warren, J.B. (1957) The design of a tractor-mounted lifter. Imperial College of Tropical Agriculture, Trinidad, West Indies.

TABLE 1

Harvesting of yams — yield and damage

	Yield t/ha	% of weight (harvest) intact tubers broken tubers	
1970			
Ouan Seguela	16.8	79.8	20.2
Krengle	9.5	57.5	42.5
1971			
N'za Seguela	12.3	91.2	8.8
Akandu	3.2	72.8	27.2
1972			
BB dato 20	8.4	91.9	8.9
N'za Seguela	10.0	96.4	3.6

TABLE 2

Statement of variable costs for mechanized cultivation per ha. (in Francs C.F.A.)

Operation	Machines	Chemicals and planting materials	Manpower	Total
Land preparation	10,143	14,327	-	24,470
Ridging	2,458	-	-	2,458
Planting	8,028	22,000	2,520	32,548
Maintenance:				
motorized	855	10,407	176	11,388
manual	-	4,282	7,560	11 842
Harvest	6,775	-	1,260	8,035
Loading, transport	8,320	-	1,764	10,084
Total	36,579	51,016	13,230	100,825

A MECHANICAL HARVESTER FOR DIOSGENIN-PRODUCING YAMS

L.W. Nystrom, J.E. Shrum Jr. and R.F. Dawson*

SUMMARY

It is possible to harvest yams which are distributed through large volumes of soil by lifting the entire soil volume with the kinds of machines usually used for digging and grading road-building materials and employing screens which can separate out the yam from the main body of the soil.

RESUME

Il est possible de récolter l'igname semée sur une large surface de sol en soulevant toute la surface du sol à l'aide d'engins ordinairement utilisés pour creuser ou d'équipements de construction routière, et en utilisant des cribles pouvant débarrasser l'igname de la motte de terre.

RESUMEN

El ñame que se encuentra distribuido a través de grandes volúmenes de suelo, se puede cosechar volteando el volumen completo con máquinas de las usadas para la excavación y nivelación de los materiales de construcción de caminos y utilizando cribas que pueden separar el ñame del suelo en sí.

INTRODUCTION

There has been considerable interest for about twenty years in developing commercial production of *Dioscorea* spp. containing diosgenin as a starting material for the production of steroidal compounds. Several projects directed towards the development of the necessary technology for commercial production are, or have been, in progress in Puerto Rico, Mexico, Guatemala, Costa Rica, Kenya and India¹. Considerable work on the diosgenin-rich *Dioscorea* spp. has been carried out at Federal Experiment Stations in Puerto Rico and in Florida, U.S.A.^{1,4,5}.

Of the diosgenin-bearing species², *D. composita* Hems¹, and *D. Floribunda* Mart. and Gal., having been most seriously considered for commercial production because of their yield potential and their high diosgenin content and purity^{4,5}. Of the two, significantly greater root and diosgenin yields per unit of land area are obtained from *D. composita* in Guatemala, making it the better prospect for commercial production. The vines of *D. composita* also grow more vigorously and the shade provided by the thick foliage helps control weeds. The white-fleshed roots are firm but brittle, and at harvest, range in thickness from 2 to about 15 centimeters.

One of the problems of the large scale, commercial production of *D. composita* is the irregular, deep position in the soil of the tuberous roots. They may occur as far as 30 centimeters to the side of the planting row, and, depending on soil conditions, may occur to a depth of over 90 centimeters during a three-year crop cycle. The major portion of the root yield is located at less than 76 centimeter depth. No common harvesting implement can dig roots from this depth, so that it was necessary to develop one. The aim was to reduce the cost of harvesting below that of hand harvesting at prevailing labour rates.

PREVIOUS ROOT AND TUBER HARVESTERS

Most authors suggest a simple, soil-loosening tuber-lifting implement for the harvest of *Dioscorea* species. Martin and Gaskins⁵ suggest a large moldboard plough and Martin et al.⁴ mention a lister-bottom plough as possibilities for turning up the tubers for subsequent collections by hand. An early cultivation project conducted by Merk & Company in Guatemala developed a soil-loosening implement for harvesting *Dioscorea* species based on the model of a seedling tree lifter. Coursey² describes the construction and operation of a tuber-lifting plough for edible *Dioscorea* species after the use of which the tubers were raked by hand from the loosened soil. It was designed to harvest the tubers from ridges of soil which is the common method of growing edible *Dioscorea* species. Efforts to select cultivars with regularly shaped roots for easier, mechanical harvesting were being made.

*Finca Concepcion Buena Vista, Guatemala.

Martin and Gaskins² discussed the development of a harvester for medicinal *Dioscorea* species based on the principles of a potato harvester. A machine of this type was designed and constructed for a project in Puerto Rico but results are not known.³ In our work such a design was considered for *D. composita* but rejected on engineering criteria. As an alternative, an existing machine was sought which could be adapted to the particular requirements of harvesting *D. composita*.

DESCRIPTION OF THE NEW MECHANICAL HARVESTER

The basic machine

The problem of mechanically harvesting a closely planted crop of *D. composita* is one of removing and sifting 7620 m³ of soil per ha. Therefore an elevating grader of the type normally used to load trucks with gravel and stones for road making, was selected as the basic component for a harvester. The standard, Model K-12, Ulrich BoMor machine acquired for this purpose, according to specifications, could dig to a depth of 61 centimeters and elevate up to 688.5 cubic meters of earth per hour. Models of greater capacity were also available.

The elevating grader is mounted on a Model 12 or 14 Caterpillar motor grader in place of the usual grader blade. Its main components are a heavy concave, disc-plough blade and a wide belt conveyor. The standard, disc-plough blade for this model is 76.2 centimeters in diameter. It is mounted on a heavy beam which can be adjusted for depth of cut. The standard belt conveyor is 1.067 m wide and 5.795 m long, and is mounted at right angles to the disc-plough blade, and can deliver earth to a height of about 2 m. The lower end is hinged to a frame, and the upper end is raised or lowered by cables and a winch. The conveyor belt is driven by a system of V-belt pulleys, shafts and gear boxes from the crankshaft of the grader engine.

The belt speed is 137.25 m per minute. As the motor grader moves forward on the bottom of the trench, the disc-plough blade shears off a strip of earth 25 – 30 centimeters wide from the face of the cut on the left and, acting as a moldboard, guides the ribbon of soil onto the lower end of the belt conveyor which delivers it upward to the right, across the direction of travel.

Modifications to the basic machine

The basic machine was modified for root harvesting by replacing the standard, disc-plough blade with one 91.5 centimeters in diameter to increase the depth of cut to 76.2 centimeters. The difference between the blade diameter and the depth of cut allows for trash and expansion of the soil as it is loosened. Other modifications were shortening of the belt conveyor to 3.66 meters and later to 3.05 meters to reduce soil displacement, and increasing the belt speed to 183 meters per minute in order to carry the increased volume of soil from the larger blade.

Separating screen-conveyor

To separate the roots from soil, a draper chain screen-conveyor was mounted on the discharge end of the belt conveyor. Draper chain conveyors are commonly used in sugar beet and potato harvesters and are made of links of steel rod with formed ends which hook together to make an endless belt. The pitch and thickness of the links can be selected to obtain the desired opening. The teeth of the driving sprockets on the head shaft mesh with the openings between the rods and pull the chain over supporting idlers.

In Models I and II of the screen-conveyor, a single, rigid frame supported two, adjacent aprons of draper chain, each 53.66 centimeters wide. The total width of the screen bed was 1.13 meters. The rod diameter was 1.11 centimeters and the straight portion of the links was coated with bonded rubber to reduce the opening to 1.9 centimeters. The aprons were supported in the area of impact by a grate of iron bars. Sets of eccentric, sprocket idlers, evenly spaced form the grate to the head shaft, supported and shook the chain.

Both models were shaft driven by a 30 h.p. gasoline engine with a 2.67 to 1 clutch reduction assembly. The final drive, mounted on the head-shaft, further reduced the shaft speed by 4.11 to 1.

The lower end of the screen-conveyor frame was hinged to the upper end of the belt conveyor and the angle of incline was adjusted for efficient screening by cables and a winch mounted on the grader frame. The incline could be varied from 25 – 35 degrees, depending on soil conditions.

Major changes in the Model II from the Model I screen were:

1. Increasing the length from 2.44 meters to 3.68 meters to provide more screening area.
2. Mounting a gear box in the drive train to reduce the screen speed.
3. Welding flights on four links of each draper chain apron to prevent round stones from tumbling.
4. Installing curtains of heavy belting over the draper chains to break clods.

Various minor changes in components or adjustments in their position were also made to improve mechanical operation or increase screening efficiency.

HARVESTING

The vines were chopped and burned to eliminate surface trash. A border, 9 m wide, was hand harvested to allow for soil displacement by the harvester. Next, a smooth incline was graded with a bulldozer or the motor grader along the harvested border to the depth of harvest. Then, with the harvester attachments mounted, succeeding cuts were made from the unharvested bank. Workers, stationed at intervals on the discharge bank, collected and put the root into sacks which were removed on a tractor-drawn wagon.

Soil displacement by the harvester left a trench in the centre of the fields about twice as wide as the belt conveyor length. Since refilling this trench would have been costly, it was left open and its sides were graded to allow further field operations. Plans are to harvest the succeeding crop of *D. composita* from the centre.

FIELD TESTS AND RESULTS

The first test in February-March, 1969, was of the modified, basic machine i.e. without the separating screen-conveyor. The root was raked out by hand from the entire discharge from the belt conveyor. A Model 12/ Caterpillar, ca. 90 h.p. motor grader was used. The rectangular field was harvested from both sides leaving a ditch 7.3 meters wide in the centre.

The modified, basic machine together with the first kind (Model I) of the screen-conveyor was mounted on a Model 12F, Caterpillar, 125 h.p. motor grader and tried in the second test in March-April, 1969. The root was hand picked from the surface of the bank of screened soil. A rectangular field was harvested from both sides and the centre ditch was 6.0 meters wide at the bottom.

The third test in March-April 1971, used the modified, basic machine combined with the Model II screen-conveyor, mounted on a Model 14E Caterpillar, 150 h.p. motor grader. The root was picked from the surface as in Test 2. The field was roughly square and was harvested from the four sides. Results on performance are presented in Table 1.

When Models I and II screens were attached the harvest time was increased by 8.5 and 9.0 hours per hectare respectively. The Model I screen reduced the percent of yield dug but not recovered from 16.6 – 11.9. The Model II screen further reduced the percent unrecovered to 4.1. The deeper harvest in Test 3 resulted in little root being left below harvest depth.

Results on the economic aspects of harvesting are presented in Table 2.

When the Models I and II screen-conveyors were attached (Tests 2 and 3) the total harvester cost increased by about 150 percent, but total gathering cost per ton harvested decreased by an average of 37.5 percent compared with the non-screening machine. The efficiency of yield recovery increased with the screen-conveyors attached as indicated by the reduction of the value of root left in the field per metric ton of root recovered. The net result was a reduction in the total cost of harvest to \$20.38 per metric ton. Estimated harvesting costs for greater yields than those of the test harvests showed that harvester costs, which are a function of land area or time, would be reduced by the increased yield. The net result would be a significant reduction in the total cost of harvesting.

In Table 3 the costs of hand harvesting are presented for comparison. Payment on the basis of the weight of root harvested decreased the efficiency of yield recovery but also decreased the total cost of harvest by \$16.14 to \$24.67 per metric ton recovered. The difference in harvest cost between Harvest Analyses 2 and 3, which were roughly equal in yield, was due to different rates of harvest because of soil condition or different groups of worker. Although the payment per unit of weight was the same for both groups, the difference in dilution of the constant overhead by the yield harvested per day changed the total cost of harvest.

When yield per hectare increased in Harvest Analysis 4, the harvest cost decreased significantly. However, total harvest cost is influenced by the yield unrecovered and data from commercial, hand harvests, other than those presented in Table 3, indicate that the unrecovered yield can vary up to 25 percent of the total yield.

DISCUSSIONS AND CONCLUSIONS

The results showed that *D. composita* was machine harvested for \$1.76 per metric ton less (\$20.38 compared with \$22.14) than by hand when yields were about 40 metric tons per hectare. This cost advantage was due to more efficient root recovery. Our analysis of costs shows that there will be a relatively greater cost advantage for machine harvesting at higher gross yields and that harvester costs per metric ton of root harvested decrease proportionately as yield increases whereas hand harvest costs are relatively inelastic. Other advantages of mechanized harvesting are better control of the rate of harvest and lesser dependence on a seasonal supply of temporary labour.

A disadvantage of this harvester is that it completely mixes the soil to the harvest depth. Harvesting by hand also churns the soil, but to a somewhat lesser degree. This is presently being evaluated by collecting yield data on subsequent crops of *D. composita*. Another disadvantage is the depression left in the centre of the field. The best solution yet found is to harvest around large, square fields so that the depression occupies the smallest percentage of field area.

Buried rocks and boulders caused delay and damaged the belt, but did not affect the screen-conveyor. Other components of the elevating grader attachment failed mechanically on several occasions due to inexperienced operators or overloading. It was concluded that an elevating grader with a wider belt conveyor was indicated.

This machine is best suited for large-scale, commercial production and its efficient use is restricted by certain conditions. Fields should be large and fairly level. The soil should be deep, friable and free of large rocks. Experience indicates that dry soil is preferable but this would depend somewhat on its physical structure. Hard, cloddy soil reduced screening efficiency but this could be overcome by further modifications.

Further development of the harvester would include repositioning the screen-conveyor to deliver to the rear and adding a narrow, long conveyor to transfer the root to a self-unloading hopper or cart attached to the rear of the motor grader. With such an arrangement, the hand labour of gathering the root would be eliminated and the machine would be a complete harvester.

REFERENCES

1. Bruhn, C., Koch, W. and Schmidt, O. (1972) Der anbau von Pflanzen, insbesondere Dioscoreen zur Steroidgewinnung, *Der Tropen Landwirt* 73, 123.
2. Coursey, D.G. (1967) *Yams*. Longmans Green and Co., Ltd. London. pp. 103-5, 217
3. Heasley, R.L. (1970) Personal communication.
4. Martin, F.W., Cabanillas, E. and Gaskins, M.H. (1966) Economics of the sapogenin-bearing yam as a crop plant in Puerto Rico. *The Journal of Agriculture and the University of Puerto Rico*. 1(1),55,57,60.
5. Martin, F.W. and Gaskins, M.J. (1968) *Cultivation of the sapogenin-bearing Dioscorea species*. U.S. Dept. of Agriculture, Production Research Report No. 103, 3-5, 13-14.

TABLE 1

Yields and efficiency of harvesting *D. composita* with the modified, basic machine (Test 1), with Model I screen (Test 2), and with Model II screen (Test 3)

Test	Harvest area (ha)	Harvest time (hrs/ha)	Harvest depth (cm)	Total yield harvested (M.T./ha)	Yield not recovered M.T./ha.	% of yield harvested	Yield*below depth of harvest (M.T./ha)
1.	3.92	23.4	76.2	41.5	6.9	16.6	13.3
2.	4.17	31.9	76.2	33.6	4.0	11.9	6.4
3.	4.98	32.4	83.8	41.7	1.7	4.1	0.2

*Yield occurring below 76.2 centimeters is variable depending on soil structure, growth time and the efficiency of previous harvests. Previous harvests of all areas reported in Table 1 were by hand and the yield below machine harvest depth was mostly due to the growth of volunteer plants.

TABLE 2

Yield recovered and cost of harvesting *D. composita* by machine

Test	Yield re- covered by machine (M.T./ha)	Total harv- ester cost \$/M.T.	Total gather- ing cost \$/M.T. harvested	Extra*cost of border harvest \$/M.T. harvested	Value** of root not har- vested \$/M.T.	Total cost \$/M.T. harv- ested
1 mod. basic machine	34.6	5.34	7.34	0.33	27.87	40.88
2 with Model I screen	29.6	13.16	4.98	0.33	16.77	25.24
3 with Model II screen	40.0	13.82	4.20	0.33	2.03	20.38
Estimates***71.0	7.47	4.20	0.33	2.29	14.29	

* The total extra cost of hand harvesting the borders, i.e. the cost above that of machine harvest, divided by the total field production harvested by the machine. The cost shown assumed equal field sizes and yields and is based on Table 3 data.

** $\$47.73/\text{M.T.} \times \text{total M.T./ha left in field}$
M.T./ha harvested by machine = Value/M.T. harvested

***The estimates of costs at the yield recovered of 71.0 M.T./ha are included to show the yield-cost relationship of mechanized harvest. They are based on Test 3 data.

TABLE 3

Wage basis, yield and cost of harvesting *D. composita* by the hand method

Harvest analy- sis	Wage basis	Total yield M.T./ha	Yield unrecovered M.T./ha	% of total yield	Harvest cost \$/M.T. harv- ested	Value* unrecover- ed root \$/M.T. harv- ested	Total cost \$/M.T. harv- ested
1.	Daily wage	41.5	1.45	3.45	43.22	1.70	44.92
2.	Unit of weight	41.5	4.36	10.5	23.18	5.60	28.78
3.	Unit of weight	39.5	4.15	10.5	16.54	5.60	22.14
4.	Unit of weight	74.4	8.41	11.3	14.17	6.08	20.25

* $\frac{\$47.73/\text{M.T.} \times \text{M.T./ha unrecovered}}{\text{Total M.T./ha} - \text{M.T./ha unrecovered}}$ = Value per M.T. harvested

MECHANIZATION OF CASSAVA PRODUCTION

A STUDY TO DETERMINE THE SUITABILITY OF PRESENT CASSAVA CULTIVARS FOR MECHANICAL HARVESTING

B.E. Onochie, G.A. Makenjuola and E.E. Schulte*

SUMMARY

The rooting patterns of four commonly grown selected cassava cultivars (60444, 60447, 60506 and 44086) in Nigeria were studied. There was variation between cultivars in root weight, depth of penetration, number of roots per stand, and root length. Large numbers of correlations and linear regressions between cultivars have been computed. The rooting patterns of none of these cultivars allow easy mechanical harvesting. An attempt is advocated to select new cultivars whose roots can be harvested cheaply and effectively.

RESUME

La structure des racines de quatre cultivars de cassava (60444, 60447, 60506 et 44086) généralement cultivés au Nigéria ont été exposées. Les cultivars varient selon le poids de la racine, la profondeur de la pénétration, le nombre de racines par pied et la longueur des racines. Un nombre important de corrélations et de régressions linéaires entre les variétés ont été estimées. Aucun des cultivars ne présente une forme d'enracinement permettant une récolte mécanisée réalisable dans de bonnes conditions. L'accent a été mis sur la nécessité de sélectionner de nouveaux cultivars dont on peut récolter les racines aisément et à peu de frais.

RESUMEN

Se estudiaron los patrones de enraizamiento de cuatro cultivares selectos (60444, 60447, 60506 y 44086), comunes en Nigeria. Hubo variación entre cultivares en cuanto a peso de raíces, profundidad de penetración, número de raíces por mata y longitud de raíces. Se computaron un gran número de correlaciones y regresiones lineales entre variedades. Los patrones de enraizamiento de ninguno de estos cultivares permiten una cosecha mecánica fácil. Se hacen intentos para seleccionar nuevos cultivares cuyas raíces puedan ser cosechadas económica y efectivamente.

REVIEW

Cassava (*Manihot esculenta* Crantz) is widely used in tropical countries as a source of carbohydrates for both humans and livestock. FAO² estimated that in 1971 Nigeria produced 7.3 million metric tons of cassava which was grown on over one million hectares, making the country the second largest producer in Africa. Most of Nigeria's production is by peasant farmers. Two factors prevent there being much increase in production: (1) high labour requirement at harvest accounts for over 40 per cent of the total costs of production and (2) peasant methods of processing the roots for food are laborious and time consuming.

The development by the Nigerian Institute for Industrial Research of an integrated cassava processing plant which processes cassava roots into gari has opened the way for large scale production and processing. Thus, cassava may shortly become an important commercial crop in Nigeria.

An integrated plant is also being operated in Gambia. This processes 45 metric tons of raw cassava roots daily. With the present average yield levels in Nigeria, such a plant would require the production from three hectares daily at full capacity, approximately 1000 hectares of production per year. This would most conveniently be produced by a commercial operation and mechanized harvesting.

Activities are already under way in Nigeria to establish processing facilities which emphasize the urgency for the development of mechanical harvesting equipment.

B.E. Onochie, Department of Plant Science,)
G.A. Makenjuola, Department of Agricultural Engineering,) Ife,
E.E. Schulte, Department of Soil Science) Nigeria.

Attempts have been made in other countries to harvest cassava mechanically. The use of the mould-board plough for cassava harvesting was suggested by Krochmal³ in Mexico and Thailand. Bates¹ proposed the use of the potato spinner, the potato digger-lifter and the sugar beet harvester for cassava harvesting. All have since been tried and found unsuitable and uneconomical.

Makanjuola *et al.*⁴ have shown that only 75% of the crop was exposed for hand picking when cultivar 53101 was mechanically harvested with a mouldboard ridger, but 81% when a mouldboard plough was used. In both instances there was about 40% of root damage.

Current opinion is that harvesting equipment of an entirely new design is necessary. To be suitable, a harvester must not only lift the roots but also separate loose soil, clods, and large stones while sufficiently exposing the roots for easy picking. A suitable device for loading the roots into a trailer would also be useful. We have therefore studied the rooting pattern of the important cultivars of cassava in Nigeria and suggest a different and desirable plant type for the future.

MATERIALS AND METHODS

Cassava was planted at the University of Ife Farm on a well-drained sandy loam soil classified in the two series. The four cultivars of cassava used included three commonly grown improved cultivars; 60444, 60447 and 60506; and one other promising cultivar, 44086. These cultivars, together with some other locally adapted ones, have accounted for practically the entire crop harvested in Nigeria since 1967.

The rooting characteristics studied included: the lateral spread of individual roots; depth of root penetration; number, weight and length of each root per stand and length of the neck (i.e. that part of the root proximal to the tuberized section). The distribution of dry matter along the length of every root was also studied. Cuttings were spaced one meter apart.

In order to measure these criteria accurately, the point at which the stem emerges from the soil was marked. The soil around the stand was carefully removed until the roots were completely exposed but undisturbed. The point at which each root was attached to the stem was determined, as was the radius of root spread by measuring the horizontal distance from the central point of root stalk attachment to a point above the tip of each root (Fig. 1). The depth of root penetration was measured as the vertical distance between the point at which the stem emerged from the soil to the distal (tail) end of the root (Fig. 2). The distal tip of the roots were usually the lowest point on the root. These two measurements were recorded for all stands.

Weights of individual roots were taken and the number of roots per stand was recorded.

In addition each root was measured to determine the length of the neck and that of the entire root. Diameter of the roots at 2.5 cm intervals were also recorded. The purpose of this was to study the concentration of dry matter along the root length.

Conventional statistical methods were used for analysis of the data.

RESULTS

Mean weights (Table 1) of individual roots varied markedly between roots within cultivars and also between cultivars. The standard deviation for tuber weights in cultivar 60506 was higher than the mean tuber weight, and for 44086 was almost as high as its mean tuber weight. Cultivar 60447 had three times the mean tuber weight of 44086 and about twice that of 60444. The standard deviation for 60447 was highest among the cultivars.

Mean depth of penetration varied from 204mm for 60444 to 256.8mm for 60447. Again the standard deviation for depth for 60506 was greater than its mean depth of penetration.

Mean radius of spread ranged from 303mm in 44086 to 386mm in 60447. The frequency distribution diagrams for the radius of spread, depth of root growth, and weight of individual tubers indicated a normal distribution in all cultivars.

Table 2 shows that the total length of the root including the neck plus tuber measurements and the variations within one cultivar were small. Cultivar 44086 had both the shortest tubers and root length (neck plus tuber).

Individual tuber weights (Table 3) were highly correlated with the radius of spread for all the cultivars. As the plant aged and stored more carbohydrate in the tuber there was not only an increase in girth of the tubers but also a greater lateral spread.

The radius of spread was highly correlated with depth of penetration in cultivars 60444, 44086 and 60506. Simple regression equations relating these parameters are presented.

Tables 1 and 2 show that cultivar 60447 differs greatly from 44086 in root weight, depth of penetration and radius of spread. Thus there is clearly genetic variation within the species which can be subjected to selection.

Cultivar 60447 is an erect growing plant with a medium canopy. It is a widely grown variety in Nigeria.

Tuber weight to tuber length relationship determines to a great extent the probability of success in mechanical lifting of the tubers. Table 4 shows a high correlation between root weight and tuber length in all the cultivars, that is, the greater the length of the tuber, the heavier it is.

Length of the tuber was significantly correlated with neck length in 60447 and 44086. Root weight is also correlated with the sum of length of tuber plus length of neck in all the cultivars except 44086.

The measurements taken at 254mm intervals along the tuber showed that the average cassava tuber tapers rather from the proximal end and that this tapering is greater beyond 38cm from the proximal end of the tuber in cultivars 60444 and 60447. For the other cultivars the roots tapered off more rapidly from about 25cm from the proximal end. Thus, the commonly grown cassava cultivars concentrate their stored carbohydrates within 25-38cm from the proximal end of the tuberous part of the roots. To lift all this length of root would require a large amount of soil to be turned over.

Table 5 shows considerable variability both within a cultivar and between cultivars for mean tuber weight per stand, mean depth of penetration and mean radius of spread. The mean number of roots per stand was less pronounced. Cultivar 60447 again contrasted sharply with 44086 in tuber weight, root spread and depth of penetration.

Table 6 shows that variability in the mean total length of the root per plant was low. Appropriate regression equations for the parameters studied, are presented in Table 7.

Tuber weight per stand was strongly correlated with depth of penetration for cultivars 60447, 60506, and 44086. Tuber weight per stand was also highly correlated with radius of spread in cultivars 60444, 60506, and 44086. This confirms that tuber expansion occurs by both increased girth and soil penetration.

DISCUSSION

The results show that the mode of lateral and vertical (downward) spread of the roots in the soil is not well adapted to allow simple mechanical harvesting. To harvest the roots in their present form would require large machinery and still entail considerable crop losses. It is apparent that the form of the root system needs to be changed in order to have a plant type whose roots are so bunched that they can be lifted cheaply and with minimum of crop damage and loss. Our study has shown that considerable variation exists between different genotypes (cultivars) as well as within cultivars (non-heritable variation) in the radii of spread, depths of penetration, numbers and weights of roots per stand and the lengths of individual roots. Thus there is scope for genetic selection for root form and number.

It is hoped that this report will create interest among plant breeders in seeking to develop a plant type which will be suitable for mechanical harvesting. The studies suggest that a desirable type of cassava plant would be one with two well formed, carrot-like roots per plant. These two roots should be bunched closely together (i.e. spreading as little as possible laterally, and short and fat rather than deep.) It would be desirable to have more than eighty percent of the stored carbohydrate occurring within the top 15 cm of the root tubers. In addition, the above ground plant type should be small so it can be grown at a much higher population (10,000 to 12,000 plants/ha.). The stem and leaves should be easy to chop and shred before the roots are lifted.

These attributes should be combined with other desired characteristics such as low cyanide content, high tuber yield, high gari/starch ratio, etc. However, as Rogers and Appan⁵ have pointed out, the need to breed a new type of cassava plant should not interfere with the ability of cassava to produce a reasonable yield on marginal and submarginal land. The problems posed in trying to mechanize cassava production are many and varied, and a multi-disciplinary approach appears necessary to meet the challenge.

REFERENCES

1. Bates, W.N. 1963. *Mechanization of tropical crops*. Temple Press Books Lt. London. P. 272-3.
2. FAO. 1971. *FAO production yearbook*. Rome. pp. 116-20.
3. Krochmal, A. 1966. Labour input and mechanization of cassava. *World Crops* 18(3), 28-30.
4. Makenjuola, G.A., Onochie, B.E., Fapohunda, H.O. A study of some physical growth characteristics of cassava roots in relation to mechanical harvesting. (In press)
5. Rogers, D.J. and Appan, S.J. 1971. What is so great about cassava. *World Farming* 17(6), 14-15, 22.

TABLE 1

Variations in tuber weight, depth of penetration and radius of spread for individual roots of different cultivars of cassava

Cultivar	Mean tuber weight (gms)	Standard Devia- tion (gms)	Depth of Pene- tration (mm)	Standard Devia- tion (mm)	Radius of Spread (mm)	Standard Devia- tion (mm)
60447	1005.46	847.64	256.80	81.0	385.60	158.00
60444	549.65	435.41	204.00	45.0	375.20	457.00
44086	383.88	360.37	205.00	54.40	302.80	82.80
60506	755.30	765.91	224.00	226.80	369.80	134.40

TABLE 2

Variations in tuber length, neck and total root length for individual roots of different cultivars of cassava

Cultivar	Mean length of tuber (mm)	Standard Devia- tion (mm)	Mean length of neck (mm)	Standard Devia- tion (mm)	Mean length whole root (mm)	Standard Devia- tion (mm)
60447	341.63	16.89	28.19	1.23	369.82	6.98
60444	358.06	16.13	11.47	0.86	369.53	6.45
44086	254.00	9.35	25.15	1.49	279.15	4.60
60506	320.60	12.75	50.83	2.02	371.43	7.90

TABLE 3

Relationship between individual weight of each tuber (X), depth of penetration (Y) and radius of spread (Z) for four cultivars of cassava

Cultivar	Correlation Coefficient between			Linear Regression Equation (where correlation coefficient is significant)
	X & Y	X & Z	Y & Z	
60447	0.80**	0.68**	0.05	$X = 67.80Y + 320.07$ $X = 93.20Z - 409.32$
60444	0.1478	0.53**	0.23*	$X = 37.692 - 7.03$ $Y = 0.06 + 7.41$
44086	0.16	0.64**	0.53*	$X = 45.47Z - 62.64$ $Y = 0.35Z + 3.90$
60506	0.60**	0.38**	0.22*	$X = 268.22Y - 1639.81$ $X = 54.63Z - 40.02$ $Y = 0.07Z + 7.91$

* Denotes significance at 5% level

** Denotes significance at 1% level

TABLE 4

Relationship between individual root weight (X), length of tuber (L), neck (P) and total root length (L + P) of four cultivars of cassava

Cultivar	Correlation Coefficient Between			Linear Regression Equation (where correlation coefficient is significant)
	X & L	X & (L+P)	L & P	
60447	0.66**	0.61*	0.32**	$X = 85.12L - 139.40$ $X = 74.36(L+P) - 77.22$ $P = 0.06L + 0.30$
60444	0.55**	0.52**	0.05	$X = 37.78L + 16.95$ $X = 34.06(L+P) + 40.98$
44086	0.52**	0.37	0.61**	$X = 51.40L - 130.32$ $P = 0.25L - 1.59$
60506	0.56**	0.27*	0.01	$X = 84.48L - 223.36$ $X = 54.77(L+P) - 45.90$

* Denotes significance at 5% level

** Denotes significance at 1% level

TABLE 5

Variation in the mean tuber weight, depth of penetration, radius of spread and number of roots for individual plants within cultivars of cassava

Cultivar	Mean tuber weight per stand (gms)	Standard Devia- tion (gms)	Mean Depth of Penetration per stand (mm)	Standard Devia- tion (mm)	Mean Radius of spread (mm)	Standard Devia- tion (mm)	Mean Number of roots per stand	Standard Devia- tion
60447	7034.08	2720.14	25.58	6.40	41.81	9.47	6.75	2.05
60444	4259.75	1537.50	19.84	37.01	3.30	8.36	2.62	
44086	2175.33	734.00	19.46	3.79	25.48	5.21	6.44	2.35
60506	4729.07	2457.70	22.12	3.12	35.84	6.71	6.14	2.04

TABLE 6

Variation in mean tuber length/stand, tuber neck/stand and total tuber length per stand for individual plants within cultivars of cassava

Cultivar	Mean tuber length per stand (mm)	Standard Devia- tion (mm)	Mean total tuber neck lengths per stand (mm)	Standard Devia- tion (mm)	Mean total length per stand (mm)	Standard Devia- tion (mm)
60447	338.43	68.28	27.18	40.64	339.50	68.78
60444	357.12	46.74	47.75	83.31	359.50	48.51
44086	260.78	33.40	98.81	14.22	262.08	34.11
60506	317.63	57.61	50.29	20.57	322.10	130.02

TABLE 7

Relationship between weight of tubers per stand (X_2), mean depth of penetration (Y_2) and mean radius of spread (Z_2) for individual plants within each of four cultivars of cassava

Cultivar	Correlation Coefficient Between			Linear Regression Equation (where correlation coefficient is significant)
	X_2 and Y_2	X_2 and Z_2	Y_2 and Z_2	
60447	0.56*	0.23	0.31	$X = 238.79Y + 931.56$
60444	-0.03	0.96**	-0.32	$X = 444.93Z + 12206.24$
60506	0.60**	0.56*	0.51	$X = 469.45Y - 9956.73$ $X = 206.22Z - 2261.89$
44086	0.50*	0.99**	0.42	$X = 97.80Y + 272.43$ $X = 140.03Z - 1392.19$

* Denotes significance at 5% level

** Denotes significance at 1% level

FIG. 1: RADIUS OF SPREAD

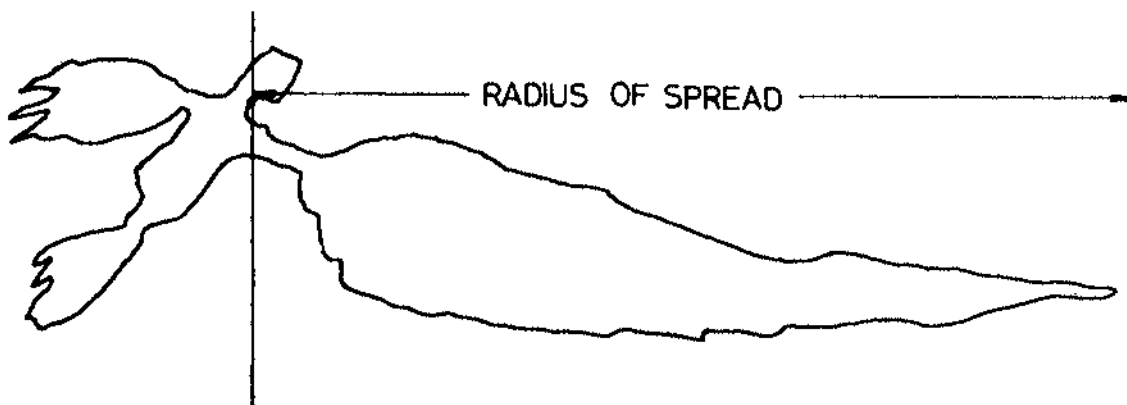
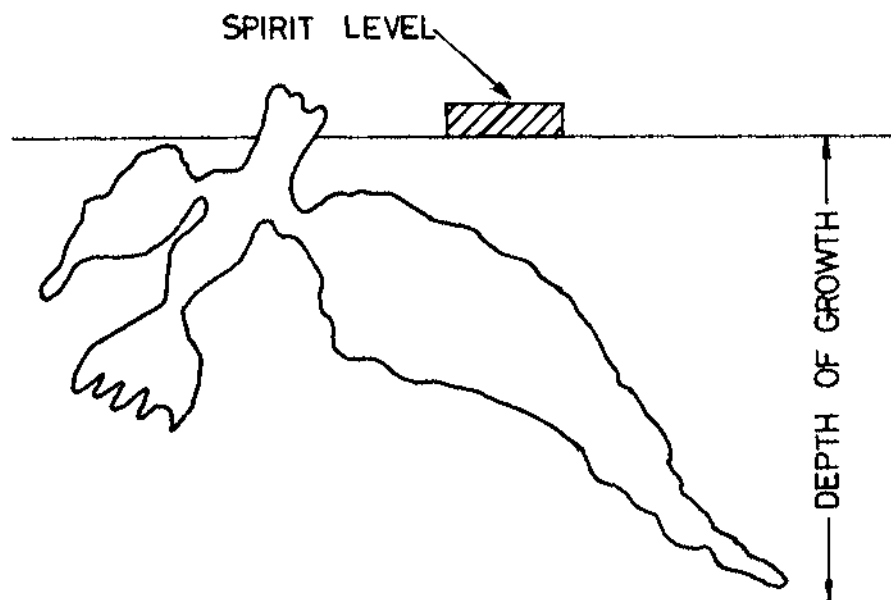


FIG. 2: DEPTH OF GROWTH



PRELIMINARY STUDIES ON THE MECHANICAL HARVESTING OF CASSAVA ROOTS IN NIGERIA

G.A. Makanjuola, B.E. Onochie and E.E. Shulte*

SUMMARY

A mould board plough and a ridger exposed respectively approximately 75 and 81 percent of the roots of cultivar 53101. With either implement, about 40 percent of the roots were damaged and some were buried by the overturned soil. The third method using a ploughshare resulted in less, though still considerable root damage.

RESUME

Une charrue à versoir et une billonneuse ont déterré respectivement 75 and 81 pour cent environ de racines du cultivar 53101. Dans chaque opération 40 pour cent environ des racines ont été endommagées et certaines enfouies dans le sol. L'incorporation de soc à la charrue a limité les dégâts, mais de façon très peu sensible.

RESUMEN

Un arado de vertedera y un bordeador expusieron respectivamente 75 y 81%, aproximadamente, de las raíces del cultivar 53101. Con cualquiera de los dos un 40% de las raíces sufrieron daños y algunas fueron enterradas con el suelo volteado por los implementos. El tercer método, utilizando un arado de doble vertedera dañó menos las raíces, si bien que este daño aún fué considerable.

INTRODUCTION

Production of cassava in Nigeria is entirely manual from stem cutting, planting and weeding to tuber harvesting. It has been estimated that digging up the tubers alone during harvesting accounts for over 40 percent of the total cost of production⁴.

There are three major problems involved in the mechanization of cassava root harvesting. These are:

1. The clearing of the above-ground parts of the plant.
2. Lifting and separation of the tubers from the soil with minimum damage.
3. Loading and transporting the tubers.

REVIEW

It is evident that, in the light of recent development in the processing and utilization of cassava tubers in Nigeria, peasant methods of production are inadequate to meet increasing food needs. Furthermore, labour is becoming more expensive, and if cost of production is to be kept to the minimum, mechanized cultivation and harvesting of cassava must be instituted.

Clearing the above-ground parts of the plant

At the time of harvest the vegetative growth above the ground weighs from 5 to 7 tons per hectare depending on cultivar and age. It is necessary to remove the top growth to make mechanical separation of the roots from soil and plant residue easier. Bates¹ suggested the use of a rotary saw or hedge trimmer for the operation of removing top growth. This equipment could be mounted in front of the tractor and powered by a separate engine, and a wide swath-board could be fitted to guide the cut stems clear of the row. Krochmal² suggested the use of a heavy shear in front of a tractor to push the tops down, and a rotary mower at the rear of the tractor to cut the felled tops into small pieces. The preliminary studies reported here tested the latter method which was considered the easier.

*G.A. Makanjuola, Department of Agricultural Engineering, Ife-Ife, Nigeria.
B.E. Onochie, Department of Plant Science }
E.E. Shulte, Department of Soil Science } University of Ife, Nigeria.

Lifting the tubers

For lifting, Krochmal² reported on the use of a mould board plough as an aid to hand harvesting. Bates¹ discussed the possibility of using a potato spinner, but suggested himself that it would not be suitable for harvesting cassava tubers. Bates also suggested that the potato digger-lifter or the sugar beet harvester might be unsuitable. He suggested that, if a deep digger harvester were to be developed, to penetrate possibly 40-45 cm, the machine would then probably be too heavy in draught. Bates concluded by observing that harvesting equipment of an entirely new design is probably needed, a view we support.

METHODS AND RESULTS

A rotary chain chopper was fixed at the back of the tractor and its level adjusted so that the cassava stems were cut to ground level. The chopping was effective, but the debris left on top of the ridges posed two problems.

1. It was difficult to find the ridges. Time and heavy rainfall (1500mm) had reduced the ridges to less than 15 cm high. The chopped residues obscured the ridges.
2. The mass of chopped material caused serious clogging of both the ridger and plough used in lifting the tubers.

The problems were more serious when the lifting was done on the same day the top growth was cut. When the cut materials were allowed to wilt for about 48 hours after the chopping, the clogging of the implements was less serious.

Three different implements were tested for lifting the tubers. These were a mould board ridger (30 cm bottom), a general purpose mould board plough (30 cm bottom), and a mould board plough with the board removed leaving only the share.

The mould board ridger was set so that it split the ridge below the centre of the crest. The result of the test showed that an average of 75 percent of the roots were exposed to an extent that they could be picked by hand. There were three main difficulties encountered with this trial. The first was the clogging of the space between the ridger body and ridger frame with plant residues, thus disturbing the flow of soil round the vertical stem holding the ridger body. Secondly, some of the tubers that were lifted by the ridger were reburied under the upturned soil. Thirdly, over 40 percent of the tubers were broken or damaged.

The second method was the use of a mould board plough. The board was set to move the ridge to the side. With this method 81 percent of the tubers were sufficiently exposed so that they could be hand-picked. By this method also many tubers were reburied by the overturned soil and there were many damaged tubers.

The third method was the use of the mould board share, which was 30 cm long and 4 cm high. With this implement 83 percent of the roots were exposed for hand picking. There was less root damage than with the ridger body or the mould board plough.

Although the implements described above exposed the tubers to some extent, they can only be looked upon as adjuncts to reduce the tedium of, and the time required for hand harvesting. A desired cassava harvesting machine is one which will not only expose the roots, but also separate them from the soil and possibly load them into a container in one operation. The functional parts of such a harvester should consist of

- (i) A topping device for cutting and removing the above ground vegetation as described earlier.
- (ii) A lifting device which not only lifts out the tubers irrespective of size, but does so with little or no breakage and with a minimum of power requirement.
- (iii) A cleaning device which will bulk the cleaned tubers into containers, thus simplifying the loading problem.

DISCUSSION

The morphological characteristics of tuber development, in addition to the other physical properties of the plant are factors which must be considered before a reliable, functional lifting device can be achieved. Onochie, Makanjuola and Schulte (this book) discuss this further.

REFERENCES

1. Bates, W.N. (1963) *Mechanization of tropical crops*. Temple Press Books Ltd., London. p. 272-3.
2. Krochmal, A. (1966) Labour input and mechanization of cassava. *World Crops* 18(3), 28-30.
3. Makanjuola, G.A., Onochie, B.E. & Fapohunda, H.O. A study of some of the physical growth characteristics of cassava roots in relation to mechanical harvesting.
4. Phillips, T.A. (1970) *An Agricultural Note Book*. Longmans Nigeria Ltd. p. 173-8.

MECHANIZATION OF TARO (*COLOCASIA ESCULENTA*) CULTURE IN HAWAII¹

D.L. Plucknett, H.C. Ezumah and R.S. de la Pena*

SUMMARY

A modified management system to allow mechanization of taro in Hawaii has been studied. A seedling transplanter has been used successfully to plant taro setts in dry soil. To achieve this the soils were prepared by using a rotovator without puddling. After planting, the fields were flooded and managed in the traditional way. Two mechanical means of herbicide application show promise. A sweet potato/solanum potato digger can be used to harvest the crop. To allow mechanization, the entire management system must be reviewed and modified.

RESUME

Un système de mise en valeur modifié en vue de la mécanisation du tarot en Hawaï a été exposé. Une repiqueuse a été utilisée avec succès pour repiquer des boutures de tarot en sol sec. Pour entreprendre l'opération, le sol a été préparé à l'aide d'un rotovator sans mise en boue. Après le semis, les champs ont été submergés et entretenus selon le système traditionnel de culture. Les moyens mécanisés d'application d'herbicide sont encourageants. On peut utiliser une récolteuse de patate douce pour faire la récolte du tarot. Pour que la mécanisation soit possible, tout le système de mise en valeur doit être revu et modifié.

RESUMEN

Se ha estudiado un sistema modificado de manejo para hacer posible la mecanización de la malanga en Hawaii. Se ha usado exitosamente un transplantador de plantas para sembrar malanga en suelos secos; para lograrlo, se prepararon los suelos con "rotovator" sin humedecer. Después de la siembra se inundó el campo y se trabajó en la forma tradicional. Dos formas mecánicas de aplicar herbicidas se muestran prometedoras. Puede usarse una cosechadora de camote/papa para cosechar este cultivo. Se debería de revizar y modificar todo el sistema de manejo para permitir la mecanización.

INTRODUCTION

Taro (*Colocasia esculenta*) is an important crop in Hawaii^{5,6}. Most of the corms are processed into poi, the paste-like staple food of the ancient Hawaiians. The crop is produced in flooded fields which are managed much like flooded rice (Fig. 1). Traditional taro production requires long hours of standing and working in mud and water. Therefore, in spite of the good income obtainable from growing taro, few young farmers are entering the industry. If taro production is to survive, the management system must, at least in part, be modified to mechanization. This work presented results from a grant by the State Legislature to the Hawaii Agricultural Experiment Station.

MECHANIZATION PROBLEMS IN FLOODED SOILS

Most mechanization problems are related to the practice of growing taro in small flooded fields⁷. Throughout most of the crop period the soil surface is covered with 2 to 10 cm of slowly moving water. Traditional land preparation consists of ploughing or harrowing and then puddling of the soil. The cuttings or setts (consisting of about 6 to 12 mm of the tip of the corm plus the lower 20 to 30 cm of the petioles) are then planted by hand in the soft mud. Plant populations range from about 12,000/ha (90 x 90 cm spacing) under high solar radiation. Weeds are controlled mainly by flooding and by hand pulling. Crop duration varies from 12 to 16 months or so. Harvesting is done by hand, using a pipe with a sharpened tip to loosen and pry the corms from the soil and to sever roots. Mud is washed from the corms which are separated from petioles and leaves, and the corms are then bagged for shipment to the processing plant.

The main hand labour requirements for taro culture occur during planting, weed control and harvesting. Of these tasks perhaps harvesting is most onerous and difficult. In our programme it was decided to examine mechanization possibilities in planting, weed control and harvesting.

1. Journal Series No. 1693 of the Hawaii Agricultural Experiment Station.

* D.L. Plucknett)
H.C. Ezumah) University of Hawaii, Department of Agronomy and Soil Science, Honolulu, Hawaii 96822.
R.S. de la Pena)

The major problem in mechanizing a flooded crop is obtaining 'trafficability' for the machines. Management studies to determine the effects of modifications in methods of irrigation, spacing and land preparation to allow machinery traffic have been conducted.² From these studies a modified management system for the crop was designed in order to obtain high yields while at the same time allowing mechanization. The studies showed that flood irrigation produced best taro growth and yields and that 90 cm row spacings could be used without loss in yield.

Trafficability depends upon how muddy the soil surface is. Under very muddy conditions most machines cannot obtain traction and may sink in the soft mud. Also, very close row spacings will not allow enough room for tractor wheels or tracks. An early question then arose: could we eliminate puddling of the soil? If so, could we then prepare the soil under relatively dry conditions, thereby allowing conventional tillage practices? One problem remained in this system: if we ploughed or disked the soil surface we could develop an uneven soil surface which would then need to be re-levelled. The solution, we believe, is to use a rotovator to prepare the soil; this machine can till fairly dry soil without leaving an uneven surface. After rotovating it would then be easy to use machines for planting and then to flood and manage the rest of the crop in the usual way.

MECHANICAL PLANTING OF TARO

We have purchased and tested one planting machine, a machine designed to transplant seedlings of tobacco or tomatoes.* This machine works well in fairly dry soil and required little modification to plant taro³. The major modification was to widen the furrow opener a little in order to handle large setts. The 3-point hitch transplanter has the following features: a furrow opener, two plant boxes in which the setts are carried, two seats for the men feeding the setts into the machine, pick-up trays upon which the plants are placed and a planting wheel which picks up the plants and releases them just behind the furrow opener and adjustable packing wheels.

The transplanter was tested for use in taro (Fig. 2). It was necessary to increase row width to 122 cm to allow use of the tractor without driving over previously planted rows. Plants were spaced 30 cm apart. The soil had been rotovated. Comparisons with hand planting showed that mechanical planting using two men to feed setts into the machine plus one tractor operator saved 59% of the time required to plant by hand in non-ridged plots (Table 1). When planted on ridges 62-68% of the hand planting labour requirement was saved by mechanical planting. The machine planted with few skips and achieved reasonably good spacing. The desired within-row spacing was 30 cm; the machine planted within a range of 27.5 to 37.5 cm, with a mean of 32.5 cm. It was concluded that the soil must be well prepared and well pulverized for best use of the transplanter. Under dry soil conditions the transplanter appears to be satisfactory for planting taro. Planting on ridges was not very successful since the ridges tend to be flattened during planting. If planting on ridges is desired, then we feel that it would be better to plant on a flat surface and then 'hill up' afterwards. Flooding after mechanical planting produced good crop growth (Fig. 3).

MECHANICAL AIDS FOR WEED CONTROL IN TARO

Until the present time nitrofen is the only herbicide which has been cleared by the U.S. Environmental Protection Agency for use in taro. However, several other herbicides have appeared to be promising and would work well if clearances can be obtained⁵.

Nitrofen works well for weed control in flooded taro when it is injected into the irrigation water which flows into the paddy¹. To ensure thorough and uniform coverage by the herbicide, an injection pump was constructed and calibrated to inject a known amount of herbicide into irrigation water. The water was pumped into a previously-drained paddy which had all outlets blocked to prevent drainage of the herbicide solution. This system provided excellent pre-emergence application of herbicides without spray injury to the vigorous, leafy, growing crop.

Another aid to weed control is still under study. A single row shielded sprayer* for application of post-emergence herbicides was purchased. This should be especially useful for upland or rainfed taro.

MECHANICAL HARVESTING

Taro yields under flooded culture can be very high⁶. The Hawaii state average in 1969 was 22.4 metric tons per ha. Some farmers obtain yields of 35 to 45 metric tons per ha. Harvesting and handling such yields in soft, deep mud can be difficult and tiring, and it is in this activity that real gains for the industry could be made if a successful mechanization system can be obtained.

*This machine was built by the Powell Manufacturing Co., Inc. Company or model names are used for the purpose of identification, and no endorsement to the exclusion of other similar equipment is intended.

Mechanical harvesting in the mud is most difficult, and it calls for light and specialized equipment. A commercial firm in Honolulu** has devised a twin horizontal auger attachment for a small Japanese rice paddy tractor as a harvesting aid in taro. This machine digs and windrows two rows of closely planted taro in standing water or mud. While this has been a major step in overcoming the labour requirement for loosening and digging the crop by hand, it also causes difficulty in gathering the loosened corms. In loosening and windrowing, this machine also mixed much mud with the corms, making pickup and cleaning of the corms very difficult. In order to assist in this problem our Department of Agricultural Engineering has designed a machine which can pick up the loosened corms from the windrow⁸. This system will require further study.

Our research group undertook the task of studying existing root crop machinery which might be used to harvest taro under fairly dry soil conditions. We purchased a commercial singlerow sweet potato/solanum potato harvester*** (Fig. 4). This 3-point hitch machine can be mounted on a conventional pneumatic-tyred or tracked farm tractor. It is equipped with a digging blade behind which is mounted an agitator chain to clean the roots before dropping them on the soil surface. The machine digs taro without difficulty in dry soils. In wet soils, however, problems arise which are related to movement of the tractor.

Ikehara and Hiroshige⁴ compiled data on the labour requirements in taro production. They found that harvesting one hectare of taro under puddled flooded culture required about 850 man-hours.

A study was conducted using the commercial single-row sweet potato harvester in taro. Three large taro fields were subdivided into 26m x 16m plots. The three plots were treated as follows:

Plot A : ridges and land intermittently flooded. Flooding interval was under a week.

Plot B : ridged and flooded throughout growing season. The field was then drained six weeks before harvesting of corms.

Plot C : nonridged (flat); field flooded throughout experimental period. The field was also drained for six weeks before harvesting. The spacing used was 1.3m x 0.3m.

Time taken to harvest taro corms (digging and collection of corms) was recorded for each of the three sub-plots per field (A, B and C). Corm yields were generally low. Large portions of the field were attacked by *Phytophthora colocasiae* and incidence of *Pythium* corm rot was high. The poorest yield was obtained from the intermittently flooded plot, while continuously flooded plots, whether ridged or not, gave almost identical yields.

An average of 186 hours per hectare was required to harvest the flat, continuously flooded plot, while 139 and 122 hours per hectare were required for the intermittently flooded ridged and continuously flooded ridged plots, respectively. By using the harvester, only 14 to 22 percent of the time needed to harvest one hectare by hand was required (Table 2). The results indicated that ridging provided some advantages in mechanized harvesting.

We believe that this digging machine can be used satisfactorily if the soil is allowed to dry enough to allow tractor movement in the field. In one test in a flooded field using a small tractor equipped with tracks as the prime mover for this digging machine, we concluded that the machine worked well enough to justify mounting of the digger at the side of the tractor to permit harvesting of single rows without running over the rows. However, this modification has not been made.

FUTURE RESEARCH

Current plans call for study and refinement of the complete mechanization system. Fields must be prepared by rotovation, followed by mechanical planting. Row spacings will be wide (probably 120 cm or so) in order to accommodate the tractor. Some plots will be ridged in order to evaluate the effect of planting on ridges to facilitate harvesting. To obtain good yields, flooding or deep furrow irrigation will be used. Weed control will be effected through injection of herbicides in shielded, single-row sprayers. As harvest time approaches, irrigation will be terminated in order to dry the soil enough for tractor use. We believe that this system will be useful for those farmers whose soils will dry sufficiently to allow machinery movement.

*. 'Uniro' Chemical Weeder, Allman Patents Ltd., Sussex, U.K.

** Rainbow Distributors, representing Iskeki Equipment Co., Japan.

*** Darf one row potato digger, Darf Corp., Edison, N.C., U.S.A.

REFERENCES

1. de la Pena, R.S., Plucknett, D.L. and Shibao, G.H. (1973) Application of herbicides through irrigation water for weed control in lowland taro (*Colocasia esculenta*). Proc. 3rd Asian Pacific Weed Sci. Conf. (Malaysia), May 1971. Vol. 2, 332-4.
2. Ezumah, H.C. (1973) The growth and development of taro, *Colocasia esculenta* (L.) Schott, in relation to selected management practices. Ph.D. Dissertation, University of Hawaii, Honolulu.
3. Ezumah, H.C. and Plucknett, D.L. Mechanical planting of taro. *Hawaii Farm Sci.*
4. Ikehara, D. and Hiroshige, H. (1967) Costs to produce taro. Coop. Ext. Serv. Univ. Hawaii (mimeo) 2 pp.
5. Plucknett, D.L. and de la Pena, R.S. Taro weed control. *Hawaii Farm Sci.*
6. Plucknett, D.L. and de la Pena, R.S. (1971) Taro production in Hawaii. *World Crops* 23, 244-9.
7. Plucknett, D.L., de la Pena, R.S. and Obrero, F. (1970) Taro (*Colocasia esculenta*). *Field Crop Abs.* 23, 413-26.
8. Smith, M.R. and Shen, H. (1972) Pick up mechanism for harvesting wetland taro. Transactions of the American Society of Agricultural Engineers. 15(6), 1005-9.

TABLE 1
Man hours of labour required to plant one hectare of taro

Treatment	M e c h a n i c a l l y p l a n t e d				
	Planting by hand hours	Ridged hours	Over hand planting %	Flat (non- ridged) hours	Time saved over hand planting %
Ridged, flooded weekly	65.1	22.3	65.8	20.4	68.6
Ridged continually flooded	52.7	23.2	55.9	20.1	61.8
Flat (non-ridged) continually flooded	46.3	24.0	48.3	19.0	59.0
Average	54.7	23.1	56.6	63.1	63.1

TABLE 2
Yield and time required to harvest 1 hectare of taro using mechanical harvesting equipment

Field	Plot	Yield tons/ha	% of hand harvest*	Time (hrs/ha)
A (Ridged flooded weekly)	1	16.03		86
	2	17.03		159
	3	22.40		172
Average		18.49	16.3	139
B (Ridged contin- uously flooded)	1	36.02		77
	2	23.87		156
	3	31.81		133
Average		30.57	14.3	122
C (Flat continuously flooded)	1	22.60		176
	2	27.68		189
	3	37.05		193
Average		29.10	21.9	186

*Based on 851 man-hours per ha. requirement reported by Ikehara and Hiroshige⁴.

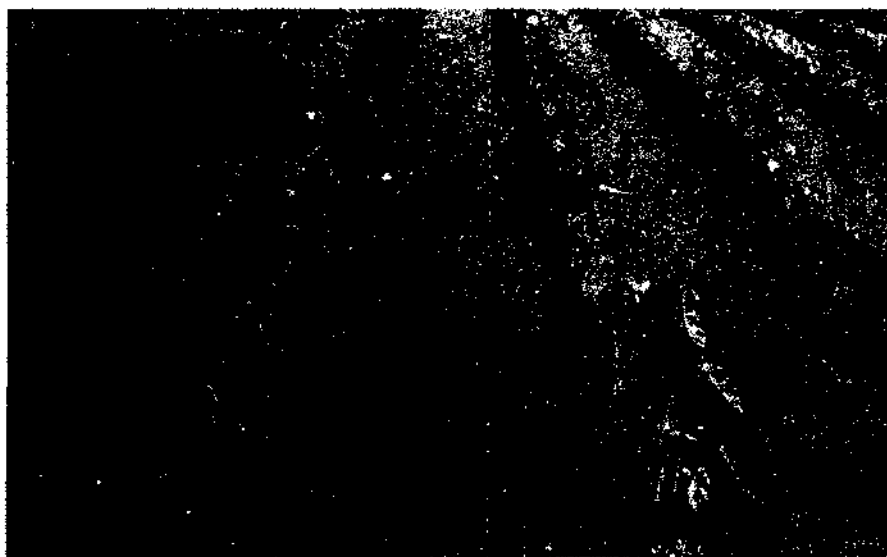
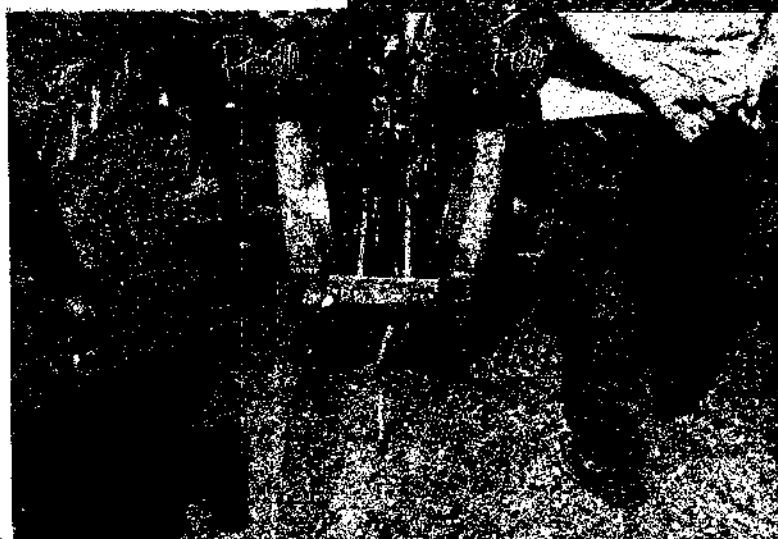


Figure 1. A taro farm on the island of Kauai. Most fields are irregular in shape and are bordered by earthen-dikes about 50-70 cm in height. Two flooded but unplanted fields can be seen on the right side.



a.



b.

Figure 2. Planting taro setts (huli) mechanically
 (a) Machine requires 3 men; 1 tractor operator and 2 men to place the setts on the pickup tray.
 (b) Close up view of the planter from the rear. Planting wheel is just in front of the twin soil-packing wheels shown at the rear.



Figure 3. This field was planted mechanically using the seedling transplanter. Row spacing was 122 cm. Spacing between plants was 30 cm. The setts were planted on ridges. After planting the field was kept flooded until harvest. At that time the soil was allowed to dry out and the crop was harvested mechanically using the potato digging machine.

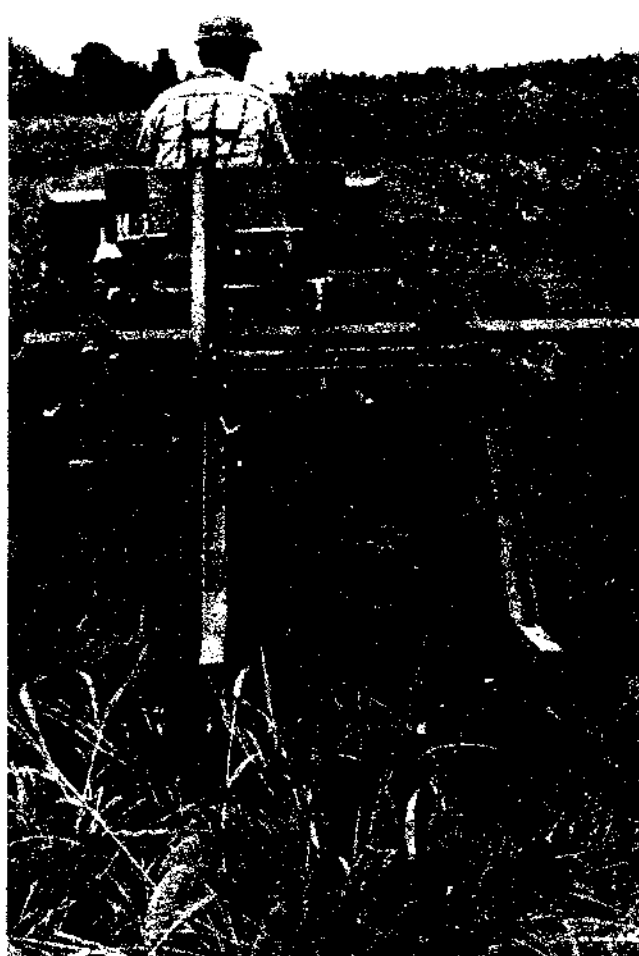


Figure 4. A solanum/sweet potato digger which is being studied to harvest taro under fairly dry soil conditions. The corms are left on the soil surface, and must be picked up by hand or by mechanical means.

EFFECT OF METHOD OF SEED BED PREPARATION, MULCHING AND TIME OF PLANTING ON YAM IN WESTERN NIGERIA

R. Lai and S.K. Hahn*

SUMMARY

Mulching of yam seed beds reduced soil temperature and improved emergence, time of emergence, yield per hill and the total yield of *Dioscorea rotundata* yams on a sandy soil in Western Nigeria. Comparison of mounds with ridged and flat seed beds showed that these different treatments had no significant effect on tuber yield. Planting about six weeks before the onset of the rains and the use of mulch is indicated as a good technique to obtain high yield.

RESUME

L'utilisation de paillis dans les lits de plantation réduit la température du sol et favorise la levée, le temps d'émergence, le rendement par poquet et le rendement global des ignames *Dioscorea rotundata* lorsqu'elles sont cultivées en sol sablonneux à l'Ouest du Nigéria. Lorsque la comparaison a été faite entre la culture en buttes et en lits de semis non élevés, les résultats ont montré que la différence de rendement en tubercules est peu sensible, qu'il s'agisse de l'une ou de l'autre méthode. La plantation six semaines avant le début des pluies et l'utilisation de paillis permettent d'obtenir un rendement élevé.

RESUMEN

El cubrimiento de almacigos de ñame redujo la temperatura del suelo y mejoró la emergencia, el tiempo de emergencia, rendimiento por cepa y rendimiento total de ñame, *Dioscorea rotundata*, en un suelo arenoso de Nigeria Occidental. La comparación de camas con almacigos alomados o planos demostró que no hay diferencia entre ninguno de estos tratamientos en cuanto al rendimiento de tubérculos. La siembra, cerca de 6 semanas antes del establecimiento de las lluvias y el uso de cobertura, se indica como una buena técnica para obtener altos rendimientos.

INTRODUCTION

Yam cultivation in West Africa extends from the central Ivory Coast to the Cameroon mountains, in both the forest zone and the southern parts of the savannah^{1,9}. Annual production in West Africa is about 31 million metric tons, or two-thirds of the total world production.

Yams require about 8 months from planting to maturity, and need, depending on soil conditions, 1500 to 1800 mm of rain during the growing period⁶. They have a shallow root system. In Western Nigeria, where the dry season occurs from November until March, 'early planting' is generally done during the period from November to February. It has been shown that yams planted from November to January give 30 percent higher yield than those planted at the onset of rains¹³.

Yams are often planted on mounds. The size of the mounds depend primarily on soil depth and the depth of the water table¹³. On sandy soils however planting is generally on flat beds¹¹. Planting of yams in trenches has been shown to be of advantage for shallow and stony soils^{8,14}. Experiments conducted at Wenchi and Ejura in Ghana showed that yams grown on ridges yielded more than those grown on mounds¹⁰. In Puerto Rico planting on raised beds increased the yield.

Farmers of West Africa traditionally place a 'cap' of dried straw on the mounds over newly planted setts¹². Previous experiments in Ghana showed a favourable effect of mulching on yam production particularly in the savannah zone^{2,4}. In Nigeria, mulching improved emergence by 50 percent and the overall yield by 3.75 tons per hectare. Mulching immediately after planting as compared with mulching at a later date was advantageous. Soil temperature measurements taken at 2 p.m. showed temperatures of 37.5 and 40°C. respectively for mulched and unmulched plots¹³. Mulching has been proved beneficial for both late and early yam plantings.⁵

*International Institute of Tropical Agriculture, Ibadan.

MATERIALS AND METHODS

A factorial experiment, involving three methods of seed bed preparation, two levels of mulching and three times of planting, was conducted at the International Institute of Tropical Agriculture (IITA). IITA is located about 30 km south of the northern limit of the lowland rain forest. Rainfall distribution is bimodal in Western Nigeria, with rains from April to July and from August to November. The experiment was conducted during 1971-72 on soil of Egbeda association derived from basement complex rocks. The soil has a sandy surface and a layer of angular and sub-angular quartz gravels in the horizon immediately below the surface horizon and below this a deep, red clay profile.

Three different kinds of seed beds, 10 x 2 m, were prepared from a disced field as follows: (1) flat, natural level surface, (2) mounds or hillocks 50 cm high and about 150 cm in the base circumference formed by scraping up the surface soil, and (3) ridges, about 30 cm high made across the slope at a spacing of 75 cm.

Mulching with rice straw at a rate of 4 tons per hectare was compared with no mulching. There were two planting dates before the onset of the rains (October 30, 1971 and February 1, 1972) and one at the start of the rainy season (April 15, 1972).

Two setts of the local cultivar 'Fele' of approximately 50 g weight were planted 10 cm below the soil surface at each mound. For flat and ridged seed beds single setts were planted at 50 cm intervals within the row. Twenty setts were planted in each plot. The experimental design was a randomized block with four replications.

Soil temperature was measured at 5 and 20 cm depth at 7.30 a.m. and 2.30 p.m. in one replication for each treatment. The emergence count and the time of emergence were recorded for all plots individual treatments. Staking of the vines was done one week after emergence. Yams planted on October 30, 1971 were harvested on September 30, 1972 and the two later plantings were harvested on November 1, 1972. Tuber weight and number of tubers per plant and the total yield per plot were determined for each plot.

RESULTS AND DISCUSSION

A. Soil temperature

Methods of seed bed preparation and mulching had a clear effect on soil temperature (Figures 1 and 2). The highest temperature was recorded for ridges and mounds. Ridge mulching decreased the soil temperature between 5 and 13.5°C at 2.30 p.m. for 5 cm depth at various times during the growing season. Diurnal fluctuations in soil temperature at 5— and 20— cm depth were also highest for heaps and ridges being in the order of 15 to 18°C. Mulching on flat beds not only gave the lowest maximum temperatures throughout the growing season but also reduced the diurnal temperature fluctuation.

B. Emergence

There was a significant effect of time of planting, mulching and methods of seed bed preparation on emergence (Fig. 3). Poor emergence for the early planting on October 30 may be due to high soil temperature and dry soil conditions. Planting on the flat seed bed with mulching gave the highest emergence for the early planting. Emergence on unmulched plots was extremely poor for the first planting, irrespective of the methods of seed bed preparation. Due to more favourable soil moisture and temperature, emergence for the second and third planting was higher than that of the first planting. Mulching significantly improved yam emergence, not only for all the methods of seed bed preparation, but also for all planting dates. With flat planting, for instance, mulching improved emergence by 73.5, 78.0 and 36.5 percent for the first, second and third planting respectively. Planting on the unmulched heaps and ridges for early planting was a total failure.

Time of emergence was also significantly affected by methods of seed bed preparation and mulching (Table 1). Emergence, in general, was the quickest for plantings on the flat. Early planting gave the slowest emergence (due to the high soil temperature and drought) (Fig. 4). Mulching reduced the time to emergence for all the methods of seed bed preparation and dates of plantings (Table 1, Figs. 5, 6).

C. Yield and yield parameters

Tuber size:

Time of planting and mulching had a significant effect on tuber size (Fig. 7). The longer the growing period, the larger the tuber size. Methods of seed bed preparation under these experimental conditions did not have a significant effect on tuber size, though planting on flat generally produced smaller tubers compared to plantings on ridge or mound. Mulching significantly affected tuber size for all the three plantings, and hence soil temperature seems to play the dominant role in determining the tuber size.

Figure 1. Effect of Mulching and Seed Bed preparation on soil temperature at 5 cm depth.

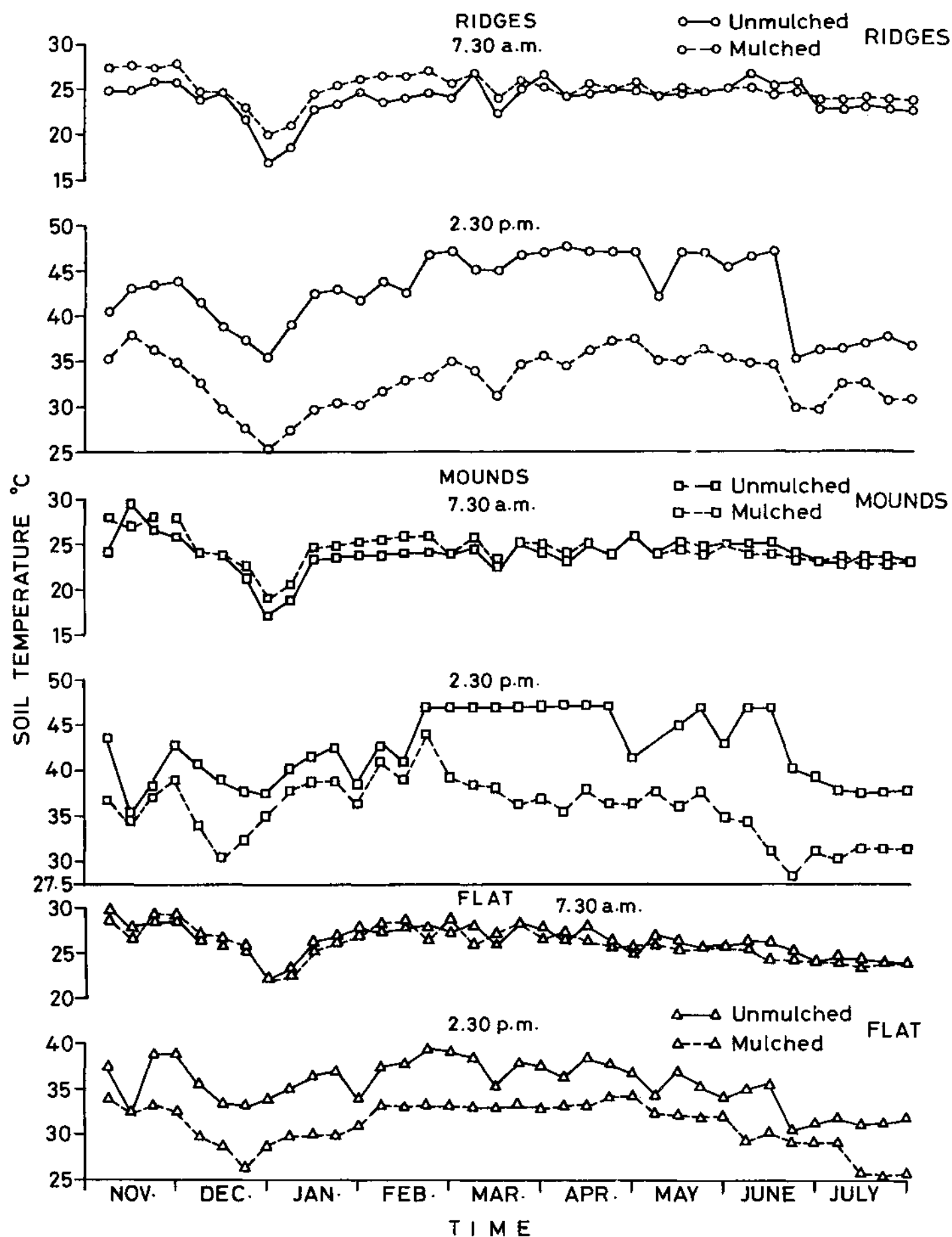


Figure 2. Effect of Mulching and Seed Bed preparation on soil temperature at 20 cm depth.

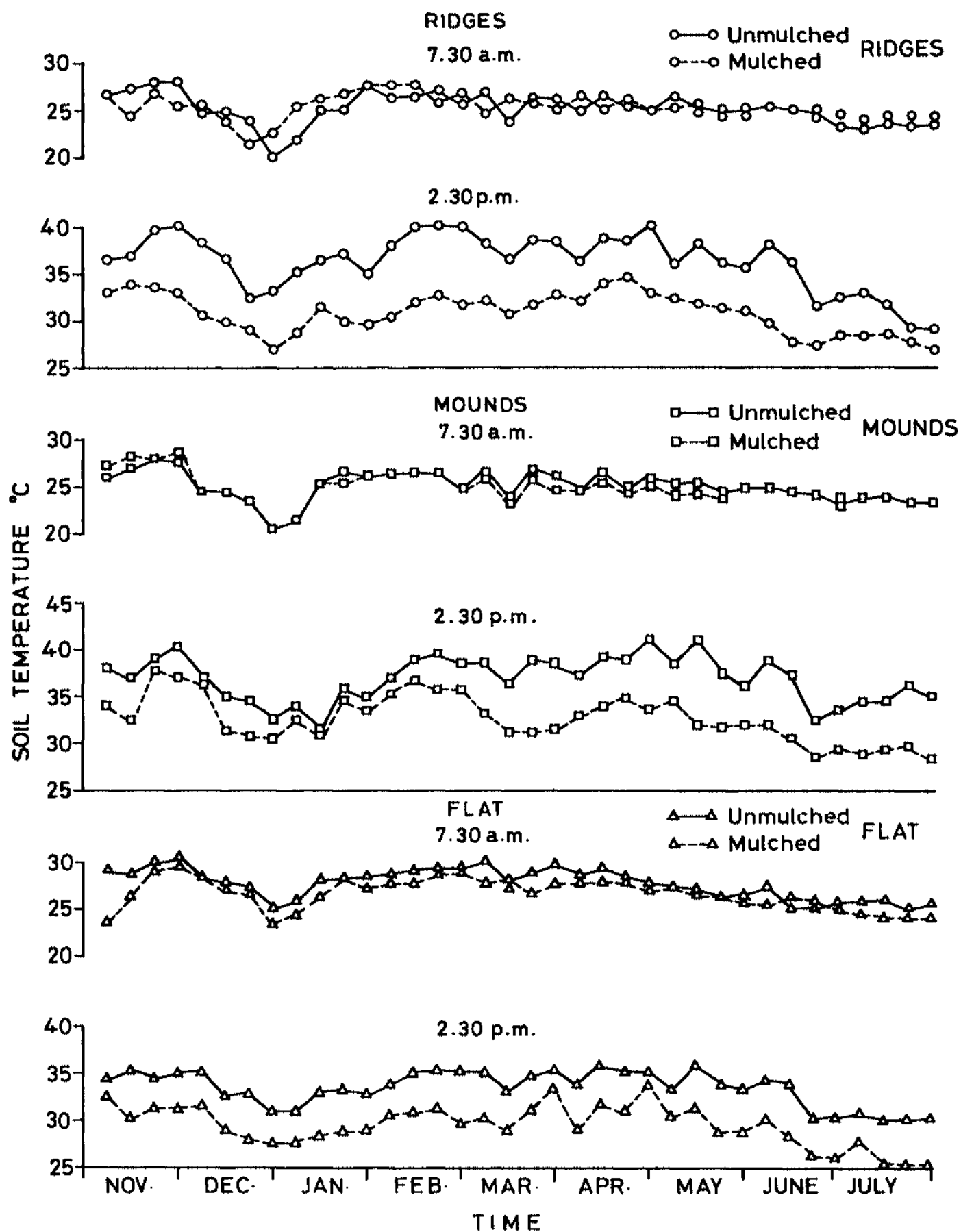
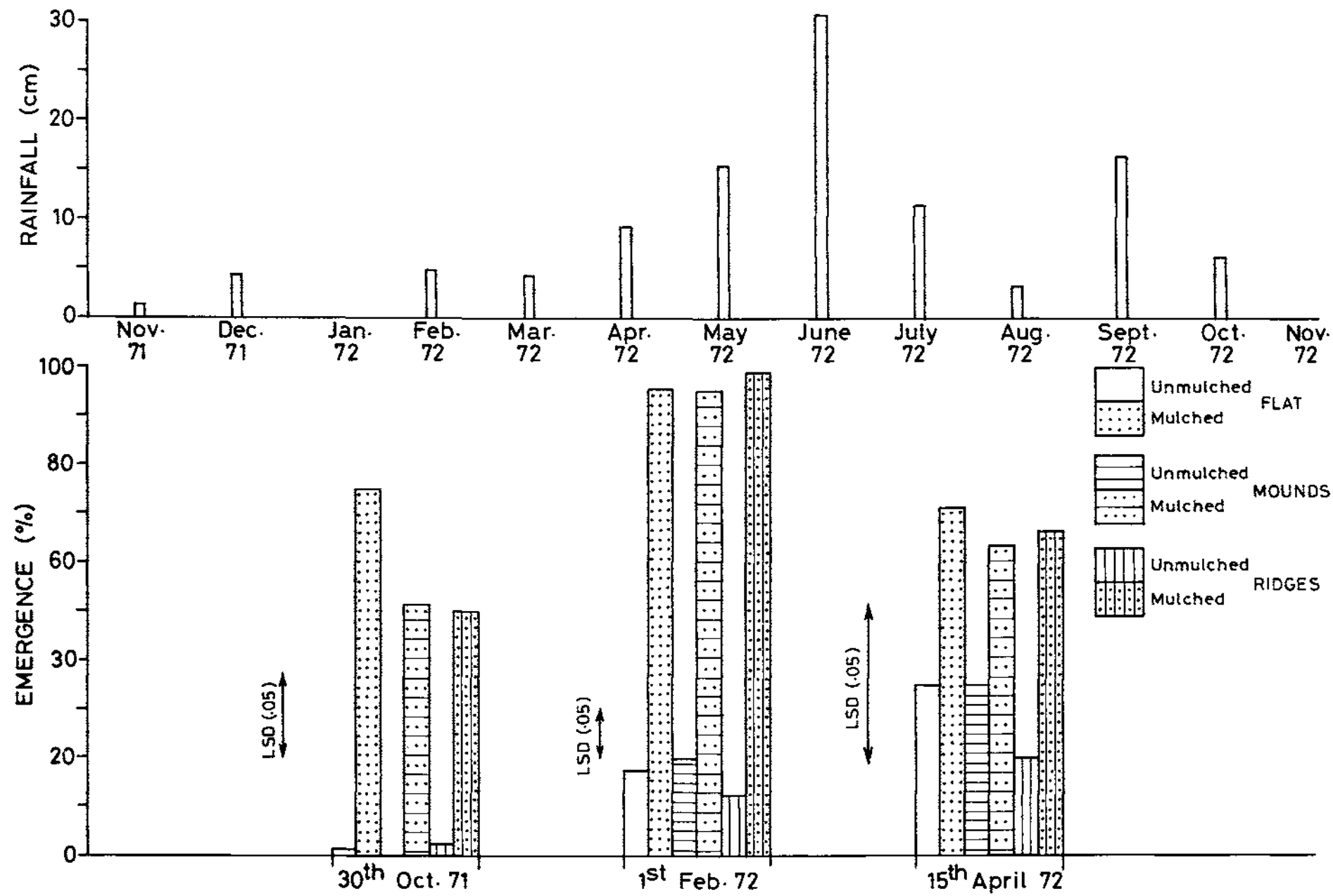


Figure 3. Effect of time of planting, mulching and seed bed preparation on emergence.



Yield per hill:

Yield per hill was also the highest for the early planting and mulching significantly improved the yield per hill for all three plantings (Fig. 8) There was an eight-fold increase in yield by mulching on flat for the early plantings as compared to a total failure for unmulched heaps and ridges. Statistical analyses of the data for the number of tubers per hill also indicated a significantly favourable effect of mulching.

Total yield per plot:

The highest yield was obtained for the February and the lowest for the April planting (Fig. 9). The yield for the flat mulched plots was equivalent to 31.6, 41.6 and 8.4 tons per hectare for the plantings on October 30, February 1 and April 15 respectively. While there was no yield for the unmulched heaps and ridges for October planting, favourable soil temperature and moisture regime produced some yield, though small, for the two later unmulched plantings.

Mulching had a highly significant effect on total yield, irrespective of methods of seed bed preparation and time of planting (Table 2). Methods of seed bed preparation *per se* had no effect on total yield.

REFERENCES

1. Agboola, S.A. (1968) The traditional significance of yam in Yorubaland in pre-colonial times. *Niger. Agric. J.* 5, 59-62.
2. Anon. (1954) Report of the Ministry of Agriculture, Ghana, 1953-54.
3. Anon. (1955) Report of the Ministry of Agriculture, Ghana, 1954-55.
4. Baker, E.F. (1962) Rep. Crop Husb. Res. Sect. Minist. Agric. Nat. Resourc. W. Nigeria 1961-2.
5. Campbell, J.S. *et al.* (1962) Recent developments in the production of food crops in Trinidad. *Trop. Agr. Trin.* 39, 261-70.
6. Costas, R.C., *et al.* (1968) Effect of various cultural practices in yields of yams in Puerto Rico. *J. Agric. Univ. P. Rico.* 52, 356-61.
7. Coursey, D.G. (1967) *Yams*. Longman, London.
8. Coursey, D.G. (1971) The history and the possible future of yam cultivation in West Africa. Seminar Root and Tuber Crops in West Africa. IITA, Ibadan, February 22-26, 1971.
9. Doku, E.V. (1970) Root crops in Ghana, *Ghana J. Sci.* 6, 15-36.
10. Morgan, W.B. (1955) Farming practice, settlement pattern and population density in southeastern Nigeria. *Geogr. J.* 121, 138-50.
11. Owusu, P.M. *et al.* (1969) Yam farming in Ghana. *Ghana Fms.* 13, 132-5.
12. Torto, J.O. (1956) The cultivation of yams in the Goldcoast. *New Goldcoast Fms.* 1, 6-8.
13. Waitt, A.W. (1960) Yam trials. Fed. Dep. Agric. Res. Nigeria 1958-9. 13-14.
14. — — — — — (1963) Yams, *Dioscorea* species. *Field Crop Abst.* 16, 145-57.

Figure 4. Effect of seed bed preparation and mulching on rate of emergence for planting on October 30, 1971.

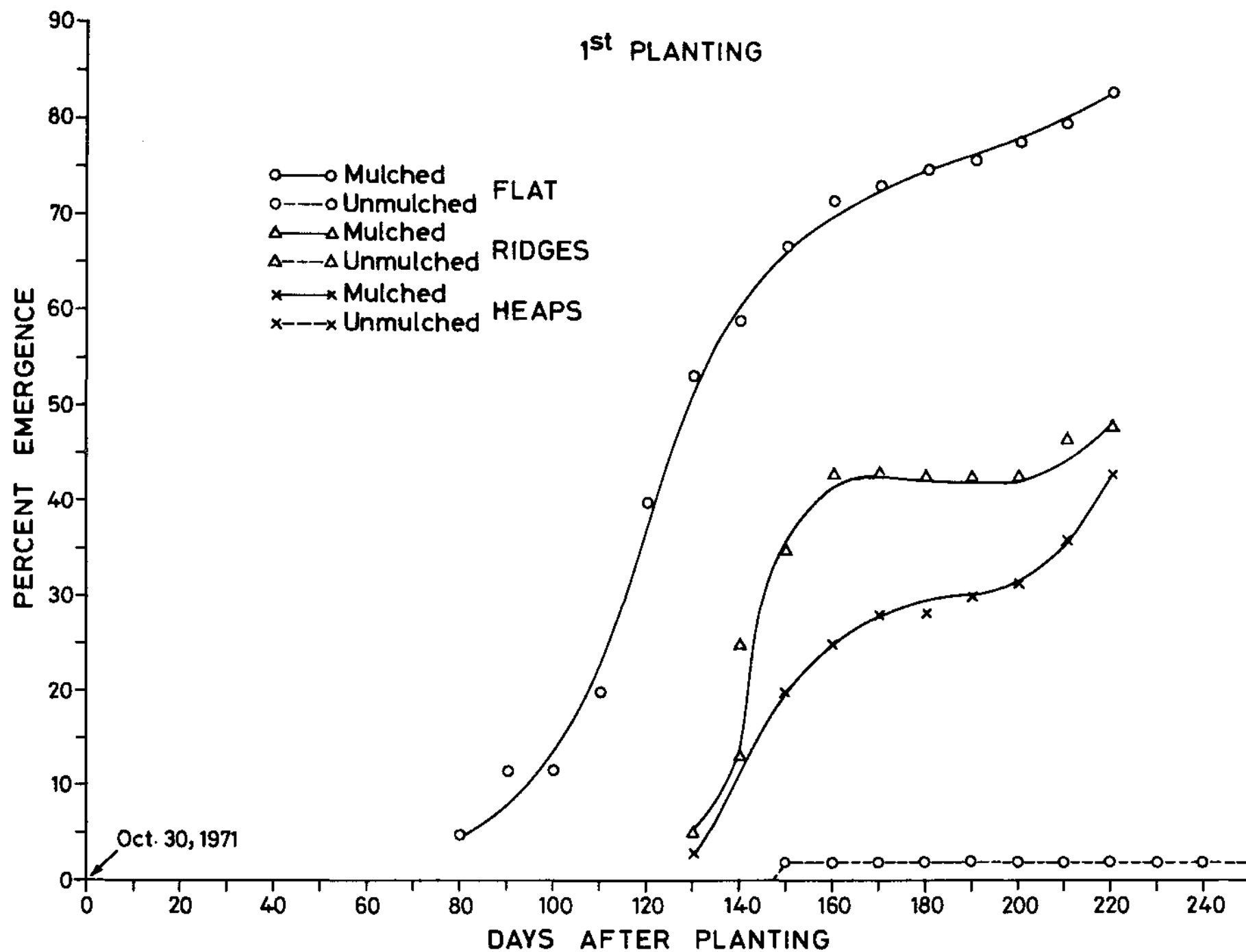


Figure 5. Effect of seed bed preparation and mulching on rate of emergence for planting on February 1, 1972.

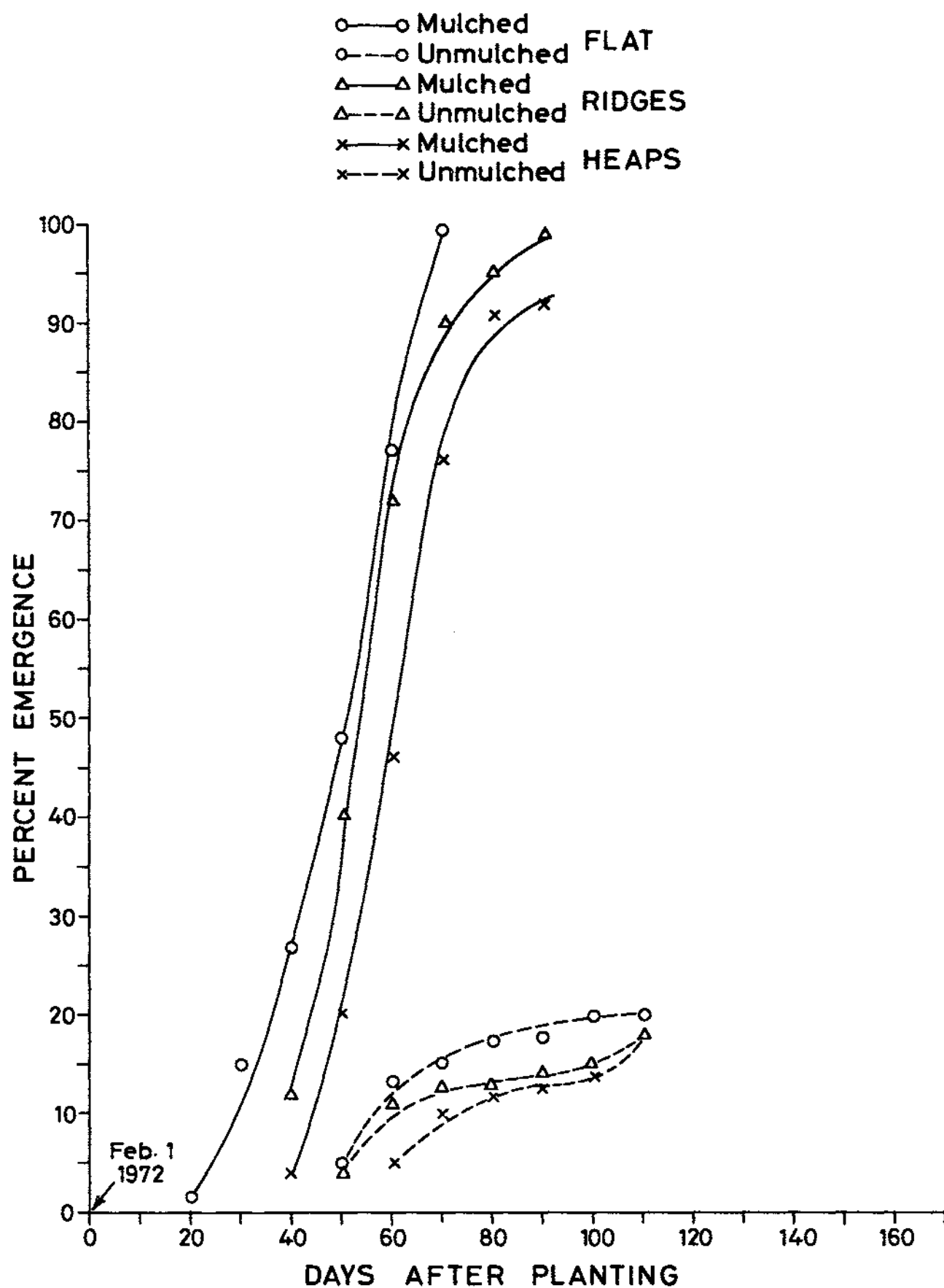


Figure 6. Effect of seed bed preparation and mulching on rate of emergence for planting on April 15, 1972.

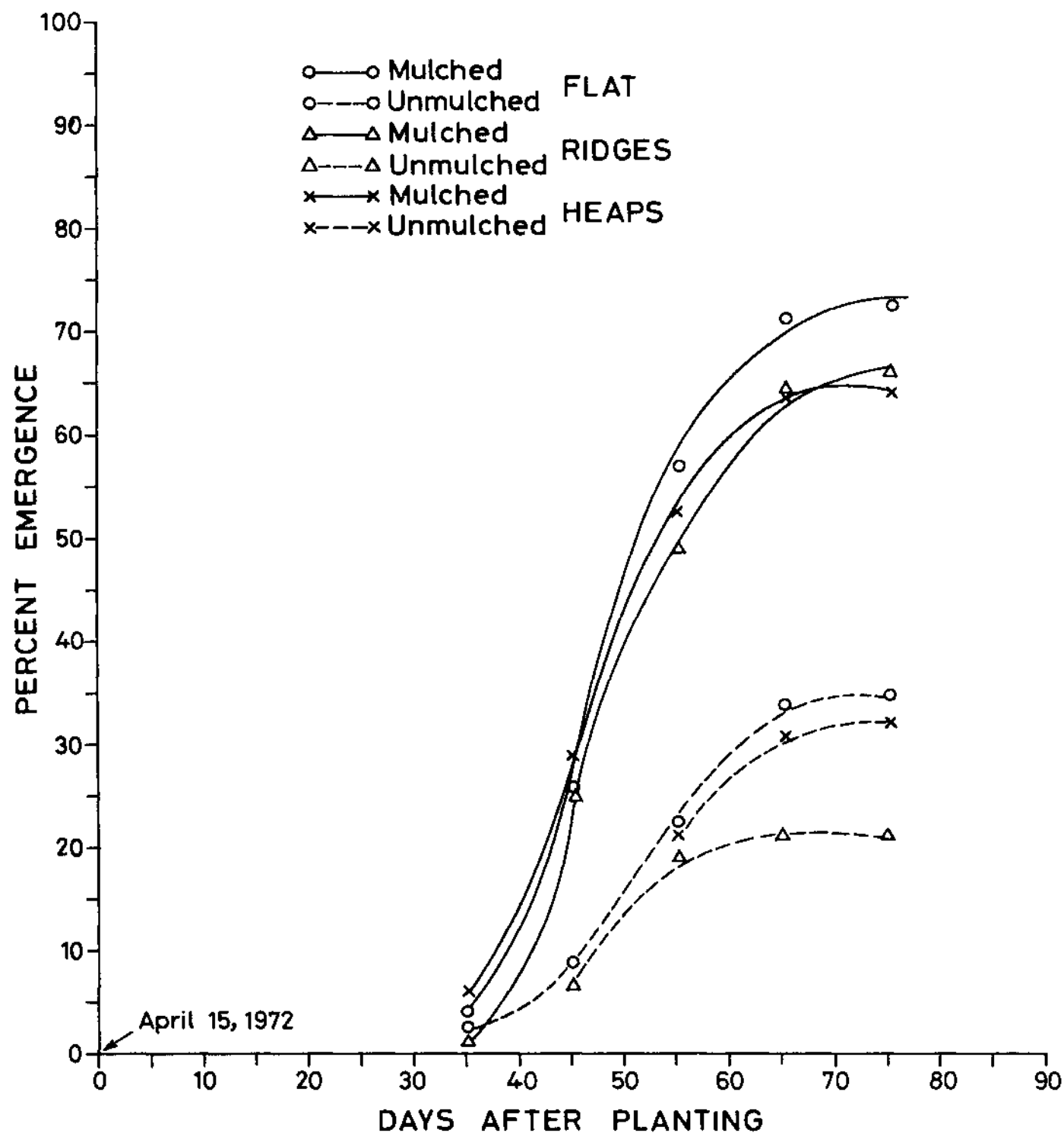


Figure 7. Tuber size as affected by seed bed preparation, mulching and time of planting

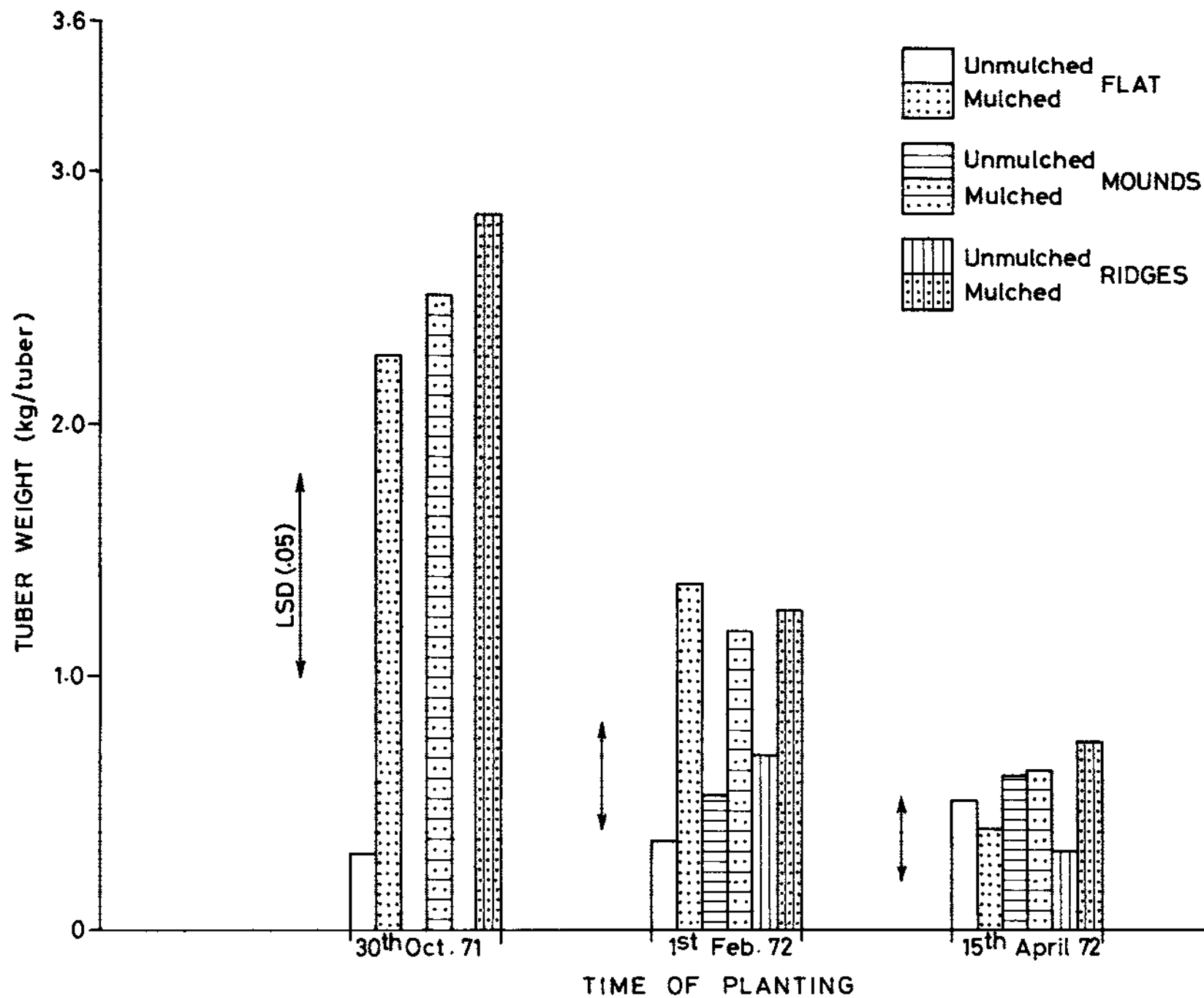


Figure 8. Yield per hill as affected by seed bed preparation, mulching and time of planting.

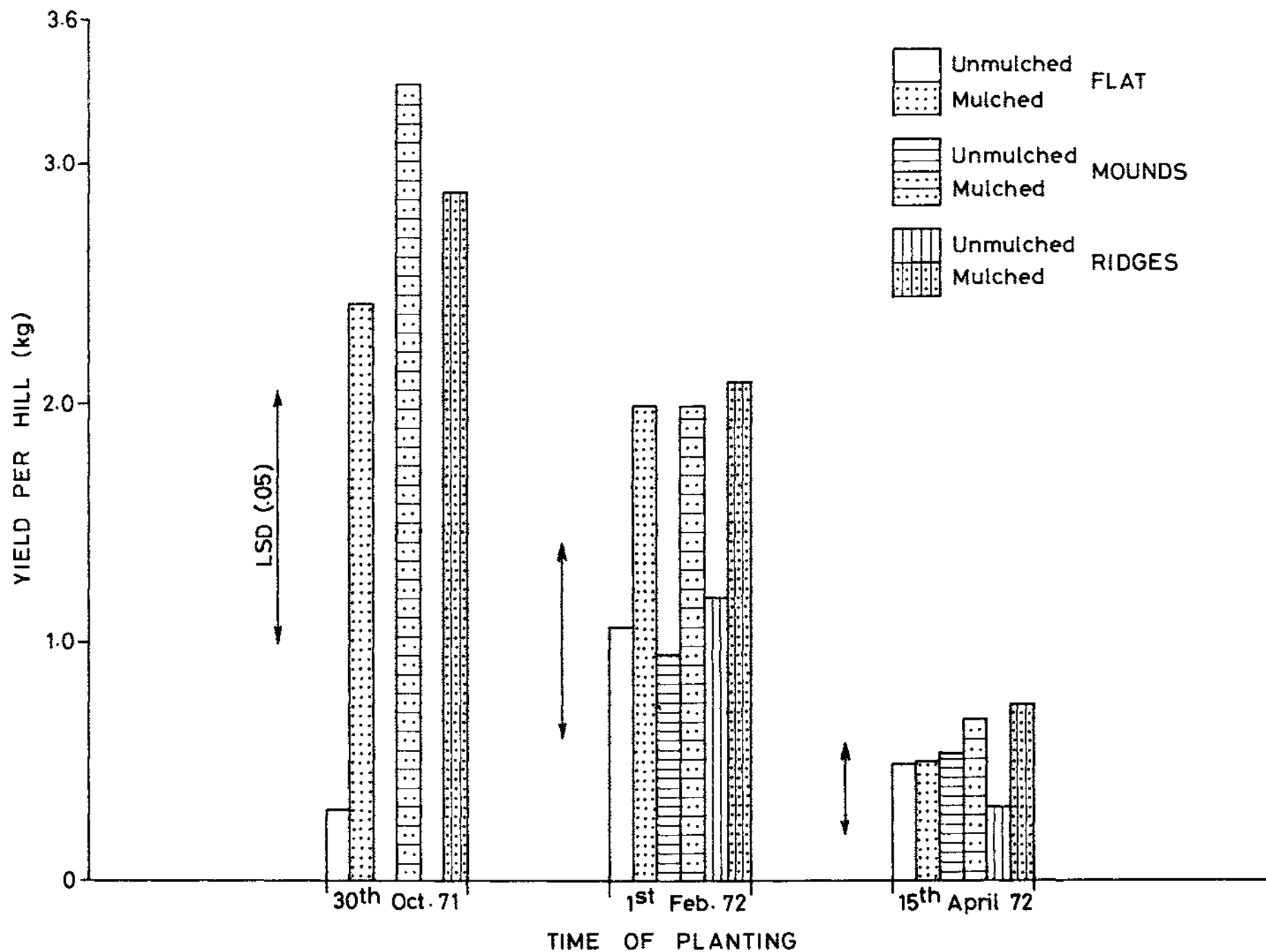


Figure 9. Total yield as affected by seed bed preparation, mulching and time of planting.

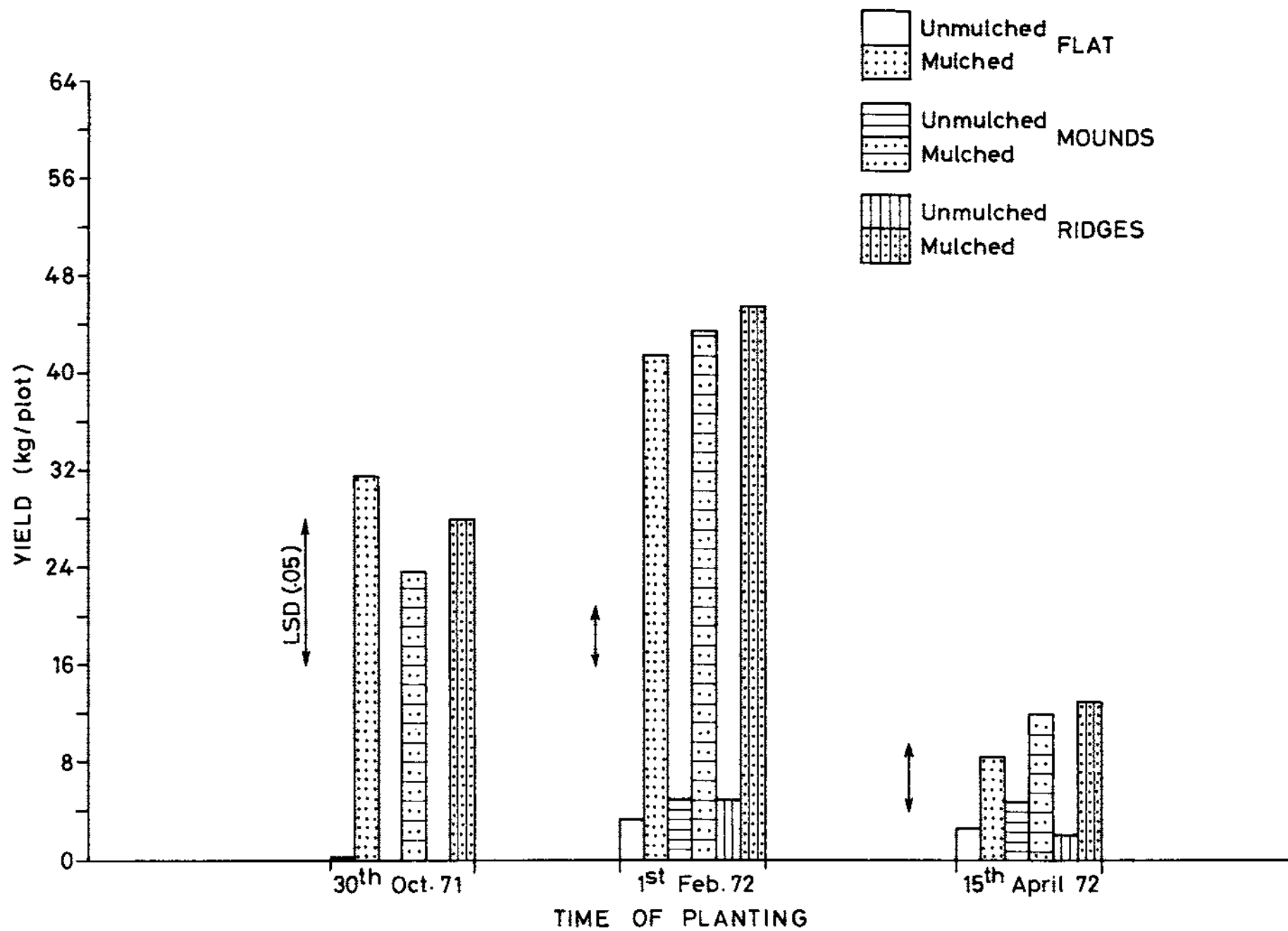


TABLE 1

Effect of method of seed bed preparation and mulching on time of emergence for different dates of planting yam setts

Surface treatment		Time in days to first emergence*		
		Planted Oct.30, 1971	Planted Feb.1, 1972	Planted April 15,1972
Mulched	Flat	75	26	30
	Heaps	127	40	30
	Ridges	122	32	31
Unmulched	Flat	148	48	37
	Heaps	+	55	40
	Ridges	+	52	50

* Average of four replications

+ No emergence

TABLE 2

Analysis of variance - table of F ratio effects of treatments on total yield

Variable	F ratio for various planting dates		
	Oct. 30, 1971	Feb.15, 1971	April 15, 1972
Mulching (M)	71.4	30.1	889.64
Seed bed (S)	0.5	1.33	1.39
M x S	0.1	1.07	

TABLE 2

Mean cumulative yields* or 'milked' and replanted setts expressed in kg fresh weight of tubers per plot and as percentages of controls or unmilked setts yield

Species or cultivars	Milking treatment	A		B		C	
		First planting date		Second planting and milking date		Third planting and milking date	
		Yields (kg)	% of control (A _a)	Cumulative yield of milked sett (b)	% of control (A _a)	Cumulative yield of milked sett (b)	% of control (A _a)
1. <i>D. rotundata</i> (cv. Aga)	a. control						
	b. milked setts	38.5	85.2	54.5	120.6	54.6	120.8
2. <i>D. alata</i>	a. control	47.6					
	b. milked setts	40.8	85.7	59.8	125.5	61.6	129.4
3. <i>D. dumetorum</i>	a. control	22.0					
	b. milked setts	20.3	92.3	24.0	109.1	24.0	109.1
4. <i>D. rotundata</i> (cv. Abi)	a. control	35.6					
	b. milked setts	42.2	118.5	56.0	157.3	56.4	158.4
5. <i>D. cayenensis</i>	a. control	25.8					
	b. milked setts	23.6	91.5	23.9	92.6	23.9	92.6

* Mean yields are based on individual plots of 20 plants each replicated three times.

TABLE 3

Mean yields* (in kg fresh weight of yam tubers) per plot and percentages of tuber yields from milked setts as compared with control (unmilked setts) yields at different planting and milking dates

Mean yields* (in kg fresh weight of yam tubers) per plot and percentages of tuber yields from milked setts as compared with control (unmilked setts) yields at different planting and milking dates

Setts milking treatment		A	B	C
		First planting date	Second planting and milking date	Third planting and milking date
(a) control	Yield(kg)	35.2	23.8	2.1
	Percentage	100	100	100
(b) milked setts	Yield(kg)	33.1	10.6	0.5
	Percentage	93.99	44.5	23.6

* Each yield figure is a mean of 20 yam stands of five yam species or cultivars replicated three times.

EFFECTS OF DIFFERENT FERTILIZERS ON CASSAVA ROOT YIELD, ROOT NUMBER PER PLANT AND AVERAGE ROOT WEIGHT PER PLANT AFTER SIX YEARS BUSH FALLOW IN SIERRA LEONE USING CUTTINGS OF DIFFERENT AGE

W. Godfrey-Sam-Aggrey*

SUMMARY

Effects of ammonium sulphate, basic slag, potassium sulphate, lime and magnesium sulphate on tuber yields, tuber number per plant and average tuber weight per plant from three differently-aged cassava cuttings have been studied. P (basic slag) significantly increased tuber yields for all types of cuttings. P and Ca with midstem cuttings and NPKMg with top stem cuttings showed significant effects on root number per plant. Effective treatments influenced yield through both tuber number and tuber weight.

RESUME

Les effets du sulfate D'ammonium, de la scorie basique, du sulfate de potassium, de la chaux et du sulfate de magnésium sur les rendements en tubercules, le nombre et le poids moyen des tubercules par pied à partir de trois boutures de manioc d'âges différents ont été exposés. P. (Scorie basique) fait augmenter d'une manière sensible les rendements en tubercules pour tous les types de bouture. Les effets de P et Ca sur les boutures de la partie centrale des tiges et de NPKMg sur les boutures de la partie extrême des tiges sont sensibles en ce qui concerne le nombre des racines par pied.

Des traitements adéquats influencent le rendement du point de vue du nombre des racines et de leur poids.

RESUMEN

Se ha estudiado el efecto del sulfato de amonio, escoria básica, sulfato de potasio, cal y sulfato de magnesio sobre el rendimiento de tubérculos, número de tubérculos por planta y peso promedio de tubérculos por planta utilizando estacas para siembra de tres edades diferentes. El P (de escoria básica) incrementó significativamente el rendimiento de tubérculos en todos los tipos de estacas. El P y el Ca con estacas de la parte media del tallo y NPKMg con estacas de la parte superior del tallo, mostraron efectos significativos en cuanto al número de raíces por planta. Los tratamientos más efectivos tuvieron influencia sobre el rendimiento a través del número y peso de tubérculos.

*Department of Agronomy, Njala University College, University of Sierra Leone Njala, Sierra Leone.

*The possible effects of sulphur were ignored.

INTRODUCTION

Bush fallow of varying duration has been used in peasant agriculture for the production of food crops in West Africa. In Sierra Leone a cereal and cassava crop mixture is often planted after the clearing and burning of a bush fallow of 4-8 years of age. The cereal is harvested leaving cassava as the dominant crop until this also is harvested, usually between 8-24 months after planting. Sometimes a cereal crop is planted and harvested before cassava is planted. The length of bush fallow preceding the growing of food crops by farmers is influenced by many factors but fertility is progressively restored in bush fallows with time. A six year fallow period would usually be considered to have fully 'restored' fertility.

MATERIALS AND METHODS

The experimental design was a 25 confounded factorial consisting of 32 plots, each plot measuring 12 x 10.8 m. Each plot was divided into three sub-plots, each sub-plot carrying either 33 basal, mid or top stem cuttings.

Fertilizer rates, applied singly or in combination (which were chosen on the basis of nutrient removal figures of Nijholt⁶) were as follows: 591 kg/ha sulphate* of ammonia, 578 kg/ha basic slag, 1217 kg/ha sulphate* of potash, 240 kg/ha lime and 71 kg/ha sulphate* of magnesium. These supplied respectively per hectare approximately 159 kg N, 153 kg P, 546 kg K, 172 kg Ca and 18 kg Mg.

Cropping history, soil and agronomy

The land, previously covered by a six-year bush fallow, was cleared, burnt, ploughed, disc-harrowed and ridged. Soil analysis figures obtained from composite core soil sampling at 10 cm deep were as follows: pH, 4.5; % carbon, 3.75; %N, 0.374; available P.ppm., 79.2; %K, 0.022; % Ca, 0.006; % Mg, 0.018.

The soil was a well-drained, gravelly exisol, i.e. a ferrallitic soil, that is strongly acid (pH 4-4.8), highly weathered, low in available plant nutrients and low in natural agricultural productivity⁷. Similar soils occur extensively in other tropical and sub-tropical areas.

Basal (0-60 cm), midstem (60-120 cm) and top (120 cm) cuttings taken from 12 month old plants of the cassava cultivar 'Cocoa', each 30 cm long, were buried to 22.5 cm depth in ridges 30 cm high and 120 cm apart. Fertilizers were applied as top dressings in four applications at 1, 3, 3 and 5 months after planting. The first and second applications consisted of one-sixth of the total amount and the third and fourth applications were of one third of the total amount. Basic slag and lime were applied a week before the corresponding application of the N-P-K mixture. Fertilizers were applied in rings 15 cm away from the plants in furrows 3.5 cm deep and 3 cm wide, and were covered immediately after application. The width of the ring was increased by 5 cm during subsequent applications, the final ring being 30 cm from the plants. Weeding was done as often as was necessary and always just before fertilizer applications.

Data Recording

Ten plants were harvested at random from each sub-plot at 14 months and average root yield, root number per plant and average root weight per plant were recorded and statistically analysed.

Economics of production

Value/cost ratios were computed for all treatments and their corresponding root yields, assessing the value of one tonne fresh cassava roots at le 22.05* and taking the subsidized costs per kg of fertilizer as follows:

Sulphate of ammonia	4 Sierra Leone cents
Basic slag	3 Sierra Leone cents
Sulphate of potash	5 Sierra Leone cents
Lime	2 Sierra Leone cents
Sulphate of magnesium	3 Sierra Leone cents

RESULTS

Yield responses

For plants grown from basal cuttings basic slag (P) significantly increased effect on root yield ($P = 0.05$). All other main treatments increased root yields but not statistically significant, except K and NPK which did not differ from the control. Mg application gave the highest economic returns, followed by Ca (Table 1).

*2 le = £1 sterling in 1972

With plants grown from midstem cuttings, basic slag (P) again showed highly significant effects on root yields at $P = 0.01$ level. Application of N or K depressed yields, but the application of Ca on Mg increased yields. The application of PMg did not increase root yields over the control. Mg application gave the highest economic returns followed by Ca (Table 2).

With the plants from top stem cuttings, basic slag (P) showed highly significant effect on root yields at $P = 0.01$ level. All other main treatments N, K, Ca and Mg increased yields (non-significantly), but application of NCa did not increase yield over the control. Mg application gave the highest economic returns (Table 3).

P consistently increased yields, and NMg depressed yields no matter which age or type of cassava cutting was used. Mg without N however gave some remarkably attractive economic returns.

Responses in root number per plant

Most of the treatments applied to basal cuttings did not show any significant effect on root number per plant; however, Mg increased the root number for plants grown from basal cuttings by 63%. P and Ca applications to midstem cuttings gave significant effects on root number per plant (at $P = 0.05$). NPKMg applied to plants grown from top stem cuttings showed a significant positive effect on root number per plant (at $P = 0.05$). Mg increased the root number per plant from the top stem cuttings by 46.6%.

Responses in average root weight per plant

None of the treatments applied to plants grown from basal cuttings showed any significant increase on average root weight per plant. Mg applied to plants grown from basal cuttings depressed average root weight per plant by about 17%. Application of K to plants grown from midstem cuttings was significant at $P = 0.05$. P application on plants grown from top stem cuttings showed highly significant effects on the average root weight per plant ($P = 0.01$). Mg application on top stem cuttings increased average root weight per plant by 18%.

The application of Mg gave considerable effects on root yield for plants grown from all types of cuttings. When applied on midstem cuttings, Mg increased average root yields.

The value/cost ratios for the rather low Mg treatments made the use of this nutrient a very profitable investment.

ACKNOWLEDGEMENT

I wish to thank Mr. H. S. Bundu, Farm Demonstrator, Department of Agronomy, Njala University College for helping with the collection of the data.

REFERENCES

1. Amara, D.S. (1971) Mineralisation of organic nitrogen in soils with bush fallow periods ranging from 0 – 6 years. B.Sc. Agric. Project, Njala University College, Sierra Leone.
2. Anon. (1951) Ann. Rep. S. Leone Dep. Agric.
3. — — — (1952) " " " " "
4. — — — (1961) " " " " "
5. Godfrey-Sam-Aggrey, W. (1976) Effects of potash fertilizers on sweet potato in Sierra Leone. *Expl. Agric.* 12, 87-94.
6. Nijholt, J.A. (1935) Opname van voedingsstoffen-uit den boden bij cassava. *Ernahrung der Pflanze* 32, 406-8.
7. van Vuure, W., Odell, R.T. and Sutton, P.M. (1972) *Soil Survey of the Njala Area, Sierra Leone*. Bulletin No. 3. Njala University College.

TABLE 1

Effects of fertilizers on cassava root yields (tonnes/ha) from basal cuttings, and corresponding value/cost ratios at 14 months

Treatment per ha.	Yield Tonnes/ha	Value/cost ratio *
0	10.97	0
159 kg N	15.42	3.58
153 " P	12.05	-
159-153 " NP	16.70	2.72
546 " K	10.97	-
159-153-546 " NPK	10.97	27.02
172 " Ca	18.91	36.86
18 Mg	14.94	-
159-18 NMg	8.09	-
172-18 CaMg	9.42	-
Mean	13.41	* for significant positive effects
s.e. $\pm$	1.0	
1.s.d. (*P = 0.05)	2.16	
(**P = 0.01)	3.01	

TABLE 2

Effects of fertilizers on cassava root yields (tonnes/ha) midstem cuttings and corresponding value/cost ratios at 14 months

Treatment per ha.	Yield Tonnes/ha	Value/cost ratio*
0	11.90	0
159 kg N	-	-
153 " P	12.96	-
546 " K	10.82	-
172 " Ca	15.27	11.36
18 " Mg	13.18	11.44
159-18 " NMg	8.84	-
153-18 " PMg	11.90	-
172-18 " CaMg	14.94	-
Mean	13.79	* for significant positive effects
s.e. $\pm$	0.70	
1.s.d. (P = 0.05)	1.51	
1.s.d. (P = 0.01)	2.11	

TABLE 3

Effects of fertilizers on cassava root yields from top stem cuttings, and corresponding values/cost ratios at 14 months

Treatment per ha.	Yield Tonnes/ha	Value/cost ratio*
0	9.77	0
159 Kg N	14.04	4.34
153 " P	15.75	6.47
546 " K	11.15	-
172 " Ca	10.52	-
159-172 " NCa	9.77	-
18 " Mg	16.77	60.94
159-18 " NMg	6.73	-
172-18 " CaMg	8.84	-
Mean	13.63	* for significant positive effects
s.e. $\pm$	0.98	
l.s.d. (P=0.03)	2.11	
l.s.d. (P=0.01)	2.94	

EFFECTS OF DIFFERENT FERTILIZERS ON ROOT YIELD, ROOT NUMBER PER PLANT AND TOP/ROOT WEIGHT RATIO OF CASSAVA IN TWO CROPPING SYSTEMS IN SIERRA LEONE

W. Godfrey-Sam-Aggrey*

SUMMARY

In two cropping systems carried out on gravelly oxisols in Sierra Leone in which cassava follows cassava and pineapple respectively, the yield responses and financial returns from the use of various fertilizer treatments have been studied. Data indicate that farmers who cannot obtain, or do not know how to use fertilizers, may be right to close their rotation with the cassava crop. However, with a suitable fertilizer application, yields can be sustained in a second crop of cassava. With the prices prevailing at the time of these experiments, the use of fertilizer would be financially advantageous.

RESUME

A partir de deux systèmes de culture menés sur oxisols de gravier sur lesquels deux cultures de manioc consécutives ont été suivies d'une culture d'ananas, les rendements et les bénéfices obtenus à l'issue de l'utilisation de divers traitements ont été exposés. Les résultats obtenus indiquent que les fermiers qui ne peuvent pas obtenir ou qui ne savent pas utiliser les engrais ont peut-être raison de terminer leur rotation avec le manioc. Toutefois, l'application adéquate d'engrais peut permettre d'obtenir des rendements de manioc en seconde culture. Eu égard aux prix en cours au moment de ces essais, l'utilisation d'engrais pourrait être financièrement bénéfique.

RESUMEN

Se ha estudiado el rendimiento de yuca y las tasas de retorno correspondientes usando varios fertilizantes en dos sistemas de cultivo llevados a cabo en oxisoles gravosos en Sierra Leona; en uno, yuca sigue a yuca y en otro yuca sigue a piña. Los datos indican que los agricultores que no pueden obtener o no saben como usar fertilizantes pueden estar en lo cierto cerrando su rotación con yuca. Sin embargo, con una aplicación adecuada de fertilizantes, los rendimientos se pueden mantener en una segunda cosecha de yuca. Con los precios que prevalecían cuando se hizo este experimento sería ventajoso, financieramente usar fertilizantes.

INTRODUCTION

In four experiments at Kenema and in nine of thirteen other trials, marked responses were observed to superphosphate and sulphate of potash, both singly and in combination^{1,2}. The trials however were confined to 'micro' plots, and it was pointed out that the results should be treated with reserve. In the four other trials in the Magburaka area, responses did not reach statistical significance. Sulphate of ammonia depressed yields at all sites whilst liming had no apparent effect. In a trial at Newton, applying single superphosphate and sulphate of potash singly and in combination, sulphate of potash applied alone gave the highest yield of 14.2 tonnes per ha.³

MATERIALS AND METHODS

Experiment 1

The experimental design was a 2⁵ confounded factorial, consisting of 32 plots, each measuring 6 x 10.8 m. Fertilizer rates, applied singly or in combination consisted of the following: 591 kg/ha sulphate of ammonia, 578 kg/ha basic slag, 1217 kg/ha sulphate of potash, 240 kg/ha lime flour and 71 kg/ha sulphate of magnesium and zero rates of each fertilizer. The respective elements actually applied per hectare were as follows: 159 kg N*, 153 kg P, 546 kg K*, 172 kg Ca and 18 kg Mg*.

*Department of Agronomy, Njala University College, University of Sierra Leone, Njala, Sierra Leone.

*Together with S from sulphate not mentioned by the author. Ed.

Experiment 2

The experimental design was a randomized complete block with five treatments and 5 replications, each plot measuring 6 x 10.8 m. Nijholt's⁹ cassava nutrient removal figures were used as the basis for the treatments. Only N, P, and K were varied in three of the treatments and then compared with the corresponding equivalent of Nijholt's removal figures and a no-fertilizer treatment. In all the treatments Ca and Mg were kept constant. The treatments were as follows:

1. Control (no fertilizer)
2. 159 - 153 - 546 - 172 - 18 kg N:P:K:Ca:Mg/ha
3. 318 - 153 - 546 - 172 - 18 kg N:P:K:Ca:Mg/ha
4. 159 - 306 - 546 - 172 - 18 kg N:P:K:Ca:Mg/ha
5. 159 - 153 - 1092 - 172 - 18 kg N:P:K:Ca:Mg/ha

N, P, K, Ca and Mg used were in the form of sulphate of ammonia, basic slag, sulphate of potash, lime flour and sulphate of magnesium respectively. The respective elements found in the treatment mixtures per hectare corresponded with those cited for Experiment 1 above.

Soils, cropping history and agronomy

The experiments were conducted on Njala upland soils which are well drained, gravelly oxisols (ferralitic soils) that are strongly acid (pH 4 - 4.8), highly weathered, low in available plant nutrients and low in natural agricultural productivity¹. Similar soils occur extensively in other tropical and sub-tropical areas.

Experiment 1

The land was covered by secondary bush which was cleared, but not burnt, ploughed and harrowed. Pineapples, cv. 'Smooth Cayenne' had been planted on the flat for two years previously without any use of fertilizer. The pineapples were removed and the land prepared immediately for planting cassava on May 1, 1970.

Soil analysis figures obtained from composite core soil sampling at 10 cm deep were as follows: pH, 4.6; % carbon, 1.99; % N, 0.29; available P, ppm., 88; % K, 0.014; % Ca, 0.034; % Mg, 0.050.

Experiment 2

The land was covered with secondary bush which was cleared but not burnt, then maize followed by cassava were planted in succession without fertilization. The cassava was harvested 10 months after planting and the land prepared immediately for planting cassava again on May 4, 1970.

Soil analysis figures obtained from composite core soil sampling at 10 cm deep were as follows: pH, 4.5; % carbon, 2.07; % N, 0.35; available P, ppm, 132; % K, 0.014; % Ca, 0.029; % Mg, 0.028. Twelve-month old basal (0-60 cm) and midstem (60-120 cm) cassava cuttings 30 cm long were prepared and 22.5 cm buried, inclined in ridges 30 cm high and 120 cm apart. The setts were planted 120 cm apart in ridges, and each type of cutting was planted in a separate experiment. 'Cocoa' the cultivar used, is a popular type in West Africa; it is sweet, with pink-skinned roots and 2-3 forks.

Fertilizers were applied in four split applications 1, 2, 3 and 5 months after planting, the first and second applications corresponding to one-sixtieth of the total amount and the third and fourth to one-third of the total amount to be applied. P and Ca were applied a week before each application of N-K-Mg mixture. The fertilizers were applied in a ring 15 cm wide and covered immediately after application. The width of the ring was increased by 5 cm during the subsequent applications, the final ring being 30 cm from the plants. Weeding was done as often as it was necessary and always just before fertilizer applications.

Data recording

Roots were harvested at 8 and 14 months. Average root number per plant and top/root weight ratio were recorded at 14 months for both experiments.

Economics of production

Value/cost ratios were computed for all treatments and their corresponding root yields*, assessing the value of one tonne fresh cassava roots at le.22.05 (£ stg. 11.03) and taking the subsidized cost per kg. of

*But these are being presented only for statistically significant effects

fertilizers as follows:

Sulphate of ammonia	4	Sierra Leone cents
Basic slag	3	" " "
Sulphate of potash	5	" " "
Lime flour	2	" " "
Sulphate of magnesium	3	" " "

Value/cost ratio was obtained by dividing the value of increased crop by the cost of the fertilizers used.

RESULTS

Root yields

Experiment 1: results obtained using basal cuttings (Table 1).

NKCa was the only significant treatment at $P = 0.05$ at 8 months, with a mean response of 237 percent. All single nutrients and their respective combinations increased yields (non-significant). At 14 months however none of the treatments showed any significant effect on root yields (Table 2).

Experiment 1: results obtained using midstem cuttings

None of the treatments showed any significant increase in root yields at 8 or 14 months.

Experiment 2: results obtained using basal cuttings (Table 3)

Treatments 2 and 4 gave highly significant effects (at $P = 0.01$) whilst treatments 3 and 5 showed effect on root yields significant at $P = 0.05$ at 8 months. Only treatments 2 and 4 gave profitable returns at 8 months. At 14 months, treatments 2, 3 and 4 showed highly significant effects on root yields (at $P = 0.01$) and gave profitable returns.

Experiment 2: results obtained using midstem cuttings

Treatments 2, 3 and 4 gave significant increases in yield (at $P = 0.01$), but treatment 5 was significant at only $P = 0.05$ at 8 months. However, none of the treatments gave profitable returns at 8 months. At 14 months, treatments 2, 3, 4 and 5 gave highly significant yield responses (at $P = 0.01$). They all gave profitable returns, especially treatment 2 (Table 3).

DISCUSSION

Most nutrient removal figures for and fertilizer trials with cassava emphasize the importance of N P K mixtures to produce high root yields^{4,8,10}. Nijholt's nutrient removal figures⁹ included the calcium and magnesium requirements. In the cropping system described, in which two years of unfertilized pineapples were followed by cassava, it was worth using fertilizers. Effective fertilizers were NKCa and PKCa combinations for 8 and 14 months harvest dates respectively. However, the most profitable returns can be obtained if it is deficient, by the use of Mg.

West African peasant farmers normally consider cassava as the last crop before allowing their land to go back to 'bush'. They would not normally plant cassava followed by cassava except when they are in commercial production. The implication of the results from Experiment 2 is that farmers can use the recommended fertilizers to obtain economic cassava root yields, even when unfertilized cassava is followed by fertilized cassava. The practice of West African farmers of allowing their land to go back to 'bush' after cassava because of low fertility appears logical if no fertilizer is to be applied to the second crop, but sustained yields can be obtained, at least for a second successive crop, with appropriate fertilizer use which moreover will be profitable.

ACKNOWLEDGEMENT

I wish to thank Mr. H. S. Bundu, Farm Demonstrator, Department of Agronomy, Njala University College for helping with the collection of the data.

REFERENCES:

1. Anon. (1951) Ann. Rep. Sa. Leone Dep. Agric.
2. Anon. (1952) Ann. Rep. Sa. Leone Dep. Agric.

3. Anon. (1961) Ann. Rep. Sa. Leone Dep. Agric.
4. Cours, G. and Fritz, J. (1961) Le Manioc. *Bull. Madagascar* 11, 178, 203-24.
5. Dijkerman, J.C. and Breteler, H. (1969) *Soil Survey of the Oil Palm Station and North-West Extension of N.U.C. Farm*. Njala University College.
6. Godfrey-Sam-Aggrey, W. (1976) Effects of potash fertilizers on sweet potato in Sierra Leone. *Expl. Agric.* 12, 87-94.
7. Krochmal, A. and Samuels, G. (1967) The influence of NPK levels on the growth and tuber development of cassava in tanks. *Proc. 1st Int. Symp. on Trop. Root Crops*, Trinidad 1, 30.
8. Malavolta, E. et al. (1955) Studies on the mineral nutrition of cassava (*Manihot utilissima* Pohl.) *Plant Physiol.* 30, 81-2.
9. Nijholt, J.A. (1935) Opname van voedingstoffen uit den bodem bij cassava. *Ernahrung der Pflanze* 32, 406-8.
10. Normanha, B.S. and Pereira, A.S. (1950) Aspectos agronomicos da culturalda mandioca. *Bragantia* 10, 179-202.
11. van Vuure, W., Odell, R.T. and Sutton, P.M. (1972) *Soil survey of Njala area, Sierra Leone*. Bulletin No. 3, Njala University College.

TABLE 1

Effect of fertilizers on cassava root yield from basal cuttings, and corresponding value/cost ratios at 8 months

Treatment per ha		Yield tonnes/ha	Effect
0		8.04	19.71 Mean
159	kg N	22.35	+2.41
153	" P	18.58	+1.46
546	" K	20.84	+0.48
172	" Ca	14.82	+1.96
153-546-172	" N:K:Ca	27.12	+3.16*
18	" Mg	18.58	+0.85
Mean		19.71	
s.e.			±1.35
*P = 0.05			2.94
**P = 0.01			4.09

TABLE 2

Fertilizer effects on cassava root yields from basal cuttings, and corresponding value/cost ratios at 14 months

Treatment per ha		Yield tonnes/ha	Effect	Value/cost ratio
0		18.83	29.23	0
159	kg N	35.14	-1.51	14.72
153	" P	32.88	+3.44	18.16
546	" K	33.89	+3.84	5.54
172	" Ca	20.83	-0.83	7.66
153-546-172	" PKCa	44.95	-0.40	6.96
18	" Mg	33.89	-1.20	158.03
Mean		29.23		
s.e.			±2.64	
*P = 0.05			5.70	
**P = 0.01			7.93	

TABLE 3
Effect of fertilizer on average cassava root yields (tonnes/ha) and corresponding value/cost ratios

				8 month harvest				14 month harvest			
* Treatment per ha				Yield		Value/cost ratio		Yield		Value/cost ratio	
N	P	K		Basal	Midstem	Basal	Midstem	Basal	Midstem	Basal	Midstem
1.	0	0	0	6.98	9.09	0	0	17.33	16.32	0	0
2.	159	153	546	14.31**	14.01**	1.48	0.99	26.62**	29.33**	1.88	2.63
3.	318	153	546	11.70**	14.82**	0.78	0.95	26.11**	27.17**	1.45	1.79
4.	159	306	546	13.96**	14.56**	1.22	0.95	30.03**	25.91**	2.22	1.67
5.	159	153	1092	12.45*	12.96*	0.53	0.37	21.85	28.78**	-	1.20
Mean				11.88	13.08			24.39	25.51		
*P = 0.05				4.24	3.31			6.30	4.97		
**P = 0.01				5.83	4.57			8.69	6.36		

* All the respective treatments excepting the control (no fertilizer) were supplied with constant amounts of 172 kg Ca and 18 kg Mg per ha.

EFFECTS OF PLANT POPULATION AND FERTILIZERS ON YIELD AND YIELD COMPONENTS OF CASSAVA IN THE FOREST ZONE OF GHANA

A.M. Gurnah*

SUMMARY

Under the soil moisture conditions of experiments carried out at Kumasi, Ghana, comparing cassava yields at five densities over the range 9259 to 74,074 per hectare, 18,500 plants per hectare increased yields; plant densities higher than this resulted in a drop in yield. Water supply was probably limiting yield since the crop did not respond to fertilizers even at high density except by increased top growth. Yield per plant, average tuber weight, weight of tops, average number of stems and tubers/plant were not affected by fertilizers, but they all decreased with an increase in plant population beyond 18,500.

RESUME

Des essais menés en conditions d'humidité du sol à Kumasi, Ghana, comparant des rendements du manioc de cinq densités partant de 9259 à 74,074 à l'hectare, ont révélé que 18,500 plants à l'hectare ont accru le rendement; des densités plus élevées entraînent une baisse de rendement. L'approvisionnement en eau limitait probablement le rendement dans la mesure où la plante en répondait pas aux engrais, même quand la densité est élevée, sauf au niveau de la croissance de la tige. Les engrais n'ont pas eu d'effet sur le rendement par plant, le poids moyen des tubercules, le poids des tiges, le nombre moyen des tiges et tubercules par plant, mais il y a eu baisse à tous les niveaux lorsque la densité dépassait 18,500.

RESUMEN

Bajo las condiciones de humedad del suelo en experimentos conducidos en Kumasi, Ghana, los rendimientos de yuca aumentaron hasta densidades de siembra de 18,500 plantas por hectárea, dentro del rango de comparación que fué de 9,259 hasta 74,074 plantas por hectárea; densidades mayores a 18,500 redujeron el rendimiento. El abastecimiento de agua limitó probablemente el rendimiento ya que no se observó respuesta a los fertilizantes aún con densidades altas, excepto en lo referente a crecimiento de la parte aérea. El rendimiento por planta, el peso promedio de tubérculos, peso de parte aérea, número promedio de tallos y tubérculos/planta no fueron afectados por el fertilizante sino que decrecieron — todos ellos — con un incremento en población mayor a 18,500 plantas por hectárea.

REVIEW

Half the area of cassava production in Ghana is grown in the Forest Zone. Cassava is usually planted as an opening crop, interplanted with maize and cocoyams, after a fallow of secondary forest (Doku⁸). Although it is an important staple food, so little work had been done on the agronomy of cassava the Doku⁸ could write "There are no records of experiments aimed at finding the best spacing, but somehow a 3 x 3 ft spacing has been accepted throughout the country as the best." Since then Koli¹² has conducted spacing and fertilizer trials throughout the country. Jennings¹¹ reviewed work on cassava in Africa.

In Senegal, Tardieu and Fauche¹⁶ obtained highest yields with a population of 10,000 plants/ha, (1 x 1m). The Department of Agriculture Zanzibar⁷ recorded highest yields with 11,900 plants/ha (3 x 3 ft), but in Argentina, Rodriguez *et al.*¹⁴ recommended much higher populations of 13,300 to 20,000 plants/ha (1 x 0.75m or 1 x 0.5 m).

Yields of cassava can be increased by the use of green manure (Childs³; Doku⁸; Silvestre¹⁵) or farm yard manure (Briant²). Cours and Fritz⁴ estimated that a 40 tonnes/ha. crop removes 85,62, 280 and 75 kg/ha each of N, P₂O₅, K₂O and CaO respectively. In field experiments cassava responds most to potash and phosphate (Tardieu and Fauche¹⁶; Doku⁸). De Geus⁶ cited instances of responses to nitrogen but also evidence that too high a rate of nitrogen application may promote stem and leaf growth at the expense of root growth. Compound fertilizers have given good responses in a number of trials (FFHC⁹; Cours *et al.*⁴; Tardieu and Fauche¹⁶). A satisfactory ratio for N, P₂O₅ and K₂O is very important and De Geus⁶ concluded that on the evidence available a ratio of 1:1:2 could generally be recommended. The optimum ratio

*Department of Crop Production, University of Nairobi, Kenya.

will of course vary depending on the type of soil. In sand culture, Krochmal and Samuels¹³ observed that phosphate induced the greatest response in yield but there was no marked response to potassium whereas nitrogen increased stem growth at the expense of roots.

MATERIALS AND METHODS

The two experiments reported were planted at the Arable Crops Farm of the University of Science and Technology Kumasi, Ghana on the Forest Ochrosols of the Akroso soil series (Bremmer¹). The land was under a *Panicum maximum* grazed pasture for four years after clearing secondary forest and was prepared for planting by two disc ploughings, one disc harrowing and making ridges 90 cm apart. Each plot spanned ten ridges containing twenty cuttings per ridge. The length of the plot thus depended on the spacing of the cuttings on the ridge. The two outer ridges in each plot were guard rows. A randomized block design was used, replicated four times in both experiments. There were paths 90 cm wide between adjacent plots in the same block and the blocks were separated by paths 1.80 m wide.

Spacing treatments

	<u>S1</u>	<u>S2</u>	<u>S3</u>	<u>S4</u>	<u>S5</u>
Spacing within ridges (cm)	15	30	60	90	120
Plant population/ha	74,074	37,037	18,519	12,345	9,259

Fertilizer treatments

	<u>F0</u>	<u>F1</u>	<u>F2</u>
N	0	45	70
P ₂ O ₅	0	45	70
K ₂ O	0	45	70

Experiment 1

Three spacings, S3, S4, S5, and two fertilizer treatments, F0, F1, were combined in all possible combinations to give six experimental treatments.

Experiment 2

Four spacings, S1, S2, S3, S4, and three fertilizer treatments, F0, F1, F2 were combined in all possible combinations to give twelve experimental treatments.

The dates of planting and harvesting and the rainfall during the growing season of the crop are as follows:

	<u>Exp. 1</u>	<u>Exp. 2</u>
Date of planting	3/4/70	29/3/71
Date of harvesting	5/4/71	10/4/72
Rainfall during season (cm)	127	124

The fertilizers were placed on the side of the ridges and covered after the cuttings had sprouted. Sprouting percentage for cuttings three weeks after planting was about 95 percent; any cutting which had not sprouted at this time was replaced. The cuttings were taken from the middle portion of the stems, each cutting containing five nodes, and were planted slanting with approximately half their lengths buried. The plots were weeded four times in each experiment at 3, 6, 9 and 15 weeks after planting. For the determination of yield and its components in Experiment 2, 80 plants from the middle 8 ridges of each plot were picked at random, carefully dug and the number of tubers and their fresh weights, the number of stems and the fresh weight of tops were determined for each plant. In experiment 1 cassava from the middle 8 ridges was weighed to determine the yield.

RESULTS AND DISCUSSION

The data for yield/ha, yield/plant, average tuber weights, weight of tops, average number of stems/plant and average number of tubers/plant were analysed statistically. Only some of the main effects, and none of the interactions were statistically significant, so only the main effect mean, their standard errors and indication of statistical significance are presented in Tables 1 and 2.

Spacing had a considerable effect on yield. The highest yield of tubers/ha was obtained at a spacing of 60 cm in both experiments (Table 1). Increasing the spacing beyond 60 cm (Exps. 1 and 2) or decreasing it (Exp. 2) lowered yield. This spacing is closer than the 91.4 x 91.4 cm spacing generally recommended throughout Ghana (Doku⁸), but it is near to the population of 20,000 p/ha recommended by Rodriguez et al.¹⁴. Similar results were obtained by Koli¹². The relationship between plant population and yield appears to be of the parabolic kind with an optimum at around 18,500 plants/ha. Holliday¹⁰ thought that for vegetative yield, the relationship between plant population and yield is asymptotic. Willey and Heath¹⁷ however cited instances where the relationship between vegetative yield and plant population was parabolic. Yields per plant, average tuber weights, average number of tubers/plant, weight of tops and average number of stems/plant all decreased with an increase in plant population, indicating competition between plants even at the moderately low populations.

Fertilizers did not affect yields/ha, yield/plant or the weight and number of tubers (Table 2). There was however an increase in the weight of tops with an increase in fertilizer levels. This increase was however not at the expense of roots. This lack of response to fertilizers is either due to the fact that there were adequate nutrients in the soil or because water rather than nutrient supply was limiting yield.

At populations higher than 18,500 plants/ha yields dropped because the increased yield brought about by an increase in the number of plants/ha did not compensate for the associated decrease of yield/plant. This indicates intense competition between plants at the higher populations. This competition is not likely to be for the nutrients NPK since there was no response to these nutrients (Table 2) even at the highest populations, and no interactions between population and fertilizer levels. It was most likely competition for water. The rainfall received was on the lower range of the requirements for cassava, 100–200 cm. (De Geus⁶). At the higher plant populations the storage of starch in the roots was probably limited by inadequate water.

REFERENCES

1. Bremmer, H. (1962) In *Agriculture and Land use in Ghana*. (Ed. J.B. Wills). London: Oxford University Press.
2. Briant, A.K. (1959) Manurial experiment on cassava. *Bull. 4/59 Dep. Agric. Zanzibar*. 5–6.
3. Childs, A.H.B. (1961) Cassava. *Bull. 15 Minist. Agric. Tanganyika*.
4. Cours, G. & Fritz, J. (1961) Le manioc. *Bull. Madagascar*. II. 178, 204–24.
5. Cours, G., Fritz, J. & Ramahadimby, G. (1961) Phellodermic diagnosis of the nutritional status of manioc. *Fertilite* 12, 3–20.
6. De Geus, J.G. (1967) In *Fertilizer Guide for Tropical and Sub-Tropical Farming*. Zurich: Centro d'Etude de l'Azote.
7. Department of Agriculture, Zanzibar. (1970) Trials on cassava. *Suppl. Dept. Agric. Zanzibar* 1959, 11–12.
8. Doku, E.V. (1969) *Cassava in Ghana*. Accra: Ghana Universities Press.
9. FFHC (1963) *Review of trials and demonstration results. 1962/63 Fertilizer Programme*. Rome: FAO.
10. Holliday, R. (1960) Plant population and crop yield I and II. *Field Crop Abstr.* 13, 159–69, 247–54.
11. Jennings, D.L. (1970) Cassava in Africa. *Field Crop Abstr.* 23, 271–8.
12. Koli, S.E. (1970) Personal communication.
13. Krochmal, A. & Samuels, G. (1967) The influence of NPK levels on the growth and tuber development of cassava in tanks. *Proc. Int. Symp. on Tropical Root Crops. Trinidad* 1, (Section 2) 97–102.
14. Rodriguez, N.F., Sanchez de B., C.A. & Tarabanoff, J.L. (1966) Influence of cultural factors on cassava in Misiones Province. *Revta Invest. agropec. Ser. 2*, 3, 167–208.
15. Silvestre, F. (1967) Research on root crops by I.R.A.T. in Africa and Madagascar *Proc. Int. Symp. Tropical Root Crops. Trinidad*. 1 (Section 3), 84–7.
16. Tardieu, M. & Fuche, J. (1961) Contribution to the study of cultivation techniques for cassava. *Agron. Trop. Paris*. 16, 375–86.
17. Willey, R.W. & Heath, S.B. (1969) The quantitative relationship between plant population and crop yield. *Advan. Agron.* 21, 281–321.

TABLE 1

The main effects of spacing

	Exp. No.	15	30	60	90	120	S.E.(±)
Tuber yield/ha (tonnes)	1	-	-	40.1a	35.4b	20.3c	1.48
Tuber yield/ha (tonnes)	2	18.0c	27.9b	37.2a	31.2ab	-	1.95
Tuber yield/plant (gm.)	2	251d	754c	2075b	2433a	-	87
Average tuber weights (gm.)	2	178b	302ab	403a	378a	-	34
Weight of tops (gm.)	2	624c	776c	1259b	1595a*	-	120
Average no of stems/plant	2	1.8b	2.0ab	2.3a	2.3a	-	0.07
Average no of tubers/plant	2	1.7c	3.2b	5.3a	6.4a	-	0.3

Means followed by different letters are significantly different (P = 0.01)

* Level of significance (P = 0.05)

TABLE 2

The main effects of fertilizers

					S.E.(±)
Tuber yield/ha.(tonnes)	1	31.6	32.3	-	1.15
Tuber yield/ha (tonnes)	2	29.8	28.2	27.2	1.69
Tuber yield/plant (gm)	2	1403	1345	1387	76
Average tuber weights(gm)	2	303	358	286	29
Weight of tops (gm)	2	904b	985b	1302a	104
Average no.of stems/plant	2	2.1	2.1	2.1	0.08
Average no.of tuber/plant	2	4.3	3.8	4.4	0.4

Means followed by different letters are statistically significant (= 0.05)

AN EVALUATION OF THE YIELD AND QUALITY OF SOME NIGERIAN CASSAVA VARIETIES AS AFFECTED BY AGE AND NITROGEN FERTILIZER APPLICATION

G.O. Obigbesan and A.A. Agboola*

SUMMARY

Dry matter and starch contents were highest fifteen months after planting, while cyanide titre tended to decrease with age. Fresh tuber yields ranged between 16-40 tons/ha over growth periods of 12-24 months. There were differences in response to N between cultivars tested. Increasing N fertilizer tended to increase the cyanide content of cultivar 53101 but lowered it in cultivar 60506. For industrial starch production harvesting during the period 12-15 months was optimum. Cultivars show differential physiological responses and generalizations for the species can be misleading.

RESUME

La teneur en matière sèche et en amidon atteignent leur niveau le plus élevé quinze mois après le semis, tandis que le titre de cyanure tend à décroître avec l'âge. Les rendements en tubercules fraîches se situent entre 16-40 tonnes à l'hectare sur une période de croissance de 12 à 24 mois. Les cultivars testés présentent des variations en réponse à N. L'accroissement de l'engrais azoté tend à augmenter la teneur en cyanure du cultivar 53101 et à décroître celle du cultivar 60506. Pour la production d'amidon industriel, le récolte entre 12 et 15 mois est optimale. Les cultivars présentent des réponses variables d'ordre physiologiques et toute tentative de généralisation de ces espèces peut induire en erreur.

RESUMEN

Los contenidos más altos de almidón y materia seca ocurrieron quince meses después de la siembra, en tanto que la concentración de cianidas tendió a decrecer con la edad. Los rendimientos de tubérculo fresco variaron entre 16-40 ton/ha en períodos de crecimiento de 12-24 meses. Hubo diferencias en respuesta a N en los cultivares probados. El incremento de fertilizante nitrogenado tendió a aumentar el contenido de cianida del cultivar 53101 y a bajarlo en el 60506. La cosecha durante el período de 12-15 meses fue óptima para la producción industrial de almidón. Los cultivares muestran repuestas fisiológicas diferentes por lo que hacer generalizaciones puede conducir a conclusiones erróneas.

INTRODUCTION

Nigeria contributed about 7.9% of recorded world cassava production in 1970 (15) ranking fourth after Zaire with 7.5 million tons. The national average yield of cassava is 8 tons/ha obtained from peasant farms where it is grown as a subsistence crop on poor soils at the end of a crop sequence. Peasant farmers do not harvest at any fixed stage of growth but at their convenience because the crop can remain in the field for more than 24 months without deterioration. Cassava has received little research attention in Nigeria, although mosaic virus disease is known to reduce cassava yields here by about 39% and by up to 43% in East Africa¹⁰.

Research on cassava in Nigeria began in 1932 when Faulkner studied the yield, disease resistance and general utility of local cultivars and introductions from the Gold Coast (Ghana), Sierra Leone and Trinidad.⁵ In 1954, cassava improvement was restarted at the Federal Department of Agricultural Research, Moor Plantation, Ibadan. The objectives were to select mosaic disease resistant strains with high root yields, high starch and protein content, but low in cyanide content. Not less than 40,000 cassava clones were assembled during the first three years of this programme. Selected and local cultivars were compared in zonal variety trials throughout the cassava growing areas of the country. As a result the cultivars 60444, 60447, 60506 and 53101 as well as the 'sweet' cassava cultivar 44086 received 'recommended' status.

All these cultivars are, nevertheless, susceptible to mosaic disease and are now regarded as low yielding⁷. These recommended cultivars are also mostly highly cynogenic. Both IITA in Ibadan and CIAT in Colombia are now undertaking full-scale research on cassava to increase yields, evolve insect and mosaic disease resistance and reduce cyanide content. We decided to reassess those already widely distributed clones previously recommended as a background for assessing the merits of any new introductions.

*Department of Agronomy, University of Ibadan, Nigeria.

Investigations have been made of the effects of N, P and K fertilizers on the yield of cassava in Nigeria^{1,4,6}, but not previously on the effects of these nutrients on chemical composition. Cultivars have been tested for cyanide content²⁴, carbohydrate fractions¹⁸ and food value, including the chronic effects of cyanide in cassava-containing diets^{14,22,23}.

RESULTS

Effect of length of growth period

Mean yields of cassava in the regions of Nigeria vary over a range of about 7.5-10 tons/ha. On poor sandy soils in Eastern Nigeria, individual field yields may reach 11 tons/ha while on soils of moderate fertility yields lie between 12.5-24 tons/ha³. About 20 ton tuber/ha has been recorded from experimental plots in Northern Nigeria¹². The average yield over a ten year study in a forest location in Western Nigeria was 15.6 ton/ha fresh tubers². In the savanna zone tuber yields were between 8.2 ton and 18.9 ton/ha⁶. From 21 demonstration plots in Western Nigeria, Lampe¹⁹ reported an average yield of 11.9 ton/ha without the use of fertilizer compared with 16.6 ton/ha with fertilizer. All these yield data were obtained from 12 month growth of the standard cassava cultivar 53101.

The results of a series of trials conducted by the Federal Department of Agricultural Research between 1958 and 1965 on the effect of the length of growth periods on the yield of a standard variety, 53101, and 13 local cassava cultivars showed that there were large yield increases during the periods 12-18 months and 18-24 months after planting. (Table 1). After the sixth month of growth there was no further increase however in the number of roots per plant. Thus increase in yield after this time results from further deposition in existing root tubers of starch produced by the photosynthesis.

The cultivar 53101 significantly out-yielded the best 'local' selection in almost all the locations at any growing period, the mean tuber yields of the standard cultivar being 23.5, 29.5 and 39.3 ton/ha while those of the local cultivars average 18.8, 24.8 and 31.5 ton/ha at 12, 18 and 24 months respectively. The tuber composition of the currently recommended cultivars are shown by an analysis of cassava tubers from a variety trial at Umudike, Eastern Nigeria (Table 2). In other locations starch content of up to 32.5 percent and cyanide concentrations of 350 ppm (53101) and 165 ppm (44086) are on record.

The results of experiments on changing the period from planting to harvesting begun in 1960 by the Federal Department of Agricultural Research and continued until 1972 are summarized in Figures 1-3. The fresh tuber yields, the dry matter, starch and cyanide content were all significantly affected by the age of the crop. Although the fresh tuber yield continued to increase up to 24 months, the dry matter content reached a peak at 15 months, and thereafter began to decline (Figure 1). At 12 months, the fresh tuber yield was 22.5 ton/ha and the dry matter content was 31% giving a total dry matter yield of 6.98 ton/ha. At 15 months the total dry matter yield was 11.25 tons/ha, while at 24 months only 9.0 ton/ha dry matter was obtained.

Figure 2 shows that the starch percentage of fresh weight also reached a peak at 15 months, after which it decreased with age. It would appear therefore that no benefits would derive from growing the variety (53101) beyond 15 months.

The cyanide content of the cultivar 53101 was highest (310 ppm) at 15 months, and then decreased with increasing age of the plant, falling to 250 ppm at 24 months (Figure 3). This finding is analogous to results on cyanogenesis in forage sorghum in which cyanide also decreased as the plant approached maturity (16, 26, 29). The present studies indicate that if 53101 cassava is cultivated for industrial starch, it should not be harvested earlier than 12 months, but could be harvested for consumption as early as ten months since cyanide is removed in processing for human consumption.

Effect of fertilizers on yield and quality of cassava

Fertilizer application was not considered economic in the savanna zone of Western Nigeria when the market price was only N10 per ton. Fertilizer investigations carried out in the forest (Agege) and savanna (Ifora and Ogbomoso) locations of Western Nigeria indicated that 28 kg N, 11 kg P₂O₅ and 68 kg K₂O per hectare should be applied in the savanna zone, while 50 kg N, 11 kg P₂O₅ and 67 kg K₂O per hectare was indicated in the forest soils at Agege². It was apparent (Fig. 4) that the yield potential of the variety 53101 did not exceed 19.0 ton tuber/ha. The data in Fig. 4 also suggest that optimum requirements of cassava are 67 kg K₂O, 30 kg N and 11 kg P₂O₅ per hectare. However, there is no official fertilizer recommendation for cassava production in Nigeria.

To study the effects of different nutrients on tuber quality cultivars 53101 and 60506 were chosen. Random samples were taken at 9 and 12 months of age for laboratory analysis. Basal dressing of 56 kg P₂O₅ and 68 kg K₂O per hectare were applied at planting. The crops were top dressed with sulphate of ammonia at the rates of 0, 67, 100, 134 and 168 kg N/ha three months after planting. There were four replicates of treatments for each cultivar.

At each sampling, four representative tubers were selected from 18 plants harvested and immediately taken to the laboratory for analysis. After washing, two tubers were peeled and split longitudinally. One half was grated for starch and cyanide determination, and the other half was cut into pieces and dried at 105°C. The grated samples were weighed, sealed up with cellophane film in conical flasks and stored in a deep freezer (-20°C) until analysis⁹. Starch was determined by the specific gravity method as recommended by the Tropical Products Institute and HCN by the A.O.A.C. titration method.⁸

Tubers of both cultivars contained higher amounts of cyanide at 9 months than at 12 months in these experiments and the cyanide concentration decreased with the age of the plant (Fig. 5), except that between 9 and 12 months, the unfertilized cultivar 53101 given no fertilizer did not show any reduction in cyanide content (297 and 298 ppm respectively). Cultivar 60506 however, even with no fertilizer, showed a considerable reduction from 324 ppm to 199 ppm. The cyanide content of cultivar 53101 was increased with increasing N application, whereas this tended to reduce the cyanide concentration in cultivar 60506.

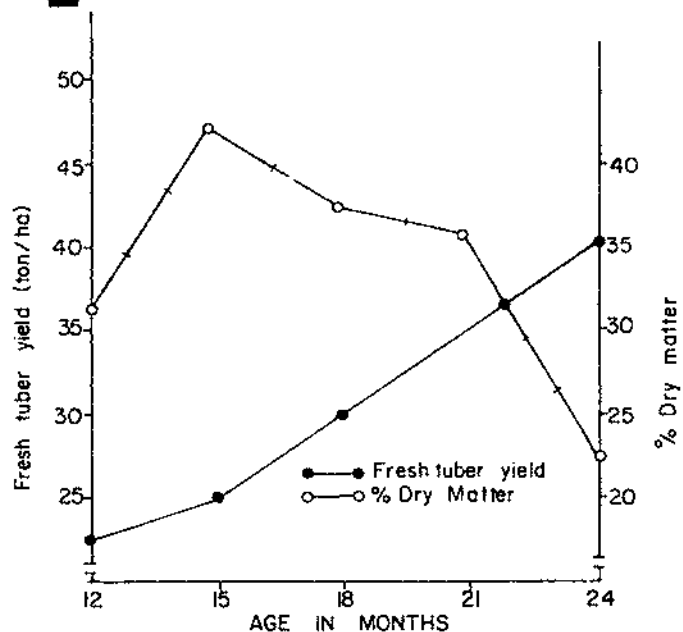


Fig. 1. Cassava var. 53101: The relationship between the age of the crop, fresh tuber yield and dry matter content.

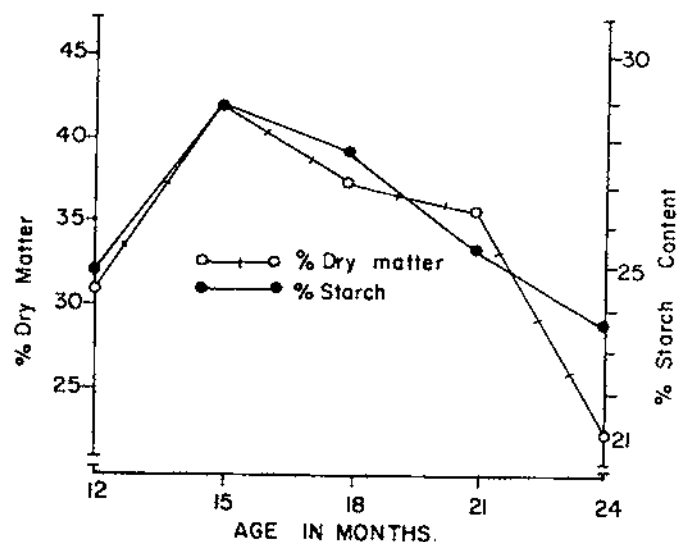


Fig. 2. Cassava var. 53101: Dry matter and Starch content, as affected by age of the plant

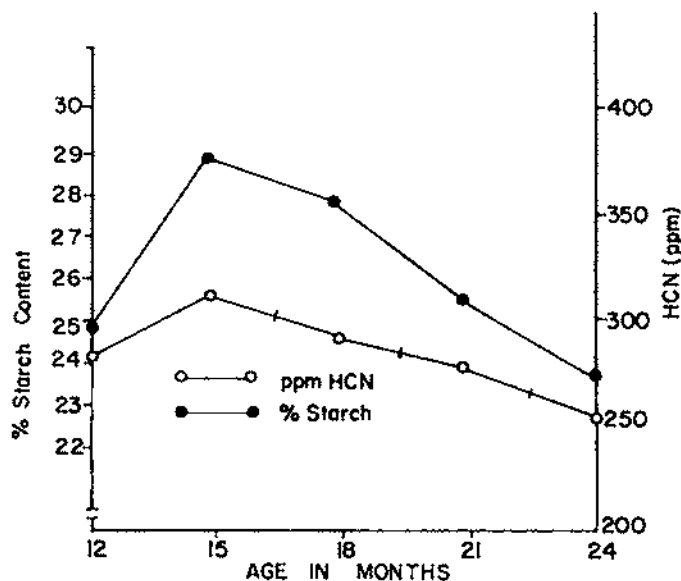
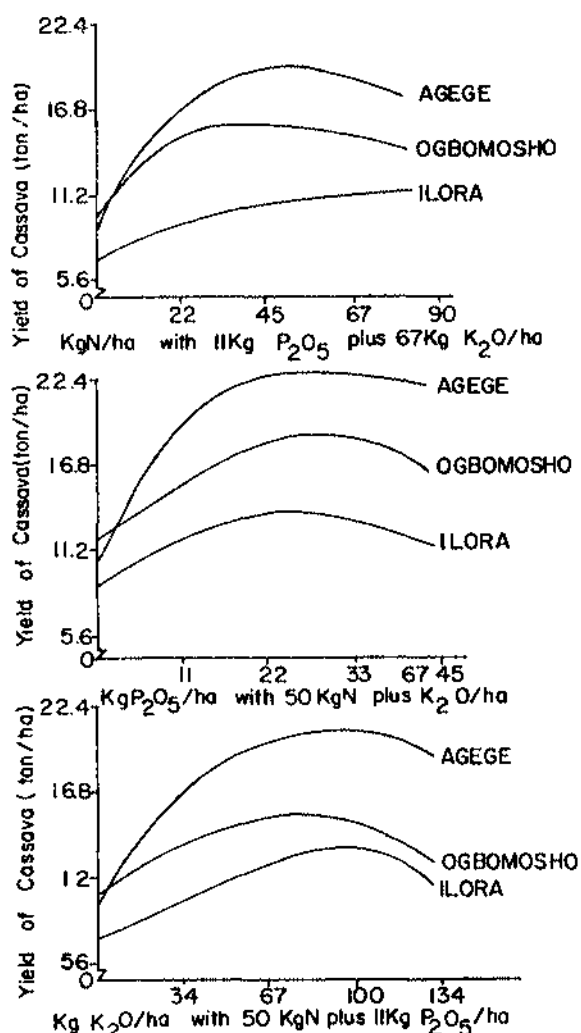


Fig. 3. The relationship between % Starch HCN content and age at harvesting.



Figs. 4. Response of Cassava to N,P,B, K-Fertilizers(2)

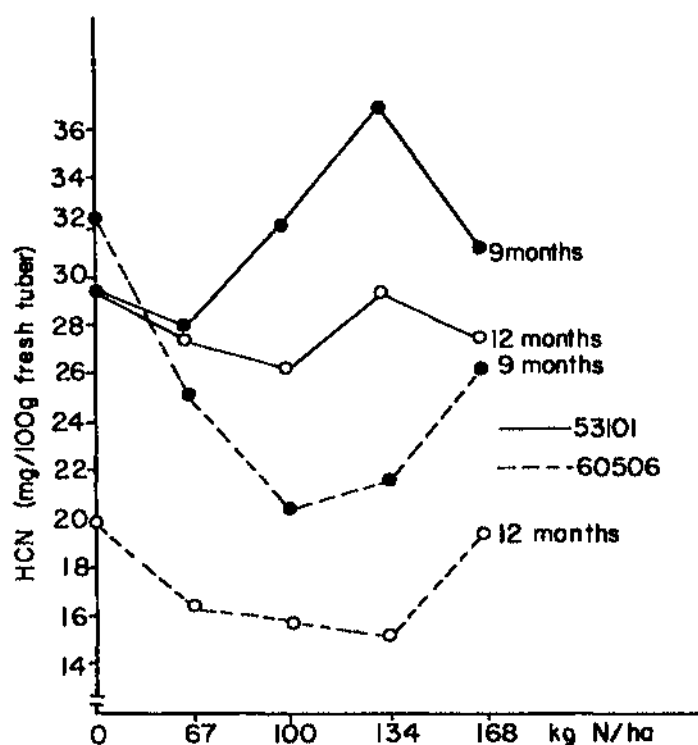


Fig.5. The influence of Nitrogen and length of growing periods on HCN content of Cassava varieties

DISCUSSION

The possible reduction of cyanide content of the cassava cultivar 60506 with increasing nitrogen application suggests that tubers of low toxicity might be produced from a 'bitter' cultivar by appropriate applications of N fertilizer. Sinha²⁶ observed that cyanide in cassava tubers of particular cultivars was markedly decreased by 100 mg n/ha applied as a foliar spray. The reported increase in the glucoside content of the leaves and roots of cassava⁹ by N application may have been only a cultivar, and not a specific characteristic. Nitrogen dosage above 67 kg N/ha reduced starch yield of the cultivar 53101, while N levels up to 100 kg/ha tended to increase the starch yield of the cultivar 60506.

ACKNOWLEDGEMENT

The authors express appreciation to Mr. P.S.I. Makam for assistance in the field work, to Mr. J.A. Williams for laboratory analysis, and to Professor A.A.A. Fayemi for reading the manuscript.

REFERENCES

1. Amon, B.O.E. (1965) The response by crops in a rotation to nitrogen, phosphorous and potassium in the savanna zone of Western Nigeria. Commonwealth Technical Cooperation, Africa Publication 98.
2. Amon, B.I.E. & Adetunji, S.A. (1970) Review of soil fertility investigations in Western Nigeria. Research Report No. 55 Res. Div. Min. Agr. Nat. Res. Western Nigeria.
3. Anon. (1961) Agriculture Division, Annual Report 1959-1960. Official Document No. 21 Min. of Agric. Eastern Nigeria.

4. Anon. (1962) Agriculture Division. Annual Report 1960-1961. Official Document No. 21 Min. of Agric. Eastern Nigeria.
5. Anon. (1958) Nigeria, Fed. Dept. of Agric. Res. Half-year report No. 3.
6. Anon. (1963) Annual Report 1961-1962. Research Division, Min. Agric. Nat. Res. Western Nigeria.
7. Anon. (1970) Identification and cultivation of currently recommended improved cassava varieties. Nigeria Fed. Dept. Agric. Res. Memo. 93.
8. Association of Official Agricultural Chemists (1965). A.O.A.C. Official methods of analysis 10th ed. p. 341. Washington, D.C.
9. Bruijn, G.H. de (1971) Etude des caractere cyanogenetique du manioc (*Manihot esculenta* Crantz). *Meded. Land-houwhogeschool Wageningen*.
10. Chant, S.R. & Beck, R.D. (1968) A preliminary investigation on the effect of mosaic virus on cassava utilization in Nigeria. *Trop. Agric. (Trinidad)* 35, 59-64.
11. Coursey, D.G. (1973) Cassava as food: toxicity and technology. In *Chronic cassava toxicity: proceedings of an interdisciplinary workshop*. London, England, Jan. 1973. Int. Develop. Res. Centre Monogr. IDRC-O10c Ottawa, Canada.
12. Ekandem, M.J. (1964) Cassava investigations carried out in Northern Nigeria; 1958-62. Federal Dept. Agric. Res. Memo. 55.
13. Ekandem, M.J. (1970) Cassava research in Nigeria before 1967. Fed. Agric. Res. Memo 103, p. 15.
14. Ekpechi, L.C. (1967) Goitrogenic activity of cassava (a staple Nigerian food). *Nature (London)* 210, 1137-8.
15. F.A.O. (1971) *Production Year Book*. Vol. 25, FAO, Rome.
16. Franzke, C.J. (1939) A study of sorghum with reference to the content of HCN. South Dakota Agricultural Exp. Sta. Bul. 1.
17. Harms, C.L. & Tucker, B. (1973) Influence of nitrogen fertilization and other factors on yield, prussic acid nitrate and total nitrogen concentration of sudan grass cultivars. *Agron. Journal* 65, 21-5.
18. Ketiku, A.O. & Oyenuga, V.A. (1970) Preliminary report on the carbohydrate constituents of cassava roots and yam tubers. *Niger, J. Sci.* 4, 25-30.
19. Lampe, S. (1970) FAO/M.A.N.R. Fertilizer Programme, Western State, Nigeria. Yield results 1969, Ibadan.
20. Nicholls, L. (1951) *Tropical nutrition and dietetics*, 3rd ed. Bailliere, London.
21. Oke, L.O. (1968) Cassava as food in Nigeria. *Wld, Rev. Nutr. Diet* 9, 227-50.
22. Oshuntokun, B.O. (1969) Cassava diet and a chronic degenerative neuropathy: an epidemiological study. *Nigerian J. Sci.* 3, 3-15.
23. Oshuntokun, B.O. (1972) Chronic cyanide neurotoxicity and neuropathy in Nigerians. *Plant foods for human nutrition*. 2, 215-66.
24. Oyenuga, V.A. & Amazigo, E.O. (1957) A note on the hydrocyanic acid content of cassava. *W. Afr. J. Biol. Chem.* 1(2), 39-43.
25. Patel, C.J. & Wright, M.J. (1958) The effect of certain nutrients upon the hydrocyanic acid content of sudan grass grown in nutrient solution. *Agron. Jour.* 50, 645-647.
26. Sinha, S.K. (1969) Cyanogenic glucoside production and its possible control in cassava. *Indian Journal of Plant Physiol.* 12, 140-7.
27. Williaman, J.J. & West, R.M. (1915) Notes on the KCN content of sorghum. *Journ. Agric. Res.* 4, 179-85.

TABLE 1

Effect of length of growing periods on the yields (ton/ha)
of standard and local cassava varieties (1 ton/acre =
2.5 ton/ha)

Trial location	Variety					
	53101			Best local		
	Crop age in months			Crop age in months		
	12	18	24	12	18	24
Akure	27.5	33.8	46.0	28.3	39.8	50.5
Iloria	23.0	30.3	40.3	21.3	31.8	39.0
Agege	29.0	34.0	34.3	17.5	16.3	24.5
Benin	23.3	31.0	40.0	22.5	34.0	39.5
Badegi	22.3	20.3	31.5	15.3	14.8	19.5
Ilorin	15.8	26.3	40.5	9.3	15.3	22.8
Osara	21.5	31.8	44.0	18.3	22.5	22.3
Mean yield	23.3	29.5	39.3	18.8	24.8	31.5

(Source: FDAR Memo 103 p. 15)

TABLE 2

Analysis of cassava tubers, Umudike 1965 variety trial

Variety	Dry matter	Starch content	% HCN per 100 peeled roots	Kg gari from 1 ton unpeeled roots
53101	40.45	15.40	0.031	323.5
60444	39.31	15.40	0.033	252.8
60447	41.39	13.20	0.021	252.8
60506	41.89	15.66	0.023	252.8
44086	39.08	14.20	0.026	305.3

(Source: FDAR Memo. 103)

A FIELD EXPERIMENTAL APPROACH TO MAXIMIZING STARCH YIELDS FROM CASSAVA IN INDONESIA

M. Rosanow*

SUMMARY

By plotting yield of starch per unit of area against crop age for different cultivars, locations and planting dates, curves with maxima are obtained. Although the occurrence of such maxima determines the best moment for harvesting each particular plot, in practice a compromise is made, taking account of harvesting and processing capacity and choosing the length of the working season which is also constrained by other labour demands. Obtaining data by the method described provides a guide for the effective organization of harvesting and processing operations.

RESUME

En comparant le rendement en amidon par unité de surface avec l'âge de la plante pour les différents cultivars, lieux et dates de semis, on obtient les extrêmes des courbes. Bien que les extrêmes représentent la meilleure période pour la récolte de chaque parcelle, dans la pratique, on adopte une voie moyenne en prenant en compte la capacité de récolte et de transformation d'une part, et en choisissant la durée de la saison de travail qui est par ailleurs soumise aux demandes de main-d'œuvre dans d'autres secteurs. La détermination des données par ce procédé permet une organisation plus adéquate de la récolte et des opérations de transformation.

RESUMEN

Se obtuvieron curvas con máximo al graficar rendimiento de almidón por unidad de área contra: edad de cultivo para diferentes cultivares, localidad y fecha de siembra. Si bien que la ocurrencia de esos máximos determina el mejor momento para cosechar cada lote particular, en la práctica se hace un compromiso tomando en cuenta la capacidad de cosecha, procesamiento y seleccionando la duración de la temporada de trabajo, la que también se encuentra restringida por otras demandas referentes a la mano de obra. La obtención de datos por el método que se describe provee una guía para la organización efectiva de la cosecha y el procesamiento de operaciones.

INTRODUCTION

Knowledge of factors determining starch accumulation in the roots is of value when cassava is grown for the purpose of starch production in order to optimise the time of harvesting for this purpose. Well organized cooperation between plantations and the factory allowed maximum production of the end product at a high standard quality.

Before World War II, Amsterdam Ltd. (H.V.A.) produced 55-60 thousand tons of cassava starch in Indonesia and was one of the largest producers. Cassava crops were grown on five plantations in rotation with sisal, sugarcane and leguminous crops, and much care was taken to maintain conditions ensuring high yields of all crops grown. Recently renewed interest and a favourable political climate may lead to reconsideration of the economic possibilities of this kind of enterprise.

REVIEW

Cultivar effects

Not only do the different cultivars produce highly differing total production of roots and starch within a certain period of time, but they may also vary in growth rate and development.

Fertility effects

When grown under conditions favouring the production of high root-yields, the rate of starch accumulation is often lower in comparison with that in a crop growing under less favourable conditions. On the other hand, excessive development of aerial parts of the plant, promoted by unbalanced nutrient supply is associated with low accumulation of starch in the roots.

*Wageningen, Holland.

Climatic effects

Temperature

Dulong² showed that starch accumulation is favoured by cool weather conditions. This observation supported the findings of Tourneur³ that a crop grown at high altitude is richer in starch as compared with a lowland crop. When grown under conditions of relatively high altitudes, cassava often flowers.

Light intensity

In Indonesia shading cassava invariably leads to losses in yield. Seasons of unusually prolonged rains are usually associated with reduced rate of accumulation of starch in the roots and reduced root yields of the fields harvested in the early part of the working season. According to Bolhuis¹, a day length of about twelve hours is optimal for the development of cassava. The increase in leaf area index (LAI) with reduced light intensity which has been found by Williams and Ghazali⁴ is not sufficient to maintain an unchanged level of accumulation of starch in the root systems of shaded plants.

Precipitation

Effects of prolonged rainfall are confounded with a decrease in the number of sunshine hours and no data clearly attributable to precipitation are available. However, early rains at the end of the dry season may lead to new growth of the aerial parts of the plant accompanied by a sharp drop in the stored starch content of the roots.

ENVIRONMENT, MATERIALS AND METHODS

Environment

Data in this paper have been obtained from Eastern Java (Indonesia). Fig. 1 gives the range of climatic conditions in this area. The total annual rainfall amounts to about 2,000mm (80 inches) and there is a distinct dry season of about four to five months (June to October). The planting period of cassava starts after the first rains (December) and ends in March-April. The length of the working period is limited by the start of the wet monsoon because at that time the planting of paddy requires much attention, rice being the most important subsistence crop. The remaining labour is needed for land cultivation, planting of the new cassava crop and sowing the leguminous crops for green manure.

Materials

Two cultivars were used, 'Singapore', a sweet cultivar and 'ISPP', a bitter cassava.

Methods – Field experiments

Each experiment consisted of two cultivar treatments, with six replications. Each plot contained $22 \times 31 = 682$ plants, and the harvest comprised 15 samples of 20 plants from every second row (thus omitting border rows and end plants), leaving one standing row between each sample row. The sampling usually started in September (at the crop age of 6-9 months) and ended in November of the following year. In each category of the crop (plantation, cultivar, month of planting etc.) a number of such experiments was undertaken each year.

RESULTS

Fig. 2 illustrates graphically the mean results of a number of these experiments of the same year, carried out with the sweet cultivar 'Singapore'. For ease of comparison all data are calculated as percentages of the maximum. Smooth curves are drawn fitting the measured data. The yield of roots shows a slight but steady increase up to the age of about 19-20 months (Fig. 2). In contrast, the starch content reaches its maximum after only 16-18 months. When the results are compiled over a number of years, the lines of Fig. 3 and 4 are obtained, showing the course of the 'starch-yield-curves' in four different plantations and for the two cultivars. In three of the four plantations there is no great difference in the position of the maxima between the experimental results of one (cultivar/date of planting) category. Cassava planted in December reaches its optimum yield in the months May-June (18-19 months). However, on the Galuhan

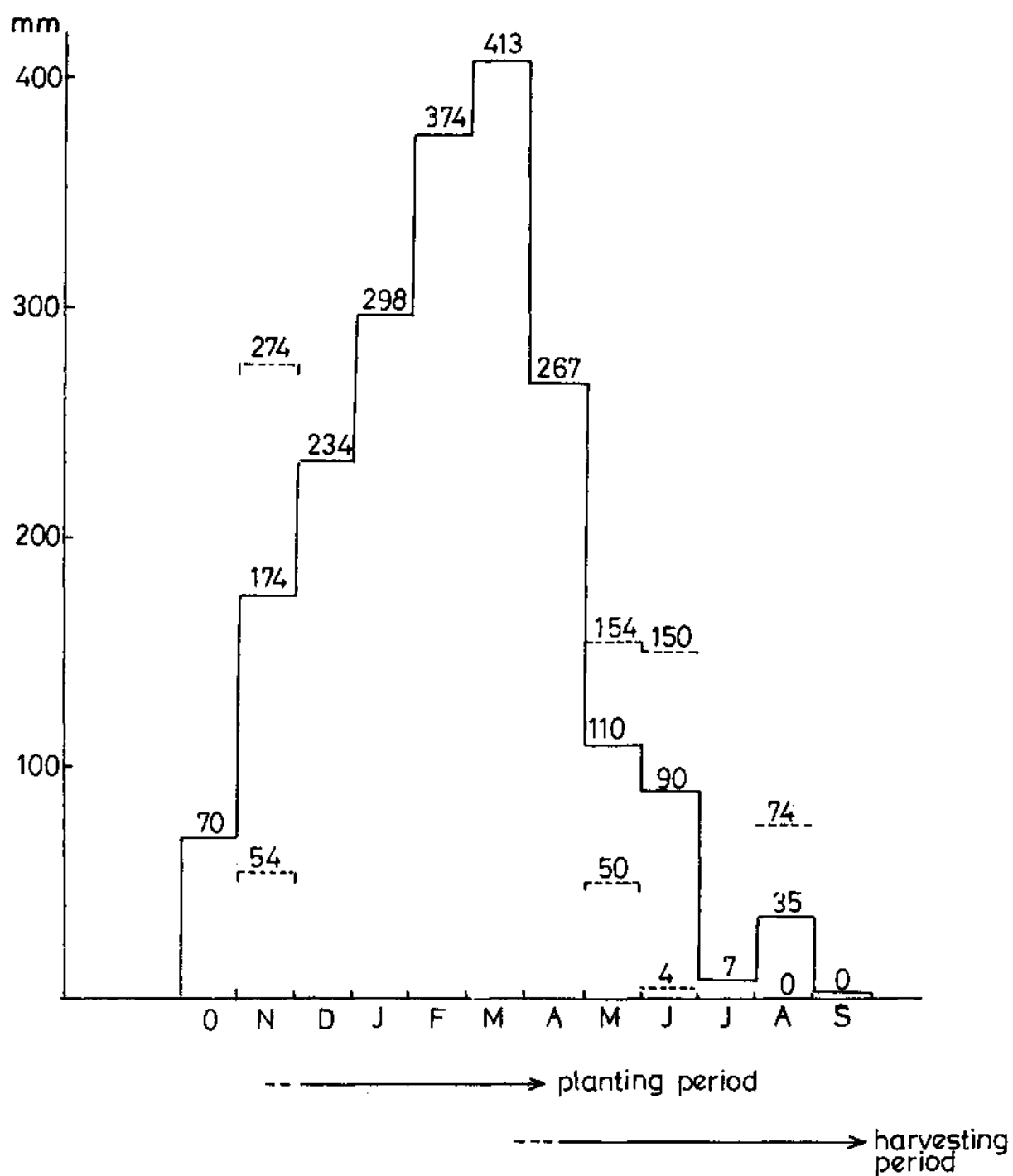


Fig. 1. Mean rainfall Karang Dinoio plantation (East Java).

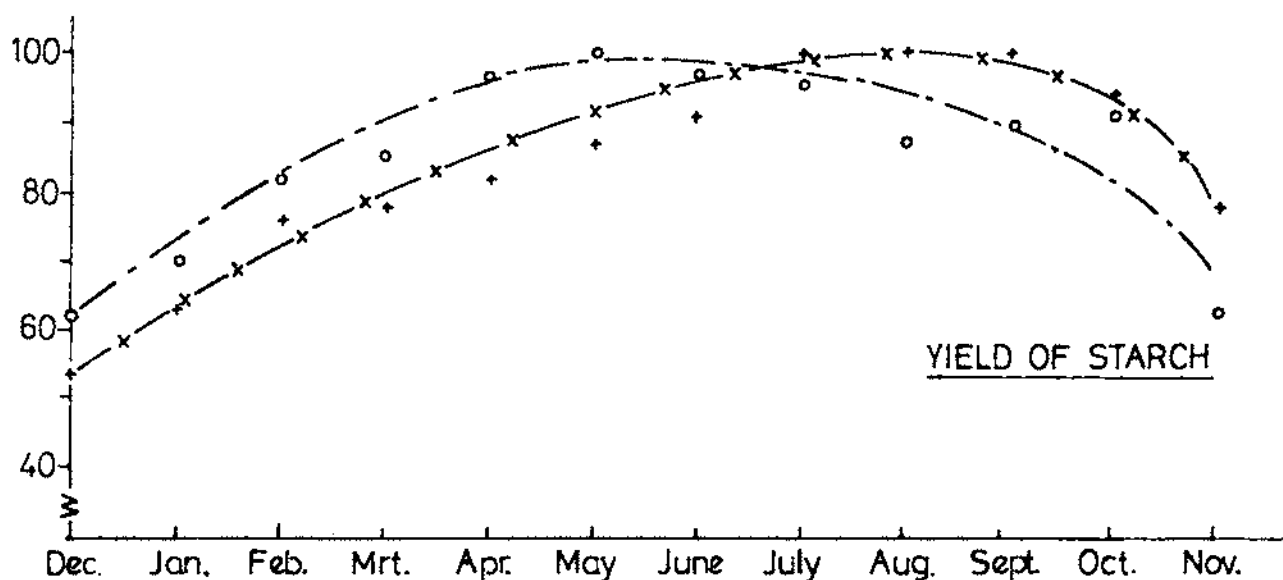
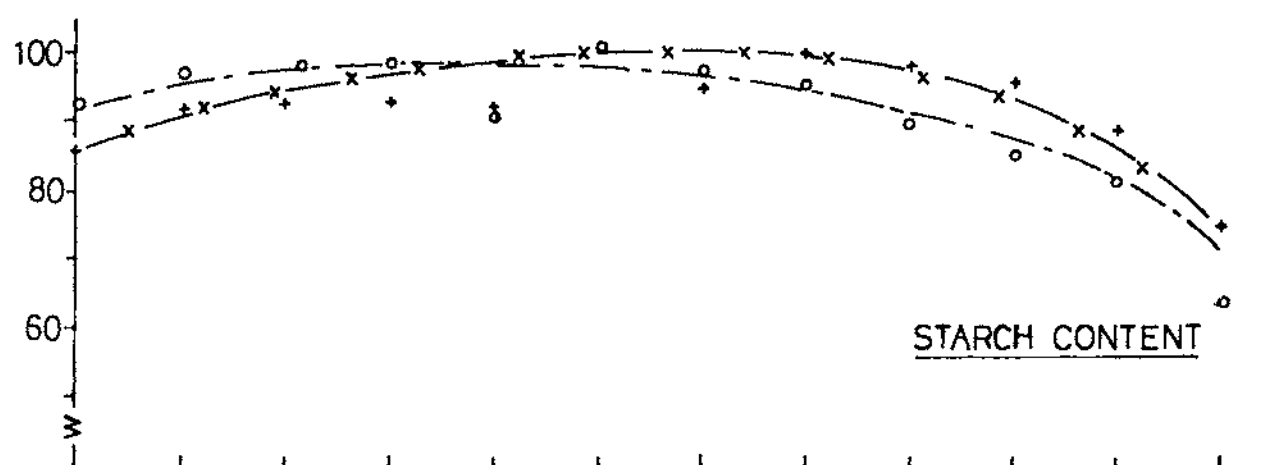
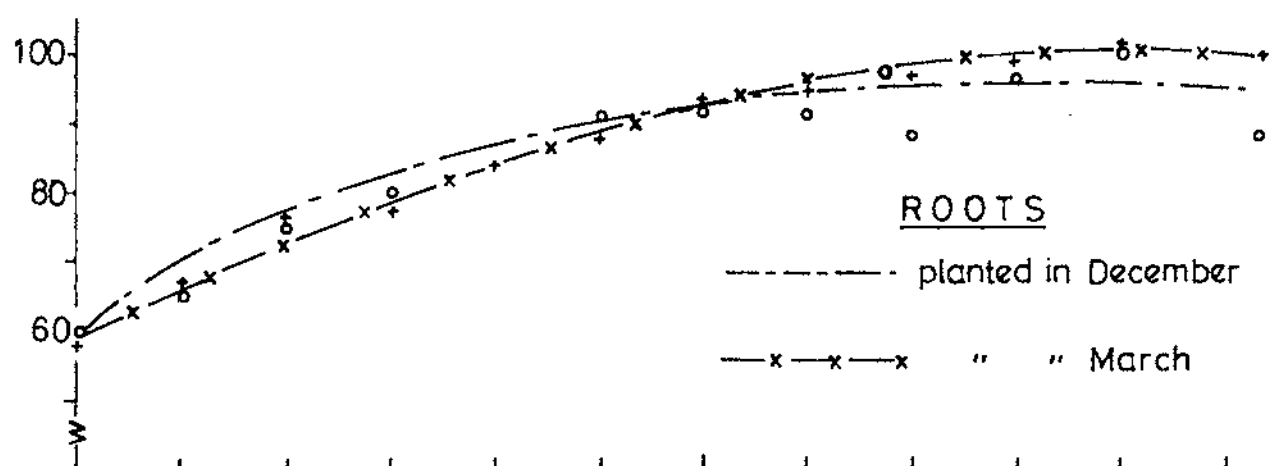


Fig.2 Results of two periodically harvested field experiments with two different planting dates. (Results calculated as percentage of optimum) Cultivar Singapore.

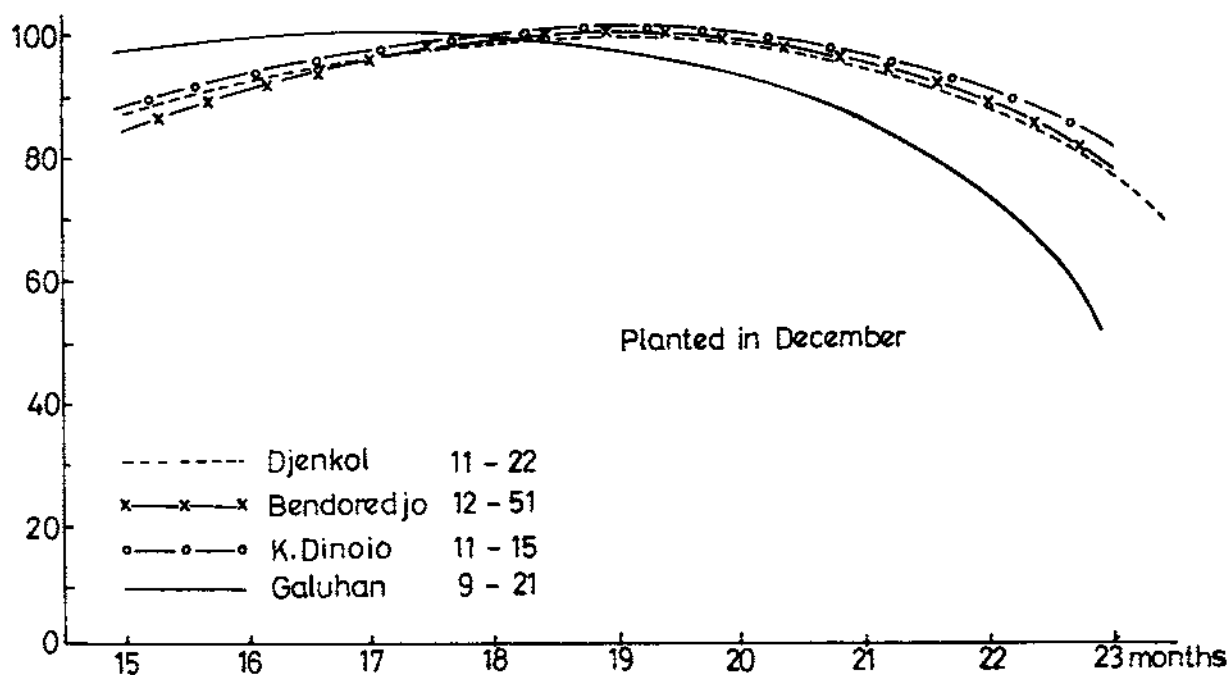
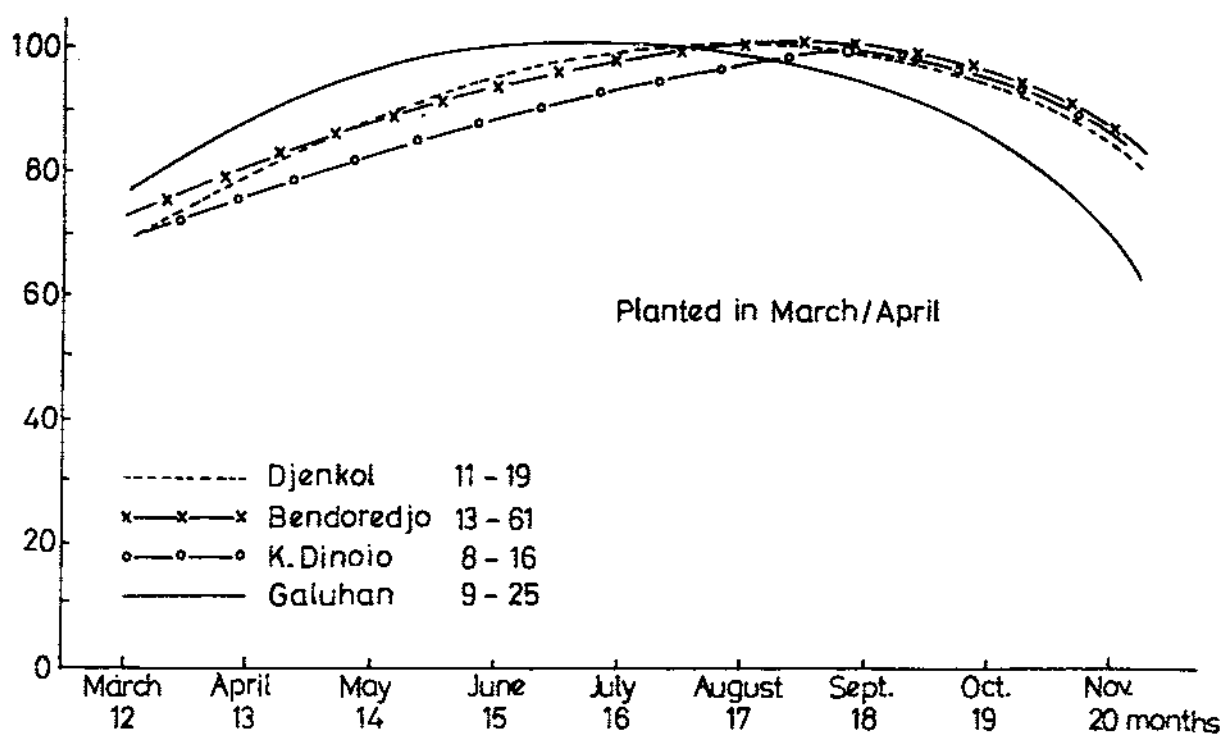


Fig. 3 Mean starch yields expressed as percentages of optimum yield (Data from four plantations; first figure = number of years, second figure = number of experiments). Cultivar Singapore.

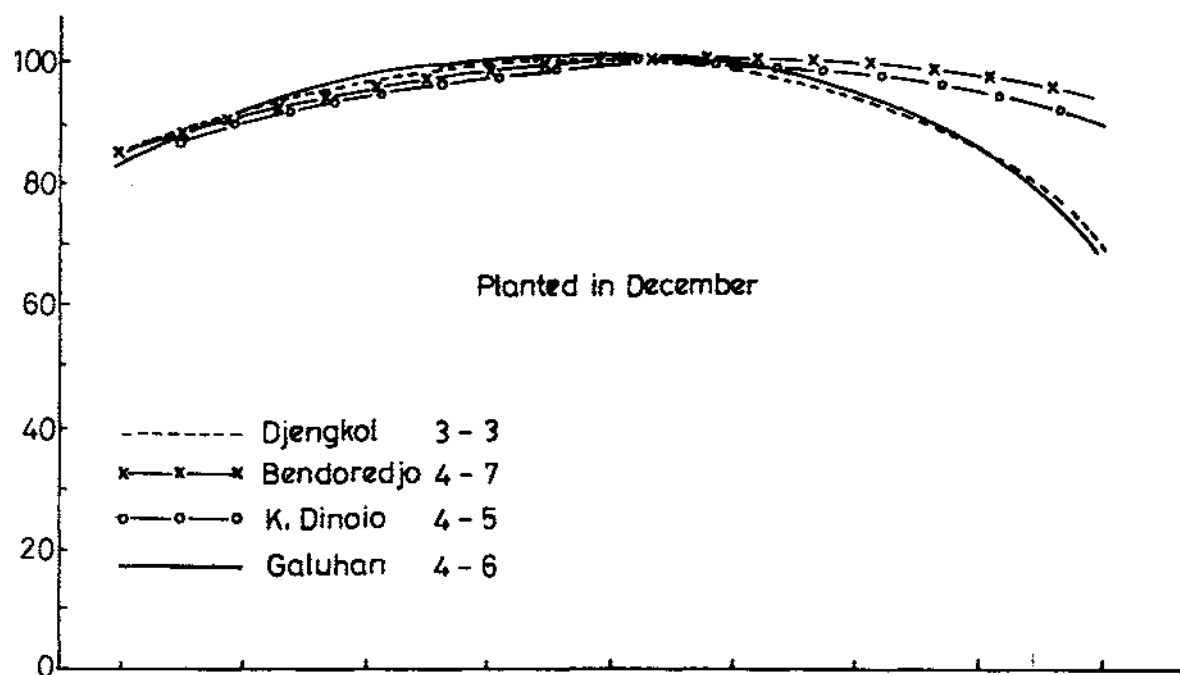
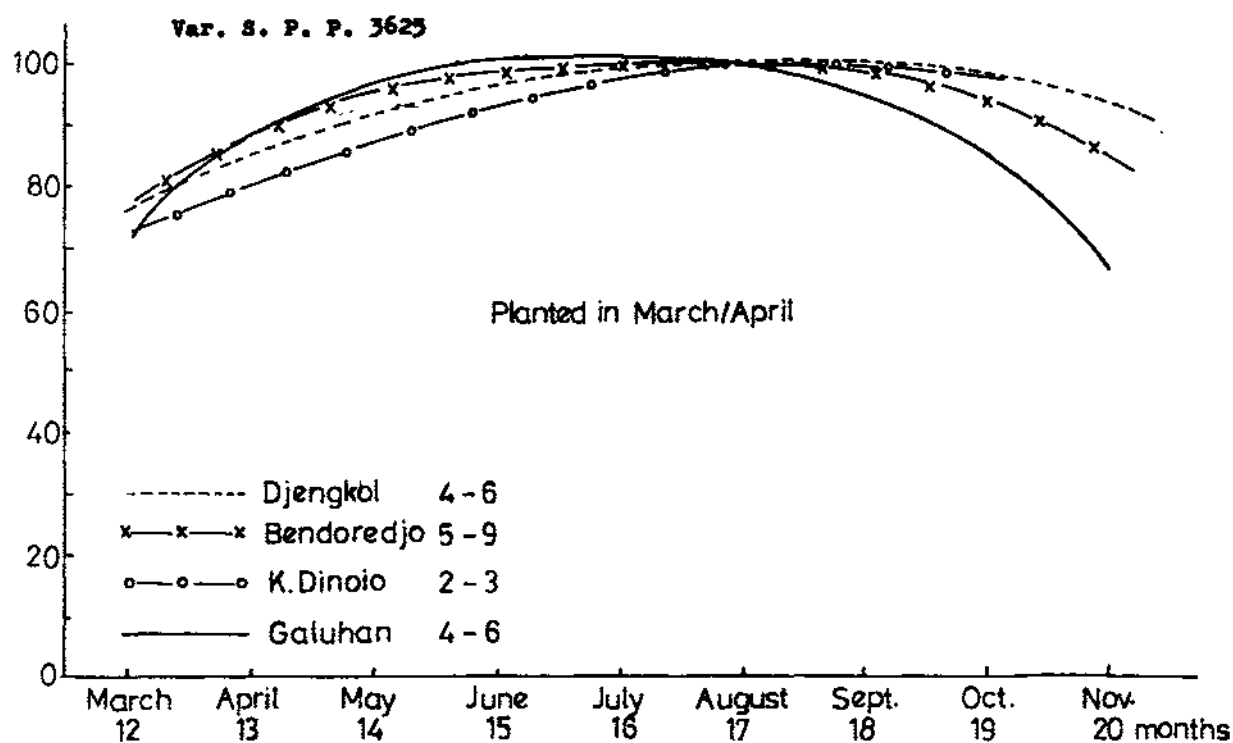


Fig. 4 Mean starch yields expressed as percentages of optimum yield (Data from four plantations; first figure = number of years; second figure = number of experiments) Cultivar S.P.P.3625.

plantation, the optimum is reached after 15-16 months, and is followed by a steady decline. The curves of the plantings of February-March reach the optimum value in August-September and tend to show more variation between the different plantations. Here also the behaviour of cassava on the Galuhan plantation is anomalous.

DISCUSSION

The observed differences between the different categories of the crop in starch accumulation make possible adjustments to the sequence of harvesting to approach maximum yields. When setting up the processing operation, the number of days necessary for the processing of each category (cultivar at one planting date) is calculated on the basis of the size of its area, the yield estimates of each plantation, and the capacity of the factory. This fixes the total length of the working period of the processing plant. The use of the starch-yield progress curves make it possible to calculate what amount of starch is lost when any particular category is harvested earlier or later than the optimal month (for this purpose the actually calculated losses are expressed in tons and not in relative values.) Hence one can determine the date of starting the processing operation which will minimize the total losses.

APPLICATION OF THE SYSTEM

This system of working proved efficient in spite of limitations caused by the following:

1. The starch-yield progress curves were constructed on the basis of average figures over several years. The annual deviations from the average figures could be considerable, especially when weather conditions at the end of the growing period differ from the 'normal' conditions. However, the climate of the region was rather steady, and the observed annual deviations in yields in most plantations were usually not great enough to affect the best course of processing that had been planned.
2. In practice it was not always possible to follow strictly the precalculated system of harvesting. Sometimes the fixed system of crop rotation requires changes in the working scheme. It may also be possible that requirements of the processing plant will call for alterations in the sequence of harvesting with regard to the quality of the final product.

To evaluate the practical usefulness of the experimental work, schedules based on production using the average production curves were checked several times at the end of the year when the scheme that would have been best in that particular season could be determined. It was found that for the cultivars 'Singapore' and 'SPP' amounts of starch corresponding to 95 and 98 percent respectively of the maximum production could be actually recovered.

The study of the rate of accumulation of starch is clearly important in the evaluation of different cultivars.

Attempts to adjust the processing operation in any one particular year by using the field experimental results of the same season are not very promising, and the use of average figures over several years provides an effective alternative basis for planning.

REFERENCES

1. Bolhuis, G.G. (1966) Influence of length of the illumination period on root formation in cassava (*Manihot esculenta* Pohl.) *Neth. J. Agr. Sci.* 14,251-5.
2. Dulong, R. (1971) Le manioc a Madagascar. *Agron. Trop.* 26, 791-829.
3. Tourneur, M. (1940) Congr. du Manioc et des plantes féculentes de terr. de l'Union Franc. Inst. Col. de Marseille, pp. 58-62.
4. Williams, C.N. and Ghazali, S.M. (1969) Growth and productivity of tapioca (*Manihot utilissima*) I. Leaf characteristics and yield. *Exp. Agr.* 5, 182-94.

ACKNOWLEDGEMENTS

References to literature data obtained in other countries than Indonesia are taken from a recent M.Sc. thesis by E. Hoving (Wageningen University), whose cooperation is hereby kindly acknowledged.

A CULTIVAR TRIAL WITH YAMS IN THE BRITISH SOLOMON ISLANDS

D.E. Gollifer*

SUMMARY

Fresh weight yields of eight cultivars of *Dioscorea alata* ranged from 15-37 t/ha and are thus comparable with those in the West Indies despite a growing period of about 200 days which is one month shorter. During 116 days of storage red pigmented tubers lost very much more weight (23%) than white fleshed (8.7%) in *D. alata*. *D. esculenta* tubers lost 24.6% in the same period. At mid-storage the moisture content had increased above that at harvest suggesting that under the conditions of the storage trial respiratory loss of weight was of major importance. The pigmented cultivar Lawanihara was significantly higher yielding than all other cultivars in the trial.

RESUME

Le poids frais des rendements de huit cultivars de *Dioscorea alata* a donné de 15 à 37 t/ha et sont ainsi comparables à ceux des Antilles, bien que la période de croissance n'a été que de 200 jours environ, ce qui représente une réduction d'un mois. Pendant 116 jours de stockage, les tubercules de pigmentation rouge ont perdu beaucoup plus de poids (23%) par rapport aux tubercules blanches, 8.7% en ce qui concerne *D. alata*. Les tubercules de *D. esculenta* ont perdu 24.6% dans la même période. A la mi-stockage la teneur en humidité s'est accrue par rapport à celle enregistrée à la récolte, ce qui laisse supposer que dans les conditions où le stockage a été expérimenté, la perte de poids due à la respiration avait une incidence non négligeable. Le cultivar Lawanihara pigmenté avait un rendement nettement supérieur à celui des autres cultivars soumis à l'essai.

RESUMEN

El rendimiento en peso fresco de ocho cultivares de *Dioscorea alata* varío de 15-37 t/ha, comparable por tanto al de las Indias Occidentales a pesar de que el período de crecimiento, de cerca de 200 días, es un mes más corto. Durante 116 días de almacenamiento los tubérculos con pigmento rojo perdieron mucho más peso (23%) que los de pulpa blanca (8.7%) en *D. alata*. Los tubérculos de *D. esculenta* perdieron 24.6% en el mismo período. A la mitad del período de almacenamiento el contenido de humedad se había incrementado por arriba del que se tenía a la cosecha, lo que sugiere que bajo las condiciones de almacenaje de la prueba, las pérdidas de peso por actividad respiratoria fueron de las más importantes. El cultivar pigmentado Lawanihara fué significativamente más alto en rendimiento que todos los otros cultivares empleados en la prueba.

INTRODUCTION

Yams (*Dioscorea* spp.), sweet potatoes (*Ipomoea batatas* (L.) Lam) and taro (*Colocasia esculenta* (L.) Schott) are major food crops in the Solomon Islands. Barrau³ has discussed the differing ecological requirements and preferences among the crops. Sweet potatoes are grown both by the taro and yam-planting communities. Taro production tends to be on the decline, while yam production is being maintained in the traditional yam growing areas.

The two most important yam species are *D. alata* L. and *D. esculenta* (Lour.) Burk. *D. bulbifera* L., *D. nummularia* Lam. and *D. pentaphylla* L. are sometimes planted, but more often collected from wild plants².

Mean annual rainfall exceeds 3.0 m for most coastal areas and is well distributed and a possible 8.0 m or more falls in the mountain ranges near the centre of the main islands. Mean maximum temperatures seldom exceed 31°C or mean minimum fall below 21°C, and relative humidity is about 80 percent throughout the year.

Many of the coastal soils are over raised coral reefs and generally deficient in available nutrients¹.

*Data Experiment Station, British Solomon Islands

MATERIALS AND METHODS

Cultivar trial

Eight cultivars of *D. alata* from Malaita were planted on 11 September 1970. In a three-replicate, randomized block experiment (excluding guard rows), plot size was 0.0018 ha with 49 plants spaced at 0.6 x 0.6 m (26,888 setts per hectare). Land was newly cleared from 4.5 m high bush. The ground was dug and loosened to a depth of about 35 cm and the diameter of the cultivated planting area for each sett was approximately 35 cm. The tubers were cut into setts nine days before planting (each sett being marked as in local practice to indicate the end taken from nearest the tuber head.) The mean weight of each sett was 88 g. and planting rates are shown in Table 1.

One sett was planted at each stand so that its top was three to four cm. below the surface. No hilling was done, the cultivated areas being only slightly higher than undisturbed ground. This is the standard planting procedure for the 'Kwara'ae' district of Malaita.

One stake of about 2.4 m height was provided 18 days after planting for each plant. No fertilizer was used. Harvesting was on 29 March 1971, 199 days after planting. Tubers were dug with digging sticks, which is the normal practice.

Storage trial 1

Harvested tubers were used in a storage trial, together with tubers from two other *D. alata* cultivars. The tubers were weighed four days after harvest and then placed on wooden shelves in a well ventilated rat proof store room. Only sound undamaged tubers were selected. The design was four randomized blocks, and each experimental unit comprising 5.0 kg of tubers.

Tubers were weighed at monthly intervals and the percentage weight losses calculated. Sprouting was assessed at monthly intervals, by scoring for the amount and length of sprouts on the following scale: 0 = no sprouting; 1 = slight sprouting; 2 = moderate; 3 = excessive sprouting.

The storage trials started on 2 April 1972, and were terminated after 172 days' storage.

Storage trials 2 and 3

These trials used a non-pigmented cultivar of *D. alata*, 'Inemaui', and of *D. esculenta*, 'Fananiu'. The trials were to determine the rate of weight loss during storage, and to determine the extent that this was due to moisture changes or other losses.

Storage commenced at seven and two days respectively after harvest for the *D. alata* and *D. esculenta* cultivars. *D. alata* tubers were stored for 213 days and those of *D. esculenta* for 123 days.

Tuber moisture was determined at monthly intervals in tubers selected at random by oven drying slices for 24 hours at 100°C. Sprouting was assessed as before. Randomized blocks had five replicates for *D. alata* and four for *D. esculenta*.

RESULTS

Cultivar trial

From Table 1 it can be seen that cultivar 'Lewanihara' had a significantly higher yield than the seven other cultivars, and there were significant differences between the tuber mean weights of cultivars. Tuber yield was not correlated with the weight of planting material used per hectare. The mean multiplication ratio of weight harvested to weight planted was 9.4. The two highest yielding cultivars had pigmented tubers. About 1 percent of tubers were damaged in a way similar to that described for *Heteroligus* sp. in West Africa, but here *Papuana* sp. is the pest involved.

Cultivar 'Asikare' suffered tuber rot of unidentified causation of about 0.55 t/ha.

At about 100 days after planting, virus-like symptoms were observed on all cultivars except for the two with pigmented tubers, cultivars 'Lewanihara' and 'Nutohuto'. Young leaves towards the tips of the shoots became curled, cupped and leathery, with brown margins and tips.

Leaf spots, from which various fungi were obtained (but not tested for pathogenicity) were observed on foliage of all cultivars at about four months after planting, but damage was very slight.

Storage trial 1

Weight losses and sprouting indices are given in Table 2. Values refer to the means of the non-pigmented cultivars¹, and of the pigmented cultivars². The red fleshed tubers had much poorer storage characterization than the white fleshed tubers, and they also sprouted more.

After 172 days' storage the non-pigmented tubers had a mean percentage loss in weight of 11.6, whilst that for the pigmented tubers was 24.5. The mean values for the sprouting indices were 42.7 and 100.0 for the non-pigmented and pigmented tubers respectively after 154 days' storage. The sprouts were removed after the weighing at 154 days' storage, but sprouts which developed after this were included in the final 'tuber' weights.

Storage trials 2 and 3

The moisture contents and percentage losses attributable to evaporation and respiration are shown in Tables 3 and 4 for the *D. alata* and *D. esculenta* tubers respectively.

After 213 days' storage the moisture content of the *D. alata* tubers had fallen from 75.4 to 69.1 percent. The total percentage loss in fresh weight for the period was 42.5 percent, the respiration loss is considered to account for 36.2 percent loss on the basis of the initial moisture content.* The sprouts were removed after weighing at 182 and 215 days of storage, and before oven drying for moisture determinations. The sprouting index at 182 days was assessed as 66.7 percent.

D. esculenta tubers lost 4.1 percent of weight due to moisture losses after a storage period of 125 days, the other weight losses, assumed to be due to respiration, were 18.6 percent** making a total weight loss of 22.7 percent. Sprouting commenced after 32 days' storage, and the sprouting index was 100 percent by 100 days.

Mealy bugs *Planococcus dioscorea* Williams¹⁴ were found on both the *D. alata* and *D. esculenta* tubers in all three storage trials and tended to be concentrated towards the head end of the tubers from which most sprouts emerged. They became apparent on the *D. alata* tubers after about 150 days of storage, and in the case of *D. esculenta* after 100 days.

No roots developed on any of the tubers in the three trials over the entire storage period.

DISCUSSION

In the 'Kware'ae' district of Malaita, the method of planting yams *D. alata* is different from that used for *D. esculenta*. In the latter, small seed tubers of approximately 0.26 kg weight are placed at the bottom of the planting hole, with the head end facing downwards. Lea¹² describes how in New Guinea, *D. alata* seed tubers are planted near the top of the planting mound. In Trinidad the normal planting procedure is for approximately 113 g. setts to be planted in ridges at a spacing of 1.2 x 0.3 m. Spacing of setts is normally wider than that used at Dala¹³.

Staking is important in its effect on yield¹³, and was considered by Chapman⁶ to increase tuber yields through greater leaf area duration, and a more efficient canopy structure.

The yields of fresh tubers ranging from 15.89 to 36.85 with a mean of 22.21 t/ha for the eight cultivars are comparable with those quoted for the West Indies, whilst the mean weight of tubers 0.58 kg, is smaller than normal⁸. This was possibly because of the close spacing used. The growing period in the trial of approximately 200 days is about a month less than that for Trinidad^{6,10}. The mean number of tubers per plant was similar to the norm for *D. alata* cultivars, and there was no correlation between the yield of tubers, and the mean number of tubers per plant.

Pests and diseases appeared to be of little importance in the trial. The leaf spots probably had little effect if any on yields, as they were not significant until towards the end of the crop cycle.

Gooding⁹ found that *D. alata* cultivars had a mean percentage weight loss after a storage period of 116 days of 14.1 percent. However, this was only accounted for by 8.7 percent for the white fleshed cultivars and 23.1 percent of the pigmented ones. The one *D. esculenta* cultivar had a weight loss of 24.6 percent. At Dala the weight losses for the non-pigmented tubers and for *D. esculenta* after 123 days' storage were similar to the values given by Gooding.⁹

Campbell *et al.*⁴ reported weight losses of 10-14 percent in *D. alata* tubers after four months' storage, and 20-24 percent at six months. By seven months weight losses had risen to approximately 47 percent. Final weight losses were similar at Dala (Table 5) to those determined by Campbell *et al.*⁴ for their untreated tubers. Sprouting was not apparent until 150 days (Table 3), whereas sprouting in Campbell *et al.*'s trial commenced after about 100 days' storage. The removal of sprouts at 182 days probably slowed down the losses due to respiration from 17.18 to 5.44 percent (Table 3).

The slight increases of moisture (Tables 3 and 4) at 59 and 91 days for *D. alata* and at 61 days for *D. esculenta* tubers suggests uptake of water from the atmosphere. Coursey⁷, working with *D. rotundata* considered that respiration accounts for considerable losses in weight of stored yams as only slight changes in

* But calculated on a dry weight basis the data given appear to indicate a respiratory loss of 27.5 percent

**Also on a wet weight basis.

the moisture content usually take place during storage. Weight losses other than those due to moisture were therefore assumed to be due to respiration in this study as no rots developed in the stored tuber.

The pigmented cultivars in the trial were the highest yielding but also the poorest; they also sprouted earlier than non-pigmented cultivars.

ACKNOWLEDGEMENTS

Thanks are due to D.G. Coursey and R.H. Booth of the Tropical Products Institute, London for helpful suggestions. The Commonwealth Institute of Entomology identified the mealybugs on the stored tubers, and the Commonwealth Mycological Institute identified micro-organisms* associated with the leaf spots. This paper is published with the permission of the Director of Agriculture, British Solomon Islands Protectorate.

REFERENCES

1. Ballantyne, A.O. (1961) *A report on the soil survey of the Guadalcanal Plain and other areas of the British Solomon Islands Protectorate. April 1959 - April 1961.* Gov't Printer, Honiara. (Mimeographed).
2. Barrau, J. (1958) *Subsistence agriculture in Melanesia.* B. Bishop Mus., Honolulu, 219.
3. ——— (1965) L'humide et le sec. *J. Polynesian Soc.*
4. Campbell, J.S., Chukwuerke, V.O., Teriba, F.A. and Hoa-Shu, H.V.S. (1962) Some physiological experiments with the White Lisbon Yam (*Dioscorea alata* L.) in Trinidad. III. The effect of chemicals on storage. *Emp. J. Exp. Agric.* 30, 335-44.
5. Campbell, J.S. and Gooding, H.J. (1962) Recent developments in the production of food crops in Trinidad. *Trop. Agric. (Trin)* 39, 261-70.
6. Chapman, T. (1965) Some investigations into factors limiting yields of the White Lisbon Yam (*Dioscorea alata* L.) under Trinidad conditions. *Trop. Agric. (Trin)* 42, 145-51.
7. Coursey, D.G. (1961) The magnitude and origins of storage losses in Nigerian yams. *J. Sci. Food Agric.* 12(8), 574-80.
8. ——— (1967) *Yams.* Longmans. London.
9. Gooding, H.J. (1960) West Indian *Dioscorea alata* cultivars. *Trop. Agric. (Trin)* 37, 11-30.
10. Haynes, P.H. (1967) The development of a commercial system of yam production in Trinidad. *Trop. Agric. (Trin)* 44, 215-21.
11. Johnston, A. (1960) *A preliminary plant disease survey in the British Solomon Islands Protectorate.* F.A.O. Rome (Mimeograph).
12. Lea, D.A.M. (1960) Yam growing in the Naprik area. *Papua, New Guinea Agric. J.* 18(1), 5-15.
13. Wyatt, A.W. (1963) Yams, *Dioscorea* species. *Field Crop Abstr.* 16, 145-57.
14. Williams, D.J. (1960) A new species of *Planococcus* Ferris (Coccoidea: Homoptera) on yams in New Guinea. *Papua New Guinea Agric. J.* 13(1), 39-40.

*List not included since leaf spot damage reported was very slight and no pathogenicity tests were undertaken.

Ed.

TABLE 1

Yield and planting data of yams in cultivar trial

Cultivar	Yield of tubers (t/ha)	Mean weight of tubers (kg)	Mean number of tubers/plant	Planting (g/sett)	Material (t/ha)
Lawanihara	36.85a	0.95a	1.7	104.3	2.81
Hutohuto	25.15	0.82b	1.2	78.5	2.11
Inemauri	21.49	0.59bc	1.4	78.5	2.11
Tomaa	20.96	0.45cd	1.8	112.8	3.04
Talabuli	20.61	0.59bc	1.4	83.1	2.23
Asikare	19.50	0.50cd	1.4	95.3	2.56
Rokee	17.19	0.50cd	1.3	71.7	1.95
Kai	15.89	0.27d	2.3	80.2	2.16
Mean	22.21	0.58	1.6	88.1	2.37
S.E.	±3.31	±0.08	±0.26	±5.11	±0.14
Coefficient of variation	25.9%	24.3%	27.9%	16.6%	16.6%

Mean separation by Duncan's Multiple Range Test.

Means followed by letter 'a' are significantly different from those means not having 'a' etc. (P = 0.05)

TABLE 2

Mean percentage weight losses and sprouting indices of yam tubers in storage trial

Percentage weight losses	Storage period (days)					
	31	62	94	123	154	172
Non-pigmented tubers (8 cultivars)	3.1	4.9	6.0	8.7	10.7	11.6
Pigmented tubers (2 cultivars)	6.2	7.8	9.6	14.6	21.0	24.5
<u>Sprouting indices</u>						
Non-pigmented tubers	0	0	0	14.6	42.7	-
Pigmented tubers	0	8.3	83.3	100.0	100.0	-
$\text{Sprouting index} = \frac{\text{Score}}{\text{Total possible score}} \times \frac{100}{T}$						

TABLE 3

Percentage weight losses of *D. alata* tubers after storage, showing moisture contents and changes due to moisture and respiration

Days of storage	0	28	59	91	120	151	182	213	Total
Moisture contents(%)	75.42	73.92	73.96	75.14	74.22	71.66	71.28	69.14	
S.E. $\pm$	0.63	0.24	0.84	2.10	1.38	0.80	0.92	0.84	
Moisture weight changes (%)	-	-1.40	+0.04	+1.18	-0.92	-2.56	-0.38	-2.14	-6.28
Other weight losses (%)	-	1.04	0.78	4.04	0.66	7.08	17.18	5.44	36.22
Total weight losses %	-	2.54	3.28	6.14	7.72	17.36	34.92	42.50	
Sprouting indices %	0	0	0	0	0	0	16.6	66.7	

TABLE 4

Percentage weight losses of *D. esculenta* tubers after storage, showing moisture contents and changes due to moisture and respiration

Days of storage	0	32	61	92	123	Total
Moisture contents(%)	72.58	70.75	74.08	71.03	68.53	
S.E. $\pm$	1.02	1.59	1.27	1.56	1.73	
Moisture weight changes (%)	-	-1.85	+3.35	-3.05	-2.50	-4.05
Other weight losses (%)	-	5.25	7.00	3.93	2.40	18.58
Total weight losses %	-	7.10	10.75	17.73	22.63	
Sprouting indices %	0	8.3	50.0	100.00	100.00	

AGRONOMIC STUDIES ON EDIBLE YAM IN THE GRASSLAND PLATEAU REGION OF THE UNITED REPUBLIC OF CAMEROON

S.N. Lyonga*, A.A. Fayemi and A.A. Aghoola**

SUMMARY

Root and tuber crop cultivation and production in Cameroon is outlined. A collection of 109 accessions of yam species and cultivars has been screened. Three promising cultivars, one from each important species are being tested for optimum planting period, size of planting setts, population density, staking, fertilizer responses and storage characteristics.

The earliest planting date (January) tried gave the highest yield, but even earlier dates are being tried. Setts of 375-500 grams are best for ware yams, setts of 125 grams are best for rapid multiplication; best spacing is 100 cm x 66 cm giving 15,000 plants per hectare. Tall stakes were best, and 80 kg/ha of N and 40 kg/ha of K fertilizers gave economic responses.

RESUME

La culture et la production des plantes à racine et à tubercule ont été soulignées. Une collection de 109 variétés d'espèces et cultivars d'igname a été sélectionnée. Trois cultivars à caractéristiques désirables issus de chaque espèce importante sont en cours d'essai pour déterminer la période optimale de plantation, la dimension des boutures, la densité de peuplement, le tuteurage, les réponses aux engrais et les caractéristiques de conservation.

La date de semis la moins tardive essayée (janvier) a donné le rendement le plus élevé et on essaie même des dates de semis encore moins tardives. Les boutures de 375-500 grammes sont les plus valables pour le marché, celles de 125 g pour la multiplication; l'espacement de 100 cm x 66 cm donne la meilleure densité, soit 15,000 plants à l'hectare. Les treillis longs sont les plus satisfaisants. 80 kg/ha d'engrais K sont également les plus satisfaisants du point de vue économique.

RESUMEN

Se reseña el cultivo y producción de raíces y tubérculos en Camerún. Se ha seleccionado una colección de 109 especies y cultivares de ñame. Se están probando tres cultivares prometedores, uno de cada especie importante, en cuanto período óptimo de siembra, tamaño de "estacas" de siembra, densidad de población, estacado, respuesta a los fertilizantes y características de almacenamiento.

La fecha de siembra más temprana que se probó (Enero) dió el más alto rendimiento pero aún se están probando fechas mas tempranas. Las "estacas" de 375-500 gramos son las mejores en ñame para venta, las "estacas" de 125 gm son las mejores para la multiplicación rápida; el mejor espaciamento es 100 cm x 66 cm dando 15,000 plantas por hectarea. Los estacados altos fueron los mejores 80 kg/ha de N 40 kg/ha de K como fertilizantes, dieron la respuesta económica.

INTRODUCTION

Investigations have been carried out mainly in the North West Province of Cameroon. The landform comprises a broad mainly rolling low lava plateau from 700 – 1400 m above sea level surmounting which there is a more rugged chain of high lava mountains with peaks from 1400 m to over 2500 m. The main vegetation is grassland savannah dominated at lower altitudes by *Hyparrhenia* spp and at higher levels by *Sporobolus* spp. These provide good cattle grazing pastures but are liable to dry season fires. Savanna trees, raffia palms and elephant grass (*Pennisetum purpureum*) compete in the narrow valleys and stream banks.

The climate is cool with temperatures ranging between 14°C and 25°C. Annual rainfall is between 200 and 300 cm occurring between mid-March and mid-November with a single peak around July or August. There is a marked dry season with strong dusty winds preceding the return of the rains (hamattan).

The soils mainly have volcanic parent material such as trachyte lavas and tertiary basalt. They are humic with a wide carbon/nitrogen ratio (16-20 in the surface layers), acidic (pH from 4.2 in alluvium to 5.5 in the high lava humic soils). The cation exchange capacity of surface layers is high (10-28) with low total exchangeable bases, the combined figure for calcium, magnesium and sodium seldom exceeding 1-4 me/100 g of soil. These soils are usually deficient in the main nutrients, mainly as a result of leaching, burning and erosion which constitute serious problems. Fertilization and conservation should therefore, be important considerations in their management.

* Institute of Tropical Agronomic Research and Food Crops (IRAT), Bambui Station, United Republic of Cameroon, West Africa.

**University of Ibadan, Department of Agronomy, Nigeria.

Cameroon is an agricultural country and will for some time remain so. Table 1 gives production figures of the main food crops of the Republic and the target tonnages for 1976.

Until the creation of the West Cameroon Yam Scheme² in 1962, almost all yams were imported from neighbouring Nigeria at prices ranging between 290 U.S. dollars to 387 U.S. dollars per ton. The Government then decided on a policy of self-sufficiency for this commodity by assisting farmers to produce it. Between 1962 and 1965 Government purchased and sold to farmers over 167,000 sets of 'Ogoja' yams from the former Eastern Nigeria. Later, attention turned to the Central South Province of Cameroon where the 'Mban' cultivar of white yam (*Dioscorea rotundata*), though smaller in tuber size and lower in yield, was a satisfactory substitute, especially in the hot lowlands.

Root crops are generally the first on newly opened land. Yams are usually planted during the dry season (November to January) on ridges or mounds and mulched with grass. Natural or artificial stakes are used. In the yam valleys of North Cameroon short stakes (about 1 m) are preferred and intercultivation with other crops is unusual. Generally, trifoliate yam (*Dioscorea dumetorum*) is not staked.

The practice of 'topping' to produce 'ware' yams and a subsequent crop of 'seed' yams is used by the Ejagham tribe bordering Nigeria and by the growers in North Cameroon and by the Oshei farmers in North West Province.

Staking and harvesting of yams are among the most costly operations in their production. The 'ton-key', a digger made in North Cameroon is regarded as an efficient harvesting tool.

With increasing production and the desire of farmers to benefit from higher prices in the off-peak season, storage problems require urgent consideration. At present, prices fluctuate from 97 dollars during peak harvest to 290 dollars when scarce. There is also a poor infrastructure in the main areas of production for transportation and marketing.

Yams in Cameroon are not a staple even among the communities producing them. They are a cash earner and their potential in this respect compares favourably with that of any other food crop. There is therefore a need to provide technical guidance to growers whose experience with this crop is comparatively limited.

For this reason yam research started in 1970 in the North West Province.

GERMPLASM COLLECTION

A start was made by collecting local material for classification. Preliminary study and screening at Bambui Plain (1330 m) of eighty nine accessions from eight species has been completed. In addition, twenty cultivars from three species have been imported from the Caribbean. The accession list is summarized below:

Local accessions

<i>Dioscorea alata</i> L.	16	accessions
<i>D. bulbifera</i> L.	11	"
<i>D. cayenensis</i> Lam.	18	"
<i>D. dumetorum</i> (Kunth.) Pax.	16	"
<i>D. esculenta</i> (Lour.) Burk.	3	"
<i>D. liebrechtisiana</i> de Wild	2	"
<i>D. rotundata</i> Poir	17	"
<i>D. schimperiana</i> Hochst.	6	"

Exotic accessions

<i>D. alata</i>	6	"
<i>D. cayenensis</i>	4	"
<i>D. trifida</i>	10	"

Three local accessions (Table 2), 'Oshei', 'Jakiri' and 'Batibo' have showed promise in nearly all the ecological areas involved and have provided the material basis for the agronomic tests discussed below.

MATERIALS AND METHODS

The investigations began in 1970 and are still continuing. They include varietal yield tests (9 trials), cultural techniques (10 trials), fertilizer trials (2 trials), storage (2 trials), and simple chemical analysis. Trials were at sites in the following ecological zones, representative of the whole province

Bambui Plain	1330 m above sea level
Babungo	1100 m above sea level
Befang	700 m above sea level
Santchou (W. Province)	700 m above sea level.

The designs used have been simple or split-plot randomized blocks with a minimum of six replications in any trial. Plot size ranged between 20-40 plants, sown at a metre square along ridges, giving a density of 10,000 plants per hectare. With the exception of fertilizer trials, all other trials received either the same fertilizer application of 80 kg of N, 50 kg P and 120 kg of K per hectare, or 15 tons of farm yard manure or compost per hectare if fertilizers were not available. N and K fertilizer applications were split into two equal applications applied by incorporation into the top soil 60 days and 120 days after planting.

Planting was in February and early March, no mulch was applied and a weight of setts (uniform in any given treatment) between 375-500 g was used. Wooden stakes of about 3 m, each supporting four plants, were used. Except for 'time of planting' trials, replanting of any stands that failed to emerge was done with pre-sprouted material of the same source about 5-6 weeks after planting. Hand weeding was done three times, and moulding up of ridges took place around the middle of the growing season.

RESULTS AND DISCUSSION

Varietal yield comparisons

Table 3 provides data comparing the performance of four popular local varieties of white yams (*D. rotundata*) at Babungo and Santchou. 'Oshei' is now recommended for the highlands. The tuber is long and cylindrical, usually tapering to a tip. It is slightly hairy and the tuber shape varies considerably with soil type. Tuber skin is thin and flesh colour temporarily becomes dull grey on exposure to air. Another short-coming is its susceptibility to anthracnose disease (*Glomerella cingulata*) which was severe in Bambui in 1972 and early 1973. 'Bonankanda' is a lowland type and has good eating qualities.

Four common yellow yam (*D. cayenensis*) types were tested in Babungo and Bambui Plain (1330 m). Two of them, 'Balikumbat' and 'Batibo' did well, yielding 24.2 tons and 21.4 tons per ha respectively. Batibo has commercial potential, having a better tuber size and shape and better eating quality. It is now recommended to growers in both zones. However, its growing cycle is long (280-315 days) and it is often attacked by the yam beetle. Multiplication of this clone is in progress.

Trifoliate yams (*D. dumetorum*) are popular among peasants who usually sell them already cooked in local markets, hence the name 'traveller's yam'. There is much variation but little commercial potential because they harden on exposure to the atmosphere and so cannot be satisfactorily stored. If this storage problem could be solved, this species might become the most popular yam in Cameroon.

Two accessions of trifoliate yams were superior in the yield trials. 'Jakiri' has a palatability score of 66%. Clonal production is already under way. 'No. 45 ex-Dschang' has a yield range of 22.5-32 t/ha, a growing cycle of 210-240 days and acceptance rating of 60%.

Aerial yams (*D. bulbifera*) are only cultivated in a few isolated communities and have little commercial value. Two accessions, No. 17 ex-Dschang (7.8 t/ha) and No. 21 ex-Dschang (6.2 t/ha) have consistently performed better than the rest.

Yield trials have not been carried out on water yams (*D. alata*) whose performance in the zones tested has been very poor. The crude protein content however (11-13%) of some accessions is the highest recorded in our analysis.

Improvement of production techniques

The effects of staking yams:

Treatments and results are summarized in Table 4.

'Topping' of white yams (*D. rotundata*) to increase planting material:

Yam setts may cost up to 600 to 750 U.S. dollars to plant one hectare. Topping of Oshei, Mbam and Ogoja yams was done 8 weeks and four weeks before maturity. In some plots the tubers were harvested and in others tubers were left to mature in the soil. There were three controls, one in each of the harvesting periods.

A higher yield of setts (yam tops) resulted from topping 8 weeks before harvest (30% of yield), but the total yield of ware yams plus setts was depressed by about 8%. Production of setts was much less by topping only 4 weeks before the main harvest (2% of total yield) but there was no depression of total yield.

Topping 8 weeks in advance may therefore be useful if the value of setts is high enough in relation to the value of ware yams to make this economically advantageous.

Land preparation, spacing and fertilizer trial on 'Oshei' yam:

Ridges were compared with planting on flat land using four population densities; 5,000, 10,000,

15,000 and 20,000 plants per hectare. Some plots received fertilizers (usual dose mentioned earlier), others were not fertilized. Results are summarized in Table 5.

The difference between ridged and flat plot yields was not significant, but the latter produced poorly shaped yams and 7.2 percent of the tubers were exposed causing greening and drying. The yield of the two higher plant populations were significantly higher than the others, and the effects of fertilizers were also significant. This trial is being repeated.

Optimum size of yam setts:

Treatments and results are given in Table 6. Sett weight and yield were correlated and heads of tubers did better as setts than the rest of tuber. The greatest margin of profit per kilogram of material invested was obtained from 125 g setts (Fig. 1). This is therefore the best sett weight for production of further yam setts if land is not the limiting factor, whereas 375-500 g sett weight is best for ware yam production.

Optimum time of planting 'Oshei' yams at Banbui Plain:

Planting dates between January 15th and May 30th were compared. January 15th gave, by far, the highest yield, with a substantial regular reduction of yield as planting date was later. The trial has been repeated starting from the middle of October.

Fertilizer trials

Factorial trials of nitrogen, potassium and phosphate on the yield of Oshei (*D. rotundata*), 'Batibo' (*D. cayenensis*) and 'Jakiri' (*D. dumetorum*) yams were carried out at Rambui Plain (1330 m) in a low humic soil.

Treatments were:

N: 0, 80, 160 kg/ha (Urea, 45%)

P: 0, 100, 200 kg/ha (single superphosphate*, 18%)

K: 0, 120, 240 kg/ha (potassium chloride, 60%)

N and K were applied in two equal doses 60 days and 120 days after planting, while P was applied as a single dose at planting.

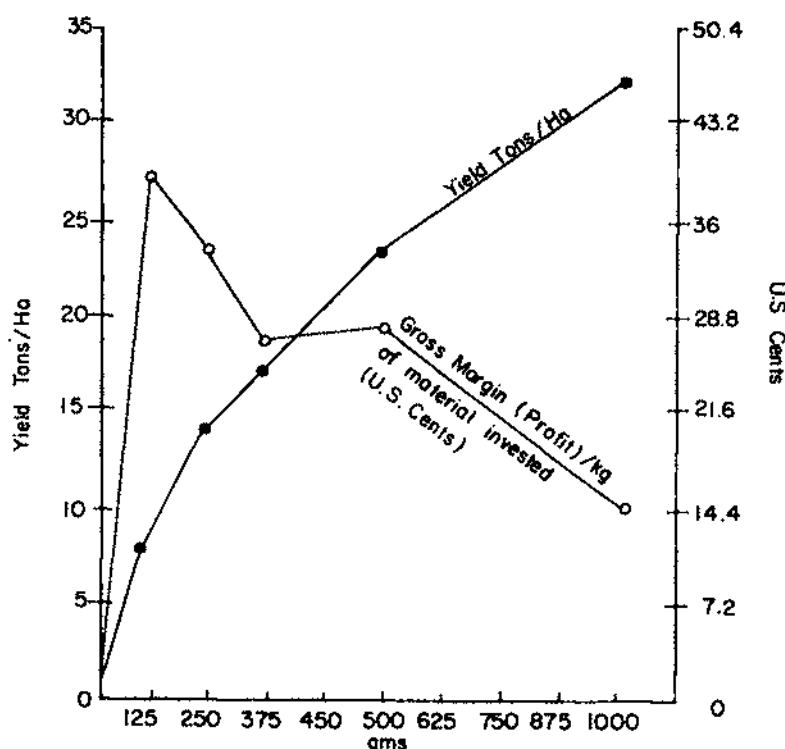


Figure 1. Graph contrasting yields with gross profit per kilograms of planting material invested (U.S. Cents).

*Any results attributed to P may be partly due to S whenever single superphosphate is used.

There was a response to both N and K and a positive interaction between them, but not to P. This agrees with previous findings.³ The economic levels of N and K are currently under investigation.

Preliminary tuber storage trials

The effects of fertilizers (NPK) on the keeping quality of 'Batibo' yam (*D. cayenensis*) were tested under room ambient temperature in wooden trays (50 kg/tray). Results were inconclusive.

ACKNOWLEDGEMENTS

Thanks are due to:

The I.R.A.T. authorities, in particular, Mr. G. Rouanet, Director I.R.A.T., Cameroon, for the encouragement, approval and financial support to carry out the investigations.

The authorities of the Department of Agronomy of the University of Ibadan, Nigeria, who have not only given guidance but also participated in the study.

The Direction of Scientific and Technical Research, Cameroon for encouragement.

REFERENCES

1. Hawkins, P. and Brunt, M. (1965) The soils and ecology of West Cameroon. 1, 106-199.
2. Ndum, S.N. (1965) West Cameroon Yam Scheme. Half yearly bulletin of the Ministry of Natural Resources, No. 3, June 1965, p. 21-4.
3. Coursey, D.G. (1967) Yams. Longmans, London.
4. Third 5 Year Economic and Social Development Plan (1971-1987) of the United Republic of Cameroon, V-VIII; p. 154-60.
5. Lyonga, S.N. (1970, 71, 72) I.R.A.T. Cameroon (Bambui Station) Annual Analytical Reports.

TABLE 1
Production data and targets for food crops in Cameroon.

Commodity	1963-64	1970-71	Target for 1975-76	% increase per annum
Millet and sorghum	381	455	540	37.4
Maize	210	265	290	18.9
Rice	14	34	50	9.4
Wheat	-	-	6	-
Yams	148	185	203.7	2.0
Cocoyams	620	695		
Cassava	433	460		
Sweet potato	101	105	1,349.8	1.3
Solanum potato,	2.7	7		
Melon seeds	8.3	11.6		
Groundnuts	88	120		
Beans	38	50		
Fresh vegetables	171	207		
Plantains	746	850	1161.2	7.3

TABLE 2
Characteristics of yams used in the experiments

Scientific name	Local name	Days to mature	Yield (t/ha)	Crude protein (% dry matter)
<i>D. rotundata</i>	'Oshei'	250-270	22-30	9.0
<i>D. dumetorum</i>	'Jakiri'	210-240	30-45	10.2
<i>D. cayenensis</i>	'Batibo'	270-290	12-18	7.8

TABLE 3

Variation in performance of four popular local varieties of white yams

Variety	Babungo(1100m) t/ha. Maturity (days)	Santchou(700m) t/ha. Maturity (days)	Crude protein % dry matter
'Oshei'	27.6 (258)	19.1 (199)	9.0
'Mbot'	25.3 (264)	15.9 (197)	5.9
'Banakanda'	16.2 (230)	22.6 (185)	9.3
'Mbam'	7.8 (233)	15.6 (183)	6.2

TABLE 4

Effect of methods of staking on yields of 3 yam species

<u>Staking methods</u>	<u>Mean yield (t/ha)</u>
Tall wooden stakes (3 m)	20.3
Tall wire lines (3 m)	17.7
Short wire lines (1.5 m)	17.4
Short wooden stakes (1.5 m)	16.7
Control (no staking)	15.3
<u>Yam species</u>	
<i>D. cayenensis</i> (Yellow Yam)	24.2
<i>D. rotundata</i> (Oshei Yam)	17.7
<i>D. dumetorum</i> (Trifoliate Yam)	10.7
Standard Error	0.83

TABLE 5

Effect of seed bed preparation, plant population and fertilizer on yam yields

Treatments	5,000 plant/ha	10,000 plant/ha	15,000 plant/ha	20,000 plant/ha
	t/ha	t/ha	t/ha	t/ha
Flat plots, fertilized	8.40	14.28	20.60	22.06
Flat plots unfertilized	8.88	12.39	18.19	20.75
Ridges, fertilized	8.48	13.54	19.72	22.03
Ridges, not fertilized	8.00	11.26	18.83	17.88
Mean of flat plots = 15.69				
Mean of ridges = 14.98				
Mean of fertilized plots = 16.14				
Mean of unfertilized plots = 14.52				
General mean = 15.33				

TABLE 6

Effect of sett size on yam yields

Treatment	Yellow yam Mean (heads and rest) t/ha	Trifoliolate Mean (heads and rest) t/ha	White Yam Mean (heads and rest) t/ha
125 g.	16.1	13.9	8.1
250 g.	19.1	21.5	14.7
375 g.	22.7	26.1	17.4
500 g.	27.9	32.4	23.5
1000 g.	31.7	44.6	30.6
Standard error	1.1	0.7	-
Mean yields of tops	26.7	30.4	not
Mean yields of rest	20.3	25.0	differen- tiated.

EFFECTS OF CULTIVATIONS AND HEIGHTS AND DIRECTIONS OF STAKING ON YIELD AND GENERAL PERFORMANCE OF EIGHT YAM CULTIVARS

B.N. Okigbo*

SUMMARY

At Nsukka in East Central State of Nigeria in 1971 and 1972 heights and orientation of rows of stakes and ridging or flat land were compared using eight cultivars within six species of yams (*D. alata*, *D. rotundata* (cv. Abi), *D. rotundata* (cv. Aga), *D. rotundata* (cv. Ji-igwe), *D. dumetorum*, *D. esculenta*, *D. cayenensis* and *D. bulbifera*). Highly significant fresh weight yield differences were observed between cultivars and between staking treatments. Staking effects on yield were mainly due to differences in height rather than orientation of the rows of stakes. Tuber yields decreased with decreasing height of stakes. In both years the order of yield among cultivars was *D. rotundata* (Ji-igwe) > *D. rotundata* (Aga) > *D. rotundata* (Abi) > *D. alata* $\approx$ *D. cayenensis* > *D. dumetorum* > *D. bulbifera*.

RESUME

En 1971 et 1972 à Nsukka, dans l'Etat du Centre-Est du Nigéria, la hauteur et la direction des lignes de treillis, le semis en buttes ou sur terrain plat ont été comparés en utilisant huit cultivars tirés de 6 espèces d'igname (*D. alata*, *D. rotundata* (var. Abi), *D. rotundata* (var. Aga), *D. rotundata* (var. Ji-igwe), *D. dumetorum*, *D. esculenta*, *D. cayenensis* et *D. bulbifera*). Des écarts très importants de poids frais de rendement ont été observés entre les cultivars et les méthodes de tuteurage. L'effet du tuteurage était surtout dû aux différences de niveau plutôt qu'à la direction des lignes de treillis. Plus les treillis sont courts, plus le rendement est bas. Sur les deux années, l'ordre du rendement des cultivars était *D. rotundata* (Ji-igwe) > *D. rotundata* (Aga) > *D. rotundata* (Abi) > *D. alata* > *D. cayenensis* > *D. dumetorum* > *D. bulbifera*.

RESUMEN

En 1971 y 1972 se compararon en Nsukka, en al Estado Este Central de Nigeria, alturas y orientación del estacado así como terreno en plano y alomado. Se usaron ocho cultivares con seis especies de ñame (*D. rotundata* (var. Ji-igwe), *D. alata*, *D. rotundata* (var. Abi), *D. rotundata* (var. Aga), *D. dumetorum*, *D. esculenta*, *D. cayenensis* y *D. bulbifera*). Se observaron diferencias altamente significativas en rendimiento de peso fresco, entre cultivares y entre tratamientos de estacado. El efecto del estacado sobre el rendimiento se debió principalmente a diferencias en altura, más que a la orientación de las hileras. El rendimiento de tubérculos decreció con la altura del estacado. En ambos años el orden que siguió el rendimiento por cultivares fué: *D. rotundata* (Ji-igwe) > *D. rotundata* (Aga) > *D. rotundata* (Abi) > *D. alata* > *D. cayenensis* > *D. dumetorum* > *D. bulbifera*.

INTRODUCTION

Types of support of wild and cultivated yams

Wild yams are climbers depending on forest trees and shrubs for support and to expose their leaves to sunlight. Staking practices for cultivated yams were reviewed by Coursey². Stakes vary in height from less than 1 to over seven metres. Sometimes, in drier areas when small setts are planted, yam vines are unstaked. Height and thickness of stakes are often selected depending on the size of setts since larger setts tend to produce stouter vines. Where stakes are scarce, as in the savannah areas of the Northern States of Nigeria, yam vines are either unstaked or allowed to grow on the dry stems of maize, sorghum or pearl millet. Yam vines are also grown up castor beans, pigeon pea or cotton plants. In compound farms of the humid southern areas of Nigeria, yams are supported on tall bamboo poles, palm petioles or various living plants such as *Newbouldia leavis*, *Ficus* spp. etc. or on heavily pruned oil palms or other trees. Yams may be supported by a single stake but very often stout and tall yam vines are first trained on smaller stakes which are in turn tied to stronger and taller stakes. Single stakes may be tied together in twos, threes or fours for greater stability. Stakes may be branched or unbranched. Trellises of wood, bamboo, chicken wire netting, wire net fence or just ordinary wire slung across two or more poles^{2,8} may also be used in place of stakes.

*University of Nigeria, Nsukka. Present address: IITA, PMB 5320, Ibadan, Nigeria.

Previous staking experiments

Experiments at Ilorin showed no significant yield differences among staking treatments from no staking to the use of 2.1 metre stakes¹. However, staking has been reported by various authors to have beneficial effects on yam yields with substantial yield increases being associated with increasing heights of staking^{3,4,5,7}. In Waitt's review⁸ staking was reported as necessary for some species but not for others. Thus *D. dumetorum* was reported not to require staking, *D. cayenensis* and *D. alata* suffered reduced yields (on a staked control) by as much as 35-66 percent as a result of no staking while *D. esculenta* on the other hand showed 50 percent yield increase from staking (on an unstaked control), and long stakes gave higher yields than short ones. Rouanet⁷ detected no yield differences from staking in *D. alata* in Guadeloupe. Doku³ reported effects of staking on yield differed with both cultivars and locations, but higher yields were obtained with both 1.8 and 3.6 m high stakes as compared to no staking. Staking of *D. esculenta* in Sierra Leone resulted in 50 percent yield increase over no staking⁴. Staking is generally recognized as a very high cost factor in the production of yams, so that it is important to assess the use of staking in economic as well as yield terms.

Soil preparation

Planting yams on mounds is the most widespread traditional practice in West Africa while planting on ridges is practised on experimental farms and sometimes elsewhere, especially when mechanical cultivation is used. Planting on the flat is practised in deep light soils or alluvial soils on river flood plains such as those of the Niger. In places subject to high water tables during certain months of the year, for example, at Abakaliki in the East Central States of Nigeria, mounds of up to 1 metre high and over 2 metres in diameter are used. Studies by Brown in 1931 reported by Coursey² indicated no significant yield differences for yams grown on mounds and ridges under similar soil conditions and Doku³ found that either mounds or ridges 1.8 metres apart gave best yields in experiments in Ghana. Growing yams on ridges and supporting them on trellises instead of stakes involved less labour and also gave better yields than the traditional method.

Most of the yield trials, staking trials and preplanting cultivation experiments reported in the literature in West Africa and elsewhere have involved only the most commonly cultivated species of yams, namely *Dioscorea rotundata*, *D. cayenensis* and *D. alata*.

MATERIALS AND METHODS

Treatments are given in Table 1. Preplanting cultivations comprised ploughing and levelling of the soil to leave a flat surface followed by moulding up into ridges and mounds. Individual stakes were laid out in rows running either east to west or north to south. However, the yam vines were trained not on stakes but on ropes slung along a few stakes at a height specified in the staking treatment. A spacing of 1 metre along ridges 1 metre apart was used so as to give a square planting pattern that would not further complicate the effects of direction of staking. Fertilizers were applied at 600 kg of nitrogen, 305 kg of phosphorus and 375 kg of potassium per hectare. Randomization procedures were those appropriate for the split split-plot design, i.e. each cultivar treatment was applied at random to each main plot, each height and direction of staking was allocated at random to each sub-plot and, similarly, each preplanting cultivation treatment was applied at random to each experimental unit within each sub-plot. The main treatments were replicated four times.

Sub-subplot size was 3m x 3m, i.e. 6 yam stands. Each sub-subplot was surrounded by a guard row of 1 metre wide. Each subplot was surrounded by 2 metres of planted guard rows and in the same way main plots and replicates were surrounded by guard rows 3 metres wide. The experiment was carried out on the Faculty of 3 metres wide. The experiment was carried out on the Faculty of Agricultural Sciences farm, University of Nigeria, Nsukka, in 1971 and 1972. Planting was done on 13th May in 1971 and on April 25th in 1972. Observations made included the following:

1. Fresh weight of tubers
2. Plant population at harvest.
3. Number of vines per stand.
4. Number of tubers per stand.

Harvesting which involved topping of 'milking' in November for *D. cayenensis*, *D. rotundata* and *D. alata* were harvested earlier. Thus the fresh weight yields included all the tubers harvested by topping, where applicable, in addition to final harvests from all cultivars. Statistical analysis was carried out on the data at the end of the experiment according to the routine analysis for the split-split plot design, with partitioning of degrees of freedom for meaningful comparisons. Duncan's multiple range tests were used to compare means.

RESULTS

Tuber yields

Data on yields expressed in metric tons fresh weight of tubers obtained in 1971 and 1972 are presented in Tables 1a, 1b, 2a, 2b, 3a and 3b.

Note that in 1971 and 1972 there were highly significant differences among both directions and heights of staking (Fig. 1, 2) but while in 1972 differences in height accounted for the main differences among staking treatments, in 1971 there was a significant difference between yam cultivars staked in an east to west direction with a mean of 10.2 metric tons/ha and those staked in a north to south direction with a mean of 9.6 tons/hectare. In 1972, not only was the difference insignificant but yams staked north to south with a mean of 8.1 tons slightly outyielded those staked east to west with a mean of 7.8 tons. The 3.6 metre stakes in north to south direction, and 1.8 metre stakes in east to west direction in 1971 and 1972 gave significantly higher yields than no staking in north to south and east to west direction in both years (Tables 1a and 1b and Figs. 1 and 2). It would appear that, although in general the yields decreased with decreases in height of staking in 1971, at each height of staking east to west staking, with the exception of 3.6 metre stakes running in a north to south direction, gave slightly higher yields than the north to south direction, while in 1972 the reverse was true (Tables 1a, 1b, Figs. 1, 2). A combined analysis of the yield data for both years resulted in an insignificant direction effect. Consequently there is a significant year $\times$ direction interaction if the two years can be treated as part of a single experiment. However, the interaction may not be a real one because in 1971 the north to south direction, on account of the slope of the site, was at right angles to the direction of ridges and mounds, while in 1972 it was the east to west direction which ran at right angles to the direction of ridges and mounds, thus making the experiments not strictly comparable.

There were significant stakings $\times$ cultivars interactions in both 1971 and 1972 (Fig. 1, 2).

There were significant differences resulting from land preparation in 1972 but not in 1971 (Tables 2a, 2b). The actual yields observed were 9.8, 10.0 and 10.2 tons per hectare in 1971 and 7.6, 8.3 and 8.1 tons in 1972 on the flat, mounds and ridges respectively. A higher percentage of the yam tubers produced on the flat were shorter than those produced in ridges and mounds. Moreover, some of the yam tubers on the flat,

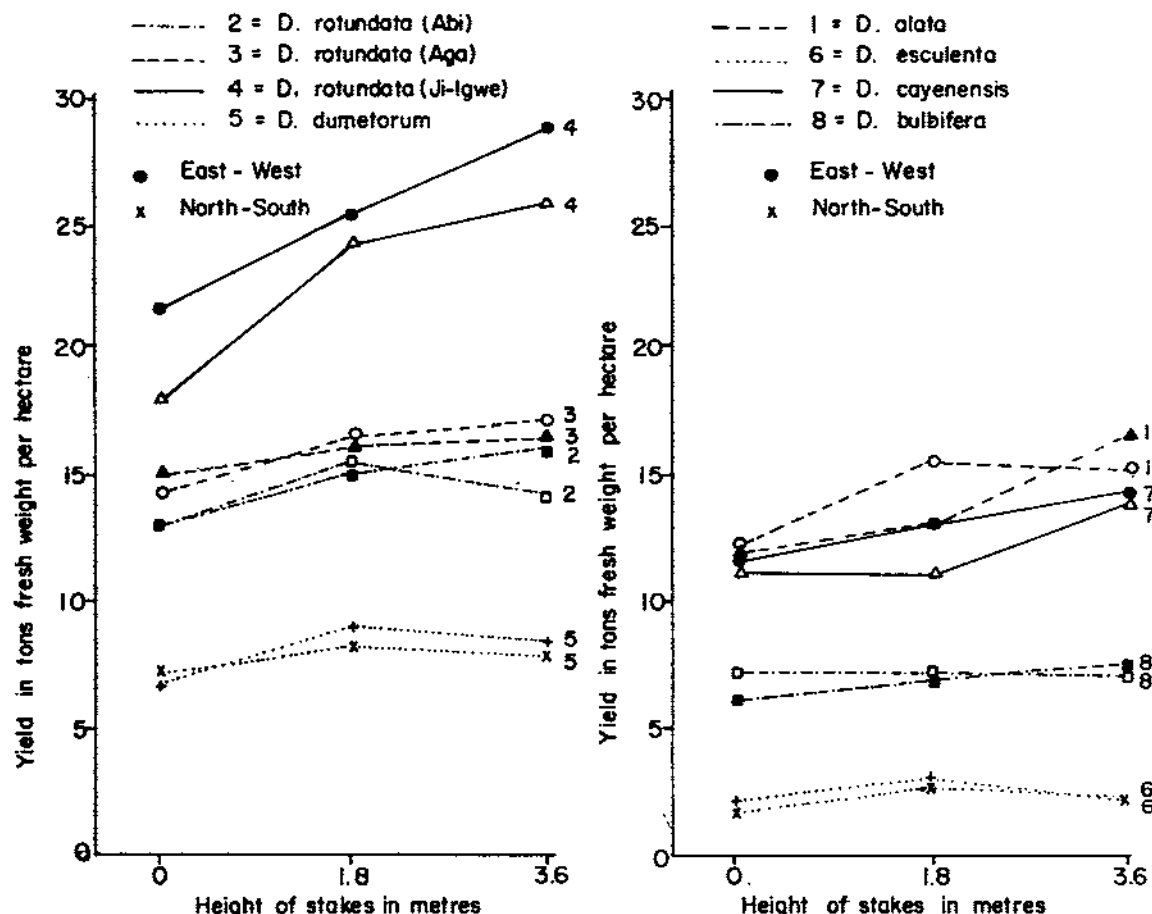


Figure 1. Mean yields (Tons fresh weight per hectare) of eight yam cultivars supported on no stakes, 1.8m and 3.8m stakes on rows running to East to West and North to South at Nsukka in 1971.

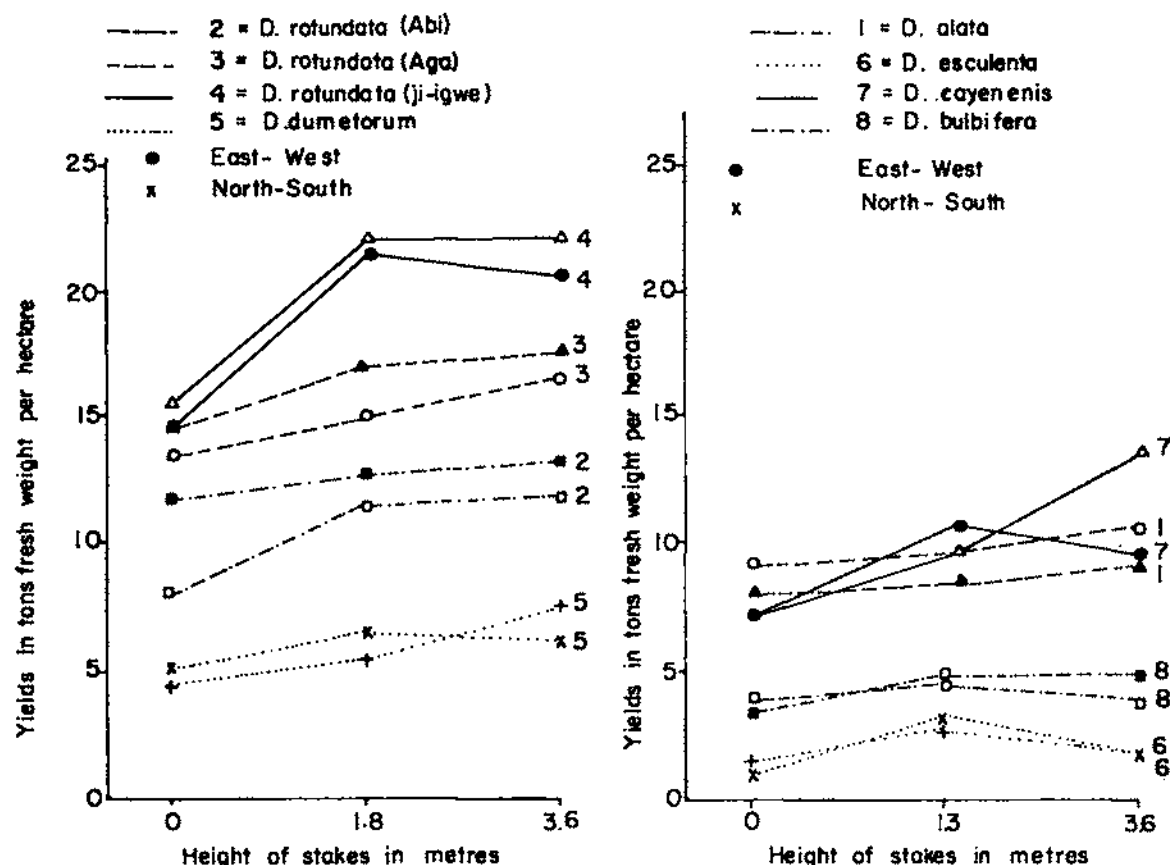


Figure 11. Mean yields (Fresh weight t/ha) of eight yam cultivars supported on no stakes, 1.8m and 3.6m stakes on rows running East to West or North to South at Nsukka in 1972.

which could not readily penetrate into the soil, grew out of the soil, thereby exposing and rupturing many of the roots. In both years the lowest yields were observed on the flat but yield differences between planting on ridges or mounds were not high enough to pay for the labour of ridging and making of mounds.

Plant population

In 1971 populations at harvest of *D. cayenensis* and *D. rotundata* (cv. Ji-igwe) were significantly greater than for *D. alata*, *D. dumetorum* and *D. rotundata* (cv. Aga) (Tables 3a, 4a).

In view of the irregularities in plant population observed at harvest in 1971, population counts were made in 1972 100 days after planting. These counts were compared with those at harvest so as to have an indication of the number of plants that might have suffered premature senescence as a result of leaf diseases (Tables 5, 6). Plant population at 100 days after planting did not markedly differ from plant population at harvest. Observations in the field however indicated that leaf spot diseases in *D. alata*, *D. rotundata* (Aga) and *D. rotundata* (Ji-igwe) may adversely affect yield. Pronounced variability in disease incidence was observed between individual plants in each cultivar.

Number of tubers per plant

Data for 1971 are presented in Tables 7a and 8a. There were highly significant differences between cultivars in the number of tubers produced per plant. *D. bulbifera* and *D. esculenta* which usually produce numerous small tubers, as expected, significantly exceeded all the other cultivars in tuber number. No significant differences in tuber number were observed in the group including *D. alata*, all the *D. rotundata* cultivars, and *D. cayenensis* (Table 7a). The smallest average numbers of tubers were observed in *D. rotundata* (Aga), *D. rotundata* (Ji-igwe) and *D. cayenensis* which were also among the highest yielders.

Highly significant effects on tuber number were observed among heights and directions of staking. The 3.6 metre staking in east to west and north to south directions gave significantly higher tuber numbers than no staking in north to south or east to west direction (Table 7a). No marked difference was observed overall between north-south and east-west directions of staking. There was a highly significant cultivar x staking interaction (Table 7a) attributable to the fact that while there was a general tendency for tuber number to decrease with height of staking irrespective of direction, some cultivars showed no such effect.

Plants grown on mounds and ridges produced significantly more tubers than those on the flat. (Table 8a) The highly significant interaction in tuber numbers between cultivations x cultivars is attributable to the tendency for *D. alata*, *D. rotundata* (Aga) and *D. rotundata* (Ji-igwe) to produce lower number of

tubers on mounds and ridges than on the flat, while other cultivars do not respond in this way.

Data for 1972 are presented in Tables 7b and 8b. *D. bulbifera* and *D. esculenta* again produced the highest number of tubers. Effects of directions and heights of staking were similar to those apparent in 1971, except that tall (3.6 m) stakes running in east-west direction gave significantly lower tuber numbers than the same stakes orientated in a north-south direction. There was a significant staking & cultivar interaction, but no significant cultivation x cultivar interaction in 1972.

Number of vines per plant

In both 1971 and 1972 there were highly significant differences among cultivars in number of main vines produced per stand or per sett (Tables 10a, 10b, 11a and 11b). From the data obtained it can be concluded that number of vines per stand or per sett is a characteristic which depends more on cultivar than environmental factors which do however influence it to some extent. No significant interactions among the various treatments were observed.

DISCUSSIONS AND CONCLUSIONS

Dioscorea rotundata cultivars, the traditional species of yam in the Nsukka area appear to give the highest yields, followed by *D. alata* and *D. cayenensis*. *D. cayenensis* is known to give higher yields in higher rainfall areas than at Nsukka. Yields of *D. alata* which has high yielding potential may exhibit low or fluctuating yields due to early senescence associated with incidence of leaf diseases such as that caused by *Glomerella cingulata*.

The effect of the preplanting cultivation on yam yields depends on the soil type, and although it has been suggested from other data not included in this paper that it is not profitable at paid labour rates to plant yams on ridges or mounds as compared to the flat, nevertheless harvesting yams on ridges and mounds requires less labour.

The yields obtained in these trials are comparable to those reported elsewhere, but this has been the first attempt in Nigeria to assess yields and characteristics of all the important yam cultivars at the same time in relation to cultural practices. The low yields observed in the species *D. esculenta*, *D. dumetorum* and *D. bulbifera* may be due to the spacing used not being suited to them. Apparent effects of direction of staking still need further attention since in these experiments there may be hidden effects of slope.

In future experiments it may be desirable to use several spacings for the different directions of staking and probably eliminate the no staking treatment: to reduce the complex effect of directions and heights of staking by using a split block design in which the staking treatments are more or less main plots for the other treatments: include observations on such physiologically important measurements such as leaf area index, leaf area duration, dry matter accumulation and tuber development which are at present lacking for some of the species: separate the cultivars into high yielders and low yielders and use them separately in different experiments with the same treatments in order to reduce the coefficient of variation and improve the homogeneity of various error components: to include more heights of staking treatments to enable a regression relationship of yield on height to be obtained.

ACKNOWLEDGEMENT

The author is grateful to Mr. D. Ibe, Mr. Okebugwu and other field assistants of the Department of Plant/Soil Science, University of Nigeria, who helped with the observations and recording of data, and to Dr. T. M. Little of IITA, who assisted with the statistical analysis.

REFERENCES

1. Anon: Annual Report of the Federal Department of Agricultural Research 1962/63 Ibadan.
2. Coursey, D.G. (1967) *Yams*. Longmans, London.
3. Doku, E.V. (1967) Root crops in Ghana. Proc. Int. Symp. Trop. Root Crops. 1(3), 39-68.
4. Enyi, B.A.C. (1970a) Yams in Africa. Proc. 2nd Int. Symp. Trop. Root Crops. 1, 903.
5. — — — — (1970b) Growth studies in Chinese yam (*Dioscorea esculenta*). Proc. 2nd Int. Symp. Trop. Root Crops. 1, 103.
6. Haynes, P.H. et al. (1967) The use of physiological studies in the agronomy of root crops. Proc. Int. Symp. Trop. Root Crops. 1(3), 1-15.
7. Rouanet, G. (1967) Experiments on yams in Guadeloupe. Proc. Int. Symp. Trop. Root Crops 1(3), 152-8.
8. Waitt, A.W. (1963) Yams, *Dioscorea* species. *Field Crop Abstracts*

TABLE 1a

Mean yields in metric tons/ha fresh weight observed in 8 yam cultivars in relation to heights and directions of stakings at Nsukka in 1971

Yam cultivars	Height and direction of staking						Cultivar means
	3.6m	3.6m	1.8m	1.8m	0	0	
	E-W	N-S	E-W	N-S	E-W	N-S	
	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha
<i>D. alata</i>	11.7	13.5	12.6	10.8	9.9	9.0	11.3a
<i>D. rotundata</i> (Abi)	11.5	13.0	12.6	12.3	10.5	10.5	11.8a
<i>D. rotundata</i> (Aga)	13.9	13.2	13.2	13.2	11.7	12.1	12.9a
<i>D. rotundata</i> (Ji-igwe)	23.1	20.6	20.6	17.9	17.5	14.3	19.5
<i>D. cayenensis</i>	12.3	11.2	11.0	9.0	9.4	9.6	10.5a
<i>D. dumetorum</i>	6.7	6.3	7.4	6.5	5.6	5.8	6.4b
<i>D. esculenta</i>	1.8	1.8	2.2	2.2	1.8	1.6	2.0c
<i>D. bulbifera</i>	5.8	6.1	5.8	5.6	6.1	5.2	5.8bc
Staking means	10.8a	10.8a	10.8a	9.6	9.0ab	8.5b	

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean fresh weight yields of different cultivars for a given height and direction of staking = 4.3

Lsd for comparison of mean fresh weight yields of different heights and directions of staking for a given cultivar = 2.8.

TABLE 1b

Mean yields in metric 5/ha fresh weight observed in 8 yam cultivars at different heights and directions of staking at Nsukka in 1972

Yam cultivars	3.6m	3.6m	1.8m	1.8m	0	0	Cultivar means
	E-W	N-S	E-W	N-S	E-W	N-S	
	t/ha	t/ha	t/h	t/ha	t/ha	t/ha	
<i>D. alata</i>	9.9	8.5	8.1	7.0	7.6	6.7	8.1cd
<i>D. rotundata</i> (Abi)	10.1	10.8	9.4	10.3	6.7	9.6	9.6bc
<i>D. rotundata</i> (Aga)	13.8	13.9	12.1	14.1	11.2	11.9	12.6ab
<i>D. rotundata</i> (Ji-igwe)	16.8	18.2	17.5	17.9	11.9	12.6	15.7a
<i>D. cayenensis</i>	8.7	11.2	8.7	8.1	6.1	5.8	8.1cd
<i>D. dumetorum</i>	6.3	4.9	4.7	5.4	3.8	4.0	4.9de
<i>D. esculenta</i>	1.6	1.6	2.0	2.2	1.3	0.9	1.6e
<i>D. bulbifera</i>	3.4	4.3	3.6	3.8	3.1	2.9	3.6e

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean fresh weight yields of different cultivars for a given height and direction of staking = 3.6.

Lsd for comparison of mean fresh weight yields of different heights and directions of staking for a given cultivar = 2.6

TABLE 2a

Mean yields in t/ha fresh weight observed in 8 cultivars grown on flat, mound and ridge at Nsukka in 1971

Yam cultivars	Flat	Mounds	Ridge	Cultivar means
	t/ha	t/ha	t/ha	t/ha
<i>D. alata</i>	12.0	10.8	11.0	11.3a
<i>D. rotundata</i> (Abi)	10.5	12.1	12.8	11.1a
<i>D. rotundata</i> (Aga)	12.1	12.8	13.7	12.9a
<i>D. rotundata</i> (Ji-igwe)	20.4	19.1	19.1	19.5
<i>D. cayenensis</i>	10.5	10.3	10.5	10.5a
<i>D. dumetorum</i>	6.1	6.5	6.5	6.4b
<i>D. esculenta</i>	1.6	2.0	2.0	2.0b
<i>D. bulbifera</i>	5.4	6.5	5.6	5.8b
Cultivation means	9.8a	10.0a	10.2a	

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean fresh weight yields of different cultivars for a given preplanting cultivation = 3.5

Lds for comparison of mean fresh weight yields of different preplanting cultivations for a given cultivar = 1.7

TABLE 2b

1972

Yam cultivars	Flat	Mounds	Ridge	Cultivar means
	t/ha	t/ha	t/ha	t/ha
<i>D. alata</i>	9.2	7.0	7.8	8.1cd
<i>D. rotundata</i> (Abi)	8.1	10.1	10.3	9.6bc
<i>D. rotundata</i> (Aga)	11.9	13.45	13.0	12.6ab
<i>D. rotundata</i> (Ji-igwe)	14.3	17.9	15.2	15.7a
<i>D. cayenensis</i>	8.1	8.1	8.1	8.1cd
<i>D. dumetorum</i>	4.9	4.7	4.9	4.9de
<i>D. esculenta</i>	1.5	1.7	1.7	1.73
<i>D. bulbifera</i>	3.6	3.4	3.6	3.63
Cultivation means	7.6	8.3a	8.1a	

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean fresh weight yields of different cultivars for a given preplanting cultivation = 2.8

Lsd for comparison of mean fresh weight yields of different preplanting cultivations for a given cultivar = 1.8

TABLE 3a

Mean plant population per hectare observed in 8 yam cultivars at harvest of 8 cultivars grown at different heights and direction of staking. Nsukka 1971

Yam cultivars	Staking treatments						Cultivar means
	3.6m	3.6m	1.8m	1.8m	0	0	
	High	High	Med.	Med.	Low	Low	
	E-W	N-S	E-W	N-S	E-W	N-S	
<i>D. alata</i>	6379	6379	6645	6645	6777	6379	6512b
<i>D. rotundata</i> (Abi)	5714	5714	5714	5316	6246	5449	6714b
<i>D. rotundata</i> (Aga)	7708	6910	7043	7043	7708	7043	7176ab
<i>D. rotundata</i> (Ji-igwe)	7575	7841	7973	7575	7841	7841	7707a
<i>D. cayenensis</i>	7973	7973	7973	7973	7841	7708	7973a
<i>D. dumetorum</i>	6246	4113	6379	5980	6910	6379	6379b
<i>D. esculenta</i>	6309	7708	7575	7309	7309	7708	7442ab
<i>D. bulbifera</i>	7309	7176	7575	7708	7408	7408	7442ab
Staking means	7043a	6910a	7043a	6910a	7309a	7043a	

Means with the same letter opposite them are not significantly different from each other at 5% level

Lds for comparison of mean plant population/ha of different cultivars for a given height and direction of staking = 370

Lsd for comparison of mean plant population/ha of different heights and direction of staking for a given cultivar = 269

TABLE 3b
1972

Yam cultivars	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	Culti- var means
<i>D. alata</i>	7575	7708	7708	7973	7707	7841	7708a
<i>D. rotundata</i> (Abi)	7708	7575	7708	7973	7973	7973	7841a
<i>D. rotundata</i> (Aga)	7708	7708	7973	7973	7973	7973	7841a
<i>D. rotundata</i> (Ji-igwe)	7841	7841	7841	7841	7973	7708	7841a
<i>D. cayenensis</i>	7309	7708	7708	6910	7442	7309	7442a
<i>D. dumetorum</i>	7841	7973	7973	7973	7708	7841	7841a
<i>D. esculenta</i>	7708	7309	7841	7841	7708	7309	7575a
<i>D. bulbifera</i>	7043	7575	7841	7708	7309	7708	7575a

Staking means 7708a 7708a 7841a 7708a 7708a 7708a

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean plant population/ha of different cultivars for a given height and direction of staking = 524

Lsd for comparison of mean plant population/ha of different heights and direction of staking for a given cultivar = 476

TABLE 4a

Mean plant population per hectare of 8 cultivars observed at harvest on the flat, mounds and ridges at Nsukka in 1971

Yam cultivars	Flat	Mound	Ridge
<i>D. alata</i>	6113	6045	7043
<i>D. rotundata</i> (Abi)	5449	5714	5714
<i>D. rotundata</i> (Aga)	7043	7043	7442
<i>D. rotundata</i> (Ji-igwe)	7841	7841	7708
<i>D. cayenensis</i>	7841	7973	7973
<i>D. dumetorum</i>	6246	6645	6113
<i>D. esculenta</i>	7442	7575	7309
<i>D. bulbifera</i>	7442	7575	7309
Cultivation means	6910a	7165b	7043ab

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lds for comparison of mean plant population/ha of different cultivars for a given preplanting cultivation = 303

Lsd for comparison of mean plant population/ha of different preplanting cultivations for a given cultivar = 153

TABLE 4b
1972

Yam cultivars	Flat	Mound	Ridge	Culti- var means
<i>D. alata</i>	7841	7708	7708	7707a
<i>D. rotundata</i> (Abi)	7841	7841	7841	7841a
<i>D. rotundata</i> (Aga)	7841	7841	7941	7841a
<i>D. rotundata</i> (Ji-igwe)	7708	7973	7973	7841a
<i>D. cayenensis</i>	7309	7309	7574	7442a
<i>D. dumetorum</i>	7841	8106	7841	7841a
<i>D. esculenta</i>	7309	7973	7574	7574a
<i>D. bulbifera</i>	7309	7309	7575	7442a
Cultivation means	7708a	7841a	7708a	

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean plant population/ha of different cultivars for a given preplanting cultivation = 361.

Lsd for comparison of mean plant population/ha of different preplanting cultivations for a given cultivar = 260

TABLE 5

Mean plant population/ha observed in 8 yam cultivars 100 days after planting in relation to heights and directions of staking Nsukka 1972

Yam cultivars	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	Cultivar means
<i>D. alata</i>	7973	7973	7973	7973	7973	7973	7973a
<i>D. rotundata</i> (Abi)	7708	7708	7973	7973	7708	7873	7841a
<i>D. rotundata</i> (Aga)	7973	7708	7973	7973	7973	7973	7973a
<i>D. rotundata</i> (Ji-igwe)	7841	7973	7973	7841	7973	7941	7973a
<i>D. dumetorum</i>	7841	7973	7973	7841	7708	7973	7841a
<i>D. esculenta</i>	7841	7575	7575	7708	7043	7309	7442b
<i>D. cayenensis</i>	7176	7708	7708	6778	7708	7309	7442b
<i>D. bulbifera</i>	6910	7575	7708	7043	7043	7841	7309b
Staking means	7708a	7708a	7841a	7708a	7708a	7841a	

Means with the same letter opposite them are not significantly different from each other at 5% level.

Lsd for comparison of mean plant population/ha at 100 days after planting of any two heights and direction of staking for a given cultivar = 98.

Lsd for comparison of mean plant population/ha at 100 days after planting of any two cultivars for a given height and direction of staking = 128.

TABLE 6

Mean plant population/ha observed on eight yam cultivars 100 days after planting on different pre-planting cultivations at Nsukka in 1972

Yam cultivars	Flat	Mound	Ridge	Cultivar means
<i>D. alata</i>	7973	7973	7973	7973a
<i>D. rotundata</i> (Abi)	7708	7973	7841	7841a
<i>D. rotundata</i> (Aga)	7973	7973	7973	7973a
<i>D. rotundata</i> (Jiigwe)	7841	7973	7973	7973a
<i>D. dumetorum</i>	7973	7841	7973	7841a
<i>D. esculenta</i>	7043	7708	7575	7442b
<i>D. cayenensis</i>	7442	7442	7309	7442b
<i>D. bulbifera</i>	7309	7176	7575	7309b
Cultivation means	7708a	7708a	7708a	

Lsd for comparison of plant population/ha at 100 days after planting of any two cultivars for a given preplanting cultivation = 108.

Lsd for comparison of plant population/ha at 100 days after planting of any two preplanting cultivations for a given cultivar = 28.

TABLE 7a

Mean number of tubers per stand observed in 8 cultivars grown at different heights and directions of stakings 1971 at Nsukka

Yam cultivars	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	Cv. means
<i>D. alata</i>	4.2	4.2	3.4	4.0	3.9	3.5	3.9ab
<i>D. rotundata</i> (Abi)	4.1	3.4	4.0	4.5	3.5	4.7	4.0ab
<i>D. rotundata</i> (Aga)	1.6	1.9	1.6	1.6	1.4	1.7	1.6b
<i>D. rotundata</i> (Ji-igwe)	2.4	2.0	2.0	1.7	1.8	1.7	1.9b
<i>D. cayenensis</i>	1.7	1.9	1.7	1.7	2.0	1.7	1.8b
<i>D. dumetorum</i>	6.2	6.4	6.7	5.8	4.9	5.2	5.8a
<i>D. esculenta</i>	12.5	10.9	10.7	12.2	11.4	9.8	13.2c
<i>D. bulbifera</i>	50.5	45.4	42.0	40.0	29.3	30.3	39.9d
Staking means	10.4a	9.5a	9.0ab	9.0ab	7.3b	7.3b	

Lsd for comparison of mean number of tubers per plant for different heights and directions of staking for a given cultivar = 8.5

Lsd for comparison of mean number of tubers per plant for different cultivars at a given height and direction of staking = 8.7

TABLE 7b

Yam cultivars	1972						Cv. means
	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	
<i>D. alata</i>	2.0	2.4	2.2	2.3	2.2	1.9	2.2a
<i>D. rotundata</i> (Abi)	1.5	1.4	1.4	1.5	1.5	1.4	1.4a
<i>D. rotundata</i> (Aga)	1.6	1.7	1.7	2.0	1.9	1.9	1.8a
<i>D. rotundata</i> (Ji-igwe)	1.7	1.9	1.8	1.7	1.5	1.3	1.7a
<i>D. dumetorum</i>	4.3	4.3	4.1	4.5	4.0	4.8	4.3a
<i>D. esculenta</i>	10.7	10.5	14.8	14.0	12.7	11.4	12.4b
<i>D. cayenensis</i>	1.9	1.9	2.0	1.8	2.0	1.5	1.8a
<i>D. bulbifera</i>	32.0	50.2	41.5	39.1	26.6	25.7	33.9a
Staking means	7.0abc	9.3d	8.7cd	8.4bcd	6.6ab	6.2a	1.7

Lsd for comparison of mean number of tubers per plant for different heights and directions of staking for a given cultivar = 9.1

Lsd for comparison of mean number of tubers per plant for different cultivars at a given height and direction of staking = 8.9

Means with the same letter opposite them are not significantly different from each other at 5% level.

TABLE 8a

Mean number of tubers per stand observed in 8 cultivars grown on flat, mounds and ridges at Nsukka in 1971

Yam cultivars	Flat	Mound	Ridge	Cv. means
<i>D. alata</i>	4.0	3.9	3.6	3.8ab
<i>D. rotundata</i> (Abi)	3.9	4.1	4.2	4.1ab
<i>D. rotundata</i> (Aga)	1.8	1.7	1.5	1.7b
<i>D. rotundata</i> (Ji-igwe)	2.0	1.9	1.9	1.9b
<i>D. cayenensis</i>	1.7	1.8	1.8	1.8d
<i>D. dumetorum</i>	5.8	5.5	6.3	5.9a
<i>D. esculenta</i>	9.5	11.1	12.6	11.1
<i>D. bulbifera</i>	33.9	45.4	38.2	38.2
Cultivation means	7.8a	9.1b	8.8ab	

Lsd for comparison of mean number of tubers per plant for different cultivars for the same preplanting cultivation = 1.09

Lsd for comparison of mean number of tubers per plant for different preplanting cultivations for a given cultivar = 2.5

TABLE 8b

1972

Yam cultivars	Flat	Mound	Ridge	Cv means
<i>D. alata</i>	2.1	2.3	2.2	2.2a
<i>D. rotundata</i> (Abi)	1.4	1.6	1.4	1.5a
<i>D. rotundata</i> (Aga)	1.8	1.7	1.8	1.8a
<i>D. rotundata</i> (Ji-igwe)	1.7	1.7	1.6	1.7a
<i>D. cayenensis</i>	1.8	1.9	1.9	1.8a
<i>D. dumetorum</i>	4.4	4.3	4.1	4.3a
<i>D. esculenta</i>	12.1	12.2	12.7	12.3b
<i>D. bulbifera</i>	38.5	33.6	35.1	35.7c
Cultivation means	7.9a	7.4a	7.4a	

Lsd for comparison of mean number of tubers per plant for different cultivars for the same preplanting cultivation = 6.3

Lsd for comparison of mean number of tubers per plant for different preplanting cultivations for a given cultivar = 2.1

Means with the same letter opposite them are not significantly different from each other at 5% level

TABLE 9

Number of tubers/plant observed in 8 cultivars on flat, mound and ridges for different heights and directions of staking, 1972.

Yam cultivars	FLAT						Cv. means
	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	
<i>D. alata</i>	1.7	2.2	2.1	2.3	1.9	2.3	2.1
<i>D. rotundata</i> (Abi)	1.3	1.4	1.4	1.4	1.1	1.6	1.4
<i>D. rotundata</i> (Aga)	1.9	2.1	1.8	1.8	1.7	2.0	1.7
<i>D. rotundata</i> (Ji-igwe)	1.8	2.3	1.8	1.8	1.5	1.2	1.7
<i>D. dumetorum</i>	4.3	3.8	4.2	4.1	4.1	6.1	4.4
<i>D. esculenta</i>	10.1	8.3	12.1	16.1	12.1	12.3	11.8
<i>D. cayenensis</i>	2.3	1.5	1.5	2.1	2.0	1.6	1.8
<i>D. bulbifera</i>	33.1	45.5	34.4	43.8	24.9	25.9	34.6
Staking means	7.1	8.4	7.4	9.2	6.2	6.6	7.5

MOUND							
<i>D. alata</i>	2.2	2.2	2.1	2.3	2.4	1.9	2.2
<i>D. rotundata</i> (Abi)	1.6	1.5	1.5	1.6	1.8	1.3	1.6
<i>D. rotundata</i> (Aga)	1.3	1.8	1.8	2.1	1.7	1.9	1.8
<i>D. rotundata</i> (Ji-igwe)	2.8	1.8	1.6	1.8	1.7	1.5	1.9
<i>D. dumetorum</i>	4.5	4.4	4.1	5.3	3.6	4.6	4.4
<i>D. esculenta</i>	8.4	7.3	16.3	14.6	15.6	10.5	12.1
<i>D. cayenensis</i>	1.5	2.1	2.9	1.5	1.8	1.6	1.9
<i>D. bulbifera</i>	32.5	44.0	48.7	29.4	21.5	24.4	33.4
Staking means	6.9	8.1	9.9	7.3	6.3	6.0	7.4

RIDGE							
<i>D. alata</i>	2.1	2.1	2.5	2.3	2.4	1.6	2.2
<i>D. rotundata</i> (Abi)	1.6	1.2	1.3	2.1	1.9	1.8	1.7
<i>D. rotundata</i> (Aga)	1.8	1.5	1.6	2.1	1.9	1.8	1.8
<i>D. rotundata</i> (Ji-igwe)	1.5	1.7	1.9	1.6	1.4	1.3	1.6
<i>D. dumetorum</i>	4.0	4.6	4.0	4.2	4.2	3.6	4.1
<i>D. esculenta</i>	12.2	15.0	15.4	11.2	10.5	11.6	14.8
<i>D. cayenensis</i>	2.1	2.1	1.8	1.7	2.2	1.4	1.9
<i>D. bulbifera</i>	29.9	35.5	31.3	40.0	33.2	25.8	31.0
Staking means	6.9	8.0	7.5	8.2	7.2	6.1	7.4

Lsd for comparison of any two cultivar number of tubers per plant means for the same height and direction of spacing or preplanting cultivation = 35.6

TABLE 10a

Mean number of vines per plant observed in 8 cultivars in relation to heights and directions of staking at Nsukka, 1971

Yam cultivars	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	Cv. means
<i>D. alata</i>	3.8	3.6	3.1	3.7	3.5	3.4	3.5a
<i>D. rotundata</i> (Abi)	4.0	3.6	3.7	4.3	3.7	4.0	3.9a
<i>D. rotundata</i> (Aga)	1.5	1.6	1.3	1.7	1.4	1.6	1.5b
<i>D. rotundata</i> (Ji-igwe)	1.6	1.3	1.3	1.3	1.4	1.3	1.4b
<i>D. dumetorum</i>	3.3	3.5	3.7	3.6	3.1	3.1	3.4a
<i>D. esculenta</i>	2.2	2.4	2.2	2.5	2.4	2.7	2.4b
<i>D. cayenensis</i>	2.0	2.1	1.9	1.9	1.9	2.0	1.9b
<i>D. bulbifera</i>	1.6	1.5	1.5	1.5	1.3	1.3	1.4b
Staking means	2.4a	2.4a	2.3a	2.4a	2.3a	2.3a	

Lsd for comparison of mean number of vines per plant for different cultivars for a given height and direction of staking = 2.1

Lsd for comparison of mean number of vines per plant of different heights and directions of staking for a given cultivar = 1.9

TABLE 10b

1972

Yam cultivars	3.6m E-W	3.6m N-S	1.8m E-W	1.8m N-S	0 E-W	0 N-S	Cv. means
<i>D. alata</i>	2.3	2.5	2.5	2.4	2.4	2.3	2.4b
<i>D. rotundata</i> (Abi)	1.8	1.6	1.5	1.4	1.5	1.4	1.5a
<i>D. rotundata</i> (Aga)	1.7	1.6	1.6	1.8	1.6	1.8	1.7a
<i>D. rotundata</i> (Ji-igwe)	1.4	1.5	1.6	1.8	1.8	1.3	1.6a
<i>D. dumetorum</i>	3.4	3.7	3.2	3.3	3.1	2.9	3.3c
<i>D. esculenta</i>	2.0	2.0	2.1	2.0	1.9	1.6	1.9ab
<i>D. cayenensis</i>	2.6	2.3	2.1	2.1	1.8	1.8	2.0b
<i>D. bulbifera</i>	1.2	1.2	1.2	1.2	1.4	1.9	1.4a
Staking means	2.0a	2.0a	2.0a	2.0a	1.9a	1.9a	

Lsd for comparison of mean number of vines per plant for different cultivars for a given height and direction of staking = 2.0

Lsd for comparison of mean number of vines per plant of different heights and directions of staking for a given cultivar = 1.9

TABLE 11a

Mean number of vines per plant observed in 8 cultivars grown in flat, mounds and ridges at Nsukka in 1971

Yam cultivars	Flat	Mound	Ridge
<i>D. alata</i>	3.5	3.8	3.2
<i>D. rotundata</i> (Abi)	3.9	4.0	3.8
<i>D. rotundata</i> (Aga)	1.6	1.5	1.4
<i>D. rotundata</i> (Ji-igwe)	1.4	1.4	1.4
<i>D. dumetorum</i>	3.3	3.3	3.6
<i>D. esculenta</i>	2.4	2.4	2.5
<i>D. cayenensis</i>	1.8	1.9	2.0
<i>D. bulbifera</i>	1.4	1.5	1.4
Cultivation means	2.4a	2.5a	2.4a

Lsd for comparison of mean number of vines per plant of different cultivars for a given preplanting cultivation = 1.8

Lsd for comparison of mean number of vines per plant of different preplanting cultivations for a given cultivar = 2.2

TABLE 11b

1972

Yam cultivars	Flat	Mound	Ridge
<i>D. alata</i>	2.3	2.4	2.5
<i>D. rotundata</i> (Abi)	1.4	1.5	1.6
<i>D. rotundata</i> (Aga)	1.7	1.7	1.6
<i>D. rotundata</i> (Ji-igwe)	1.6	1.6	1.5
<i>D. dumetorum</i>	3.0	3.6	3.1
<i>D. esculenta</i>	1.9	1.9	2.2
<i>D. cayenensis</i>	1.9	2.0	1.9
<i>D. bulbifera</i>	1.2	1.4	1.4
Cultivation means	1.9a	2.0bc	2.0bc

Lsd for comparison of mean number of vines per plant of different cultivars for a given preplanting cultivation = 1.9

Lsd for comparison of mean number of vines per plant of different preplanting cultivations for a given cultivar = 2.2

Means with the same letter opposite them are not significantly different from each other at 5% level

TABLE 12

Coefficient of variability based on smallest units (sub-sub-plots) calculated on different characteristics observed in 8 yam cultivars at different heights and directions of staking and preplanting cultivations at Nsukka in 1971 and 1972

Observations	1971	1972
Tuber yield	29.59	25.21
Plant population at harvest	6.83	12.77
Number of tubers/plant	56.81	59.80
Number of vines per stand	27.32	32.28

EFFECTS OF DIFFERENT RATES OF NPK FERTILIZERS ON YIELD AND STORAGE PROPERTIES OF WHITE YAM

E.E. Umanah*

SUMMARY

Experiments were carried out for three years, 1968 to 1970, to determine the most effective rates of application of N P K on the tuber yields of white yam and to assess the effect of the fertilizers on the storage properties of the tubers. Nitrogen application gave higher yield than no nitrogen; 33.6 kg N per hectare was significantly better than no nitrogen ($P = 0.05$) for 1969 and 1970 seasons. However, no significant increase in yield was obtained by increasing nitrogen from 33.6 kg N per hectare to 67.3 kg N per hectare. Phosphate application depressed yield throughout, though not significantly. Effect of potash application on yield was inconsistent; a nonsignificant yield increase in the first year and depression in the last two years were obtained. Fertilizer applications had no significant effect on weight losses in storage.

RESUME

Des essais ont été menés pendant trois ans, de 1968 à 1970, pour déterminer les taux les plus satisfaisants d'application de NPK sur le rendement en tubercules d'igname blanche et pour évaluer l'effet des engrais sur les propriétés de conservation des tubercules. Le rendement lorsqu'on applique l'azote a été plus élevé que celui obtenu sans recours à l'azote ($P = 0.05$) pendant les saisons 1969 et 1970. Toutefois on n'a pas noté d'augmentation sensible lorsqu'on a accru l'azote de 33.6 kg à 1'hectare à 67.3 kg à 1'hectare. Le phosphate a un effet dépressif sur le rendement, mais à un moindre degré seulement. L'effet de l'application de la potasse sur le rendement est resté très léger; il n'y a pas eu d'accroissement sensible pendant la première année, ni de dépression pendant les deux dernières années. L'effet d'applications de l'engrais sur les pertes de stockage était peu sensible.

RESUMEN

Por tres años, de 1968 a 1970, se llevaron a cabo experimentos para determinar las dosis de aplicación más efectivas de NPK, en el rendimiento de tubérculo de ñame blanco y para establecer el efecto de los fertilizantes sobre las propiedades de almacenaje de los tubérculos. Las aplicaciones de nitrógeno produjeron mayor rendimiento que cuando no se aplicó; 33.6 kg N por hectárea fué significativamente mejor que no nitrógeno ($P = 0.05$) para las temporadas de 1969 y 1970. Sin embargo, no se obtuvo un incremento significativo del rendimiento cuando el nitrógeno se aumentó desde 33.6 kg N por hectárea hasta 67.3 kg N por hectárea. La aplicación de fosfato redujo el rendimiento, si bien que no significativamente. El efecto de las aplicaciones de potasio, sobre el rendimiento, fué inconsistente; se obtuvo un incremento no significativo del rendimiento el primer año y descenso de él, en los dos últimos años. La aplicación de fertilizantes no tuvo un efecto significativo sobre la pérdida de peso durante el almacenamiento.

INTRODUCTION

Several investigators have demonstrated positive response of yams (*Dioscorea* spp) to nitrogen fertilizer. Irving⁴ obtained a significant response to nitrogen applied as ammonium sulphate. He obtained no response to phosphorus application, and sometimes its use actually depressed tuber yield. For potassium, there was a general overall response to lower rates of application, but higher rates usually had little further effect. Significant response to K was only obtained on sites that were under permanent rotations. When yams were grown after 'bush fallow' where K was available from the burning of the bush, lower response resulted. Coursey³ has reviewed most of the literature on yams including fertilizer trials. Sobulo⁶ studying nutrient content of yams with age, found an increase in potassium content of the soil after a yam fertilizer trial.

Okafor⁵ studied incidence of rotting of yams and concluded that 5.0 to 68.5 percent of the yams rotted in storage. The objectives of this study were to investigate the response of yams to N P K fertilizer and the effect of these fertilizers on the storage qualities of yam tubers.

*Federal Department of Agricultural Research, Ibadan, Nigeria

MATERIALS AND METHODS

The white yam cultivar 'Gwaguzu' which is widely grown in the middle belt of Nigeria was used. Yam setts consisted of either whole yams of 340 g in weight or large yam tubers cut into three parts of top, middle and bottom, each weighing approximately 340 g and randomly selected for each plot. The layout was a 3^3 factorial design, partially confounded and arranged in blocks of 9 units, and replicated three times. Each plot consisted of five one metre ridges, each 7.3 m long, with plants spaced 1.20 m apart on the ridges and with 30 plants per plot. One row of discard was planted around each plot, and one guard row of the same cultivar surrounded the whole trial area. Planting was in the first and second week of March of each year. Fertilizer rates were: N (sulphate of ammonia*) 0, 33.6 and 67.3 kg per hectare, P (single superphosphate*) 0, 22.4, 44.8 kg per hectare and K (sulphate of potash*) 0, 22.4 and 44.8 kg per hectare applied at the middle of May in accordance with the recommendation of Bromfield². Soil analysis was carried out for each plot before and after the experiment. Dry matter and starch contents of tubers were determined at harvest. Some tubers were stored for 5 months on raised platforms, and weighing was done at fortnightly intervals.

RESULTS AND DISCUSSION

Yield and quality of tubers

Positive and significant response to 33.6 kg per hectare N was obtained for 1969 and 1970. The response for 1968 was not significant (Table 1). Response to higher N levels was not significantly superior to this. The first and second order interactions were not significant. When results for the three years were jointly analysed the mean yield for the three years was not significantly different from the control. No significant yield response to P or K was demonstrated. The experiments were carried out in fields of Iwo soil series (1968 and 1969) and Iregun soil series (1970). These soils are very shallow and are still in the process of formation from the sedimentary parent materials.

Phosphorus and potassium status in the soil during the trials was high; 13.45 to 213.66 kg P per hectare and 35.06 to 214.58 kg K per hectare before and after the experiments. The high levels of these elements in the soil probably accounted for the absence of response when fertilizers were applied. This was confirmed for the three years when no positive response was demonstrated. These results agree with those of Amon and Adetunji¹ in which response to P and K was clearly related to the parent materials from which the soil was formed.

Dry matter and starch contents of tubers as influenced by the elements applied are shown in Table 2. There was no significant difference between treatments. Interactions were not significant. Thus N did not appear to affect the quality of the tubers.

Effect of fertilizer on yam storage

There were no significant losses in weight due to treatment (Table 3). Mean weight losses due to storage was 20 percent of initial weight. This weight loss appeared to be directly proportional to the initial weight of stored tubers. In this experiment care was exercised in selecting for storage only tubers which had received little or no bruising at harvest. The incidence of rotting was therefore negligible.

In the farmers' fields, it is probable that large tubers resulting from fertilizer use receive more bruises at harvest than unfertilized yams, hence a high incidence of rotting in storage is often noticed on them. This observation would probably be supported by the results of Okafor³ in which up to 68.5 percent of damaged tubers rotted in storage. This experiment did not indicate that the tuber quality was impaired by fertilizer application.

ACKNOWLEDGEMENT

I am grateful to the Director of Agricultural Research for permission to publish this paper, to Mr. U.U. Ebong, Principal Research Officer for a critical review of the manuscript and to Mr. A. Bamiduro for statistical assessment of the results.

REFERENCES:

1. Amon, B.O.E. and Adetunji, S.A. (1969) Fertilizer work in Western Nigeria, Results 1960-69. Ministry of Agric. and Natural Resources, Western Nigeria.
2. Bromfield, A.R. (1967) End of tour report — yam responses to fertilizers. Ministry of Agric. and Natural Resources, Western State, Ibadan (MP).

*Responses obtained with any of these fertilizers may be partially due to S as well as to N, P or K. Ed.

3. Coursey, D.G. (1967) *Yams*. Longmans, Green and Co. London.
4. Irving, H. (1956) Fertilizer experiments with yams in Eastern Nigeria. 1947-51. *Trop. Agric. Trin.* 33(1), 67-78.
5. Okafor, N. (1966) Microbial rotting of stored yams (*Dioscorea* spp.) in Nigeria. *Exp. Agric.* 2(3), 179-82.
6. Sobulo, R.A. (1972) Studies on white yam (*Dioscorea rotundata*) II. Changes in nutrient content with age. *Exp. Agric.* 8(2), 107-115.

TABLE 1

Summary of mean yield of tubers in t/ha

A Nitrogen

N kg/ha	1968	1969	1970	Mean
0	17.32	15.86	16.79	16.64
33.6	18.80	17.57*	19.43*	18.60
67.3	18.51	17.87*	21.13*	18.97
Mean	17.95	17.09	19.19	
S.E. of treatment Mean	± 1.70		* Significant difference at	
CV	=13.6%		P = 0.05	

B Phosphorus

P kg/ha	1968	1969	1970	Mean
0	18.12	18.07	19.57	18.57
22.4	17.39	16.69	17.49	17.19
44.8	18.37	16.56	18.17	17.95
Mean	17.95	17.09	18.39	
S.E. of treatment Mean	± 1.93			
CV	=12.5%			

C Potassium

K kg/ha	1968	1969	1970	Mean
0	17.57	17.69	20.33	18.42
22.4	18.42	16.82	18.52	17.92
44.8	17.90	17.12	18.70	17.89
Mean	17.94	17.09	18.25	
S.E. of treatment Mean	± 1.80			
CV	=11.4%			

TABLE 2

Effect of fertilizer treatments on dry matter and starch contents of tubers

Treatment kg/ha	Dry matter content (%)	Starch content (%)
N 0	30.4	18.9
N1 33.6	33.0	19.6
N1 67.2	32.8	17.4
P0 0	31.5	18.9
P1 22.4	32.3	19.3
P1 44.8	32.5	17.9
K0 0	32.2	19.1
K1 22.4	31.9	17.4
K1 44.8	32.1	19.2

S.E. of treatment Mean $\pm 1.82 \pm 1.64$
 C.V. = 13.3% ± 10.4

TABLE 3

Effect of fertilizer treatments on weight loss

Treatment kg/ha	Wt. loss (grams)
N0	599.6
N1 33.6	637.8
N1 67.2	624.8
P0	600.7
P1 22.4	617.4 N.S.
P1 44.8	629.9
K0	595.3
K1 22.4	632.0
K1 44.8	624.5

S.E. of treatment Mean ± 21.26
 CV = 17.8%

RESPONSE OF TARO, *COLOCASIA ESCULENTA* (L) Schott TO WATER MANAGEMENT PLOT PREPARATION AND POPULATION

H.C. Ezumah and D.L. Plucknett*

SUMMARY

Greenhouse and field experiments showed that when nutrients were not limiting, taro corm yields increased significantly in flooded but not puddled culture in comparison with non-flooded soil conditions. Differences in yield were attributable to higher suckering capacity and restricted capacity for root penetration in dry soil. Yield per hectare increased significantly with increasing populations. Ridging might be of some advantage in mechanized harvesting of taro, but did not significantly effect yield.

RESUME

Des essais menés en serres et aux champs révèlent que lorsque les éléments nutritifs ne sont pas dé-faillants, le rendement des tiges bulbeuses du taro accroît sensiblement en culture submergée mais non de mise en boue par rapport aux conditions de sol non submergé. Les écarts de rendement sont imputables à une plus grande capacité de production de surgeons et à une capacité limitée de pénétration des racines en sol sec. Plus la densité est grande, plus on enregistre de façon sensible un accroissement du rendement à l'hectare. La culture en buttes pourrait être avantageuse pour la récolte mécanisée du taro, mais elles n'ont pas d'effet sensible sur le rendement.

RESUMEN

Experimentos de invernadero y de campo mostraron que cuando los nutrientes no son limitantes, los rendimientos de cormo de malanga se incrementaron significativamente en un cultivo inundado sin formar encharcamientos, en comparación con uno en el que el suelo no se inundó. Las diferencias en rendimiento fueron atribuibles a una capacidad más alta de ahijamiento en un caso y a la capacidad de penetración de la raíces que se vió restringida en el caso del suelo seco. El incremento en rendimiento, aumentó significativamente cuando la población aumentó. El alomado puede ser de alguna ventaja en la cosecha mecánica de la malnga sin embargo, no afectó significativamente el rendimiento.

INTRODUCTION

In Hawaii, taro is grown as a commercial crop under flooded puddled soil conditions.^{1,5} The taro industry in Hawaii has been declining mainly due to lack of mechanization and hence lack of attraction to younger farmers.^{1,15} The production of taro is too small to justify high expenditure on developing and producing equipment specifically for this crop. Adjustment of the techniques for taro may enable equipment designed for other crops to be successfully employed. Such equipment as seedling transplanters and potato diggers could be used if a firm enough land surface for their movement could be obtained. A change from flooded puddled soil (as practised in Hawaii) to 'dry land' culture was suggested¹⁰. This study was undertaken to determine the effects of some cultural adjustments on taro. Enyi⁸ obtained higher yields under ridged culture of *Xanthosoma* sp. in dry land rainfed conditions in Nigeria and ridging would be likely to make harvesting easier even if it gave no direct income yield.

The degree to which vegetative development (or top growth) is related to root (or tuber) growth in root crops are of importance in overall yield. Milthorpe¹³ discussed the relationship of top to root growth for sugarbeet and illustrated the concurrent growth of roots and tops in which neither dominated at any time. In *Solanum* and sweet potatoes however, top growth dominated at early phases of development while root growth dominated at later phases. Several studies relating leaf area of *Xanthosoma* to corm yield have been conducted^{8,9,12}, but there have been relatively few such studies for taro¹⁶. As we have reported elsewhere^{11,12}, total leaf area of taro at 3, 5 and 10 months of age can be correlated linearly with corm yields, but the highest correlation coefficients of leaf area and corm yields for 5 and 10 months measurements were 0.56 and 0.54 respectively. The 5th month is the period of maximum leaf growth and 3rd and 10th months represent periods of rapid development and senescence respectively.

*University of Hawaii, Department of Agronomy and Soil Science, Honolulu, Hawaii 96822.

TREATMENTS AND RESULTS

Water regimes and method of application

Experiments were conducted from May 1970 to July 1971 to study the effects of flooded and non-flooded soil conditions on taro yield. Equal but limited amounts of water were applied by sprinkler and furrow methods and a third treatment comprised continuous flooding by maintaining inflow and outflow of water in the plots during the growing season. Taro yield (tons/ha and kg/plant) increased as water treatment method was changed from sprinkler through furrow to continuously flooded soil condition (Table 1). However the difference between continuous flooding and furrow irrigation was not significant. With increasing age from 7 through 10 to 13 months at harvest, corm yield increased in the flood and furrow treatments. Much of the differences in yield in the flooded and furrow irrigated treatments were attributable to sucker corm yields.

A further comparison was made between corm yields from flooded puddled soil, flooded unpuddled soil and yields from non-flooded soil conditions (Table 2). Corm yields obtained from unpuddled furrow irrigated plots was 54.0 tons/ha while that from unpuddled flooded plots was 54.5 tons. When the soil was continuously flooded, a yield of 63.9 was obtained in 12 months. Unpuddled ridged flooded soil gave lower yields than its corresponding unpuddled flat flooded land, probably because of competition with patches of weeds which were observed on the ridges. These weeds escaped destruction by water.

Effects of land preparation and age at harvest on taro yield

Land preparation methods comprised ridged and non-ridged conditions. Ridge widths were 60 and 90 cm apart while flat row widths were 60 cm apart. There were no significant effects in this experiment either of land preparation methods or of harvesting time on total corm yields per hectare (Table 3).

Effects of plant spacing within the row and age at harvest on taro corm yield

The highest corm yield per hectare was obtained at a spacing of 30 cm within rows under ridged culture. The spacing for maximum yield was not attained in this study (minimum within row spacing was 30 cm). With increasing age from 7 through 10 to 13 months, the differences between yields per hectare decreased significantly with increasing plant spacing (Table 4). These differences can be attributed to increases in the main (rather than sucker) corm sizes. (Table 5).

Interaction between maturity and water regimes

An interaction occurred in this study between spacing and water treatment on yield measured at 10 and 13 months. Maturity is apparently reached earlier under non-flooded treatments than in flooded plots in which the crop is still immature at 7 and 10 months⁴. Maturity is indicated by specific gravity². Table 6 shows the effects of moisture regime in potted soils under greenhouse conditions on the specific gravity of taro.

LEAF DEVELOPMENT OF TARO IN RESPONSE TO CULTURAL TREATMENTS

Leaf area of taro is estimated using the method of Chapman³. The equation $Y = 1.5x + 1.06x^2$, where x is the linear measurement in cm from the leaf apex to the point of attachment of the leaf to the petiole, related leaf area $Y(\text{cm}^2)$ to x with a fit of $R^2 = 0.996$. For all methods of irrigation, maximum leaf area occurred during the 5th month from time of planting. Equations relating leaf area and yield under the different cultural treatment were developed. Table 7 relates the maximum leaf area during the fifth month with corm yields measured at 10 months.

Under sprinkler irrigation, corm yield at 10 months increased with increasing leaf area index (LAI) to 2.8 and declined with further increase to LAI. The equation of this relationship was $Y = 128x^{1/2} - 39.9x - 67.0$ ($R^2 = 0.64$) where Y = yield in tons/ha and X = leaf area index. Under furrow irrigation, the optimum LAI for corm yield ranged from 4.5 to 6.5 and the corresponding equation was $Y = 4.5x^2 - 0.56x^3 - 22.0x^{1/2} + 54$. Flooding resulted in no distinct optimum, with corm yield increasing as LAI increased up to 3.0 and remaining constant with further increase in LAI to 7.0 at 5 months. This relationship was expressed in the following equation: $Y = 210x^{1/2} + 0.25x^3 - 65.6x - 120.6$ ($R^2 = 0.87^{**}$).

Effect of water treatments on nutrient uptake

Nutrients such as P, Mn and Fe are usually more available under flooded than dry land culture. De la Pena^{5,6} has determined critical levels for nutrients in petioles. (Table 8). Data in Table 9 show that nu-

trients did not become limiting in our experiments under any method of water treatment and hence that it is unlikely that nutrient availability was an important factor in the higher yields obtained by flooding the soil.*

Effect of moisture treatment on root growth of taro grown in pots

Root dry weights of taro were measured in 5 gallon pots containing 15 kg soil. Moisture levels ranged from below field capacity (FC) to flooded soil. The levels were designated as low and medium (in ranges below field capacity), high (about FC) and flooded soil (3-5 cm layer of water was maintained during growing period)¹². There were four harvesting dates (3,6,9 and 12 months).

Table 10 shows that dry weights of roots increased with increasing water levels and age. The dry weight of roots at the 'high' water level was only about 40 percent of the weight obtained under flooded soil conditions, while at lower moisture levels it was much less.

One of the problems in taro harvesting is the extent of root growth¹⁴. Root growth at 12 months was very extensive under the flooded and high water levels (Table 10). More limited root extension was observed in the non-flooded treatments.

Table 11 shows the distribution of roots under the various water treatments. At the low and medium moisture levels, over 90 percent of the roots developed at 9 months occurred in the top 14 cm of the soil. Only 71 percent occurred in the upper 14 cm at high moisture level, with 20 percent occurring between 14 and 21 cm and 9 percent reaching a depth greater than 21 cm. With flooding only 42 percent of the roots occur in the first 14 cm. In the field we observed over 95 percent of taro roots within 30 cm soil depth, with about 90 percent occurring within the first 21 cm under both dry land and flooded soil conditions. The exact effect of root penetration and development on yield of taro needs further study.

REFERENCES

1. Anderson, R.N., Barron, J.C. and Marders, W.G. (1972) Hanalei development plan — a socio-economic prelude. Hawaii Agric. Exp. Sta. Agric. and Res. Econ. Dept. Paper 2. 71 pp.
2. Bowers, F.A.I., Plucknett, D.L. and Younge, O.R. (1964) Specific gravity evaluation of corm quality in taro. Hawaii Agric. Expt. Stat. Circ. 61. 19 pp.
3. Chapman, T. (1964) A note on the measurement of leaf area of the tannia, *Xanthosoma sagittifolium*. *Trop. Agric. Trin.* 41, 351.
4. Ching, K.W. (1970) Development of starch, protein, leaf and corm in *Colocasia esculenta*. *Proc. Int. Symp. Trop. Root and Tuber Crops, Honolulu Vol. I*, 143.
5. de la Pena, R.S. and Plucknett, D.L. (1967) The response of taro, *Colocasia esculenta* (L) Schott, to N, P and K fertilization under upland and lowland conditions in Hawaii. *Proc. Int. Symp. Trop. Root Crops, Trin. Vol. I* (2), 70.
6. de la Pena, R.S. (1967) Effects of different levels of N, P and K fertilization on the growth and yield of upland and lowland taro, *Colocasia esculenta* (L) Schott. var. Lehua. Ph.D. Diss. Univ. Hawaii, Honolulu.
7. Duncan, D.B. (1965) A Bayesian approach to multiple comparisons. *Technometrics* 7, 171.
8. Enyi, B.A.C. (1967a) Effect of spacing, sett size, ridging and mulching on the development and yield of cocoyam, *Xanthosoma sagittifolium*. *Trop. Agric. Trin.* 44, 53.
9. Enyi, B.A.C. (1967b) Growth of cocoyam, *Xanthosoma sagittifolium* Schott. *Indian J. Agric. Sci* 38, 627.
10. Ezumah, H.C. and Plucknett, D.L. (1973) Cultural studies on taro, *Colocasia esculenta* (L) Schott.
 1. Effects of irrigation, land preparation and plant spacing on corm yield. Hawaii Agric. Expt. Station
11. Ezumah, H.C. and Plucknett, D.L. (1973) Cultural studies on taro *Colocasia esculenta* (L) Schott.
 2. The relationship of leaf area, suckering capacity and planted population with yield of taro grown under different irrigation and land preparation methods. Hawaii Agric. Expt. Station.
12. Ezumah, H.C. (1973) The growth and development of taro, *Colocasia esculenta* (L) Schott, in relation to select cultural management practices. Ph.D. Diss., University of Hawaii, Honolulu.
13. Milthorpe, F.L. (1967) Some physiological principles determining the yield of root crops. *Proc. Int. Symp. Trop. Root Crops, Trin. 1 Sect. II*, 1.
14. Plucknett, D.L., de la Pena, R.S. and Obrero, F. (1970) Taro, *Colocasia esculenta*. *Field Crop Abstr.* 23, 413.
15. Plucknett, D.L. and de la Pena, R.S. (1967) Taro production in Hawaii, *World Crops, Sept. Oct.* 244.

*The comparative data provided after presentation, but before publication (Table 8) do not appear to support this statement.

16. Reddy, V.B., Moredith, W.F. and Brown, B.T. (1968) A note on the relationship between corm yield and certain leaf measurements in taro (*Colocasia esculenta* (L.) Schott.) *Trop Agric. Trin.* 45, 243.
17. Slatyer, R.O. (1979) Physiological significance of internal water relations to crop yield. In *Physiological aspects and crop yield*. (Ed. J.D. Eastin et al. Amer. Soc. Agron. and Crop. Sci. Soc. p. 53.
18. Snedecor, G.W. and Cochran, W.G. (1967) *Statistical Methods*. The Iowa State Univ. Press, Ames. Iowa. VI Ed. 593 pp.
19. Spence, J.A. (1970) Growth and development of tannia (*Xanthosoma* sp.). *Proc. Int. Symp. Trop. Root and Tuber Crops*, Honolulu. VII. II

TABLE 1

Effects of methods of irrigation on corm yield of taro at three harvest dates

Irrigation method	Months after planting					
	7	10	13	7	10	13
	Tons per ha*			Kg per plant*		
	Total yield			Total yield		
Sprinkler	24.8a	34.8a	26.0a	0.97a	1.44a	1.06a
Furrow	27.1ab	41.0a	62.0b	1.09ab	1.71a	2.56b
Flood	32.8b	48.2b	64.6b	1.31b	1.80a	2.76b
	Main corm yield			Main corm yield		
Sprinkler	11.4a	13.6a	9.1a	0.42a	0.52a	0.34a
Furrow	11.8a	15.1a	19.4b	0.45a	0.58a	0.75b
Flood	14.0a	17.7a	20.3b	0.53a	0.63a	0.88b
	Sucker corm yield			Sucker corm yield		
Sprinkler	13.4a	21.2a	16.9a	0.56a	0.92a	0.72a
Furrow	15.3a	26.0ab	42.6b	0.63a	1.13a	1.81b
Flood	18.8a	30.7b	44.2b	0.78b	1.17a	1.88b

* Values in the same column followed by the same letters are not significantly different by the DLSD Test (P = 0.05)⁷

TABLE 2

Effects of cultural adjustments on relative yield of taro (corms) at different ages

Age at harvest (months)	Cultural treatment	% control yield crop	Yield/ha/yr tons	% control yield/yr
Control(12)	PPF	100.0	63.9	100.0
13	a) UPR	92.3	54.5	85.3
	a) UPF	105.9	62.5	97.8
13	UFR	91.6	54.0	84.5
10	USR	64.9	49.5	77.9

PPF = puddled, flooded (paddy)flat UPR = unpuddled, paddy,ridged
 UPF = unpuddled, paddy flat UFR = unpuddled, flat ridged
 USR = unpuddled, sprinkler, ridged.

TABLE 3

Effects of land preparation on corn yield of taro at different ages.

Land preparation	Months after planting					
	7	10	13	7	10	13
	tons per ha*			kg. per plant*		
60 cm ridged	27.8a	42.3a	49.2a	1.0a	1.4a	1.6a
90 cm ridged	27.0a	40.8a	51.8a	1.4b	2.1b	2.8b
60 cm flat rows	29.8a	40.9a	51.5a	1.0a	1.5a	1.8a

* Values in the same column followed by the same letters are not significantly different by the Duncan's (modified) Bayesean Test at the 5% level.⁷

TABLE 4

Effect of Plant spacing on corn yield of taro at different harvest dates

Plant spacing	Age at harvest					
	7	10	13	7	10	13
	tons per ha*			kg. per plant*		
30	35.7a	47.2a	57.4a	0.8a	1.0a	1.2a
60	25.5ab	41.9b	49.7b	1.2b	1.7b	2.2b
90	22.5b	35.0c	45.4c	1.5c	2.2c	3.0c

* Values in the same column followed by the same letters are not significantly different by the Duncan's Modified Multiple Range Test ($P = 0.05$)^{7,18}.

TABLE 5

Effect of plant spacing on corn yield of taro — main and sucker corn components

Plant spacing	Age at harvest (months)					
	7	10	13	7	10	13
	Main* t/ha.			Sucker* kg/pl.		
30	17.3a	20.2a	22.2a	0.4a	0.4a	0.5a
60	10.9b	15.1b	15.3b	0.5a	0.6b	0.7b
90	9.0b	11.1c	13.3c	0.6b	0.7b	1.9c
	Sucker			Sucker		
	7	10	13	7	10	13
	t/ha.			kg/pl.		
30	13.4a	27.0a	35.3a	0.4a	0.6a	0.8a
60	15.5b	26.8a	34.4a	0.7b	1.1b	1.5b
90	13.5b	23.9a	32.1a	0.9c	1.5c	2.1c

* Values in the same column followed by the same letters are not significantly different by the Duncan's Modified Multiple Range Test ($P = 0.05$)^{7,18}.

TABLE 6

Specific gravity of main and sucker corms of taro as effected by moisture regime and age

Moisture level	Age at harvest					
	Six months		Nine months		Twelve months	
	Main	Sucker	Main	Sucker	Main	Sucker
Low	1.03	-	1.01	1.22	1.16	1.58*
Medium	0.95	0.99	1.05	1.00	1.15	1.33
High	1.00	1.03	1.10	1.27	1.14	1.17
Flood	0.93	0.94	1.09	0.99	1.09	1.12

* Only one observation: no sucker in two replications.

TABLE 7

Relationship of Leaf Area Index (LAI) at 5 months and corm yield of taro at ten months age: effect of irrigation

Planting population per ha.	Planting spacing (cm)						
53,840	60 x 30	3.3*	38.1	5.3*	41.3	6.9*	61.7
26,910	60 x 60	2.3	41.5	3.8	41.8	3.2	51.9
17,940	60 x 90	1.3	23.3	2.0	35.8	1.8	39.5
35,880	90 x 30	2.2	44.6	4.1	47.7	3.6	56.9
17,940	90 x 60	1.6	29.5	2.0	40.4	1.8	41.9
11,940	90 x 90	1.2	31.0	2.6	38.1	1.3	36.8
53,840	60 x 30	4.7	34.1	4.9	51.5	4.9	48.8
26,910	60 x 60	3.9	37.0	6.2	37.7	2.5	49.0
17,940	60 x 90	1.3	34.0	2.4	35.0	1.5	41.3

* Each value is an average of 9 individual observations

TABLE 8

Comparative data from previous research. Percent nutrients in taro petiole at 3 months

	Rainfed culture	Flooded culture
N%	2.00	1.10
P%	0.24	0.38
K%	9.00	4.00
Projected yield T/ha.	20	30

Source: De la Pena and Plucknett, 1967⁵

TABLE 9

Nutrient content of taro petioles under different water treatments: sprinkler (SP), furrow (FU), flood or paddy (PA) irrigation

Element	Treatment			LSD 0.05	
	SP	FU	PA		
	Concentration in petiole at 3 months(%)				
N	1.76	1.60	1.86	0.58	NS
P	0.19	0.19	0.22	0.04	NS
K	0.65	6.77	0.28	3.14	NS
Ca	0.63	0.57	0.65	0.11	NS
Mg	0.49	0.45	0.33	0.17	NS
	ppm				
Fe	89	100	109	71	NS
Mn	348	244	301	206	NS

TABLE 10

Relationship between moisture regime and age on root dry weights of taro grown for twelve months at a gradient of four moisture levels

Moisture level	Age of plants and root dry weight as a % of that under flooded conditions					
	3 months	%	9 months	%	12 months	%
Low	1.99*	0.60	3.23	8.4	4.1	1.57
Medium	5.32	16.00	5.06	13.1	15.8	5.78
High	14.25	42.90	15.58	40.4	106.5	40.87
Flood	33.24	100.00	38.58	100.0	260.6	100.00

* Each value is an average of three observations

TABLE 11

Relative root penetration of nine month old taro grown in potted soil at four moisture levels in the greenhouse

Moisture level	0-7		% 7-14		% 14-21		% 21-30		Total
	Depth (cm)	%	Depth (cm)	%	Depth (cm)	%	Depth (cm)	%	
Low	2.20*	68	0.94	29	0.09	1.7	-0	-	3.23
Medium	3.74	74	1.21	24	0.11	2.0	Trace	-	5.06
High	4.36	28	6.71	43	3.18	20.4	1.33	8.5	15.58
Flood	7.33	19	8.87	23	10.41	27.0	11.90	31.0	38.58

* Averages of 3 individual observations.

Depth of soil (cm)
Root dry weight (g/pot) and % of total root found at the different depths.

ASPECTS OF TARO PRODUCTION ON THE SHALLOW CALCAREOUS SOILS OF NIUE

R.J. Lucas*, B. Punu** & W.J. Cable***

SUMMARY

Methods of subsistence taro growing on the Pacific island of Niue (19°S) are described. Also described in outline is a package of practices based on research that can substantially increase yields. The 'package' includes use of a siratro-taro rotation with siratro being undersown in taro and taro hulis being planted in siratro stubble killed by herbicides. Trials with responses to N, K and Zn are reviewed. Soil pH increases between 6.7 and 8.2 with percent coral sand and taro weight decreases linearly as pH rises, unless induced deficiencies are remedied. Foliar analysis confirms, and can be used to measure K and Zn deficiency. Iron may also be deficient at high pH.

RESUME

Les méthodes de la culture du taro de subsistance dans l'île pacifique de Niue (19°S) ont été exposées. De même un paquet technologique permettant d'accroître sensiblement le rendement a été exposé dans ses grandes lignes. Le "paquet" comprend une rotation siratro-taro; l'opération consiste à semer le siratro au bas du taro et à planter les hulis du taro sur le chaume du siratro détruit par des herbicides. Des essais de réponses à N, K et Zn ont été passés en revue. Le pH du sol accroît entre 6, 7 et 8.2 pour cent quand il s'agit du sable coralligène, et le poids du taro décroît de façon linéaire quand pH monte, à moins de pallier aux défaillances provoquées. L'analyse foliaire confirme et peut être utilisée pour mesurer le manque de K et de Zn. Le fer fait aussi probablement défaut quand pH est élevé.

RESUMEN

Se describen métodos de cultivo (de subsistencia) de malanga en la Isla del Pacífico de Niue (19°). Se reseña también un paquete de prácticas, basadas en investigación, que pueden incrementar substancialmente los rendimientos. El "paquete" incluye el empleo de una rotación siratro malanga con el siratro sembrado antes de malanga para despues sembrar las "estacas" (hulis) de la malanga sobre el rastrojo del siratro, eliminado con herbicidas. Se revizan ensayos sobre respuesta a N, K y Zn. El pH del suelo se incrementa de 6.7-8.2 a medida que aumenta el porcentaje de arena coralífera y el peso de la malanga decrece linealmente a medida que el pH se eleva, a menos que las deficiencias inducidas se subsanen. El análisis foliar confirma y puede ser usado para medir deficiencias de K y Zn. El Hierro puede ser deficiente a pH elevados.

INTRODUCTION

The Pacific island of Niue is an isolated coral atoll of 26,300 ha which lies south of Samoa and east of Tonga at 19°S and 170°W. The Niuean people are Polynesians who have close cultural relationships with their Tongan and Samoan neighbours. Taro is the staple food, and on ceremonial occasions the number and size of taros presented by a family or village are a measure of vigour and status.

The humid tropical trade wind climate is favourable for crop growth. Mean annual rainfall is 2000 mm with about 60% falling during the warmer wetter season from December to April.

The principal soil parent material is volcanic in origin. Soil depths vary considerably over very short distances because of the irregularity of the underlying former lagoon and reef formations. Crop growth and natural vegetation reflect variations in soil depth. On substantial areas mechanical cultivation is impossible because of limestone outcrops, while in other places where the absence of rock allows the use of machinery, the mantle of soil over the underlying makasea (coral sand) is often so shallow that cultivation can result in mixing this sand with top soil. The consequent increases in calcium carbonate and pH aggravates trace element deficiencies.

Wright and van Westerndorp¹ presented a comprehensive account of the soils and agriculture of Niue, but this was before Widdowson's important work on zinc deficiency. In general the soils are classified as latosols of high base status with large amounts of aluminum and iron oxide clays. Silica content is low and mineral reserves of potassium are extremely low. Exchangeable potassium is also low on account of high

* Agriculture Department, Niue, South Pacific.

** East-West Centre Grantee, University of Hawaii.

***East-West Centre Grantee, Department of Botany, University of Hawaii, Honolulu, Hawaii 96822.

levels of exchangeable calcium and magnesium. Both total and available phosphorus values are high, but sulphur is considered to be marginally deficient. Widdowson demonstrated the presence of marked zinc deficiency in most crops growing on the shallower soils^{2,4}, and in a soil with pH 8 and 41% calcium carbonate he showed that *Crotalaria anagyroides* responded to iron.³ Leaf analyses have shown that manganese and copper are sometimes below optimum in some crops, and molybdenum is currently being investigated. Molybdenum levels in legume leaves were unexpectedly low for plants growing in soil with such high pH. Responses to fertilizer nitrogen are usually obtained but the magnitude of the response depends on growing conditions and previous land use. Table 1 presents some chemical analyses of a shallow and deep soil to show the range encountered within one soil type. Most topsoils have pH values between 6.8 and 7.4.

SUBSISTENCE TARO GROWING

Shifting cultivation has enabled a population of up to 5000 to maintain themselves on their infertile island. Bush fallows of at least ten year duration after a single taro crop are necessary to maintain soil fertility. Taro yields in general are low and depend on the length of the preceding bush fallow, rainfall, the depth of soil to rock or coral sand, amount of coral sand in soil (pH), the cultivar planted and the thoroughness of weeding. Fresh corms in an average to good crop weigh about 400 g (500 kg corms/ha) but the yield range is wide.

Land clearing and burning, planting, weeding, and harvesting are the main operations of which the three or four hand weedings are by far the most laborious. Practices such as mulching are not normally considered; irrigation is impossible because there is no surface water and fertilizer is rarely used in crops grown in the traditional way. The average taro garden is about 0.1 ha and, as taros are planted successively at about two week intervals, a balanced age range results and harvests for domestic consumption can be taken throughout the year.

Over 30 taro cultivars are recognised and at least seven of these are commonly grown. The most popular 'talo fase' matures from seven to nine months and accounts for approximately 70 percent of all taro planted. Talo fase is favoured for its sweet taste and moderate size, for while large, later-maturing cultivars may bring status to the grower, the smaller corms are generally considered more palatable.

EARLY FERTILIZER TRIALS ON TARO

Since its establishment in 1954 the Niue Agriculture Department has made efforts to assist subsistence taro production as well as cash cropping. Initial fertilizer trials were conducted using taro as the test crop, as it was considered that the use of fertilizer for all crops would be adopted more readily if yield increases could be demonstrated in the main subsistence crop.

Sulphate of ammonia, superphosphate and muriate of potash were used in various combinations and rates of application in a series of field trials¹. Results were often statistically inclusive because of poor conditions for experimentation, but N and K gave varying responses depending on rainfall, time of planting, the length of the previous bush fallow, and cropping history of the land. Phosphate however did not appear to increase yields in any of the trials.

ZINC DEFICIENCY

After Widdowson's visit to Niue in 1964 and his subsequent pot trials in New Zealand confirming general conditions of zinc deficiency in Niue's shallow calcareous soils, the application of Zn to cash crops such as passionfruit and limes became normal practice. However, the use of Zn for subsistence taro crops has not yet been adopted.

Despite some outstanding responses to soil-applied Zn in several trials it was unsuccessful. Reasons for failure to obtain statistically significant responses to Zn in field trials were again related to soil variability and hence poor local control in experiments.

Taro is not well adapted to the calcareous high pH soils but, as it is the favoured staple, efforts must be made to overcome all deficiencies. The apparent inability of taro to take up trace elements from these soils in comparison with the apparent responsiveness of weeds is a problem, and nutrient placement will be important.

Methods which have been tried in recent trials have included: placement of Zn compounds in the base and sides of the hole before the huli (planting material or sett) is planted; placement of Zn in the side of the hole after the huli is planted but before consolidation with the koho (planting stick); soaking huli overnight in 1% zinc sulphate solutions before planting; and placement of Zn solutions in the taro leaf. The current recommendation is for 2 or 3 g of zinc oxide or 5 g of zinc sulphate to be placed on the soil surface at the planting hole site. Normal use of the planting stick in making the hole then ensures that the Zn is mixed throughout the soil immediately surrounding the newly planted huli.

CURRENT TARO FIELD TRIALS

Efforts are being made to define the relationships between soil properties and taro yield so that treatment responses can be assessed with more precision. Soil depth and pH are the most easily measured soil characteristics, and these have been recorded for each individual taro plant at harvest time in experiments on methods of Zn application.

A fairly close linear relationship between soil pH and taro weight has been demonstrated in the data from the Zn application trials. Taro yield per plant decreased from about 400 g where the soil pH was less than 7.0 to 200 g at 7.6 and 100 g at 7.8. Soil depth did not have a strong influence in this highly calcareous soil, but some of the deviation from the soil pH — taro weight relationship appears to be partially explained by soil depth variation.

A further problem encountered in field trials on such variable soils is the wide range in rate of taro maturity. The taro must either be harvested at some arbitrary time when most have matured but before appreciable corm deterioration occurs, or individual taros must be harvested as they mature. This second alternative is more realistic in relation to the subsistence garden situation, but it creates experimental and statistical difficulties which might be overcome by expressing yield in terms of production per unit time. Under Niuean conditions the harvest period for a single planting date could extend from seventh to ninth month in a crop of the 'talo fase' cultivar. Table 2 illustrates the situation when a trial of rates of zinc sulphate was harvested seven months after planting.

The top/root ratio is a useful index of 'maturity'. Thus control taro plants were mainly mature at seven months, but Zn treated taro was still in a state of vigorous leaf growth. Mature corm weights for the Zn-treated plants would have been considerably greater if they had been allowed a longer growth period than the weights of the immature corms harvested at the date considered appropriate for the untreated control plants.

DEFICIENCY SYMPTOMS AND FOLIAR ANALYSES

Because of the rather variable and sometimes inconclusive results obtained in field trials and the need for numerous soil depth and pH measurements, less laborious and expensive approaches to plant nutrition problems are being sought. Visual assessment (qualitative assessment) of crop nutrient deficiencies can be helpful in understanding some of the apparent anomalies encountered with conventional field trials. Foliar analysis is likely to provide a quantitative dimension.

Three month old, third leaves of the cultivar 'talo fase' with symptoms which were assumed to indicate K and/or Zn deficiency were collected, sorted into groups, dried at 80°C and analysed in Hawaii. Potash deficiency was assumed initially to be indicated by marginal chlorosis followed by necrosis which extended from the leaf margins into the interveinal areas in older leaves. Interveinal chlorosis without the marginal necrosis and spreading necrosis was considered to be characteristic of Zn deficiency.

Assumed zinc deficient leaves were sorted into four groups for analysis. Results are presented in Table 3. The field diagnosis of K deficiency was confirmed. The level of K decreased with increasing severity of marginal chlorosis and necrosis. Calcium, Mg and P levels were all very high, while N was deficient. Sulphate, Mn, and Cu all appeared to be adequate, but nitrate had accumulated in the most extreme K and Zn deficiency groups. Iron and Zn were both in the deficient range in all samples, and while their values did not decrease much with increasing severity of chlorosis, it was notable that P, Ca and Mg levels all increased considerably from high to excessive values in the most K- and Zn-deficient samples.

Comparison of results in Table 3 with Hawaii tentative standard values for dryland taro leaves confirmed that present fertilizer recommendations are along the correct lines, with the exception that N, K and Zn applications may have to be supplemented with Fe if optimum growth is to be achieved. Trials will be initiated to test the need for Fe in taro.

INCREASING THE EFFICIENCY OF SUBSISTENCE TARO PRODUCTION

Labour in the active age group is increasingly scarce through migration to New Zealand, so there is a need in Niue to reduce the amount of time required to produce taro for domestic use. Also, labour released from taro production can be diverted to cash cropping, such as the provision of an adequate and regular supply of fruit to the recently completed food processing factory.

Widespread adoption of chemical weed control could lead to large increases in taro production per unit of labour. Mixtures of contact and pre-emergence herbicides show great promise. Paraquat mixed with prometryne is the best combination tested so far.

Herbicides can also play a role in assisting the growing of siratro (*Macroptilium atropurpureum*) as rotational cover crops in place of a bush fallow between taro crops. A continuous four year rotation

between these would be attractive. It has been demonstrated that taro can be planted directly into siratro which had been killed with either 2,4-D or a mixture of 2,4-D and picloram. Taro growth was not affected by residues at any of the herbicide rates used, but all rates killed the siratro. Accessible, easily worked land could therefore be cropped much more intensively than usual without any deterioration in soil fertility, if siratro seed was undersown in the maturing taro crop ahead of the usual pre-harvest weed invasion. Then, after about three years of soil rejuvenation and application of 2,4-D, the area could be replanted in taro by using the planting stick to make planting holes through the mulch of dead legume stems and leaves.

Increased fertilizer use on taros results in increased yields. Closer spacing than the traditional 90 cm x 90 cm in good soil pockets should prevent corm size from becoming undesirably large. N and K fertilizer is recommended in at least two applications after weeding during the first four months. Zinc should be incorporated with the soil when the planting hole is made.

Considerable increases in subsistence taro production are easily attainable if the presently available technology is adopted. Unfortunately, traditional subsistence agricultural methods are often extremely slow to change, but hopes are held that increasing material aspirations may provide the incentive for greater use of herbicides, fertilizers and cover crops.

REFERENCES

1. Wright, A.C.S. and van Westendorp, F.J. (1966) Soils and agriculture of Niue Island. New Zealand Soil Bureau Bulletin 17, 80 pp.
2. Widdowson, J.P. (1966a) Zinc deficiency on the shallow soils of Niue. I. Field investigations. *New Zealand J. Agric. Res.* 9, 44-58.
3. — — — — (1966) Chlorosis in seedling *Crotalaria anagyroides* on a calcareous soil. *New Zealand J. Agric. Res.* 9, 261-7.
4. — — — — (1966c) Effects of zinc sulphate on the yield and nutrient composition of crotalaria and sweet corn. *New Zealand J. Agric. Res.* 9, 748-70.

TABLE 1

Chemical analyses of soils
(from Widdowson 1966a)

Fonuakula silty clay loam	Depth horizon (cm)	pH	Truog P (mg%)	Cation exchange properties								CaCO ₃ (%)
				CEC	TEB	Base satn (%)	Ca	Mg	K	Na		
Shallow site	0-10A	7.7	7	27.0	Free lime	-	-	3.5	0.38	0.2	8	
Deep site	0-13A	6.2	8	29.4	25.3	86	19.1	5.7	0.30	0.2	0	
	13-20AB	5.9	4	8.7	3.8	44	2.9	0.6	0.07	0.2	0	
	20-43B	6.0	5	7.0	2.8	40	2.3	0.5	0.03	0.0	0	

TABLE 2

Top/root ratios at harvest in relation to Zn weight applied

Treatment kg/ha ZnSO ₄ ·7H ₂ O	Top/root ratio	Mean corm (g)
0	44	210
25	32	300
50	30	370
100	31	330

TABLE 3

Foliar analyses of taro leaves showing chlorotic symptoms (3rd leaves from 3 month unfertilized taro crop)

Deficiency symptoms: degree of severity	Major elements %					Trace elements ppm				NO ₃	SO ₄
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn	ppm	ppm
Zn ₃ Moderate	2.95	.69	1.79	4.08	.92	200	34	7.6	11.2	210	510
Zn ₂ Present	3.07	.53	1.66	3.52	.69	140	39	7.1	12.2	90	560
Zn ₁ Slight	3.17	.59	1.62	3.4	.65	186	42	8.1	12.4	96	530
Zn ₀ Faint	3.12	.54	2.1	3.0	.47	175	40	7.2	13.4	88	440
K ₃ Obvious	2.60	.63	0.78	4.52	1.15	165	34	7.0	11.8	140	350
K ₂ Moderate	2.50	.57	0.66	4.35	1.02	207	37	7.2	12.8	88	360
K ₁ Slight	3.07	.65	1.51	4.00	.82	203	39	7.2	11.0	88	435
Above normal range		.56									
Normal				1.27	0.19	24	58	5	26		
Critical level	4.5	.40	6.2								
Sub normal	3.6	.20	3.2								
Deficient	1.8		1.5	0.55	0.09		45	2	14		50

THE EFFECT OF RAINFALL AND TIME OF PLANTING ON YIELD OF TARO (*COLOCASIA ESCULENTA* (L.) Schott) IN WESTERN SAMOA

S.G. Reynolds and P. Netram*

SUMMARY

The best time for planting rainfed taro in Samoa is in the second half of the year. This is explained on the basis of correlations between yield and cumulative rainfall occurring during the months of tuber bulking. Rainfall during the period up to tuber initiation is only weakly correlated with yield. If irrigation is practised, the time of planting is less important.

RESUME

La meilleure période pour planter le taro pluvial en Samoa se situe dans la seconde moitié de l'année. Cette observation est fondée sur les corrélations existant entre le rendement et l'accumulation de la pluie pendant les mois où le tubercule se développe. L'intervention de la pluie jusqu'à la période de d'initiation du tubercule n'a qu'une faible corrélation avec le rendement. Si on pratique l'irrigation, la période de plantation a moins d'importance.

RESUMEN

La mejor época de siembra para malanga de temporal en Samoa, es en la segunda mitad del año. Esto se explica sobre la base de correlaciones entre el rendimiento y la lluvia acumulativa que ocurre durante los meses de abultamiento de tubérculo. La lluvia caída hasta la iniciación del tubérculo, correlaciona sólo débilmente con el rendimiento. Cuando se tiene riego, la época de siembra es menos importante.

INTRODUCTION

Taro is primarily adapted to moist environments, but can be grown under a wide range of agricultural circumstances ranging from paddy culture in swampy lands, upland conditions with irrigation, or as a rain fed crop⁶. In Samoa, most taro is grown as a dry land rain fed crop. As in many Pacific islands where taro forms a staple diet item, planting is carried out every month and fresh taro is available throughout the year. Reynolds⁸ has shown responses to irrigation during the dry season. Little is known in detail on the influence on yield of dry spells occurring during different parts of the growth cycle. We have examined the effect of rainfall and time of planting on taro yields in Western Samoa in an attempt to gain some information on this.

MATERIALS AND METHODS

Twelve blocks of taro were planted at Alafua College on a uniform area during the period September 1969 to March 1970. A single block was planted on the 15th day of each month. A block comprised 4 plots measuring 5.5 x 4.6 m on each of which a different spacing was used (91.5 x 1.5 cm, 76 x 76 cm, 76 x 61 cm and 61 x 61 cm): The spacing trial is not analysed in this paper but yield data from the 4 plots at each harvesting date have been combined to give a mean taro yield in kilograms per plot. All the plots were harvested after a growth period of 7 months. For various reasons yield data for only 9 harvests were obtained. We have assessed the relationship between yield data and rainfall occurring at certain growth stages by correlation.

RESULTS

The rainfall pattern over the growth period for each planting date is presented in Table 1 with details of taro yields. Correlation coefficients for taro yield on rainfall for 10 different cumulative combinations of monthly rainfall are presented in Table 2. It is apparent that r values are highest for sets of rainfall occurring in periods of a few months leading up to the second half of the seventh month of growth, hence, this is the critical period for yield depression by drought. Eighty three percent of variation in taro yield is accounted for by rainfall in months 4,5 and 6 ($r = 0.91^{***}$).

*No. 29 P.O. Box Garha, Jhalpur 3, India.

DISCUSSION

Previous attempts at predicting taro yields^{5,6,7} have focused attention on foliar parameters. Where leaf area values at 5, 7 and 10 months have been used results have been unsatisfactory in that relationships between leaf parameters and corm weight have been generally low — at most only 33% of variation in corm weight has been able to be explained, and then only after much laborious measurement. However, in Hawaii, leaf area at 3 months⁵ was closely related to corm yield ($r = 0.83$). While leaf growth studies are continued, it is suggested that a supplementary method of assessing relative yields, and relating these to rainfall, in a given area is to use our method.

Clearly the amount of rainfall in the second half of the growth period is far more important than that in the first 3 months. Wright¹⁰ described the climate of Samoa in terms of 7 environmental classes. Our results indicate that the best time, of those we have tried, for planting taro in Samoa is in September, October or November, but data were not available for June, July and August plantings which we might anticipate could show higher yields than from plantings in the first part of the year. Taro planted in the second half of the year produced yields up to 150 percent higher than that planted from January to May.

Our results can be explained in the light of the growth stage studies of Campbell et al^{1,2} and Chapman³ on White Lisbon Yam (*Dioscorea alata* L.), and Ching⁴ on taro (*Colocasia esculenta*). These authors have identified three stages of growth for taro (and yam).

1. One to four/five months — essentially a period of rapid development of root and shoot with corm/tuber initiation only.
2. Four/five to six months — a climax of root and shoot growth together with maximum rate of corm/tuber development.
3. Six to nine/eleven months — senescence and decay of root and shoot with reduced rate of corm/tuber enlargement, leading to maximum size in the eighth/eleventh month.

It is clear from a separate study⁹ that Samoan taro, often pulled after seven to nine months, follows similar growth stages. The rainfall requirement in months, follows similar growth stages. The rainfall requirement in months 4, 5 and 6 of the seven month growing period enables maximum corm development to take place.

REFERENCES

1. Campbell, J.S. (1962) Some physiological investigations into the White Lisbon Yam (*Dioscorea alata* L.) II. Growth period and out-of-season production. *Emp. J. Exp. Agric.* 30, 232-8.
2. Campbell, J.S. and Gooding, H.J. (1962) Recent developments in the production of food crops in Trinidad. *Trop. Agric.* 39, 261-70.
3. Chapman, T. (1965) Some investigations into factors limiting yields of the White Lisbon Yam (*Dioscorea alata* L.) under Trinidad conditions. *Trop. Agric.* 42, 145-51.
4. Ching, K.W. (1970) Development of starch, protein, leaf and corm in *Colocasia esculenta*. *Trop. Root and Tuber Crops Tomorrow*. I. Coll. Trop. Agr. Univ. Hawaii. 143-6.
5. Ezumah, H.C. (1972) The growth and development of taro *Colocasia esculenta* L. Schott, in relation to selected cultural management practices. Ph.D. thesis, Univ. Hawaii.
6. Plucknett, D.L. et al. (1971) Taro (*Colocasia esculenta* Field Crop Abs. 23, 413-425.
7. Reddy, V.B. et al. (1968) A note on the relationship between corm yield and certain leaf measurements in taro (*Colocasia esculenta* (L.) Scott) *Trop. Agric.* 45, 243-5.
8. Reynolds, S.G. (1972) The influence of irrigation on taro and a number of vegetable crops: a report of an irrigation trial conducted at Alafua College in 1969. S.P.R.C.T.A. Res. Pap. Ser. 17, pp. 22.
9. — — — — (1973) A study of the growth period of the taro plant (*Colocasia esculenta* L. Schott cv. Niue) in Western Samoa, S.P.R.C.T.A. Res. Pap. Ser. 26.
10. Wright, A.C.S. (1963) Soils and land use of Western Samoa. *N.E.D.S.I.R. Soil Bur. Bull.* 22, 190 pp.

TABLE 1
Rainfall (cm) and taro yield

Planting date	15.9.69	15.10.69	15.11.69	15.12.69	15.1.70	16.2.70	16.3.70	15.4.70	15.5.70
Harvesting date	13.4.70	15. 5.70	15. 6.70	15. 7.70	14.8.70	15.9.70	15.10.70	16.11.70	17.12.70
Month*									
1	9.02	16.46	43.92	40.28	33.25	43.21	57.84	20.72	23.52
2	16.46	43.92	40.28	33.25	43.92	62.26	20.73	23.52	12.34
3	43.92	40.28	33.25	43.92	62.26	20.73	23.52	12.34	4.62
4	40.28	33.25	43.92	62.26	20.73	23.52	12.34	4.62	11.84
5	33.25	43.92	62.26	20.73	23.52	12.34	4.62	11.84	23.55
6	43.92	62.26	20.73	23.52	12.34	4.62	11.84	23.55	29.59
7	60.99	20.73	23.65	12.34	4.62	12.19	23.55	29.59	93.27
Cumulative rainfall over growth period	247.84	260.82	268.01	236.30	200.64	159.07	154.44	126.19	198.73
Taro yield (kg/plot)	30.39	25.20	27.62	21.61	12.15	13.62	12.03	16.45	17.05

* Each month taken from 15th to 14th (inclusive) of following month except in last month when taken to harvesting date.

TABLE 2
Relationships between rainfall and taro yield

	Months	r value
1.	1,2	-0.41
2.	1,2,3	-0.20
3.	1,2,3,4	0.14
4.	4,5	0.83**
5.	6,7	0.50
6.	4,5,6,7	0.87**
7.	5,6	0.86**
8.	5,6,7	0.72
9.	4,5,6	0.9.***
10.	All	0.80**

* P > 0.05

** P > 0.01

*** P > 0.001

EFFECTS OF SPACING IN TARO (*COLOCASIA ESCULENTA*)

P. Sivan*

SUMMARY

In Fiji taro is generally grown at spacings wider than 90 x 90 cm. Earlier experiments had indicated that closer spacings were superior only with the use of nitrogen fertilizer. Recent experiments have shown that yield can be more than doubled by closer spacings. Closer spacing increased corm yield per unit area and height of the plant but reduced the mean corm weight, the number of leaves and the number of suckers per plant. Spacing of 60 x 60 cm produced the highest yield of marketable size corms (over 450 gms). The yield was about 15 t/ha at 11 months maturity at this spacing, averaged over two sites and two seasons with several cultivars.

RESUME

Les espacements pour la culture du taro dans les îles Fiji dépassent généralement 90 x 90 cm. Des essais antérieurs avaient montré que des espacements plus étroits étaient plus satisfaisants seulement quand on utilise l'engrais azoté. Des essais récents ont montré qu'on peut doubler le rendement, et même plus, avec des espacements plus étroits. Des espacements plus étroits font augmenter le rendement en tiges bulbeuses par unité de surface de même que la taille de la plante, mais réduisent le poids moyen de la tige bulbeuse, le nombre des feuilles et le nombre de surgéons par plante. L'espacement de 60 x 60 cm donne le rendement le plus élevé de tiges bulbeuses commercialisable (plus de 450 g). Avec cet espacement on obtient environ 15 t/ha à 11 mois de maturité cette moyenne ayant été obtenue à partir de plusieurs cultivars essayés sur deux sites et deux saisons.

RESUMEN

En Fiji, la malanga se cultiva con espaciamentos mayores a los 90 x 90 cm. Los primeros experimentos habían indicado que los espaciamentos menores eran superiores sólo cuando se empleaba fertilizante nitrogenado. Experimentos recientes muestran que el rendimiento puede ser más que duplicados con espaciamentos mas cerrados. Tales espaciamentos incrementaron el rendimiento de cormo por unidad de área y la altura de la planta, pero redujeron el peso medio del cormo, el número de hojas y el número de hijos por planta. El espaciamento 60 x 60 produjo el más alto rendimiento de cormos de tamaño comercial (más de 450 gms.). El rendimiento fue alrededor de 15 t/ha a los 11 meses con ése espaciamento, como promedio de dos sitios y dos temporadas, con varios cultivares.

INTRODUCTION

Taro (*Colocasia esculenta* (L) Schott) is grown throughout the tropics and sub-tropics for its edible corms or leaves. The effect of spacing in this crop has been little studied and Plucknett *et al.*⁵ have reviewed this topic.

Taro in Fiji is grown mostly on the wet sides of the islands in either mixed or pure stands. In mixed stands, various crops including other root crops such as yams, cassava or sweet potato are grown together. The taro spacing used in this system has not been studied but it is both wide and very variable. With pure stands of taro two brief reports^{3,4} published about 1938 suggested the traditional spacing to be around 90 x 90 cm. In the 1968 census¹, a large number of plots of pure stands of taro were enumerated, but measurements of spacing and yield were obtained from only 91 of these, the results of which are now shown in Table 1.

The yields were recorded as yield of taro as marketed, i.e. the corms plus about 30-40 cm of petiole-base attached. The petiole base comprises about 25 percent of the total weight, so the yield of corms alone will be only about 75 percent of that shown in the Table. (All other yields shown in this paper are for corms only). Despite this, the survey strongly suggests that spacings wider than 120 x 90 cm (9,000 p/ha.) are usual in Fiji, and that within these limits there is a general trend of increasing yield with increasing plant population.

The table also shows that in Fiji, taro yields are very low (about 6 t/ha) in comparison with those recorded in other countries. Plucknett *et al.*⁵ reported yields of about 25 t/ha in the Philippines, 34 t. in India and 15-25 t. for upland taro in Hawaii. In both India and Hawaii, the crop is grown at much closer spacing than that in Fiji.

*Department of Agriculture, Koronivia Research Station, Nausori, Fiji Islands.

METHODS

1965-68 series

The first series of spacing experiments were planted at Koronivia Research Station in alluvial soils using the cultivar Vavai Dina during the winters of 1965, 1966 and 1967 and harvested about eleven months later. They have been described in detail by Rhodes and Siven *et al.*^{6,9}.

Only two spacing treatments 90 x 90 cm and 90 x 60 cm were common to all experiments. In 1965 and 1967 there was also a 90 x 75 cm spacing. The first two experiments were unfertilized; the third was a spacing (S) x nitrogen (N) factorial, with each spacing occurring with N at the rates of 0.85 and 170 kg/ha. Various ridging and mulching treatments were also included but these will not be discussed here.

1971-1972 series

The 1965-68 experiments had an insufficient range of spacings. The 1971-72 series of experiments tested a much wider range of spacings varying from 120 x 90 cm to 60 x 45 cm. Details of these experiments have been published elsewhere^{7,8,9}. Both in 1971 and 1972 the experiments were carried out at two sites, at Koronivia Research Station on flat alluvial soils, and at Waidradra Research Station on hilly, humic latosolic soils. Both stations lie in the wet zone of Fiji and receive over 3200 mm of rain evenly distributed throughout the year. The 1971 Koronivia experiment was a spacing x variety factorial with the spacing whole plots split for the two cultivars, Qawe ni Urau and Kurokece. The 1971 Waidradra experiment was a spacing x nitrogen factorial with the spacing whole plots split for three rates of N (0, 112, and 224 kg/ha).

Both the 1972 experiments were spacing x cultivar factorials with the spacing whole plots split for cultivars. At Koronivia the same cultivars were used as in 1971, whereas at Waidradra two commercially grown hill soil cultivars, Samoa and Tausala ni Samoa, were used.

The whole plot layouts for all experiments were 5 x 5 latin squares.

RESULTS

1965-68 series

The effects of spacing and N treatments in this series of experiments are shown in Table 2.

The spacing x N interaction in the 1967/68 experiment was highly significant, so in considering the results across all experiments only the N₀ results of this experiment could be averaged with those of the other two. The mean results in the absence of N were as follows:

90 x 90 cm — 10.2 t/ha.

90 x 60 cm — 11.5 t/ha.

The S.E. of these figures based on the 'pooled' internal errors of the experiments was about ± 0.5 t/ha, so that the difference between the mean results was not significant at 5 percent level. The variations from experiment to experiment (i.e. experiment x spacing interaction) was rather more significant. The highly significant superiority of 90 x 60 cm over 90 x 90 cm spacing in the presence of N in the 1967/68 experiment suggested the experiment to experiment variation might be due to N status of the soil.

The overall results therefore were a strong suggestion that 90 x 60 cm was better than 90 x 90 cm spacing, particularly in the presence of N.

1971-72 series

The N effect in the 1971 Waidradra experiment and the varietal effect in the other three experiments have been discussed elsewhere^{7,8,9} and will not be discussed here.

Individual yield results of the spacing treatments for the four experiments together with the aggregate yield data are shown in Table 3. The interaction between spacing and N in the 1971 Waidradra experiment and the interaction between spacing and cultivar in the other three experiments were negligible and non-significant, so the spacing results of these can be shown fully as in Table 3.

The aggregate means show that yield increases with close spacings. The yield of two closest spacings did not differ significantly, but both these spacings significantly outyielded all other spacings. In a recent experiment at the Fiji College of Agriculture², yield increases were obtained with populations up to 17,800 plants/ha. The replication in the college experiment was so slight that little confidence can be placed in the results, however, the suggestion that yield continues to increase with increasing plant population, even to this very close spacing, is noteworthy.

Closer plant spacing was observed to have various other effects on the plant. These are shown in Table 4. Apart from the data for sucker numbers per plant, all other data shown in the table are the means of the four varieties from the 1972 trials. The data for the suckers are the means for three cultivars only; the fourth cultivar, Samoa, hardly produced any suckers at all at any spacing. The heights and the leaf numbers

were recorded when the plants were about 6 months old; that was near their peak vegetative growth, and the sucker numbers and corm weights were recorded at harvest (10-11 months).

The mean plant height increased at first with closer spacing and then levelled off with a further decrease in spacing. The plant heights at the three closest spacings did not differ significantly. The mean leaf number and the mean corm weight per plant decreased almost linearly as spacing decreased. The mean number of plantable suckers per plant fell off rapidly at first with decrease in spacing but at closer spacings it appeared to be levelling off.

Figure 1 shows the yield distribution of various size of corms for different spacings. At closer and at wide spacings the yields of various size corms appeared to have a skewed distribution; at closest spacing the total yield consisted of a high proportion of small sized corms and a low proportion of large corms, whereas at wide spacings the yield consisted of a very high proportion of large corms and a low proportion of small corms. At an intermediate spacing of 60 x 60 cm corm size distribution tended towards normal. At this spacing over half the corms were of medium size (450-900 gms).

DISCUSSION

The extension of the range of treatments in the 1971-72 experiments, as compared with the previous experiments has clarified the situation. It shows that yield of taro, under upland conditions in Fiji, continues to increase with closer spacing, certainly down to about 60 x 45 cm. Spacings as close as 60 x 45 cm in Hawaii and 45 x 30 cm in India, were reported to be used for upland taro⁵.

Although total corm yield increased with closer spacing, the mean weight of corms per plant decreased. For many vegetable crops there is a point at which increasing yield with closer spacing is unprofitable because the decreasing size of marketable products makes them less valuable per unit weight. This applies well to taro in Fiji where corms under 450 gm (1 lb.) are regarded as too small for marketing. As can be seen from Fig. 1, although 60 x 45 cm gave slightly higher yield than 60 x 60 cm spacing, it consisted of a much higher proportion of corms less than 450 g in weight. Spacing of 60 x 60 cm gave the highest yield of corms over 450 g. This spacing appears to be more suited for the wet zones of Fiji where taro is grown in pure stand and is hand cultivated. However, since at this spacing taro forms a dense canopy, it will not be suited for intercropping.

Close spacing, apart from giving higher yield, has an added advantage in that it provides a much earlier, full ground cover which suppresses weeds. Weed competition during the early stages of growth has been reported to be most critical for taro.⁵

The main method of propagating taro in Fiji is by suckers. Suckers for planting cost between \$1.00-\$2.00 per hundred, a price at which close spacing could be expensive in planting material. However, in practice, markets for suckers are very limited. Most established growers plant their new crop after harvest and the old crop furnishes planting material for the new crop.

Some cultivars may produce less suckers than others, and suckering is generally depressed by closer spacing. The cultivar Samoa produced few suckers at any spacing. At 60 x 60 cm spacing the three remaining cultivars each produced more than two plantable suckers/plant. Hence, at this spacing for most cultivars there should be ample planting material, not only for maintaining the previous acreages but also for expansion if needed.

Although close spacing will require extra labour for planting and harvesting a unit area of crop, the vast increase in yield, together with savings in weed control costs, should more than offset the additional planting and harvesting costs. An economic study of spacing and these factors is planned for the near future.

REFERENCES

1. Asley, D.J.L. (1969) Report on the Census of Agriculture 1968. Fiji Legislative Council Paper No. 28 of 1969. 90-94.
2. Berwick, J., Biutisuvu, F., Ratuva, L.V., Kamilo, A.V. and Raghwaia. (1972) Dalo (*Colocasia esculenta*) fertilizer, variety, weed control, spacing and palatability trial. *Fiji Agric. J.* 34, 51-6.
3. Coster, S.E.H. (1938) Some notes on taro, sweet potato and banana growing. *Fiji Agric. J.* 9(4), 24-8.
4. Pharham, B.E.V. and Raikiso, F. (1939) Dalo. *Fiji Agric. J.* 10, 102-4.
5. Plucknett, D.L., de la Pena, R.S. and Obrero, F. (1970) Taro (*Colocasia esculenta*) *Field Crop Abstr.* 23, 413-26.
6. Rhodes, P.L. (1969) Dalo cultural and spacing trials. Station Reports 1966-8. (Dept. Agric. Fiji). 1, 128-31.
7. Robinson, J.B.D., Sivan, P. and Prasad, C. (1972) Dalo. Annual Res. Report 1971 (Dept. Agric. Fiji) 187-9.
8. Sivan P., Prasad, C. and Lagai, I. (1972) Dalo. Annual Res. Report 1972 (Dept. Agric. Fiji)
9. Sivan, P., Vernon, A.J. and Prasad, C. (1972) Dalo (taro) spacing trials 1971. *Fiji Agric. J.* 34, 15-20.

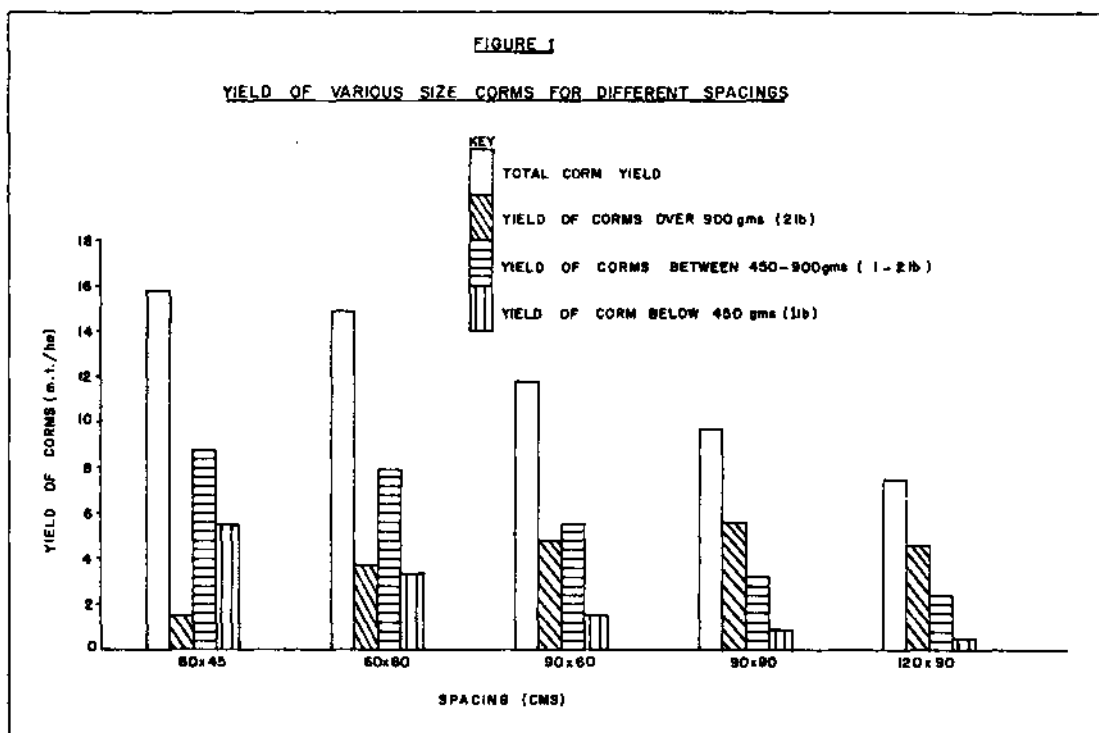


TABLE 1
Result of 1968 survey (I)

Province	Average no. of plants/ha.	Average yield* metric tons/ha
Cakaudrove	1,900	2.2
Tailevu	3,500	4.8
Macuata	4,500	6.9
Naitasiri	4,900	4.6
Others	6,400	7.9
Kadavu	8,650	8.0
Average	5,000	5.7

* Yields include yield of corm plus about 30-40 cm of petiole-base attached.

TABLE 2
Taro yields, 1965-1968 spacing experiments (t/ha.)

Spacings (cm)	Nitrogen treatments				
	N ₀ 1965/66	N ₀ 1966/67	N ₀ 1967/68	N ₁ 1967/68	N ₂ 1967/68
90 x 90	11.0	12.1	7.5	7.0	7.5
90 x 75	12.5	-	7.8	8.0	9.0
90 x 60	12.0	16.6	6.0	8.5	12.5
SE±	0.75	1.1	0.9	0.9	0.9

N₀ = Nil N, N₁ = 85 kg N/ha, N₂ = 170 kg N/ha.

TABLE 3

Effect of spacing on taro corm yield (t/ha)

Spacings (cm)	Population plants/ha.	Waidradra site		Koronivia site		Aggregate means
		1971	1972	1971	1972	
120 x 90	9,000	8.5	8.0	6.6	6.8	7.5
90 x 90	11,950	10.6	0.8	9.8	8.6	9.7
90 x 60	17,930	12.6	13.1	10.3	11.1	11.8
60 x 60	26,900	14.1	17.3	15.5	12.5	14.9
60 x 45	35,860	14.1	18.3	17.4	13.2	15.8
S.E.†		0.92	0.34	0.90	0.68	0.65*

* This S.E. is based on experiment x treatment interaction

TABLE 4

Effect of spacing on corm size, height, leaf number and sucker number and sucker production in taro

Spacings (cm)	Mean height (cm)	Mean leaf no/plant	Mean no. of plantable suckers/plant*	Mean corm weight/plant (gms)
120 x 90	102.1	3.47	7.2	870
90 x 90	100.6	3.34	5.5	820
90 x 60	116.3	3.19	4.1	710
60 x 60	115.9	3.00	2.5	570
60 x 45	115.0	2.76	1.9	460
S.E.†	3.0	0.08	0.8	40

* Suckers over 2.54 cm (1") in diameter were taken as plantable.

A LONG TERM ROTATION TRIAL IN NEW BRITAIN, PAPUA NEW GUINEA

R.M. Bourke*

SUMMARY

A twenty year rotation trial is described from the wet tropical lowland in New Britain.

Continuous cropping of sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), and peanuts (*Arachis hypogaea*) or cowpeas (*Vigna sinensis*) (narrow rotations) is compared with a one and a half year period of food crops rotated with a one and a half year period of food crops rotated with a one and a half year green manure crop (wide rotations). No cropping pattern has maintained yields of all crops at or near the original levels. The wide rotations are less bad than the narrow rotations. Fertility has dropped markedly, particularly in the narrow rotations.

RESUME

Un essai de rotation mené en vingt ans sur les basses terres de la Nouvelle-Bretagne a été exposé.

La culture ininterrompue d'*Ipomoea batatas*, de *Colocasia esculenta* et d'*Arachis hypogaea* ou de *Vigna sinensis* (rotations étroites) a été comparée à la culture de plantes vivrières sur une période d'un an et demie en rotation avec celle d'une plante verte cultivée avec application d'engrais sur un an et demie (rotations larges). Aucun des systèmes essayés n'a maintenu ou approché le rendement initial de toutes ces plantes. Les rotations larges ne sont pas aussi mauvaises que les rotations étroites. Il y a eu baisse sensible de la fertilité, surtout en rotations étroites.

RESUMEN

Se describe un ensayo de rotación, por veinte años, de las tierras bajas tropicales en Nueva Bretaña.

El cultivo continuo de camote (*Ipomoea batatas*), malanga (*Colocasia esculenta*) y maní (*Arachis hypogaea*) o chícharo de vaca (*Vigna sinensis*) (rotaciones cortas) se compara con un período de año y medio de cultivos para producción de alimentos rotados con año y medio de cultivos para forraje (rotaciones largas). Ninguno de los patrones de cultivo ha mantenido los rendimientos de todos los cultivos a los niveles originales o cerca de ellos. Las rotaciones largas son menos perjudiciales que las cortas. La fertilidad ha bajado mercadamente, particularmente en las rotaciones cortas.

INTRODUCTION

In Papua New Guinea sweet potato, taro, yams, bananas and the sago palm provide the bulk of the food for its two million inhabitants. A bush fallow farming system is employed in the lowlands and normally provides adequate crops. Under this system the cropping period is characteristically only about one year and the fallow period at least 10 years. However, as population increases, the fallow period is being reduced and the system becoming inadequate to provide sufficient food. So far this has occurred only in a few localities and has been alleviated by migration and some changes in farming systems.

In anticipation of such developments, a rotation trial in the lowlands was laid down in the early nineteen fifties and is reported here. The trial was near sea level at Keravat on the islands of New Britain at 4°21'S, 152°2'E. Annual rainfall is 2760 mm fairly evenly distributed throughout the year, although 1 or 2 dry months can be expected to occur in most years. The climax vegetation is lowland forest and the soil a young alluvial sandy loam derived from tuff.

METHODS

The trial has 7 rotational treatments (Table 1) each with a different sequence of 6 plantings. Each complete sequence of plantings is termed a cycle. Each cycle takes 3-3.5 years to complete. The first cycle of each treatment was planted in January 1954, and 19 years later in 1973 the trial is in its 6th cycle.

Each treatment is replicated 3 times in position. There are also 3 replicates in time, termed series. The 3 replicates within each series are associated in an incomplete block layout with 3 plots per sub-block. The 3 series were planted contiguously in the field.

Thus there are 63 plots in the trial (7 treatments x 3 replicates in space x 3 replicates in time (series). Each plot being 9 metres square.

* Lowlands Agricultural Experiment Station, Keravat, East New Guinea, Papua New Guinea.

Rotations 1,2,6 and 7 are termed wide rotations. In the wide rotations half of each cycle is cropped to a leguminous green manure crop and the other half to food crops. In rotations 1 and 2 half of each cycle is cropped to *Mimosa invisa* (see Table 1). In rotations 6 and 7 half of each cycle is cropped to *Pueraria phaseoloides*. These green manure crops are planted for about 1½ years. Sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*) or sorghum (*Sorghum vulgare*) and peanuts (*Arachis hypogaea*) make up the rest of the cycle. Taro occurs in rotations 1 and 6 and sorghum in rotations 2 and 7.

Rotations 3, 4 and 5 are termed narrow rotations. These are cropped continuously with food crops. Rotations 4 and 5 are identical and consist of a continuous rotation of sweet potato, taro and peanuts. Initially, the 2 rotations differed slightly in the treatment of residues of the peanut crop. Peanut residues were removed in rotation 4 and returned to the plots in rotation 5. Rotation 3 is the same as the other narrow rotations except that a short term green manure crop *Vigna sinensis*, or another short term leguminous crop, replaces peanuts. At maturity of each food crop the following yields per plot were recorded — weight of main corms only in taro, weight of all sweet potato tubers, weight of dried, unshelled peanuts and weight of sorghum grain. From the 3rd planting, 4th cycle onwards quality of the root crops was also assessed. Sweet potato tubers longer than 10 cm and wider than 5 cm were classified as marketable and those with smaller dimensions as not marketable. Taro corms larger than 7 cm by 5.5 cm were classified as marketable. Top growth vigour, leaf colour, and flowering have been visually assessed from time to time by allocating a score to each plot after a visual assessment.

Residues from green manure crops were slashed, dried and incorporated in the soil upon maturity of the corresponding group of food crops.

Soil samples were collected before and during the trial using a 2 cm diameter soil auger. Ten samples were collected per plot for a depth of 0 — 30 cm, bulked and air dried before analysis.

YIELDS RESULTS

Results from the commencement of the trial until the completion of the 2nd planting, 6th cycle (March 1973) are presented. Yield levels of rotation 1 and 2 are generally similar, as are those of rotations 6 and 7, and the yields of the pairs have been plotted together. Rotation 1 differs from 2 and 6 differs from 7 only in that sorghum replaces taro in the cropping sequence.

Sweet potato yields

Yield trends for sweet potato are shown graphically in Figures 1 and 2. Statistical analysis has been performed on sweet potato only since this is the crop common to all rotations. Rotational effects are highly significant. The least significant differences between rotations were 5280 kg/ha (5% level) and 6979 kg/ha (1% level) for comparing means of one rotation only and 3734 kg/ha (5%) and 4935 (1%) for comparing means of two rotations.

Yield levels of all rotations were initially very similar, but differences between rotations became apparent by the middle of the second cycle (Fig. 1). Yields have declined from initial levels to a lower level, about which large fluctuations occur. The wide rotations (1,2,6 and 7) have yielded significantly more than rotations 4 and 5 in 10 out of 16 crops at the 5% level of significance, and better than rotation 3 in 6 crops. Rotation 3 has significantly outyielded rotations 4 and 5 in 3 crops.

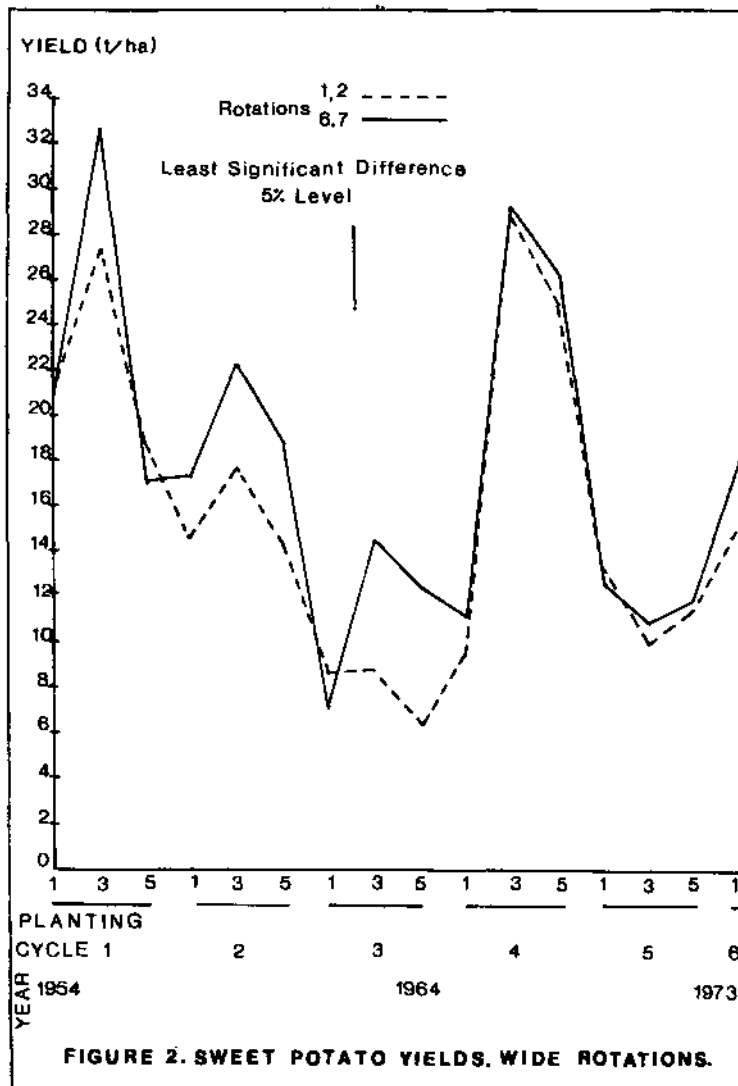
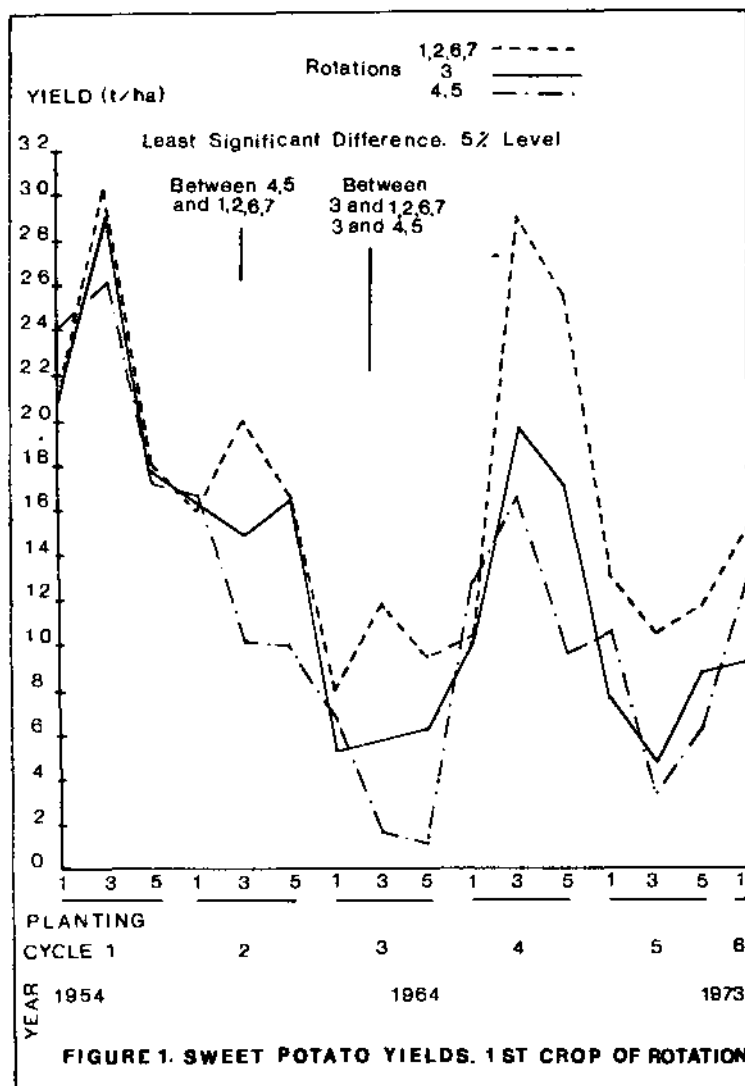
Because narrow rotation plots are cropped twice as often with sweet potato as wide rotation plots, the cumulative yield per plot for that crop plant over the period of the trial is greater in the narrow than in the wide rotations, even though the yield per crop is lower. Similarly this occurs for taro and peanuts. The high yields obtained in the 3rd and 5th plantings in the fourth cycle cannot be readily explained from weather conditions at the time.

Large yield fluctuations can be attributed in some crops to particularly severe pest and disease attack and variations in cultural treatments, such as the cultivar used. These same factors are also responsible for some of the yield fluctuations in the other crops.

The two groups of wide rotations are compared in Fig. 2. Rotations 6 and 7 have significantly outyielded 1 and 2 in 5 crops. This may be because the *Pueraria* green manure crop (Rotation 6 and 7) breaks down faster than the *Mimosa* and provides more nutrients to the following sweet potato crop. Rotations 6 and 7 have yielded less than 10 t/ha of sweet potatoes in one crop only.

The yields shown in Fig. 1 do not reflect the difference in root quality between rotations. As the data in Table 2 show, wide rotation crops often produce a greater proportion of saleable roots than the narrow rotations. No earlier records are available for root quality, but from experience with other sweet potato crops on newly opened land, it can be assumed that in the first few plantings of the trial most roots would have been classified as marketable.

Top growth vigour assessments for 2 crops are given in Table 3. High scores were allocated to more vigorous plots. Vigorous growth was characteristic of wide rotation plots, while the plants in narrow ro-



tations showed poor, chlorotic growth. Rotation 3 is not very different from the other two narrow rotations in these 2 assessments. Top growth vigour scores reflect yield performance and have provided a quick qualitative way of estimating yield levels. Vigorous top growth and a high score are associated with high yields.

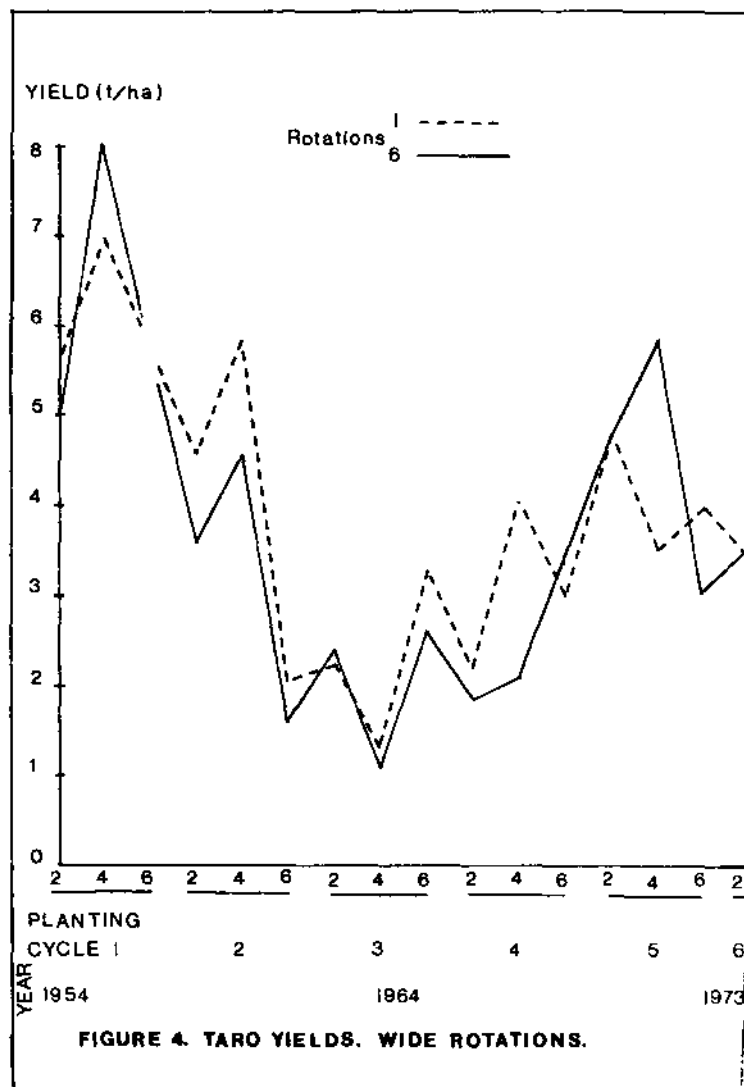
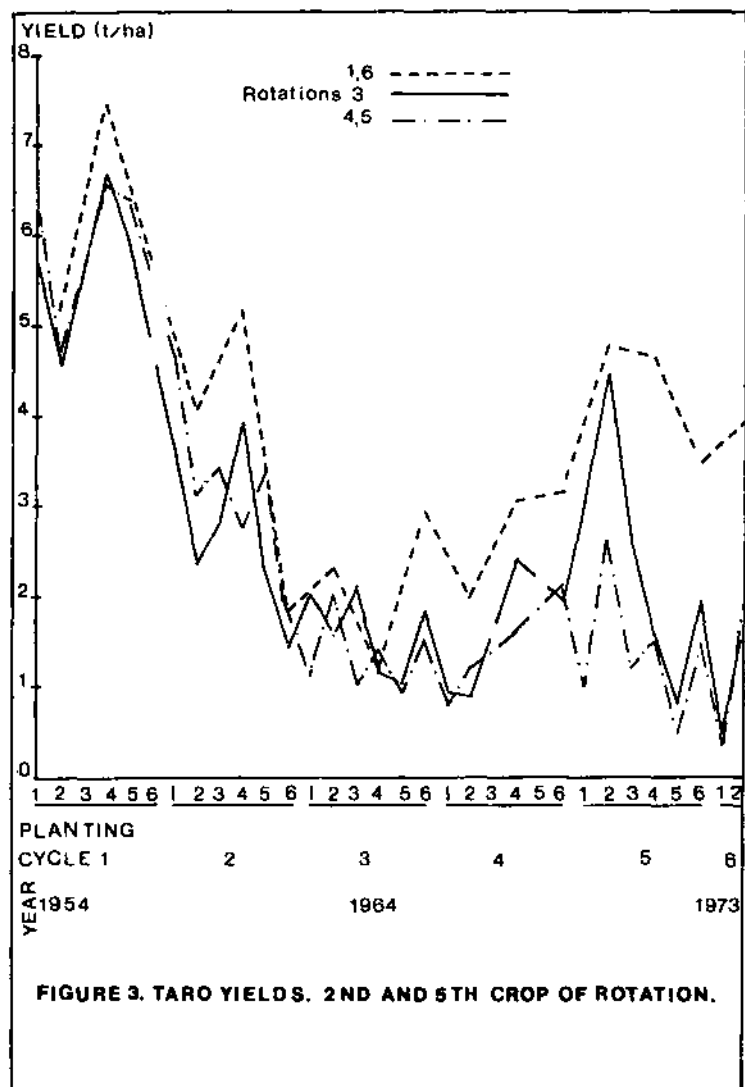
Taro yields

Yields are plotted in Figures 3 and 4. They were initially similar for all rotations, but differences between rotations became apparent by the 2nd cycle. Yields declined rapidly to very low levels but there was some yield recovery in the wide rotations. The wide rotations are clearly superior to the narrow rotations. Only in a few crops has rotation 3 yielded better than the other narrow rotations. In these rotations yields are very low.

There is little difference between yields of the two wide rotations (Fig. 4). There is some indication that rotation 1, with *Mimosa* as the green manure crop, is superior to rotation 6 with *Pueraria*, but the trend is not very strong. There is a greater proportion of larger corms in the wide rotations as can be seen from the two plantings given in Table 4. More suckers are also produced in the wide rotation plots.

Peanuts yields

Yields are given in Figure 5. Crop to crop fluctuations are large. Little or no long term yield trends are discernible, although there is a weak suggestion that there has been an overall downward trend. The wide rotations have yielded better than the narrow rotations fairly consistently from the end of the 3rd cycle, but the differences were small. There is little difference in peanut yield among the various wide rotations.



Sorghum yields

Sorghum yields are given in Figure 6. Sorghum only occurred in the wide rotations. As with peanuts, long term trends are not clear and crop to crop fluctuations are large. There is little difference between the rotations, except that, as with taro, there is a suggestion that the wide rotation, including *Mimosa* (rotation 2) may give superior yields to that including *Pueraria* (rotation 7).

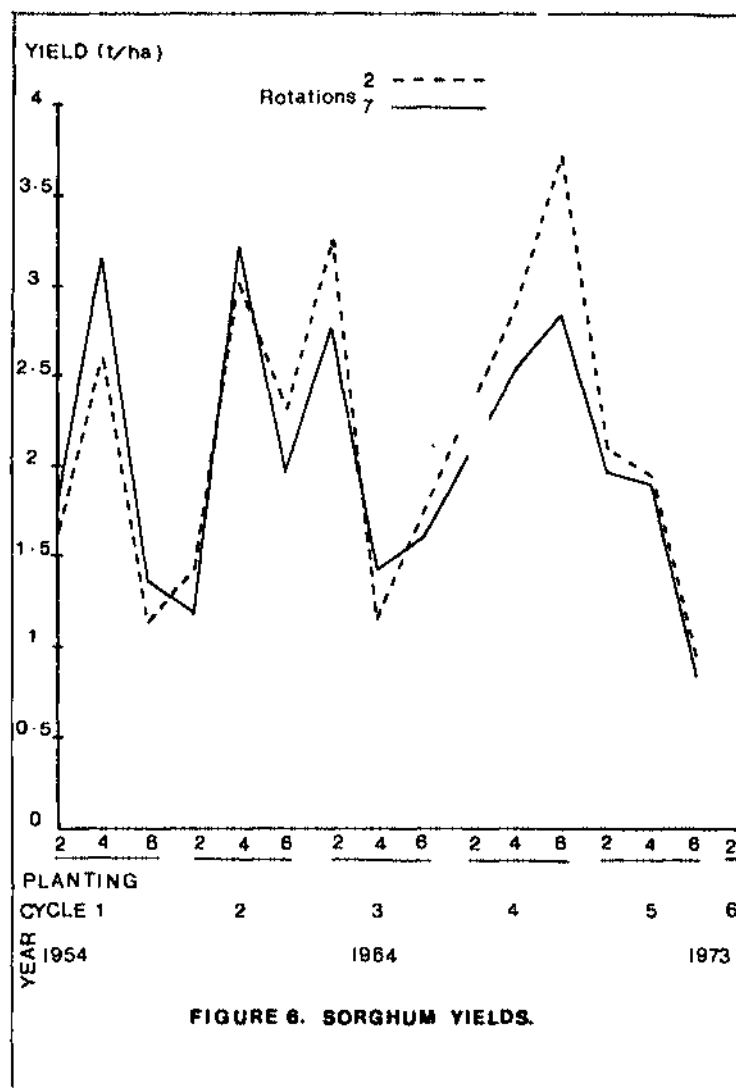
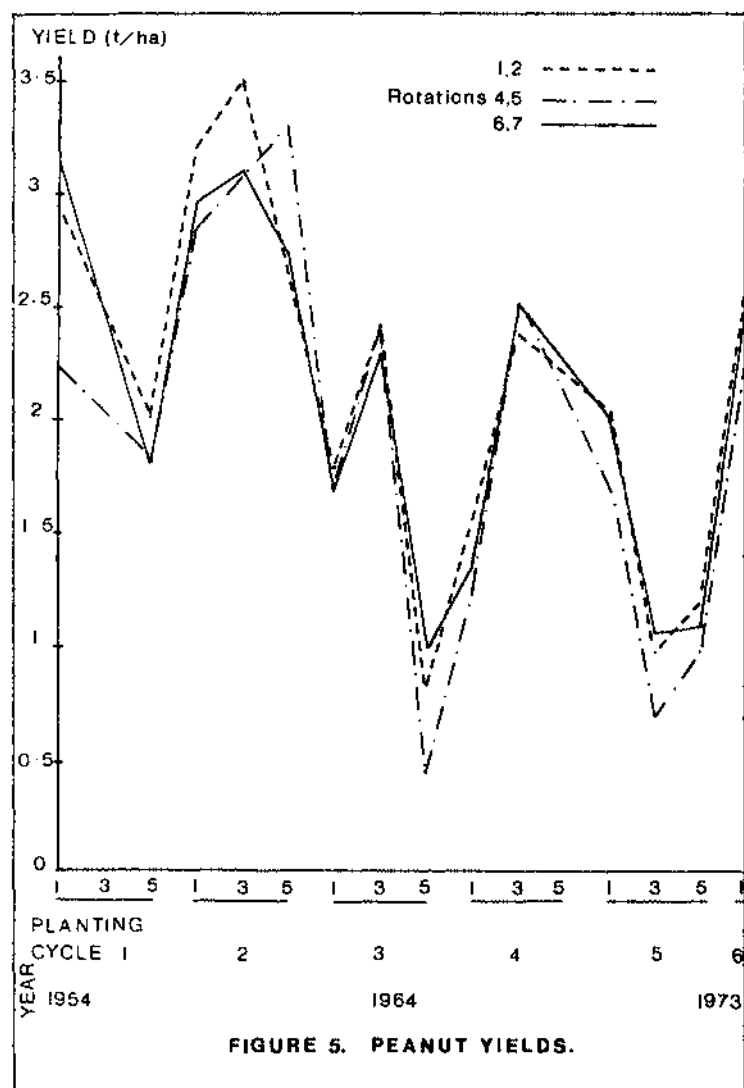
Soil analysis results

A summary of the chemical analysis for 10 soil factors from four samplings over a period of 17 years is presented in Table 5. Other samples were not analysed. Rotation 3 has been grouped with the other narrow rotations as the values differ little between these 3 rotations. The first sampling was done before the first planting, first cycle in January 1954. The 8th sampling was done after harvesting the first planting, 3rd cycle in October 1961. The 9th sampling was done after harvesting the 6th planting, 3rd cycle in December 1964, and the 10th sampling was collected during the 3rd planting, 5th cycle in August 1970. The 1st and 8th samplings were analysed on an oven dry basis, and the 9th and 10th samplings on an air dry basis.

Soil analysis has shown declines in N%, C%, pH, specific conductivity, exchangeable Ca, Mg, K and Na as well as the total exchange capacity and the K/N ratio (Table 5). For most factors the decline was greater in the narrow than in the wider rotations and especially for exchangeable K and Mg.

The differences in N% between wide and narrow rotations is not very large, suggesting that the leguminous green manure crops in the wide rotations have not prevented long term soil N decline. Because the soil is low in clay content, maintenance of fertility and exchange capacity is expected to depend upon maintenance of soil humus. This had dropped to about half of the original levels.

Olsen-P level had apparently increased with time. However both the 1st and 8th samplings were analysed in 1963, 9 and 2 years after collection respectively. The apparent rise between these 2 samplings might be due to P fixation during storage of soil from the first sampling. Other P analyses from the area suggest that the first sampling figure is incorrect, and P levels have changed little over the period of the trial.



Pests and diseases

Few quantitative assessments of damage have been made, but in some crops very high pest and disease incidence is likely to be the cause of low yields or crop failures. Chemical control has been used to reduce the incidence of the most severe pathogens and insect pests. Hand weeding has been used to control weeds.

DISCUSSIONS AND CONCLUSIONS

Sweet potato and taro yields have declined markedly over 19 years of cropping. The wide rotations were less deleterious than the narrow rotations but total production from the narrow rotations over the trial period has been greater than from the wide rotations because there are twice as many crops in the narrow rotations. The narrow rotation that included a short term green manure crop (rotation 3) was the least bad.

More severe pest and disease problems have been experienced in the trial than are usually encountered with traditional, less intensive farming systems. It can be anticipated that pest and disease problems will be more severe in any intensive farming system than under the traditional bush fallow system.

None of the rotations tried (which have not included fertilizer dressings) has provided a satisfactory alternative to the bush fallow farming system. The use of inorganic fertilizers has now been introduced.

ACKNOWLEDGEMENTS

The trial, established by Mr. J.M. Richardson has been under the supervision of various officers of the Department, including K. Newton, G.I. Jamieson, N.J. Mendham and P.N. Bryne. A.E. Charles has supervised the project for over a decade. G.A. McIntyre carried out the statistical analysis and D.W.P. Murty carried out the soil chemical analysis.

TABLE 1

Plan of rotations in one cycle. Series A.

Planting No. (6 plantings = 1 cycle)	Rotation						
	1*	2*	3+	4+	5+	6*	7*
1	SP	SP	SP	SP	SP	SP	SP
2	To	So	To	To	To	To	So
3	P	P	CP	P	P	P	P
4	M	M	SP	SP	SP	Pu	Pu
5	M	M	To	To	To	Pu	Pu
6	M	M	CP	P	P	Pu	Pu

SP Sweet potato (*Ipomoea batatas*) M *Mimosa invisa* (as green
 To Taro (*Colocasia esculenta*) So *Sorghum vulgare* manure)
 P Peanuts (*Arachis hypogaea*) Pu *Pueraria phaseoloides*
 CP Cowpeas (*Vigna sinensis*) or (as green manure)
 Vigna calcarata or * Wide rotation
 Indigofera calcaratus + Narrow rotation

TABLE 2

Percentage of sweet potato tubers which were marketable (larger than 10 cm x 5 cm)

Rotation	3rd planting 5th cycle		5th planting 5th cycle		1st planting 6th cycle	
	Market- able	Non Market- able	Market- able	Non Market- able	Market- able	Non Market- able
1,2	66	34	39	61	30	70
3	48	52	49	51	12	88
4,5	50	50	41	59	18	82
6,7	72	28	43	57	28	72

TABLE 3

Sweet potato. Top growth vigour assessment. Maximum score 30.

Rotations	1st planting, 3rd cycle 20 weeks after planting	3rd planting, 5th cycle 8 weeks after planting
1,2	18.5	23.5
3	3.5	15.0
4,5	5.0	13.0
6,7	16.5	23.0

TABLE 4

Percentage of taro corms which were marketable

Rotations	4th planting, 5th cycle		2nd planting, 6th cycle	
	Marketable	Non Marketable	Marketable	Non Marketable
1	59	41	81	19
3	40	60	70	30
4,5	45	55	61	39
6	71	29	76	24
Critical limit	8.5 x 6 cm.		7 x 5.5 cm.	

TABLE 5

Summary of chemical analysis of soil

Rotations	Sampling	pH	Spec.	Olsen	Exchangeable				Total	Car-	N	K/N
			Cond.	P	cations			m.e.%	exch.	bon		
			mhos	ppm.	Ca	Mg	K	Na	cap.	%	%	ratio
			x108						m.e.%			
1,2 (Wide)	1st(Jan.54)	6.6	.122	4	18.3	2.4	1.24	-	2.5	6.0	.653	1.90
	8th(Oct.61)	6.2	.135	8	16.1	1.9	0.75	-	23.4	6.0	.551	1.36
	9th(Dec.64)	6.1	-	-	12.0	1.5	0.85	0.6	16.7	-	-	-
	10th(Aug.70)	5.5	.045	7.6	9.0	0.6	0.4	0.1	14.0	3.3	.33	1.21
3,4,5 (Narrow)	1st(Jan.54)	6.3	.109	3	15.4	2.5	1.2	-	24.3	6.2	.579	2.06
	8th(Oct.61)	6.2	.123	7	15.3	1.9	0.6	-	21.5	5.3	.486	1.26
	9th(Dec.64)	6.1	-	-	10.0	1.2	0.7	0.5	14.7	-	-	-
	10th(Aug.70)	5.6	.028	7.8	8.1	0.5	0.2	0.2	11.4	2.5	.280	0.75
6,7 (Wide)	1st(Jan.54)	6.6	.128	5	21.3	2.8	1.41	-	27.0	5.9	.591	2.39
	8th(Oct.61)	6.2	.133	7	15.4	2.0	0.75	-	24.3	5.6	.519	1.45
	9th(Dec.64)	6.1	-	-	10.0	1.4	0.81	0.5	15.9	-	-	-
	10th(Aug.70)	5.5	.037	7.7	9.3	0.7	0.41	0.2	12.8	3.0	.340	1.21

INTEGRATION OF YAM INTO A CONTINUOUS FARMING SYSTEM IN DAHOMEY

R. Dumont*

SUMMARY

Although it is technically possible to integrate yam production into continuous rotations with a sufficient level of fertilizer use, this creates particular secondary problems for yam production. These are intense weed competition, which yams are badly adapted to meeting, and the build up of populations of yam root nematodes. As an intermediate practice between shifting cultivation (or long natural fallows in settled farming) the use of planted grass fallow of *Andropogon gayanus* is a practicable alternative but one which, without the use of fertilizers, must be expected to continue a slow downward trend of fertility, and require increased land holdings per family to maintain food production.

RESUME

Bien qu'il soit techniquement possible d'intégrer la production de l'igname dans des rotations permanentes en maintenant un niveau suffisant d'engrais, cela crée des problèmes secondaires particuliers à la production de l'igname. Ce sont d'une part, la compétition active des mauvaises herbes que l'igname n'arrive point à supporter, et la formation de populations de nématodes d'igname d'autre. Une pratique intermédiaire entre la culture itinérante (ou de longues jachères naturelles en culture permanente) consisterait à utiliser l'*Andropogon gayanus* comme jachère, ce qui représente une voie pratique possible, mais qui, faute d'engrais, renforcera la tendance à la baisse de la fertilité et nécessitera que chaque famille augmente les superficies qu'elle cultive pour maintenir la production alimentaire.

RESUMEN

Aunque técnicamente es posible integrar la producción de ñame a una rotación continua, con el uso adecuado de fertilizantes, se crean problemas secundarios particulares para la producción de este cultivo. Tales problemas son: competencia acentuada de malas hierbas, para lo cual el ñame está poco adaptado, y el crecimiento de poblaciones de nematodos de la raíz del ñame. Como una práctica intermedia entre la agricultura nómada (o empleo de descansos largos del terreno en la agricultura sedentaria) el establecimiento del pasto *Andropogon gayanus* (para el período de descanso) es una alternativa práctica en la cual, sin embargo, puede esperarse un continuo descenso de la fertilidad del terreno si no se usan fertilizantes; requiere por otra parte que la tierra que detenta cada familia se incremente, para mantener la producción de alimentos.

INTRODUCTION

Shifting cultivation occurs side by side with cotton farming in northern Dahomey. Cotton farming, which can be integrated into settled farming based on a variety of crops has made great strides recently, but yam cultivation is a major obstacle. Yam farming methods are highly traditional and there are also many technical problems. This paper reports attempts by IRAT to integrate yam production into a modern production system.

SOIL: PHYSICAL PROBLEMS

Farming without very great care toward this rapidly reduces the organic matter content of the soil leading to degradation of its structural characteristics, especially porosity.

Yam cultivation is not well suited to compacted soils. The harmattan winds, starting immediately after the normal time of ridging for yams in March-April, and with alternate moistening by the early rains and dessication due to the wind and high temperatures, accelerate soil deterioration. Soil compaction seems to have at least two serious adverse effects on yam growth. It increases heat conduction considerably, which causes an increased risk of rotting of the setts, and also causes considerable resistance to shoot emergence.

For continuous yam cultivation it is necessary either to work out farming practices to overcome the drawbacks associated with physical degradation of the soil, or develop a method that will periodically

*IRAT, Dahomey.

renew good soil structure. At present a solution to the first problem seems to be to delay ridging and planting until the start of the rains. This seems also to be useful for the control of yam nematodes. The traditional periodical long fallow, or the use of an artificial fallow, is undoubtedly the easiest way to manage the soil for yam cultivation. The benefits of artificial fallow extend also to other crops and can therefore be regarded as a definite advantage for stable farming systems including yams.

CHEMICAL FERTILITY

Many fertilizer trials in northern Dahomey over the past 10 years have shown a positive response to mineral fertilizers, but some depressive effects have been often reported, especially from the use of nitrogen. Although organic manuring has given positive responses, the generally low responses obtained do not justify, on economic ground, the use of this type of fertilizer in preference to leaving the land fallow. However, it has to be admitted that the number of experiments on these subjects has been very limited and it is necessary to conduct further studies.

With adequate use however of chemical fertilizers it seems clear that a continuous farming system can return a profit and maintain fertility at a level high enough to produce good yam yields within a rotation of crops.

ADAPTATION OF FARMING PRACTICES

In an area where yam is the staple food, the successful integration of this crop into a continuous cropping system depends on assuring the farmer that he can get at least the same advantages as he can with the traditional system by employing the necessary inputs. Three requirements are essential to him: increased production of *D. rotundata*; large size of tubers; high overall production. Experimentation has shown that modifications in farming practices can to a large extent already achieve these objectives.

Reduction of plant density by increasing the size of ridges can considerably improve production per ridge, but, of course, yields per unit of land are consequently lower. If fertility conditions have not been extremely degraded, the reduction in plant density can usually be offset by increasing the area cultivated. With an increase in area proportionally less than the decrease in plant density, the farmer can still produce tubers of normal size and maintain production to meet his needs.

The efficiency of trellising in yam production is well known, but because of the amount of work involved it is not used in the traditional system. Experiments have shown that *Dioscorea rotundata* cultivars respond best to trellising and that the operation proves relatively more efficient with the second crop.

In practice, these results have two applications: By speeding the growth of tubers, trellising can be used to correct the consequences of less favourable fertility conditions as far as early growth is concerned. Thus, this method can be justified primarily for use with relay cropping. By speeding the development of shoot growth trellising helps to increase yield by extending the first harvest.

The weight of the setts used for planting has a considerable influence on early growth. Although planting heavier setts is expensive and results cannot be generalized, this practice can be combined with trellising to enhance early crop production or to compensate for a delay in sowing.

THE PROBLEM OF WEEDS IN CONTINUOUS CROPPING SYSTEMS

In stable farming systems, the general use of fertilizers, particularly nitrogen, results in proliferation of weeds which are difficult to control in yam farming. Studies have shown that the amount of care needed to produce yams in a continuous farming system without fallows amounts to 70–100 days' work compared to 30–40 days in the traditional system.

Many African farmers are extremely sensitive to the weeding requirement, and one of the essential conditions needed before he will accept any modification to his traditional farming methods is the inclusion of a provision for effective weed control so that the new system will not involve extra work. The few experiments on herbicides conducted in Dahomey over many years have not yet generated much interest in chemical weed control in yam husbandry.

Yams are rather uncompetitive, even when well established and hence a single herbicide treatment to control early weeds is not sufficient. Experimentation has shown that an efficient and less expensive solution than that involving herbicides can be reached with occasional recourse to artificial fallow.

Since 1966 IRAT, Dahomey, has studied artificial fallows. A method has been worked out and is now ready for extension. *Andropogon gayanus* has been selected as the species best suited for artificial fallow. It establishes well if sown under sorghum, completing the rotation with no adverse effects on the cereal: it resists fire: it can be sown easily and seed is readily available. Introduced at the end of the farming cycle,

Andropogon gayanus takes advantage of residual fertility, develops quickly and spreads over the soil when the first rainy season comes. With the exception of *Imperata cylindrica* weeds are totally eliminated after three years, and when it is time to farm again, the soil is cleaner than with the traditional system and there is no regeneration of woody species.

PROBLEMS OF NEMATODES

When yam is grown other than on newly cleared land, it tends to become quickly invaded by nematode parasites which reduce yields considerably by slowing its growth (by rotting of plant roots) and generally weakening the crop.

Fallow effectively eliminates yam nematodes. When inexpensive, easy-to-use nematicides are not available, the only solution proposed at the present time is to leave planting until the first rains come in order to put into the ground only good setts which have started sprouting. Such a solution has two important disadvantages however. First, it reduces yields, and second, it implies the need for new cultivars with storage characteristics different from those of present ones.

CONCLUSIONS

Data collected in experiments have identified two possible alternative ways to integrate yams into settled farming systems.

- (a) By a continuous farming system with a relatively high fertilizer input which provides yams with excellent conditions of chemical fertility but which presents problems with physical fertility, weed competition and parasitic nematodes.
- (b) By a farming system including an artificial grass fallow to eliminate, or at least considerably reduce, problems associated with continuous cropping.

At the present stage of agricultural development in northern Dahomey where, on the one hand the farmer seems to be unable to make proper use of land and protect it from fires, and on the other hand, fertilizer use has so far proved unsuccessful, it is obvious that the prime disadvantage of not intervening to change the system is the declining fertility which will otherwise continue.

In northern Dahomey it appears technically possible to achieve acceptable yam production in the framework of a permanent farming system based on discontinuous cultivation.

- (a) Considering that land is readily available in that area and that population pressure is low, occasional recourse to fallow seems acceptable.
- (b) The techniques for artificial fallow are now established and can be extended without much difficulty.
- (c) Modifications worked out in farming methods can largely help compensate for soil fertility degradation inevitable for the moment. These include:
 - trellising: limited to rainy season varieties, it does not impose a considerable increase of work.
 - reducing plant population: this alternative is possible within a stable and continuous system of cultivation. Under present conditions land used for yam cultivation is less than half that used for cereals and cotton. Integrating all of these crops into a single production system should, by doubling the land use per rotation, allow the farmer more freedom to reduce plant population and to maintain production at usual levels of quality and quantity. The necessity to cultivate more acres of land would be compensated by little or no land clearing and the possibility of carrying out plough tillage.

TABLE 1

Influence of planting density on the yield per ridge and on yields/ha.

Cultivar	Spacing (m)	Ridges/ ha	%	Yield/ ridge	%	Yield t/ha	%
Terkokonou	1.2 x 1.2	6945	100	2.49	100	17.29	100
	1.6 x 1.6	3906	56	3.68	148	14.37	83
	2.4 x 2.4	1736	25	5.71	229	9.91	57
Singou	1.2 x 1.2	6945	100	1.950	100	13.54	100
	1.6 x 1.6	3906	56	2.500	128	9.76	72
	2.4 x 2.4	1736	25	4.500	230	7.81	58

TABLE 2

Influence of trellising on production of species of yams

Species	No trellising	Trellising	%
<i>D. cayenensis</i>			
cv. Terkokonou	16.780 kg	24.950 kg	+ 46
<i>D. rotundata</i>			
cv. Agogo 1st harvest	8.315	15.400	+ 85
2nd harvest	2.590	7.920	+206
Total yield	10.905	23.320	+113

TABLE 3

Influence of the weight of the cutting on production in terms of two periods of planting

Date of planting	Weight of setts		Increase of yield to setts of 1 kg.
	0.5 kg	1.00 kg	
10 March 1972	19.00 t/ha	24.1 t/ha	+ 5.1 t/ha
10 May 1972	11.4	17.3	+ 5.9
Effect of early planting	+7.6	+6.8	

SOME INDIGENOUS CROPPING SYSTEMS OF EASTERN NIGERIA

N.A. Nwosu*

SUMMARY

In Eastern Nigeria, except in the dry zone, root crops are very important in all rotations and provide the basic staples. Whereas much early work on rotations was concerned with the fallow period and the way in which this restored fertility, little was done on the nutrition of the crops in the economic part of the rotation. A traditional rotational cropping system comprises a two-years arable phase followed by one or more years of natural bush fallow. In this part of Nigeria, in the rain forest zone, tuberous root crops dominate the cropping systems. For several reasons, the traditional arable rotation has been challenged and numerous variants have been developed and are in use in different agricultural zones.

RESUME

A l'Est du Nigéria, sauf en saison sèche les plantes à racine sont très importantes dans toutes les rotations et fournissent les denrées de base.

Alors qu'un nombre important des premiers travaux consacrés aux rotations s'étaient consacrés à la période de jachère et comment celle-ci restaure la fertilité, peu de choses étaient faites sur la nutrition des plantes dans l'aspect économique de la rotation. Un système traditionnel de culture à rotation comporte un premier stade arable de deux ans suivi d'une ou de plusieurs années de jachère naturelle. Dans cette région du Nigeria, dans la zone forestière pluvieuse, les plantes à racine tubéreuse dominent les systèmes de culture. Pour plusieurs raisons, la rotation arable traditionnelle est en voie de régression et diverses variantes ont vu le jour et sont pratiquées dans les différentes zones agricoles.

RESUMEN

En Nigeria Oriental, excepto en la zona seca, los cultivos con raíces comestibles son muy importantes en todas las rotaciones y proveen los artículos básicos de consumo. En tanto que una gran parte de los primeros trabajos sobre rotaciones se refirió al período de descanso de la tierra y a como éste restaura la fertilidad del suelo, muy poco se hizo sobre nutrición de cultivos y el papel económico de la rotación. Una rotación tradicional de cultivos abarca una fase de dos años de uso, seguido por uno o más años de descanso. En esta parte de Nigeria, en la zona de bosque lluvioso, los cultivos con raíces tuberosas dominan como sistema de cultivo. Por diferentes razones, la rotación tradicional ha sido cuestionada y se han desarrollado numerosas variantes que están en uso en diferentes zonas agrícolas.

INTRODUCTION

The agricultural situation in South Eastern Nigeria is one of very heavy population and offers a challenging opportunity to study the problems encountered by the subsistence farmer in such regions of the humid tropics. As one moves from the more sparsely populated to the more densely populated parts of the Eastern Region of Nigeria, one witnesses a transition from the so-called 'shifting cultivation' to a more settled cropping system, employing bush fallow to maintain or regenerate soil fertility. Travelling along the major highways during the early part of the growing season, which extends from March to June, one observes also different soil management practices and an amazing combination of crops in mixed cultivation, with dominance of root crops, notably cassava, yams and cocoyams, in that order of importance.

Several writers have described the system of farming in South Eastern Nigeria, a good deal of which lies within what is generally known as the 'oil palm belt.' Vine¹⁵ and Sly¹¹ briefly described the system, but recently, Obi and Tuley⁸ gave a more detailed account of the different types of farms, as well as the structure and merits of the bush fallow. Early experiments in the maintenance of soil fertility were also described.

In the past, considerable attention has been devoted in Nigeria to the study of the fallow phase of arable crop rotations with a view to better understanding its role, and as a basis for devising an alternative based on green manures or planted fallows which could be as efficient as, or better than natural bush in maintaining soil fertility. A good account of earlier work is given in the Third West African Conference papers¹². More recently, Vine¹⁵, Nye and Hutton⁹, Nye¹⁰, Kowal and Tinker⁶, Tinker and Ziboh¹³ and Tinker¹⁴ continued the work but with special reference to oil palm production. Unfortunately, much less

*Federal Agricultural Research and Training Station, Umudike, Umuahia-Ibeku, Nigeria.

effort has been spent on the study of the cropping phase in the rotation which exploits soil fertility and converts it into crop products required by man. Consequently our knowledge about this equally important part of the cropping system in Eastern Nigeria is scanty.

Just as potentially valuable germplasm of a crop may be identified in the centre of diversity of a particular crop, so it is possible that a survey of the indigenous cropping systems developed over the years by hit-and-miss method may identify one or more of them as superior to all other systems practised in the area and capable of being applied more widely.

METHOD OF STUDY

This paper reports a cursory survey from observations and discussions while on journeys through the areas shown in the sketch map in Fig. 1. Only the superficial or macrofeatures of the cropping systems are revealed. Detailed analysis of the cropping systems of North East Nigeria will have to await a more scientific and carefully conducted survey.

THE BASIC ROTATION

The expression 'bush fallow rotation' used to describe the system of farming in the area emphasises the method adopted by farmers in the area to maintain the fertility of the soil rather than the actual crops. The term is a generic one covering a wide range of crop rotations which have developed, having in common only natural regeneration of bush for restoring soil fertility.

The cropping systems practised in the region are dominated by three basic food crops, yams, cassava and maize, though maize is of less significance than either of the tuberous crops.

A basic rotation referred to by previous writers is as follows:

- * 1st Year: yams icw early maize and vegetables ipw cassava.
- 2nd Year: cassava ctd fb bush fallow.
- 3rd-9th Year: bush fallow.

In the long past, before any population pressure developed, this rotation was probably the only one in use around the villages, i.e. there was no differentiation into compound land and distant farmland rotations as occurs now. More detailed characteristics of the basic rotation is as follows:

1. Yam is always planted as the first crop after fallow, and cassava is interplanted with other species though it is the last crop which phases out into the traditional bush fallow.
2. Minor crops such as maize, melons, yam beans, cowpeas, lima beans, okra, pumpkin, telfairia, castor and pigeon peas are interplanted through the yam garden as 'catch crops.' Cassava is generally interplanted into the last phase of the yam crop.
3. The cropping phase generally lasts not more than two years, and is followed by the bush fallow phase which is characteristically at least three times as long as the cropping phase.

Other rotations that now occur in the region are postulated as being derivatives which have evolved from the basic rotation under the particular agricultural situations of each zone of the region. The variants of the basic rotation which occur are now described.

DISTANT FARMLAND ROTATIONS

As population pressure develops a distinction begins to occur between the rotations practised on land near to settlements ('compound' rotations) and land remote from habitation ('distant' farmland). The further away the farmland is from the village, the less the extent of intercropping in the first course of the rotation, and generally, vegetables are omitted from the rotation. Also, even though the fallow period continues to be long, because of pressure of population on the land, the length of the regenerative part of the 'compound' rotation becomes reduced in some places to four or five years, whereas in the 'distant farmland' the basic rotation survives. Distant farmland rotations can still be found in use in most of the agricultural zones of the region.

The commonest distant farmland rotation is as follows:

- 1st Year: yams ipw cassava.
- 2nd Year: cassava ctd fb bush fallow.
- 3rd Year — 7th Year: bush fallow.

In some areas melon is occasionally intercropped through yam in the first course of the rotation.

*In this paper, cropping practices abbreviations used have the following meaning:

icw	means the following crop is planted after, but within the previous crop and harvested before it (i.e. inter-catch-cropped-with)
ipw	means that the following crop is inter-planted in the preceding (standing) crop and harvested after the crop into which it has been interplanted (inter-planted-with)
fb	means followed by
ctd	means the crop continues its growth from one planting season to the next.

COMPOUND LAND ROTATIONS

Here the basic rotation has undergone a series of fundamental and far-reaching changes and evolved into a variety of different crop rotations. In areas of dense settlement, especially in zone 3,4,5, and part of 6, practically all land is cropped with short cycle rotations, the curtailment in the length of the rotation having been achieved by a reduction in the number of years the land is rested under bush fallow. The most that can be attempted in this section is to give a few examples of the commoner compound land rotations and briefly to indicate the characteristics of six types that have been encountered.

- Type 1. 1st year: yams icw early maize ipw cassava.
2nd year: cassava ctd fb bush fallow.
3rd year: bush fallow.
4th year: bush fallow.
- Type 2. 1st year: yams and cocoyam icw early maize and vegetables ipw cassava.
2nd year: cassava ctd fb bush fallow.
3rd and 4th year: bush fallow.
- Type 3. 1st year: cocoyam icw vegetables ipw cassava.
2nd year: cassava ctd fb bush fallow.
3rd and 4th year: bush fallow.
- Type 4. 1st year: groundnuts ipw cassava.
2nd year: cassava ctd fb bush fallow.
3rd and 4th year: bush fallow.
- Type 5. 1st year: early maize ipw okra or groundnuts.
2nd year: yams icw early maize and vegetables, cassava.
3rd year: cassava ctd fb bush fallow.
4th year: bush fallow.
- Type 6. 1st year: cocoyams or vegetables or both.
2nd year: yams or cocoyams icw early maize ipw cassava
3rd year: cassava ctd fb bush fallow.
4th year: bush fallow.

Wherever the farmland is sufficiently fertile to support a yam crop, the first year is generally yam as a principal crop.

The following characteristics apply to the set of types described above:

1. All the rotations are of short cycle types.
2. The bush fallow phase lasts generally between one to two years.
3. The first course of the rotation is generally heavily loaded with intercrops grown in different combinations.
4. Where yam beetle is a serious pest and tree shade is heavy, cocoyam displaces yam as the first crop in the first course of the rotation.
5. Domestic refuse thrown into the farm is the basic means of maintaining soil fertility. In some areas domestic refuse fortified with leaves collected from distant bush is made into compost by the farmer and applied to the first course of his rotation.
6. The use of mulch is widespread primarily to discourage poultry and village livestock from damaging the newly planted crops.

HIGH FOREST ZONE ROTATION

The high forest zone (zone 8) occurs in the east of the region stretching from the coast to the foothills of the montane zone (zone 9) in the north-east of the region. A smaller high forest area exists in the south-west as well as in the fresh water part of the Niger Delta. The main distinguishing features of this zone are the high rainfall, 254 cm (100 ins.) per annum, and sparse population density. Land is therefore plentiful for agricultural development and exploitation, and for the practice of long cycle rotations. It is in this zone also that plantation agriculture has great scope. Most of the large commercial oil palm and rubber plantations are located in this zone.

The major food crops, plantain and cassava, continue to grow admixed with the invading bush fallow at the end of the cropping phase, the farmer harvesting both crops for food as and when required.

There is hardly any differentiation of the rotation into compound and distant farmland rotations. The range of food crops grown is narrow and the intensity of cropping is light. Plantain replaces yams as a major food crop.

The rotation:

- 1st year: plantain ipw cassava, sugar cane, early maize and okra.
- 2nd year: plantain, cassava, sugar cane ctd.
- 3rd year: cassava, plantain ctd fb bush fallow.
- 4th-11th year: bush fallow.

RIVERINE ZONE ROTATIONS

The riverine zone (zone 2) experiences annual river flooding. This zone is found around the Niger-Anambra and the Cross-River basins. The planting season begins in November of each year after the floods have receded. The residual moisture in the loamy or clay-loamy soil is normally sufficient for the raising of dry season vegetables and to allow the growth of early-planted long-term crops such as yams. All the crops mature and are harvested before the onset of river flood in September. It is in this zone that the largest and some of the best ware yams are grown. Here too the art of yam cultivation is most highly developed. Over most of the country the average size of yam setts planted is about 225 g (8 ounces). But in the riverine zones the 'seed' yams planted generally weigh about 450 g (1 lb) and over.

Continuous cropping is practised in this zone, apparently with no ill-effects on the soil and its fertility. Yam beetle is, however, a serious pest and aldrin dust is used extensively as a control measure. Fertility is replaced annually through silt deposited by floods and the organic matter added by grasses and herbs which colonise the soil as soon as the flood recedes. Three typical rotations for the riverine zone are:

Type 1. Root crop dominant rotation:

- 1st year: ware yams only, or icw early maize.
- 2nd year: " " " " " " "
- 3rd year: " " " " " " "
- 4th year: " " " " " " "
- 5th year: yams/sweet potatoes or groundnuts or early maize.
- 6th – 9th year: grass fallow.

Type 2. Cereal dominant rotation:

- 1st year: swamp rice
- 2nd year: " "
- 3rd year: " "
- 4th year: " "
- 5th year: yams icw early maize and vegetables ipw cassava.
- 6th year: cassava ctd fb fallow.
- 7th – 9th year: bush fallow.

Type 3. Legume dominant rotation:

- 1st year: groundnuts ipw early maize or melons or local vegetables
- 2nd year: groundnuts ipw local vegetables fb cassava.
- 3rd year: cassava ctd bush fallow.
- 4th – 8th year: bush fallow.

DRY ZONE ROTATIONS

The 'dry zone' of South Eastern Nigeria is part of the 'derived savannah' zone of Nigerian vegetation. Annual rainfall is generally below 203 cm (80 inches) being as low as 152 cm (60 inches) at the extreme north-western corner of the zone.

In the 'dry zone' grain legumes and other grain crops, such as castor, benniseed and sorghum become important crops and feature regularly and prominently in rotation with other basic food crops both in 'compound' and 'distant farmland' rotations. Some of the commoner rotations are as follows:

Type 1.

- 1st year: yam icw vegetable crops and maize ipw pigeon peas.
- 2nd year: pigeon peas ipw cassava.
- 3rd year: cassava ctd fb bush fallow.
- 4th – 6th year: bush or grass fallow.

Type 2.

- 1st year: yams icw melon ipw maize and vegetables.
- 2nd year: early groundnuts ipw cassava.
- 3rd year: cassava ctd fb bush fallow.
- 4th – 5th year: bush fallow.

Type 3.

- 1st year: yam icw early maize, melon and vegetables.
- 2nd year: benniseed/early groundnuts fb guinea corn or cowpeas or bambara groundnuts.
- 3rd – 5th year: bush fallow.

Table 4.

- 1st year: yams icw early maize and vegetables.
- 2nd year: upland rice fb bambara groundnuts.
- 3rd – 5th year: bush fallow.

Type 5.

- 1st year: bambara groundnuts or cowpeas or groundnuts.
2nd — 4th year: bush fallow.

DISCUSSION

The following general observations may be made on the cropping systems developed.

Short cycle rotations and intensive cropping are normally practised around the homestead. The universal dominance of root or tuberous crops (yam, cassava and cocoyam) is evident, and these constitute the basis of food supply for the population. Grain legumes occupy dominant positions in crop rotations only in the relatively 'drier' low rainfall northern strip of the region, while plantain replaces yams in the coastal high rainfall zone. Mixed cropping, which is now variously described in current agricultural literature as relay cropping or multiple cropping, is the traditional system of arable farming.

Mixed cropping was for long thought to be of low productivity, but recent research work has endorsed this practice. Alapaggan *et al.*¹, Evans and Sreedham⁴, Andrews² and Enyi³ have conclusively shown that, all things being equal, a higher aggregate yield is obtained from a mixed-cropped plot than from a sole or mono-cropped plot. Also Obi⁷ in his crop sequence studies reached supporting conclusions.

REFERENCES:

1. Alapaggan, R., Thandavarayan, K. and Venkatasubramanian, M.K. (1960) Mixed cropping. *Madras Agric. J.* 47(4), 172-8.
2. Andrews, D.J. (1972) Intercropping with guinea corn — a biological co-operative. II. *Samaru Agric. Newsletter* 14, 40-42.
3. Enyi, B.A.C. (1973) Effects of intercropping maize or sorghum with cowpeas, pigeon peas, or peas. *Expl. Agric.* 9, 83-83-90.
4. Evans, A.C. and Sreedham, A. (1962) Studies in intercropping II. Castor beans with groundnuts or soyabeans. *E. Afr. Agric. For. J.* 28(1), 7-8.
5. Junguerius, P.D. (1964) Publication service geologique de Luxemburg. 14, 185-98.
6. Kowal, J.M.L. and Tinker P.B. (1959) Soil changes under a plantation established from high secondary forest. *J.W. Agric. Inst. for Oil Palm Research* 2, 376-89.
7. Obi, J.K. (1965) The influence of previous crops on subsequent crops following bush fallow in Umudike, Eastern Nigeria. Proceedings, OAU/STRC Symposium on the Maintenance and Improvement of Soil Fertility, Khartoum, Sudan.
8. Obi, J.K. and Tuley, P. (1973) The bush fallow and ley farming in the oil palm belt of south-east Nigeria. Misc. Report No. 161. Foreign and commonwealth Office, O.D.A., London.
9. Nye, P.H. and Hutton, R.G. (1957) Some preliminary analyses of fallows and cover crops at the West African Institute for Oil Palm Research. *J.W. Agric. Inst. for Oil Palm Res.*
10. Nye, P.H. (1958) Plant nutrient in some indigenous systems of agriculture. Report of a Conference of Directors and Senior Officers of Overseas Depts. of Agriculture and Ag. Institutes at Wye College, Kent. Misc. Rep. No. 536, 43-47.
11. Sly, J.M.A. (1968) The results of pruning experiments on adult palms in Nigeria. *J. Nigerian Inst. for Oil Palm Res.* 17, 89-99.
12. Third West Africa Agricultural Conference (Nigeria) (1958) Govt. Printer, Lagos.
13. Tinker, P.B.H. and Ziboh, C.D. (1959) A study of some typical soils supporting oil palm in Nigeria. *J.W. Afric. Inst. for Oil Palm Research* 3, 16-51.
14. Tinker, P.B.H. (1963) Changes occurring in the sedimentary soils of Southern Nigeria after oil palm plantation establishment. *J.W. Afric. Inst. for Oil Palm Research* 4, 66-81.
15. Vine, H. (1956) Studies of soil profiles at the WAIFOR Main Station and at some other sites of oil palm experiments. *J. W. Afric. Inst. for Oil Palm Research* 4, 8-59.
16. Zeven, A.C. (1965) Oil palm groves of Southern Nigeria. I. Types of groves in existence. *J. Nig. Inst. for Oil Palm Research* 15, 226-250.

EFFECTS OF TIME OF WEEDING AND PLANT POPULATION ON THE GROWTH AND YIELD OF CASSAVA

J.D. Doll and W. Piedrahita C.*

SUMMARY

The critical period competition for cassava (*Manihot esculenta* Crantz) by weeds occurs between 60 and 120 days after planting. Weeds competing with cassava during the first 60 days reduced production by 50 percent. Cassava kept weed-free from the first 60 days produced 76 percent of yield of fully weed-free cassava and that kept weed-free for 120 days, 88 percent of the maximum.

The optimum plant density varied with the weed control practice used. Densities of 6000 to 8000 plants/ha were optimal for cassava kept chemically weed-free, whereas for cassava hand-weeded only once at 30, or twice at 30 and 60 days after planting, densities greater than 8000 plants/ha were necessary to obtain the maximum yield.

RESUME

Le période critique de concurrence entre le manioc (*Manihot esculenta* Crantz) et les mauvaises herbes se situe entre les 60 et 120 jours qui suivent le semis. La concurrence des mauvaises herbes avec le manioc pendant les 60 premiers jours réduit la production de 50 pour cent. Libéré de la concurrence des adventices pendant les 60 premiers jours, le manioc donne 76 pour cent de manioc entièrement débarrassé d'adventices; dans les mêmes conditions et pendant 120 jours, on obtient 88 pour cent du maximum.

La densité optimale de peuplement varie en fonction de la méthode de lutte contre les adventices. 6,000 à 8,000 plants à l'hectare représentent les densités optimales quand les adventices sont maîtrisés par des produits chimiques, alors que des densités supérieures à 8,000 plants à l'hectare sont nécessaires quand le désherbage se fait à la main une fois à 30, ou deux fois à 30 et 60 jours après le semis pour obtenir un rendement maximum.

RESUMEN

En yuca, (*Manihot esculenta* Crantz), el período crítico de competencia de malas hierbas ocurre entre 60 y 120 días después de la siembra. Las malas hierbas compiten con la yuca durante los primeros 60 días reduciendo la producción en un 50 por ciento. La yuca que se mantiene libre de hierbas los primeros 60 días produce el 76 por ciento de lo que produce un cultivo que se mantenga completamente deshierbado. La yuca que se mantenga libre de hierbas 120 días, produce el 88 por ciento del máximo.

La densidad de población óptima varió con la práctica empleada en el control de las malas hierbas. Las densidades de 6000 a 8000 plantas/ha fueron óptimas cuando la yuca se mantuvo libre de hierbas químicamente, en tanto que los cultivos de yuca, donde se hizo un solo deshierbe manual a los 30 días o dos a los 30 y a los 60 días después de la siembra, se requirieron densidades mayores a las 8000 plantas/ha, para obtener los rendimientos máximos.

INTRODUCTION

Relatively little is known about the losses due to weed competition in cassava (*Manihot esculenta* Crantz). For many annual crops, the critical period of weed competition is from 30 to 40 days after planting² This is the period during which these crops, if freed from competition, can completely shade the inter-row area, thereby greatly reducing subsequent weed germination and growth. Cassava, on the other hand, due to its slow initial growth, may often require three months or longer to attain a closed canopy. The wide spacing usually used for cassava makes it more susceptible to losses from weed competition than the use of close spacing.

It was anticipated in planning our study that the initial growth period could be the most important one in which to keep cassava weed free, and that this period would be more prolonged than for annual crops.

*Centro Internacional de Agricultura Tropical, A.A.67-13, Cali, Colombia.

Completely weed-free cassava will be able to utilize all the available nutrients, light and water. Lower plant populations, which nevertheless attain a closed canopy, may be able to yield as much or more than higher ones under weed free conditions. However, when weeds are potentially competing with the crop, the plant density which produces the maximum competitiveness against weeds may yield better than more widely spaced plantings. Higher plant populations are expected to be more competitive against weeds than lower ones. Thus the optimum plant density may be expected to interact with measures to control weeds. This interaction has been studied in two cassava cultivars.

MATERIALS AND METHODS

Study of the critical period of competition

This experiment was designed to compare the production of two cassava cultivars CMC39 and CMC84, weeded at various times and frequencies with that of cassava kept completely free of weed competition by the use of herbicides (hereafter called 'chemically weed-free cassava'). Weeds were allowed to grow with cassava for varying periods at different growth stages of the crop.² Weeding times and frequencies are presented in Table 1. In the first four treatments weeds competed during the initial growing stages, and the crop was thereafter kept weed-free. In treatments five to eight, weeds were controlled initially and then weed control measures were stopped. Treatments of two weeding, at 30 and 60 or 15 and 45 days, were included as being typical of practices used by cassava growers. The unweeded check was included to measure the loss when no weed control measures were taken. The chemically weed-free treatment, included as well as complete hand weeding, indicated whether or not the soil disturbance which occurred during normal weeding affected root yield.

The competitive ability of the cultivar CMC39 (a tall and branched type) was compared with that of CMC84 (a shorter and less branched type). Cassava was planted in a clay soil containing 6.3 percent organic matter with a pH of 6.8. The crop population was 10,000 plants/ha. The experimental design was a split-plot with cultivar as the main plot and weeding as the sub plot treatment. Four one-meter wide rows comprised each subplot and ten plants were spaced one meter apart in each row. Four replications were used. Stem cuttings of 20 cm were planted. These were inclined and planted just below the soil surface on May 10, 1972. Missing plants were replaced three weeks later by cuttings propagated on the same date in polyethylene bags.

Fluometuron (3 kg/ha a.i.) was applied pre-emergence in the treatment of chemically weed-free cassava. Post-emergence applications of 0.5 percent v/v paraquat with 0.25 percent surfactant, were directed to the weeds as often as they emerged. A total of eight such applications were made.

The height of the cassava was measured 160 days after planting. Harvesting was carried out 9.3 months after planting and the fresh and dry weights were measured for the roots and aerial part of 16 plants per plot. Weed counts and the weights of weeds removed were recorded at each weeding.

Cassava density and competition

A systematic design was used to obtain plant populations ranging from 2380 to 13,850 plants/ha¹. Twenty five stem cuttings were planted, inclined in ridges. Weed control treatments included one hand weeding at 30 days, two weeding at 30 and 60 days, a chemically weed-free treatment (fluometuron and alachlor pre-emergence at 2.0 + 1.5 kg/ha a.i. respectively, followed by a total of 12 directed post-emergence applications of a 0.5 percent solution of paraquat as needed), and a weedy check. The cultivars Llanera and CMC84 were used. Missing plants were replaced three weeks after planting with plants of the same age grown in polyethylene bags. The soil characteristics were similar to those of the previous experiment. The predominant weed species were *Cyperus rotundus* L. (purple nutsedge), *Cenchrus brownii* Roem & Shult. (sandbur), *Amaranthus* spp. (pigweed), *Ipomoea* spp. (morning glory), *Leptochloa filiformis* (Lam.) Beauv. (springletop) and *Digitaria sanguinalis* (L.) Scop. (crabgrass).

Plant heights were taken 30, 90, and 180 days after planting. Soil moisture was determined at 100 days. Three central rows were harvested 8.4 months after planting and the data are expressed as three point moving averages.

RESULTS AND DISCUSSION

Critical period competition

Weed competition reduced the height of both cultivars 160 days after planting. Non-weeded cassava was less than half as tall as that kept chemically weed-free. Cassava free of weed for 60 days was as tall as that weeded for 120 days or more. Plant heights with two weeding at 30 and 60 days or 15 and 45 days were similar to those with four weeding. Waiting 120 days before beginning weeding gave cassava little

height advantage over the weedy check. No hand weeding system produced cassava as tall as that kept chemically weed-free. The two cultivars were similar in responses.

The fresh weight yield data show that the maximum production for each cultivar was achieved in the chemically weeded treatment (Table 2). CMC39 and CMC84 kept mechanically weed-free throughout the season produced 86 and 96 percent, respectively, of the yield of chemically weeded cassava. There was a more or less complete crop failure when no weed control measures were practiced as the yields were less than five percent of the chemically weeded cassava.

There was a yield reduction in CMC84 but not in CMC39 caused by weeds that germinated after 120 days (Table 2, treatments one and five.) The shorter stature of CMC84 makes it more susceptible to late season competition, especially in the presence of *Rottboellia exaltata* L.f. (itch grass), a weed which germinates throughout the season and grows and competes even under the reduced light conditions of the cassava canopy.

Weed competition occurring only during the first 60 days reduced the yield by 50 percent. Thus it is extremely important to control the weeds during the initial growth period. Starting the weeding operations at 120 days after planting proved less detrimental for CMC39, the taller cultivar, than for CMC84, the shorter one. By this time, CMC84 had already suffered severely from the competitive effects of the weeds.

Similarly drastic yield reductions occurred when only a single weeding was carried out at 15 days. Weeding twice at 15 and 30 days was also insufficient and yields were still reduced to 60 percent of the weed-free control.

In contrast, with two weedings performed at 30 and 60 days, yields were reduced only 10 to 15 percent compared with the hand weeded all season. Weeding at 15 and 45 days was less effective than weeding at 30 and 60 days (Table 2).

There was no effect of difference in the weeding system on root moisture content (Table 3). However, the harvest index (ratio of root dry weight to total plant dry weight) was lower in both the weedy check and the chemically weed-free treatment than the mechanically weeded treatments. Thus, under severe weed competition or in complete absence of this, there is proportionately a greater production of the aerial plant parts than of roots. This means that in the chemically weed-free cassava, there is not only greater root production, but also proportionately more aerial production. This would be beneficial in areas where the leaves are consumed and also where planting material is being produced.

Weeds present, in order of abundance, were purple nutsedge, itch grass, morning glory, and *Sorghum halepense* (L.) Pers. (Johnsongrass). Weed counts and weights are not presented due to the difficulty of data interpretation. The greatest confounding factor is the relative shortness of the weed life cycles in comparison to that of cassava. Several generations of weeds may be produced in the time it takes cassava to mature and also the weeding systems used gave a great diversity of stages of weed growth at any one time. To indicate the high degree of weed infestation, however, there were an average of 918 and 717 weed plants/m² in plots weeded for the first time at 30 and 60 days respectively. Over 90 percent of the total population was composed of purple nutsedge and due to this species the eight post-emergence herbicide applications were necessary in the chemically weed-free cassava.

Cassava density and competition

Plant heights in this experiment reveal some interesting trends. At 30 days after planting, both cultivars were the same height and the chemically weeded cassava was only slightly taller than that of the other treatments. At this early stage there was no response to differences in population density.

By 90 days after planting, the chemically weed-free cassava was two to three times taller than any other treatment and this was so for both cultivars. There is a tendency for cassava plants to be taller at higher populations in this treatment. The Llanera cultivar responded more to the hand weeding treatments than did CMC84.

The trend toward taller plants at higher plant populations was more marked at 180 days for the chemically weeded cassava, especially for CMC84. This indicates the existence of intra-specific competition between the cassava plants. When one or two weedings were performed, this tendency was less pronounced and it was completely lacking in the non-weeded treatment. Fresh root weights 8.4 months after harvest for Llanera are somewhat variable (Figure 1). However, the maximum production for chemically weed-free cassava occurs at a lower plant population than for hand weeded cassava.

More marked differences are seen for CMC84 (Fig. 1). In the chemically weeded plots the maximum yield is reached with 6000 to 8000 plants/ha., and yield then decreases by 50 percent at 13,850 plants/ha. In contrast, for cassava hand weeded at 30 or 30 and 60 days, yield was continuing to increase even at the higher densities. This means that cassava in the presence of some weeds has a higher optimum density for yield than when grown in weed-free conditions. When no weed control was practiced, yields were close to zero for both cultivars.

Data on daily production of root matter lead to the same conclusions. Completely weed-free Llanera reached its maximum production between 6000 to 11,000 plants/ha, while the same cultivar weeded at 30

and 60 days yielded the maximum even at high plant densities. Yields for cassava weeded at 30 days was irregular for Llanera, but the same trend of higher yields at high plant densities was present in CMC84.

The harvest index for Llanera decreased as plant density increased regardless of the weeding system. This was also true for the chemically weed-free CMC84.

The trend was not consistent for the hand-weeded treatments. Thus there may be an interaction between cultivars and weed control measures. The yields of the weedy checks were so low that harvest index data provide no useful information other than that in general they are considerably lower than any other treatment. This supports the observations made in the previous experiment.

Percentage dry matter in harvested roots and in relation to soil moisture

Percent root dry matter was similar in all treatments with Llanera. However, in CMC84 at densities above 6000 plants/ha in the weedy checks, the percentage dry matter was nearly ten percent greater than in the chemically weed-free plants. Percentage dry matter in the hand-weeded cassava was intermediate. It is possible that by this time large vigorous plants in the chemically weed-free treatment had used up the available soil moisture and thus the roots were drier. In support of this suggestion, it was observed during harvest that the soil in plots with this treatment was noticeably harder and drier than in the others. Also, in the weedy check, the annual weeds matured several months earlier and by the time of cassava harvesting were serving as a mulch and so probably conserving soil moisture in comparison with bare soil beneath cassava.

However, this was not the case earlier in the season (Table 4). At 100 days after planting, the highest soil moisture contents occurred under the chemically weed-free cassava. At this time the cassava root system had not extended fully and in the absence of weeds probably there was less uptake by infiltration. The canopy had closed at densities of 5,530 plants/ha and above in the chemically weed-free cassava and hence shaded the soil surface. However, no difference in soil moisture between shaded and unshaded areas was detected. The weedy check had the least available soil moisture at this time. Plots weeded at 30 or 30 and 60 days were intermediate in soil moisture availability.

CONCLUSIONS

Cassava is seriously affected by weed competition. Even hand weeding throughout the crop period may not be sufficient to produce the maximum yield when heavy infestations of weed seeds are present. Weed competition occurring during the first 60 days reduced yields by 50 percent for both CMC39 and CMC84.

However, cassava kept weed-free during the first 60 days produced 76 percent of the yield of chemically weeded cassava. Weeding for the first 120 days gave 88 percent of the maximum and full-season weeding produced 91 percent of the maximum (averages over the two cultivars).

The harvest index was lowered by full-season weed competition or the complete absence of the same for both cultivars as compared to any hand-weeding practice. Root moisture content was not affected by any treatment.

The optimum plant density is related to the weed control system. For CMC84, populations of 6000 to 8000 plants/ha have maximum yield in the chemically weed-free treatment, but the maximum production for cassava weeded at 30 or 30 and 60 days was always produced at populations above 8000 plants/ha. Similar but less defined trends were observed for Llanera.

Harvest indices decreased with increasing plant populations and this was especially so for the chemically weed-free cassava. This means that proportionately less dry matter is being accumulated in the roots at higher populations. Root dry matter content was 10 percent higher for chemically seed-free CMC84 as compared to the weedy check. There was no such difference for Llanera.

REFERENCES

1. Bleasdale, J.K.A. (1967) Systematic designs for spacing experiments. *Exptl. Agric.* 5, 73-85.
2. Furtick, W.R. and Romenoski, R.R. Jr. (1971) *Weed Research Methods Manual*. Intl. Pl. Prot. Center, Oregon State University, Corvallis, 80 pp.

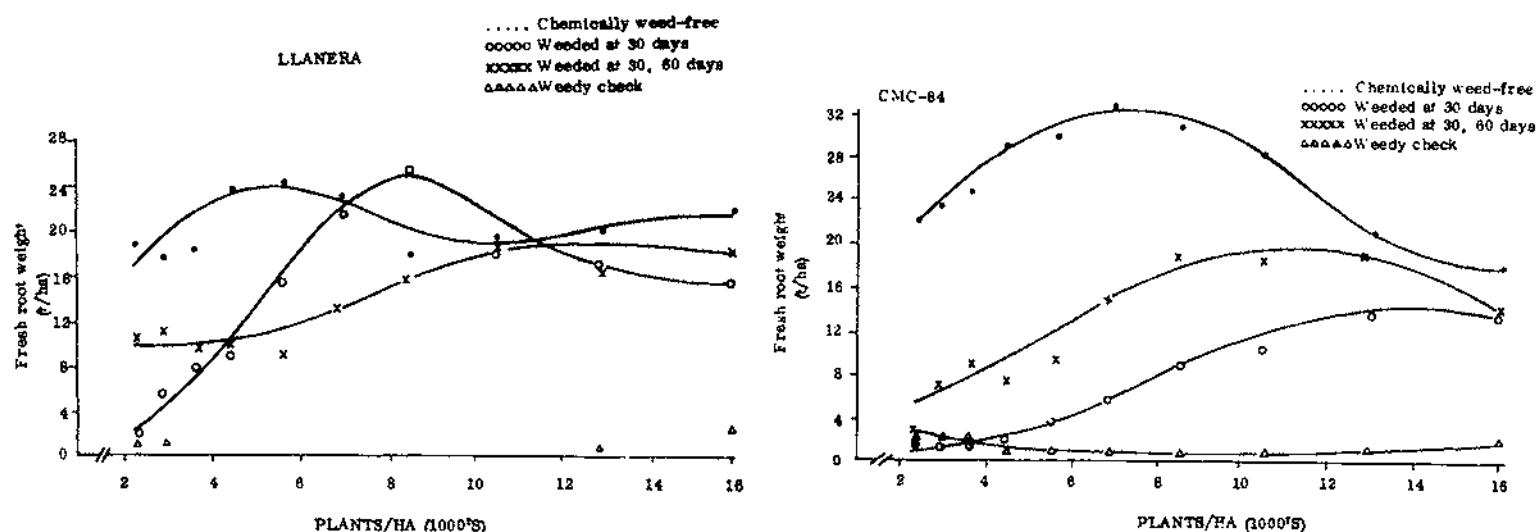


Figure 1. Fresh root weight of Llanera (above) and CMC-84 (below) as affected by plant density and weed control practices 250 days after planting.

TABLE 1

Number and timing of hand weedings for the cultivars CMC39 and CMC84

Treatment (see text)	No. of hand weedings	Days after planting when weeded				
1	4 + *	15	30	60	120	UH**
2	3 +		30	60	120	UH
3	2 +			60	120	UH
4	1 +				120	UH
5	4	15	30	60	120	
6	3	15	30	60		
7	2	15	30			
8	1	15				
9	2		30	60		
10	2	15	45			
11	0	Weedy check				
12	0	Chemically weed-free check				

* The plus sign indicates additional weedings were carried out to maintain the plants weed-free until harvest.

** UH = until harvest.

TABLE 2

Effects of varying the period of weed competition on the fresh root yields of cassava and percent yield as compared with chemically weed-free cassava 9.3 months after plant. CMC39 and CMC84 cultivars.

Treatment (see text)	No. of weedings	Frequency of weeding						CMC 39		CMC 84	
								f.w. (t/ha)	% yield*	f.w. (t/ha)	% yield*
1	4 + **	15 30 60 120	UH					18.05	85.7	19.32	96.3
2	3 +	30 60 120	UH					16.01	76.0	15.53	77.4
3	2 +	60 120	UH					11.00	52.2	9.47	42.2
4	1 +	120	UH					7.00	33.2	2.75	13.7
5	4	15 30 60 120						19.50	92.5	14.71	73.3
6	3	15 30 60						12.94	61.4	16.82	83.8
7	2	15 30						13.31	63.2	11.64	58.0
8	1	15						5.83	27.7	5.99	29.8
9	2	30 60						16.28	77.3	16.87	84.0
10	2	15 45						15.39	73.0	13.23	65.9
11	0	wd.ck.						1.40	6.6	0.96	4.8
12	0	chem.ck						21.07	100.0	20.07	100.0

* Yield is expressed as a percent of the chemically weed-free treatment.

** The + indicates weeding until harvest

≠ UH = until harvest

TABLE 3

Effects of varying weed competition periods on the harvest index and percent root moisture in cassava cultivars CMC39 and CMC84 at 9.3 months after planting.

Treatment	No. of weeding	Frequency of weeding	Harvest Index*		% root moisture	
			CMC 39	CMC84	CMC39	CMC84
1	4 +	15 30 60 120 UH	.52	.64	64.3	64.8
2	3 +	30 60 120 UH	.62	.68	66.0	64.5
3	2 +	60 120 UH	.57	.70	66.0	65.2
4	1 +	120 UH	.54	.62	66.2	65.5
5	4	15 30 60 120	.50	.68	68.2	63.6
6	3	15 30 60	.51	.62	64.6	62.1
7	2	15 30	.57	.70	63.3	61.2
8	1	15	.59	.70	63.7	60.0
9	2	20 60	.55	.61	63.8	62.3
10	2	15 45	.54	.65	64.1	64.0
11	0	wd. ck.	.49	.49	65.0	61.6
12	0	Chem.ck.	.48	.54	63.8	65.4
Mean:			.54	.64	64.9	63.4

* Harvest index = root dry weight/total plant dry weight.

TABLE 4

Soil moisture 100 days after planting the cultivars Llanera and CMC84

Weed control system	Soil moisture	
	Llanera	CMC84
1. Chemically weed-free	13.0	13.4
2. Weeded at 30 days	10.4	11.1
3. Weeded at 30, 60 days	10.8	9.7
4. Weedy check	9.5	9.1

WEED CONTROL IN CASSAVA

J.R. Barrios*

SUMMARY

DNPB, CMU, atrazine, linuron fluometuron, metabromuron, chloroxuron, diuron, ametrine, prometryne, neburon, simazine, atraton, fenac, 2-4D ester, MCPA, MCPA + PCP and 2-4D + PCP at various rates have been tested previously as weedicides for cassava and results are briefly reviewed.

New, careful experiments at two planting dates compared a short list of the more promising chemicals from the above list. Fluometuron 2.0 kg/ha a.i., prometryne 2.0 kg/ha a.i., atrazine 2.0 kg/ha a.i., difenamid 3.0 kg/ha a.i. were compared with a weedy check. Fluometuron appeared to be the best.

RÉSUMÉ

Des taux variés de DNP, de CMU, d'atrazine, de linuron, de fluométuron, de métabromuron, de chloroxuron de diuron, d'amétrine, de prométrine, de néburon, de simazine, d'atraton, de fénac, d'éther 2-4D, de MCPA, de MCPA + PCP et 2-4D + PCP ont été précédemment testés comme herbicides pour le manioc et les résultats qui en sont issus ont été brièvement passés en revue.

De nouveaux essais menés avec précaution à deux dates de semis ont permis de comparer un nombre réduit de produits chimiques les plus satisfaisants dans la liste ci-dessus. Le fluométuron 2.0 kg/ha i.a., le prométrine, 2.0 kg/ha i.a., l'atrazine 2.0 kg/ha i.a., le difénamid 3.0 kg/ha i.a. ont été comparés sur un témoin adventice. Le fluométuron s'est révélé le plus satisfaisant.

RESUMEN

Se revisan brevemente los resultados de pruebas previas en las que DNPB, CMU, atrazina, linuron, fluometurón, metabromurón, chloroxurón, diurón, ametrine, prometrine, neburón, simazine atratón, fenac, 2-4 D ester, MCPA, MCPA + PCP y 2-4D + PCP en varias dosis, han sido empleados como herbicidas en yuca.

En nuevos y cuidadosos experimentos en donde se usaron dos épocas de siembra, se compararon unos cuantos de los más prometedores productos químicos de la lista que se mencionó antes. Se compararon fluometurón 2.0 kg/ha i.a., prometrina 2.0 kg/ha i.a., atrazina 2.0 kg/ha i.a., difenamida 3.0 kg/ha i.a., con un testigo enhierbado. El mejor pareció ser fluometurón.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), as other crops, is affected by weeds. These reduce its production due to competition for nutrients, water and light.

Throughout the life of the crop, production of carbohydrate is greater day by day, on a unit area basis than that of cereal crops. The habitat of cassava is in the hot humid tropical and subtropical regions, where a great part of the human population lives and where conditions generally are not favourable for cereal crops.

The world's total production of cassava is about 100×10^6 t., and the mean yield is 10 t/ha⁶. This mean yield is very low when compared with those yields obtainable in experimental trials^{15, 16, 17}.

As a substitute for cereals, cassava meals and pellets have been increasingly used in recent years. Increased yields can be obtained both by use of improved cultivars and by cultural practices including efficient chemical control of weeds.

REVIEW

The Venezuelan Institute of Agronomy (U.C.V.) has been testing pre-emergence herbicides such as DNPB, CMU and Atrazine since 1963, but no results have been published¹⁴.

At Cagua, Venezuela, the Shell Service for Farmers³ tested substituted ureas and triazines. These damaged the crop when applied at 19 and 60 days after planting. The most promising products were fluometuron, linuron and metabromuron. Subsequent trials indicate the value of fluometuron applied at 2 kg/ha of product (80 percent a.i.).

The use of substituted urea herbicides has also been reported by Silva²² from Minas Gerais, Brazil. The evaluation there was made on the basis of the weight of roots, foliage and branches. The best results were obtained with linuron, followed by diuron, chloroxuron and fluometuron.

*Universidad Central de Venezuela, Institute de Agronomia, Maracay, Venezuela.

No damage to cassava was found by Kasasian⁸, when amiben, atrazine, prometrine, ametrine and diuron were used at doses of 2.25 to 4.50 kg/ha. There was also no damage to cassava from applications of 3.7 to 6.7 kg/ha of neburon, 5.6 to 11.2 kg/ha of TCA or PCP, 2.25 kg/ha of simazine with 5.6 kg/ha of atraton or 3.5 kg/ha of fenac. The crop was, however, affected by 6.7 kg/ha of fenac. Bouriquet² showed the following products effective for cassava weed control: 1.6 to 1.8 kg/ha of 2-4D ester; 4.8 kg/ha MCPA sodium salt; 1.6 kg/ha MCPA + 3.5 lt/ha of PCP.

According to Goaring⁷, 2-4D acid, MCPA, 2-4D + PCP; monouron and simazine were all rather toxic to cassava. Amiben at 3.5 to 6.7 kg/ha, applied at planting time, was recommended by Mortensen and Bullard²⁰.

MATERIAL AND METHODS

Environmental conditions

The trial now described was carried out at Maracay, Venezuela. Lat. N 10° 17'00"; Long. W67° 37'00"; alt. 455 m. The mean annual temperature is 24.5° C; the soil is a slightly acid alluvial sandy loam.

Two planting dates were used. The first was at the end of the rainy season, and during the growing season of six months the crop received only 250 mm of rainfall. The second planting date was in the middle of the rainy season, and the crop received 828 mm of rainfall during six months growth.

Herbicides

All herbicides were applied pre-emergence by application in water at a rate of 400 l./ha.

Treatment	Doses kg/ha commercial products	Doses kg/ha active ingredient
1. Fluometuron 80%	2.0	1.6
2. Prometrine 50%	2.0	1.0
3. Atrazine 80%	2.0	1.6
4. Difenamid 80%	3.0	2.4
5. Check (no herbicide, no deweeding)		

Experimental design

Randomized blocks were used with three replications at the first and four at the second date of planting. A plot consisted of four rows, 11 m long. The distances between rows was 1.40 m.; spacing in the row was 1.0 m. A single cutting was planted at each hill.

Planting method

25 cm. cuttings were planted at 45° in one side of the row and 10 cm deep. This system was used as it has been shown to favour earliness and high yield.^{16, 23}

Herbicide application

The herbicide mixture was applied immediately after planting over the entire plot area, thus wetting both the soil and the cuttings.

Cultural practices

Irrigation was used as considered necessary. Observations were made as follows: number of plants harvested; number and yield of tuberous roots by weight (fresh and dry weights); fresh weight of foliage; number, mean size of the main stem and stem fresh weight; visible damage attributable to herbicides; the weight of weeds produced on both a wet and dry weight basis.

RESULTS AND CONCLUSIONS

The results are presented in Tables 1—8, and from the data presented we conclude that:

1. In large areas of cultivation of cassava, the use of herbicide control of weeds can be recommended.
2. The best product tested was fluometuron when applied at doses of 2 kg/ha (80% a.i.).
3. Atrazine can be used at a rate of 2 kg/ha (80% a.i.) when conditions are not very wet at the time

- of application, but if fluometuron is available there is no advantage in using atrazine.
4. The herbicides prometryn and difenamid, at doses tested did not provide good weed control. However, they did not damage the crop.
 5. Cassava yield is very seriously reduced by uncontrolled weed competition.

REFERENCES:

1. Barret, O.W. 1930. *Los cultivos tropicales*. S.A., Havana, Cuba. 525 pp.
2. Bouriquet, G. 1961. C.C.T.A./F.A.O. Symposium on weed control, Ibadan.
3. Chicco, G. and Guedez, H. 1968. Control de malas hierbas en Venezuela. III. Recomendaciones en cultivos tropicales y areas no cultivadas. Reunion Internacional de Weed Society of America I. New Orleans. 16 pp.
4. Detroux, L y J.G. 1967. *Los herbicidas y su empleo*. Oikos-Tau S.A. Barcelona, Spain. 476 pp.
5. Facultad de Agronomia U.C.V. Seccion de Agrologia. Estudio agrologico del campo del Instituto de Agronomia (unpublished).
6. F.A.O. 1970. *Production Yearbook*.
7. Goaring, P. 1961. C.C.T.A./F.A.O. Symposium on weed control, Ibadan.
8. Kasasian, L. 1969. Chemical weed control in tropical roots and vegetable crops. *Trop. Agric. Trin.* 44(2), 143-50.
9. ———— 1968 Chemical weed control in tropical roots and vegetables crops. *Exp. Agric.* 4(1), 1-16.
10. L'Avvenire della manioca nella Comunita Europea. 1969. *Agric. Forum* 10(2), 57-8.
11. Leslie, K.A. (1967) The significance of root crops in the tropics. In *Proc. Int. Symp. on Trop. Root Crops*. Trinidad. V. 1-13.
12. Anon (1969) Manioc, Asian exports to European countries could reach 1,1 millions by 1970. *Far East Trade and Development* 24(4), 238-9.
13. Ministerio de Agricultura y Cria. Venezuela. (1970) Seccion de Meteorologia Agricola. Maracay. Hoja para el suministro de datos 1968, 1969, 1970.
14. Montaldo, A. (1966) Trabajos en yuca (*Manihot utilisima*) en Venezuela. Maracay, Inst. de Agronomia. 31 p. (mimeo).
15. ———— (1971) Los cultivos de raices y tuberculos tropicales en el presente y futuro. Maracay, Instituto de Agronomia.
16. ———— (1971) Yuca. Maracay, Instituto de Agronomia. 108p. (multigraf).
17. ———— (1972) Fases de desarrollo de la yuca (*Manihot esculenta*). Maracay, Instituto de Agronomia. 11 p. (mimeo).
18. Montaldo, A., Barrios, J.R. and Buillen, R.D. (1969) Evaluacion agronomica de la yuca (*Manihot esculenta*). Palmira. American Society for Horticulture. XVII. Tropical region. 10 p. (mimeo).
19. Montaldo, A. and Barrios, J.R. (1972) Descripcion de seis variedades de yuca (*Manihot esculenta*) Maracay, Instituto de Agronomia. 13 p. (mimeo).
20. Mortensen, E. and Bullard, E.T. (1966) *Handbook of tropical and subtropical horticulture*. Washington.
21. Servicio Shell Para el Agricultur. (1969) Control de malezas en yuca. *Agricultural Notes*. 5(17), 65-7.
22. Silva, J., Ribeiro da. (1970) O program de investigacao sobre mandioca no Brasil. En: Encontro de engenheiros agronomos pesquisadores em mandioca dos paises andinos e do estado de Sao Paulo, I. Campinas, 14 p. (mimeo).
23. ———— (1970) A programa de mandioca no Instituto Agronomico Estado de Sao Paulo. En: Encontro de engenheiros agronomos pesquisadores em mandioca dos paises andinos e do estado de Sao Paulo, I Campinas, 1970. 23 p (mimeo)
24. Thompson, P.C. and Kelly, W.C. (1959) *Vegetable Crops*. Mc.Graw-Hill. 5th ed. New York. 611 pp.
25. Weed Society of America. *Herbicide handbook*. (1970) 2nd ed. W.F. Humphrey Press, Geneva, New York. 2nd ed., 368 pp.

TABLE 1

Effect of herbicides* on cassava; yield of roots (fresh and dry weight); number of roots; mean weight of roots.

	Treatment					1.s.d.5%
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding)	
Yield roots t/ha (fresh weight)	6.30	2.07	4.87	1.78	0.66	3.28
t/ha (dry weight)	1.86	0.62	1.70	0.47	0.19	1.27
Number of roots/ha.	65,802	57,261	73,376	32,142	20,455	44,113

* Herbicides were applied at the end of the wet season.

TABLE 2

Effect of herbicides* on cassava. Fresh weight of aerial parts (stems + leaves); fresh weight of leaves (blades + petioles); fresh weight of blades. Leaf area and leaf area index.

	Treatment					1.s.d.5%
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding)	
Aerial part t/ha (fresh)	11.65	4.32	10.40	4.00	2.10	4.86
Leaves t/ha (fresh)	5.13	1.71	4.77	1.66	0.84	2.13
Blades t/ha (fresh)	3.69	1.09	2.93	1.10	0.52	1.36
Leaf area m ² /ha	21,688	6,828	21,748	6,783	2,298	11,722
Leaf area index	2.17	0.68	2.17	0.67	0.23	1.17

* Herbicides applied at the end of the wet season

TABLE 3

Effect of herbicides* on cassava and weeds. Weight of weeds (fresh and dry weights); yield of roots (dry weight); ratio of dry weight of roots to dry weight of weeds.

	Treatment					1.s.d.5%
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding)	
Weeds t/ha (fresh wt)	5.68	6.11	4.05	8.77	8.33	4.39
Weeds t/ha (dry wt)	1.24	0.30	0.83	2.74	1.89	1.11
Roots t/ha (dry wt)	1.86	0.62	1.70	0.47	0.19	1.27
Ratio dry wt. roots:dry wt. weeds	1.5	0.48	2.05	0.17	0.10	-

* herbicides were applied at the end of the wet season

TABLE 4

Effect of herbicides* on the number of cassava plants harvested; the number of main stems per hectare, and the rate of number of stems/plant.

	Treatment				
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding) s.d.5%
No. plants harvested/ha.	6,925	5,951	6,386	6,383	6,295 1.948
No. main stems/ha.	43,505	25,756	30,408	20,778	17,856 14,903
Number of stems/plant	6.28	4.33	4.76	3.25	2.85 -
* herbicides applied at the end of the wet season					

TABLE 5

Effect of herbicides* on the yield of cassava roots (fresh and dry weights); the number of roots and the mean weight of roots.

	Treatment				
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding) 1.s.d.5%
Yield roots t/ha (fresh weight)	6.25	1.55	1.36	0.75	0.39 1.90
t/ha (dry weight)	2.00	0.53	0.42	0.24	0.11 0.65
Number of roots/ha.	54,383	23,116	20,941	15,422	8,603 17,110
* herbicides applied in the middle of the wet season					

TABLE 6

Effect of herbicides* on cassava. Fresh weight of aerial parts (stems + leaves); fresh weight of leaves (blades + petioles); fresh weight of blades. Leaf area and leaf area index.

	Treatment				
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding) 1.s.d.5%
Aerial part t/ha (fresh)	8.19	3.29	2.17	1.37	1.08 2.80
Leaves t/ha (fresh)	3.07	1.03	0.79	0.30	0.32 1.19
Blades t/ha (fresh)	1.81	0.53	0.63	0.20	0.16 0.77
Leaf area m ² /ha.	12,188	1,892	2,924	706	581 7,390
Leaf area index	1.21	0.19	0.29	0.07	0.06 0.73
* herbicide applied in the middle of the wet season					

TABLE 7

Effect of herbicides* on cassava and weeds. Weight of weeds (fresh and dry weights). Yield of roots (dry wt.); ratio of dry weight of roots to dry weight of weeds.

	Treatment					
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding)	
Weeds t/ha (fresh wt)	2.84	7.84	3.70	6.74	8.94	1.s.d.5% 4.07
Weeds t/ha (dry wt)	2.05	5.76	2.49	4.98	6.82	2.51
Roots t/ha (dry wt)	2.00	0.53	0.42	0.24	0.11	0.65
Ratio dry wt. roots:dry wt. weeds	0.96	0.09	0.17	0.05	0.02	-
* herbicides applied in the middle of the wet season						

TABLE 8

Effect of herbicides* on the number of cassava plants harvested; the number of main stems per hectare, and the rate of number of stems/plant.

	Treatment					
	Flumeturon 80% a.i.	Prometrine 50% a.i.	Atrazine 80% a.i.	Difenamid 80% a.i.	Control (no herbicide, no weeding)	
No. plants harvested/ ha.	6,818	6,575	4,870	5,925	6,736	1.s.d.5% 1,364
No. main stems/ha.	43,911	21,834	15,740	13,879	10,389	19,924
Number of stems/plant	6.44	3.32	3.15	2.34	1.54	
* herbicides applied in the middle of the wet season						

INSECTICIDE RESIDUES IN SOILS AND IN ROOT CROPS GROWN ON TREATED SOILS

B.P. Srivastava and V.S. Kavadia*

SUMMARY

Studies were conducted on the persistence of aldrin and BHC in two different types of soils viz. sandy (sandy loam) and clay (clay loam) and the extent of their residues in root crops grown in treated soils. The rate of loss of aldrin was between 30 – 50 percent in 113 days in both soil types whereas 74 – 87 percent BHC was lost during the same period in clay as well as sandy soil. Beetroot absorbed more aldrin when grown in sandy soils than in clay soils, but carrots absorbed aldrin more from clay than sandy soils. No aldrin was found in radish when grown in aldrin treated clay and sandy soils. BHC was accumulated more in carrots, beetroot and radish when these were grown in sandy than in clay soils. Although carrot absorbed more BHC than the other crops, the level, even in this was below the acceptable tolerance level of 8 ppm.

RESUME

Des études ont été menées sur la persistance de l'aldrin et du BHC avec deux types de sols différents, sablo limoneux et limono-argileux et l'importance de leurs résidus dans les plantes à racine cultivées sur sols ayant subi de traitements. Le taux de perte de l'aldrin se situe entre 30-50 pour cent en 113 jours dans les deux types de sol, et entre 74-87 pour cent de BHC pendant la même période en sol aussi bien argileux que sablonneux. L'absorption d'aldrin est plus élevée chez la betterave cultivée sur sols sablonneux que sur sols argileux, mais l'absorption d'aldrin par la carotte est plus élevée en sols argileux qu'en sols sablonneux. Il n'y a pas de trace d'aldrin dans le radis cultivé en sols argileux et sablonneux traités à l'aldrin. La carotte, la betterave et le radis accumulent beaucoup plus de BHC en sols sablonneux qu'argileux. Bien que l'absorption du BHC par la carotte soit supérieure par rapport aux autres plantes, le niveau, même dans le cas de la première, reste en dessous du niveau de tolérance acceptable de 8 ppm.

RESUMEN

Se condujeron estudios sobre la persistencia del aldrin y el BHC en dos diferentes tipos de suelos: uno arenoso (migajón arenoso) y otro arcilloso (migajón arcilloso) y también sobre el grado de residuos de los insecticidas encontrados en diferentes cultivos (para producción de raíces), desarrollados en esos suelos. La pérdida de aldrin a los 113 días fue de 30-50 por ciento en ambos suelos, en tanto que BHC se perdió en un 74-87 por ciento — durante el mismo período — en ambos suelos también. El betabel absorbió mas aldrin cuando se cultivó en un suelo arenoso que en uno arcilloso, en tanto que la zanahoria absorbió mas aldrin del suelo arcilloso que del arenoso. No se encontró aldrin en rábanos desarrollados en ninguno de los dos suelos. El BHC se acumuló mas en el betabel, las zanahorias y los rábanos, cuando se cultivaron en el suelo arenoso que cuando se desarrollaron en el suelo arcilloso. Si bien que las zanahorias absorbieron mas BHC que los otros cultivos, el nivel encontrado aún en éste caso estuvo por debajo de lo aceptable como límite de tolerancia, que es de 8 ppm.

INTRODUCTION

Insecticides are frequently applied to soil to control termites, white grubs and other soil insects. However, their applications into the soil is a cause of concern due to the potential accumulation of toxic residues either in the soil or in crops grown on treated soils.

There have been many studies on the persistence of insecticides in soils and their possible accumulation in the plant parts^{2,4,6,9,10}. We have worked in two widely different soil and agro-climatic conditions, have soils and wet climate of Udaipur region and light soils and semi-arid climate of the Jaipur region of India.

*Department of Entomology, Rajasthan College of Agriculture, University of Udaipur Udaipur 313001, India

MATERIALS AND METHODS

Beetroot, radish and carrot were grown in our study. Four levels of aldrin, 0, 3, 6 and 12 kg a.i./ha, and of BHC 0, 5, 10 and 20 kg e.i./ha, were applied to soils with three replicates per treatment. Each plot was 2.1 x 2.1 m. Insecticidal dusts were thoroughly incorporated in the soil to a depth of 4 — 6 inches before sowing. Soil samples were drawn randomly with an auger from five different locations in each plot and were mixed and quartered before analysis. Plant samples (root only) were collected by uprooting the plants from the same five points. Roots were washed thoroughly under tap water to remove soil and were chopped, mixed and quartered before analysis.

Air dried soil samples were extracted in suitable solvents by tumbling over a motorized shaker for 30 minutes. The plant material was extracted by blending with a suitable solvent. Redistilled n-hexane and acetone (2 ml per g sample) were used as solvent for the extraction of samples containing aldrin and BHC respectively. Photometric methods were based on the phenyl azide reaction for aldrin¹⁴ and we used a modified Schechter and Hornstein method¹⁵ for analyses of BHC using standardized levels of direct contamination of plant materials by the chemicals. Recoveries of aldrin by photometric method were 88, 76, 87 and 69 percent for beetroot, carrot, radish and radish leaves, and that of BHC were 83, 90, 100 and 93 percent for beetroot, carrot, radish and radish leaves respectively.

RESULTS AND DISCUSSION

Aldrin residues

Results are presented in Table 1. The rate of decline of residues was greatest for a treatment level of 3 kg/ha applied to the clay soil, being about 50 percent loss in 113 days. The rate of loss of aldrin was much the same for all the three dosages when applied to sandy soils. Elgan³ also found that aldrin (2 lb/acre) and telodrin (0.5 lb/acre) disappeared rapidly from soil immediately following application with levels dropping to about 15 percent of the initial values after a year. Lichtenstein *et al.*⁷ also reported rapid disappearance of DDT, lindane and aldrin from experimental soils in Kansas.

Data collected showed that some aldrin was absorbed by beetroot grown in sandy soil than in clay soil. The quantity of aldrin found in beetroot after 101 days in sandy soil was more than 30 percent of the initial deposit as against 9 — 17 percent after 113 days in clay soil. For carrot, more of aldrin was absorbed when grown in clay soils (17 — 46 percent) after 113 days than when grown in sandy soil (8 — 33 percent after 101 days). Lichtenstein *et al.*⁸ found that concentrations of insecticidal residues in carrots varied from 22 — 80 percent of the concentration in the soil. Lichtenstein and Schulz¹¹ and Harris and Saus⁵ also reported that in loam soils carrots absorbed more aldrin residues than any other crop tested. No aldrin was detected in radish either from clay or sandy soils. This finding supports Muns *et al.*¹³ who reported that radishes grown in soils treated with 4 pounds of aldrin per acre contained no aldrin but did however contain 0.24 ppm of dieldrin.

BHC residues

About 74 — 87 percent of BHC was lost in 104 — 112 days in both clay and sandy soils. Lichtenstein *et al.*⁸ also reported that lindane was the least persistent insecticide among the three insecticides DDT, lindane and aldrin tested in Kansas soils. Allen *et al.*¹ found that four and a half years after a single application, 38 percent of DDT and 6 percent of BHC remained.

The amount of BHC accumulating in beetroot varied between 6 — 11 percent of the initial deposit in heavy soil in 112 days and 4 — 13 percent in sandy soil in 104 days. The absorption figures of BHC for carrots were 11 — 15 percent in clay soil and 12 — 18 percent in sandy soil of the concentration available in the soil. Macphee *et al.*¹² showed that 0.94 ppm of BHC was found in carrot grown in soil treated with BHC and the insecticide was distributed throughout the root. Only 1 — 5 percent BHC was found in radish after 73 days of application. There appeared to be more accumulation of BHC in all the three crops carrot, beetroot and radish when grown in treated sandy soils than in clay soils. Carrot seemed to absorb more BHC than the other two crops, but the amount of BHC absorbed never exceeded the tolerance levels of 8 ppm in any root crop.

ACKNOWLEDGEMENT

The authors are grateful to PL-480 authorities for supporting these investigations and to the University of Udaipur authorities for providing the field and laboratory facilities.

Editorial note: Tabulated data, which however provide no statistical analysis or other measure of precision, were provided, but the authors' summary as printed presents an adequate summary of the data.

REFERENCES

1. Allen, N., Walker, R.L., Fife, L.C., Chisholm, R.D., Kabitsky, L., Bullock J.F., Hodge, C.R. and Hall, E.E. (1954) Persistence of BHC, DDT and toxaphene in soil and the tolerances of certain crops to their residues. *Tech. Bull. No. 1090 USDA*, pp. 19.
2. Chisholm, R.D., Kobitzky, Z.K., Fabey, T.E. and Westlake. (1951) DDT residues in soil. *J. econ. Ent.* 43, 841.
3. Elgan, K.E. (1966) Analysis of crops and soils for residues of the soil insecticides aldrin and telodrin. *J. Sci. Fd. Agric.* 17, 541-5.
4. Ginsburg, J.M. (1955) Accumulation of DDT in soils from spray practices. *J. agric. Fd. Chem.* 3, 322.
5. Harris, C.R. and Saus, W.W. (1967) Absorption of organochlorine insecticide residues from agricultural soils by root crops. *J. agric. Fd. Chem.* 15, 861-3.
6. Lichtenstein, E.P. (1957) A survey of DDT accumulation in midwestern orchard and crop soils treated since 1945. *J. econ. Ent.* 50, 545-7.
7. Lichtenstein, E.P., Delew, L.J., Eshbangh, E.L. and Slesman, J.P. (1960) Persistence of DDT, aldrin, and lindane in some mid Western soil. *J. econ. Ent.* 53, 136-42.
8. Lichtenstein, E.P., Myrdal, G.R. and Schulz, K.R. (1965) Insecticide uptake from soils — absorption of insecticidal residues from contaminated soils into five carrot varieties. *J. agric. Fd. Chem.* 13, 126-31.
9. Lichtenstein, E.P. and Polivka, J.B. (1959) Persistence of some chlorinated hydrocarbon insecticides in turf soils. *J. econ. Ent.* 52, 289-93.
10. Lichtenstein, E.P. and Schulz, K.R. (1959) Persistence of some chlorinated hydrocarbon insecticides as influenced by soil types, rates of application and temperature. *J. econ. Ent.* 52, 124-31.
11. Lichtenstein, E.P. and Schulz, K.R. (1965) Residues of aldrin and heptachlor in soil and their translocation into various crops. *J. agric. Fd. Chem.* 13, 57-63.
12. Macphee, A.W., Chisholm, D. and MacEachern, C.R. (1960) The persistence of certain pesticides in the soil and their effect on crop yields. *Canad. J. soil Sci.* 40, 59-62.
13. Muns, R.P., Stone, M.W. and Foley, F. (1960) Residues in vegetable crops following soil applications of insecticides. *J. econ. Ent.* 53, 832-4.
14. O'Donnell, A.E., Neal, M.M., Weish, F.T., Bann, J.M., Decino, T.J. and Lau, S.C. (1954) Chemical determination of aldrin in crop materials, *J. agri. Fd. Chem.* 2, 573-80.
15. Schechter, M.S. and Hornstern, I. (1952) The determination of benzene hexachloride by a colorimetric method. *Analy. Chem.* 24, 544.

BIOECOLOGICAL STUDIES ON THE CASSAVA MITE *MONONYCHELLUS TANAJOA* (Bondar) (Acarina: Tetranychidae)

Z.M. Nyiira*

SUMMARY

Two mites, *Mononychellus tanajoa* and *Tetranychus telarius* attack cassava in Uganda. The former is a recent introduction and is causing severe damage during the dry seasons. Biological studies suggest a possibility for biological control by either *Stetnorus* sp. or *Oligota* sp. The use of acaricides present continuing problems and it is concluded that carefully conceived integrated control will be necessary.

RESUME

Deux acariens, *Mononychellus tanajoa* et *Tetranychus telarius* attaquent le manioc en Ouganda. Le premier, d'apparition récente cause des dégâts importants pendant la saison sèche. Des études biologiques indiquent la possibilité de lutte biologique soit par *Stetnorus* sp. ou *Oligota* sp.

L'utilisation d'acaricides entraîne des problèmes permanents et on tire la conclusion qu'il sera nécessaire de concevoir une lutte prudente et intégrée.

RESUMEN

Dos ácaros, *Mononychellus tanajoa* y *Tetranychus telarius* atacan a la yuca en Uganda. El primero es una introducción reciente y causa daños severos durante las estaciones secas. Los estudios biológicos sugieren la posibilidad de controlarlos biológicamente bien sea con *Stetnorus* sp. o con *Oligota* sp. el uso de acaricidas presenta problemas continuos y se concluye que es necesario un cuidadoso control concebido de manera integral.

INTRODUCTION

The green cassava mite, *Mononychellus tanajoa* Bondar is a neotropical species. It is believed to have been introduced into the Ethiopian region of Africa in 1971. It belongs to the Caribbeanae group of mites (Paschoal⁶) characterized by irregular, anastomised striae at the mediodorsal portion of propodosoma, around the setae bases and at other hysterosomal areas. They are further characterized by having clavate dorsal body setae and a conical stylophore with the anterior margin rounded and with longitudinal striae. The other Tetranychid pests of cassava are *Mononychus planki* (McGregor), *M. caribbeanae* (McGregor) and *Tetranychus cinnabarinus* (Boisduval). A very comprehensive key separating the more closely related species of this group has been provided by Paschoal⁶.

Although both *M. tanajoa* and *Tetranychus telarius* L. (= *T. urticae*) attack cassava in Uganda, their identity and damage are quite distinct. The former is green and smaller in size and attacks young leaves preferentially up to the thirteenth leaf. *T. telarius* is red and bigger in size and normally found on the old leaves.

DAMAGE

Cassava leaves infested by *M. tanajoa* develop mosaic symptoms. The leaves show pin point pricks and mottling and fold dorsally without any signs of necrosis. Badly infested leaves drop off leaving only the apical growth. Severe damage to cassava occurs in the dry season but subsides during rainy periods.

CLIMATOLOGY IN UGANDA

Temperature and humidity are well known to affect the survival and the reproductive potential of mites.

*Kewanda Research Station, P.O. Box 7065, Kampala, Uganda.

The Lake Victoria and Western region zone of Uganda has two rainy seasons, from mid-March to May and from August to November with the peaks in April and November. Over most of the northern and eastern regions of Uganda, rainfall is sparse with more pronounced dry spells, the usual two rainy seasons between March and May and between August and November are less distinct, tending to merge into a monomodal pattern with increasing distance from the equator.

The mean temperatures over the whole of Uganda show little variation except those of the mountain districts of western and eastern Uganda. In the west and south, temperatures range between 9°C and 28°C while in the northern and eastern regions they range between 16°C and 35°C. Relative humidities are fairly low where temperatures are high and over 70% around the lake shores areas.

DISTRIBUTION OF THE PEST

The green cassava mite is distributed in the neotropical region. It was first recorded in Brazil (Bondar¹) where its damage was referred to by the natives as "tanajoa de Mandioca" meaning disease of the cassava. In addition to Brazil and Uganda, the known distribution covers Trinidad and possibly Colombia (Flechtmann, personal communication) and it is suspected to exist in Jamaica, Venezuela, Mexico and in the states adjacent and north of Brazil. There is a possibility of this mite spreading to countries surrounding Uganda because of its mode of dispersal.

BIOLOGY

Oviposition

Eggs are laid singly on the under surface of cassava leaves. Initial oviposition starts at the base of the leaves along the veins but later eggs are often randomly placed. The mean incubation period at a mean temperature of 22°C was 5.1 days whereas at 32°C it was 4.0 days. The preoviposition period ranges between 1–3 days.

Fecundity and longevity

The average fecundity under room temperature (17–29°C) was 3.5 eggs per female per day. The total number of eggs laid per female during its life, ranged between 35–111 eggs. Longevity of individuals varied between 22 and 35 days, with a mean longevity period of 30 days.

Immature stages and reproduction rate

M. tanajoa has a life cycle similar to other tetranychid mites. The egg hatches into a larva which is characterized by having only 3 pairs of legs. This moults into a protonymph, and later to deutonymph and adult. The duration of the stages from larva to adult ranges between 3–11 days at room temperature. Life history studies reported by Nyiira⁴ indicate a net reproductive rate of 70.12 and an intrinsic rate of natural increase of 0.2498.

Alternative host plants of *M. tanajoa*

Although the green cassava mite has long been known in Brazil on cassava, there is no record of alternative hosts. In Uganda, however, *Manihot glaziovii*, *M. cartagenensis* and *Manihot* sp. are recorded as wild hosts of the green cassava mite. *Euphorbia prunifolia* and *Euphorbia* sp. commonly used in Uganda for cattle hedges are closely observed as suspected hosts though confirmation of this suspicion is as yet lacking.

Natural enemies

A predacious coccinellid *Stetnorus* sp. and a staphylinid *Oligota* sp. are very abundant and feed on all stages of the green cassava mite in Uganda. The species involved have not yet been identified. The common species of *Oligota* recorded feeding on adults of *M. tanajoa* in Trinidad was confirmed to be *O. minuta* (Bennett, personal communication). Other predators recorded feeding on the green cassava mite include Phytoseiidae mites (*Typhlodromus* sp.), *Orius* sp. (Anthocoridae), Arachnids, Syrphid fly larvae and Chrysopids.

Predator populations

Greater predator populations are found where the population of the host mites is high. Initial trials indicated that higher predator and mite populations existed on the fifth to eighth leaves. Rain reduced both

predators and mites. It is possible that this effect on predators was both direct by physical destruction, and indirect by destruction of mites and depriving the predators of food causing their migration. *Oligota* sp. and *Stethorus* sp. migrated by flight while phytoseiid mites and arachnids depended on walking.

The egg laying potential of *Oligota* sp. and *Stethorus* sp. are being investigated through life history studies to enable comparisons to be made of the net reproduction rate and the intrinsic rate of natural increase of the predators and their hosts. According to McMurtry *et al.*², *Stethorus* spp. and *Oligota* spp. have a maximum daily rate at least as high as that of tetranychids, and considerably longer oviposition period. Their total fecundity rate is, therefore, considered greater. However, these authors show that phytoseiid mites seem to have a lower maximum daily egg deposition than do the tetranychids.

The microclimatic distribution of the more common predators of the cassava mite on plants is associated with the existence and abundance of the prey.

Although their macroclimatic distribution has not been fully studied there is a possibility that it is to a certain extent related to its prey, especially the spider mite host.

MITE POPULATIONS

Observations and counts of eggs and adult mites carried out on leaves 1, 3, 5, 7, 9, 11, 13 and 15 or individual cassava trees established that the greatest populations of mites and their eggs occurred on leaves 5th to 8th.

The population trend of adult mites in time, showed that higher mite population density was related to several factors. These were the dry periods and the new leaf growths, and presence and quantity of chlorophyll. Dry periods were favourable for development of the mite. Heavier damage occurred during the dry period probably because of the rapid population build-up and severer destruction of leaves by mites extracting moisture from them. New leaf growth provided fresh food and areas for reproduction and support for high population densities.

The major dispersal means by which the green cassava mites were spread were by airdrift and animal or human movement through the crop. Because of these modes of dispersal and the existence of wild alternative hosts it was difficult to devise any eradication programme as a means of control. The mites were responsive to morning warm temperatures and light winds, actively moving up the cassava stems and suspending themselves on self-produced silk thread from which they were easily blown off into air currents.

RELATIONSHIP BETWEEN LEAF NUTRIENTS AND MITE POPULATIONS

The leaf nutrient percentage in leaves of three cassava cultivars when six months old is given in Table 1. Generally phosphorus, nitrogen and potassium content was greater in young leaves whereas calcium content was more in old leaves. The percentage of magnesium remained more or less constant in all the leaves.

The relation between nutrient content of leaves and mite population was negative for P, Ca, Mg, but positive for N and K. The correlation coefficient in each case was however very low and not statistically significant.

RESISTANCE TO MITES OF CASSAVA CULTIVARS

Montaldo³ reported differential resistance to spider mites in cassava cultivars in Venezuela. He showed that three cultivars were resistant to *Eotetranychus planki* McGregor (= *M. planki*). Studies in Uganda (Nyiira⁵) show that there is so far no primary resistance recorded in any of the cultivars presently grown. All cultivars however, recover from attack, especially during the rainy spell. There is an indication that some cultivars may be more tolerant than others, although they may not be the best yielding.

ACARICIDES AND THEIR ECONOMIC IMPLICATION

Trials have been carried out to test the effect of kelthane, chlorobenzilate and rogor on the cassava mite populations. Acaricides were effective suppressants of the cassava mite. All the three acaricides had persistence that extended beyond three weeks, maintaining a percentage reduction of mite population above 80% after the initial application. Rogor and kelthane had longer persistence than chlorobenzilate. The difference in reduction of mites between kelthane and rogor was not statistically significant but they were both more effective than chlorobenzilate when assessed ten days after spraying and thereafter.

Although acaricides were found to be effective against *M. tanajoa*, they are expensive to apply to a crop like cassava which, although widely grown in Uganda, is not income-earning, usually being grown by peasant farmers for subsistence. Mites are also known to develop resistance to acaricides and so these chemicals provide only an uncertain control. Further, McMurtry *et al.*² have shown that acaricides have adverse effects on the predators of tetranychid mites, let alone the unknown, less obvious, but possibly detrimental

indirect influences. Similar observations were recorded during these trials including resurgences of the green cassava mites in areas where cassava had been sprayed with acaricides.

Whereas, therefore, the use of acaricides may be possible for the short term control of the green cassava mite, they do not seem to present a hopeful long-term solution to the country-wide infestation of cassava by *M. tanajoa*. The complexity of the problem calls for a carefully conceived integrated control programme in which a diversity of research scientists would participate —

REFERENCES

1. Bondar, G. (1938) Notas Entomologicas de Bahia. *Rev. Ent.* 9, 441-9.
2. McMurtry, J.A., Huffaker, C.B. & van de Vrie, M. (1970) Ecology of Tetranychida mites and their natural enemies. A review. *Hilgardia* 40, 331-90.
3. Montaldo, A. (1972) La yuca. Trabajos sobre este cultivo con especial referencia a Venezuela *Oficina de comunicaciones Agricolas Maracay edo Aragua*.
4. Nylira, Z.M. (1973) Life history of *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae). In preparation.
5. Nylira, Z.M. (1973a) Report of investigation on cassava mite *Mononychellus tanajoa* (Bondar) for 1972. *Entomology section. Kawanda Research Station, Uganda*.
6. Paschoal, A.D. (1971) A review of the Caribbeanae group (Acarina: Tetranychidae) *Rev. Per. Entom.* 14, 177-9.

ACKNOWLEDGEMENTS

The help of Messrs. A. Mukasa-Kiggundu and T. Mafulira, Chemist and Statistician, respectively, is acknowledged for the chemical and statistical analyses.

TABLE 1

Nutrient % in leaves of three cassava cultivars when six months old

Cultivar	P	N	K	M	Ca
Bukalasa	0.26	5.03	1.11	0.09	0.64
Mpologoma	0.28	4.85	1.09	0.09	0.55
Bintimisi	0.30	5.96	1.24	0.13	0.66

BACTERIAL BLIGHT OF CASSAVA IN CENTRAL AND SOUTH AMERICA: ETIOLOGY, EPIDEMIOLOGY AND CONTROL

J.C. Lozano*

SUMMARY

Bacterial blight of cassava caused by a taxon of the genus *Xanthomonas* is a serious disease in Central and South America and has been observed in parts of Africa. Symptoms include leaf spotting, wilting, die-back, gum exudation on young shoots, and vascular discoloration in mature stems and roots of susceptible cultivars. Dispersal by rain splashing is the most important means of dissemination within localized areas. Dissemination from one area to another occurs through movement of infected planting material or by the use of contaminated tools. Delay in the spread of the disease has been obtained by pruning infected plants. The use of resistant cultivars and the production of certified bacteria free planting material, obtained from plants propagated from shoot tip cuttings, provides a satisfactory means of control.

RESUME

Le wilt bactérien du manioc provoqué par un taxon du genre *Xanthomonas* représente une maladie grave en Amérique Centrale et du Sud et a été observé en maints endroits de l'Afrique. Parmi les symptômes il y a la tache des feuilles, le flétrissement, la fanaison, l'écoulement de la sève sur les jeunes pousses et la décoloration vasculaire des tiges adultes et des racines des cultivars sensibles. La diffusion par les gouttes d'eau de pluie est la voie la plus rapide de dissémination dans les zones affectées. La dissémination d'un endroit à un autre se fait par le déplacement de matériel végétal infecté ou à travers des outils déjà contaminés. Le retardement de la diffusion de cette maladie a été rendu possible en éliminant les plantes infectées. L'utilisation de cultivars résistants et la production de matériel végétal certifié indemne de bactérie obtenue à partir de plantes propagées issues de boutures d'extrémité des pousses constituent un moyen satisfaisant de lutte.

RESUMEN

El tizón bacterial de la yuca, causado por una especie del género *Xanthomonas*, es una enfermedad seria en Centro y Sud América y ha sido observado en algunas partes de Africa. Los síntomas incluyen el manchado de la hoja, marchitez, acronecrosis, exudación de goma en vástagos jóvenes y decoloración vascular de tallos maduros en los cultivares susceptibles. La dispersión por salpicaduras debidas a la lluvia es la forma principal de diseminación dentro de un área localizada. La diseminación de un área a otra ocurre por el movimiento de material infectado o por el empleo de herramientas contaminadas. Con la poda de las plantas infectadas se ha obtenido un retraso en la dispersión de la enfermedad. El uso de cultivares resistentes y la producción de material certificado de siembra libre de bacterias, obtenidos de plantas propagadas a partir de estacas terminales, provee un medio satisfactorio de control.

*Centro Internacional de Agricultura Tropical, (CIAT), Apartado Aereo 67-13. Cali. Colombia.

INTRODUCTION

Cassava bacterial blight is the most important of several bacterial diseases of cassava reported^{12,17,18,20}. This disease has caused severe losses in several Latin-American countries and Africa where epidemics have been recorded in several of the important cassava growing areas. The disease is now recognized as one of the most important factors limiting production in affected areas where, in wet seasons, it can result in complete loss of yield^{12, 18, 19, 20}.

The disease was first recorded in Brazil in 1912⁶, but has since been reported in Colombia and Venezuela^{18, 19, 20}, Nigeria¹⁷ Zaire (Cock, personal communication) and has been observed in several other countries of tropical America and Africa. It has only been recorded in species and cultivars of the genus *Manihot*.^{1, 7, 8}

SYMPTOMS

Symptoms of the disease comprise angular leaf spotting and leaf blight, wilting, die-back, gum exudation, and necrosis in the vascular tissues of stems and roots. This complete syndrome is unique among diseases induced by a single plant pathogenic bacterium. Primary symptoms, following the planting of infected material, are wilting of the young germinated sprouts followed shortly by die-back. (Fig. 1) Secondary symptoms, following secondary infections, consist of angular leaf spotting followed by blight, defoliation, wilting and die-back. Leaf spots develop initially as water-soaked, angular areas, clearly visible on the abaxial surface of the leaves (Fig. 2). These spots become brown or dark-brown and sometimes, depending upon the susceptibility of the cultivar, a yellow halo surrounds the spots. Spots enlarge and coalesce, forming a large necrotic 'blighted' area. Necrosed areas spread throughout the entire leaf which, as a result, rolls and dries up. These blighted leaves remain attached to the stem for a short time before falling. (Fig. 3).



Figure 1. Dissemination of CBB by infected vegetative "seed". Left: Healthy sprout from a healthy stem cutting. Right: Diseased sprout from an infected stem cutting (18).

Figure 2. Cassava leaf lobes showing typical leaf spots on abaxial side.



Figure 3. Infected cassava plant showing wilting, necrosed leaves still attached to stem. Note that young or emerging sprouts are not affected yet by the pathogen.





Figure 4. Sprouting cassava plants after the tops were heavily infected by CBB. Some of the new shoots that emerged remain apparently healthy, but others are already infected showing wilting and die-back.

Leaf spots often exude a yellowish, sticky gum that collects in droplets, mostly on the lower leaf surface and along major and minor veins. Gum is usually also exuded from cracks which develop on young infected stems and petioles. This gum dries to form a yellowish glistening scab.

The vascular strands of infected petioles and stems appear as brown strings. Leaves fed by these necrosed vascular strands wilt, and young stem tissues rot, particularly in those parts of the shoot where the primary infection first occurred. Rotting is faster in young (green) than in mature (green-brown) stems, and old stem tissues remain apparently healthy. Rotting of young stem tissues results in the characteristic die-back symptom, which is therefore restricted to the immature stem portions of the plant. (Fig. 4)

Generally, roots of infected plants remain healthy. However, in some susceptible cultivars, swollen roots (tubers) may show dry-rotted spots around the necrosed vascular strands. This rotting is usually restricted to the vascular tissues; other tissues of the root remain apparently healthy.

When infections occur on young immature plants, the aerial portions may be completely destroyed. When this occurs the plants usually produce new shoots either from above or below ground portions of the stem. These young shoots are extremely susceptible and during rainy seasons rapidly become infected and so prolong the epidemic.

ETIOLOGY

The causal agent was first named *Bacillus manihotis* Arthaud-Berthet⁶, but later renamed *Phytomonas manihotis* (Arthaud-Berthet and Bondar) Viegas²². Drummond and Hipolito¹³, however, found that some of the characteristics of the bacterium they isolated from cassava were different from those originally described by Bondar⁶. The species was included under the name *Phytomonas manihotis* Burkh. in Bergey's Manual⁴. Comparative studies of a new isolate with the strains of Burkholder and of Drummond and Hipolito were made by Amaral and Vasconcellos³. They concluded that all three strains belonged to *Phytomonas manihotis*. Later, Starr²¹ transferred the name to *Xanthomonas manihotis* (Arthaud-Berthet) Starr⁵. Resulting from studies on morphology, physiology, serology, and phage susceptibility of the bacterium as isolated in Colombia, Brazil and Venezuela, Lozano and Sequeira^{10, 11, 18, 19} concluded that these were sufficiently different from *x. manihotis* to be considered as a distinctive strain. They reported¹⁹ that the

cassava blight bacterium differed from typical *x. manihotis* in cell size, motility and flagellation, production of H_2S , utilization of nitrate, hydrolysis of starch, and in several serological relationships. They also reported¹⁹ that a comparison with a type culture of *x. manihotis* revealed differences in pathogenicity, growth rate, serological characteristics, and phage susceptibility.

Recently, comparative studies among different American and African isolates from blighted cassava have revealed that they possibly all belong to the same bacterial species although there are some differences in virulence and in a few physiological characteristics (Sequeira, personal communication; Ikotun, personal information).

Lozano and Sequeira¹⁹ reported that the cassava blight bacterium (CBB) is as a Gram-negative slender rod, mobile by means of a single polar flagellum, not encapsulated, and non spore-forming. It is an aerobic, fast-growing bacterium which forms no pigment on sugar-containing media. It hydrolyzed starch and gelatin, and shows acid formation with litmus milk. It does not induce a hypersensitive reaction on tobacco leaves or cause soft-rotting of potato tubers or cassava roots. It produces catalase, arginine dehydrolase, and lipase, but does not produce H_2S , indole, urease, tyrosinase or phenylalanine deaminase. It is able to grow in ordinary media plus NaCl or tetrazolium chloride at maximum concentrations of 2.5 and 0.2 percent respectively. The bacterium uses nitrate and ammonium as sources of nitrogen; most simple sugars can serve as sources of carbon; various amino acids and other organic acids are readily utilized. It can be separated by serological and phage-typing methods from species of *Erwinia*, *Pseudomonas*, and *Xanthomonas*, including the type strain of *x. manihotis*. *Bdellovibrio* sp. causes lysis specifically of this bacterium and can be used to separate it from other plant pathogenic bacteria. As a result of this, Lozano and Sequeira¹⁹ concluded that although the cassava blight bacterium could be considered as a strain of *x. manihotis* its taxonomy needed further revision.

EPIDEMIOLOGY

The bacterium normally penetrates the host via stomata or through epidermal wounds^{18, 19}. After penetration, the organism first invades and destroys the spongy mesophyll and then enters the vascular tissues. Once inside the vascular system, the bacterial cells are able to move systematically throughout the plant^{18, 19}. Movement into the stem and petioles is thought to take place primarily through the xylem vessels^{1, 13} and possibly through the phloem^{1, 20}. Movement through the pith tissues also has been reported.

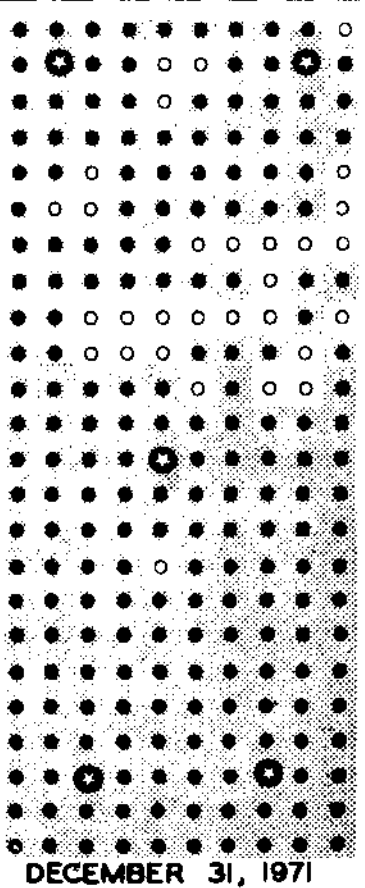
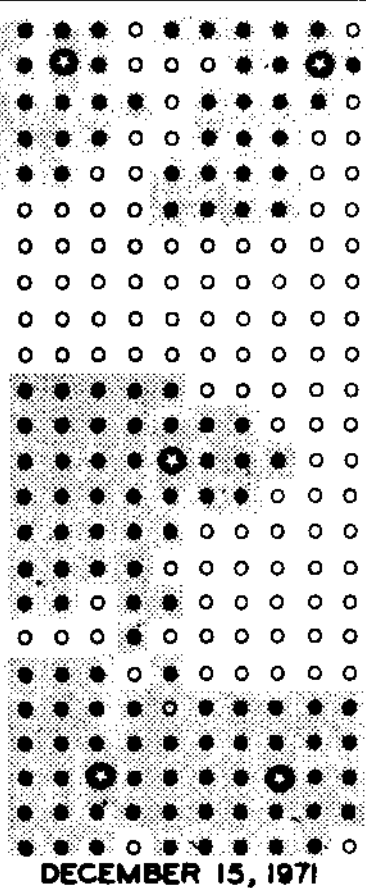
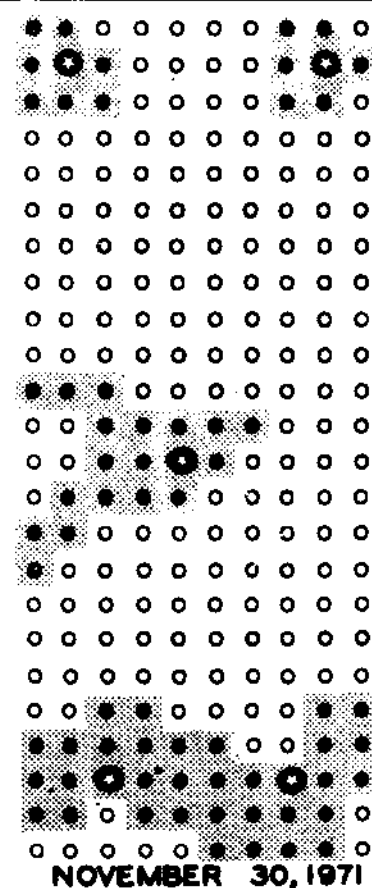
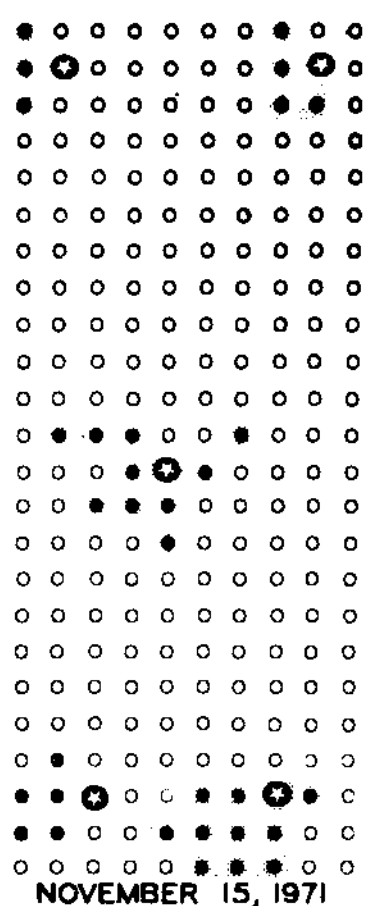
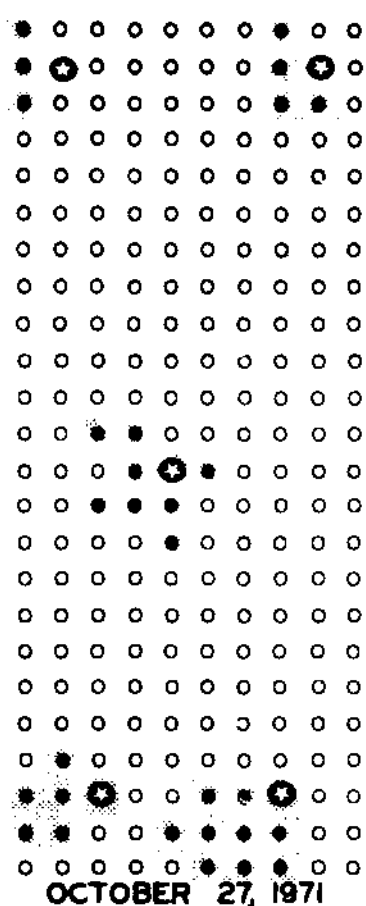
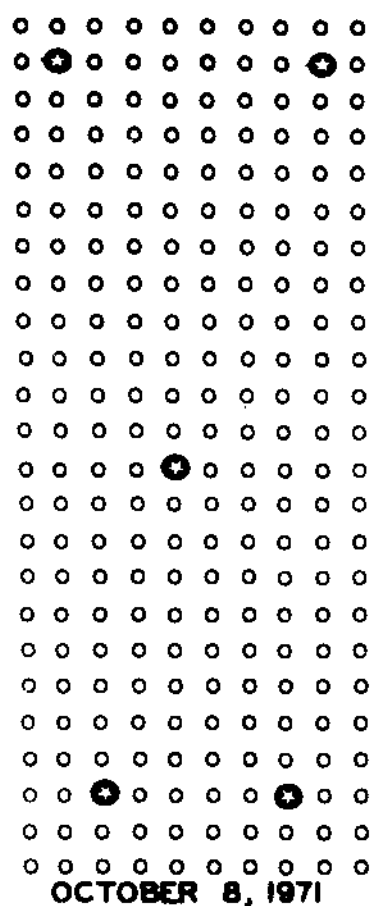
Infection by this organism is more common in, and is frequently limited to, the young tissues of the plant where it causes extensive breakdown of parenchymatous tissues of susceptible cultivars. In general, symptoms develop within eleven to thirteen days of infection^{18, 19}. In highly lignified stems the bacteria remain restricted to the vascular tissues where they can survive for relatively long periods (Lozano, unpublished). It is through the lignified secondary wall, and possibly also the middle lamellae of mature vessels, forming a barrier, that the enzymes of this bacterium cannot penetrate^{18, 19}.

In inoculation experiments it has been found that at least 12 hours at 100 percent relative humidity is required for consistent bacterial establishment¹⁸. The influence of other environmental conditions on infection and disease development have not been reported.

The possibility that the pathogen spreads from one area to another by the use of infected cuttings was suggested by Amaral² and demonstrated by Lozano¹⁸ and Lozano and Sequeira¹⁹. (Fig. 1). Lozano¹⁸ and Lozano and Sequeira¹⁹ also have clearly demonstrated that the use of infected cuttings is largely responsible for the dissemination of the disease from one growing season to another and that rain splashing is the most important means of dissemination in localized areas (Figs. 5,6). This accounts for the increased incidence of the disease in the rainy seasons reported by Drummond and Hipolito¹³.

Some workers have suggested that the pathogen could be readily spread by movement of soil during cultural operations or by the use of contaminated tools during pruning^{9, 13, 14, 15, 16}. Although it is considered possible that bacteria may be able to penetrate roots when plants are grown in heavily infested soils^{3, 13, 19}, this means of disease spread is considered to be of minor importance because of the short survival of this pathogen in the soil (Lozano, unpublished). Similarly, contaminated irrigation water is at present regarded as being of minor importance. In contrast to this, however, the use of contaminated tools is considered to be an important means of bacterial dissemination^{18, 19}, especially considering the extensive amount of cutting that is required during harvesting and preparing planting material.

As the bacteria enter plants through wounds, the movement of man, animal, and insects through a crop is also likely to spread the disease although little evidence is available to demonstrate this. Insects have been suggested as possible agents for dissemination² and their possible role in disseminating bacteria has recently been demonstrated at CIAT. Controlled experiments, using insecticides, have shown that dissemination because of insects could account for as much as 10 percent of the total dispersion from primary foci within a plot (Ikotun, personal information).¹ However, studies on dissemination from an inoculum source to plants located at different distances from it indicated that spread attributable to insects only occurred over short distances^{11, 18, 19}.



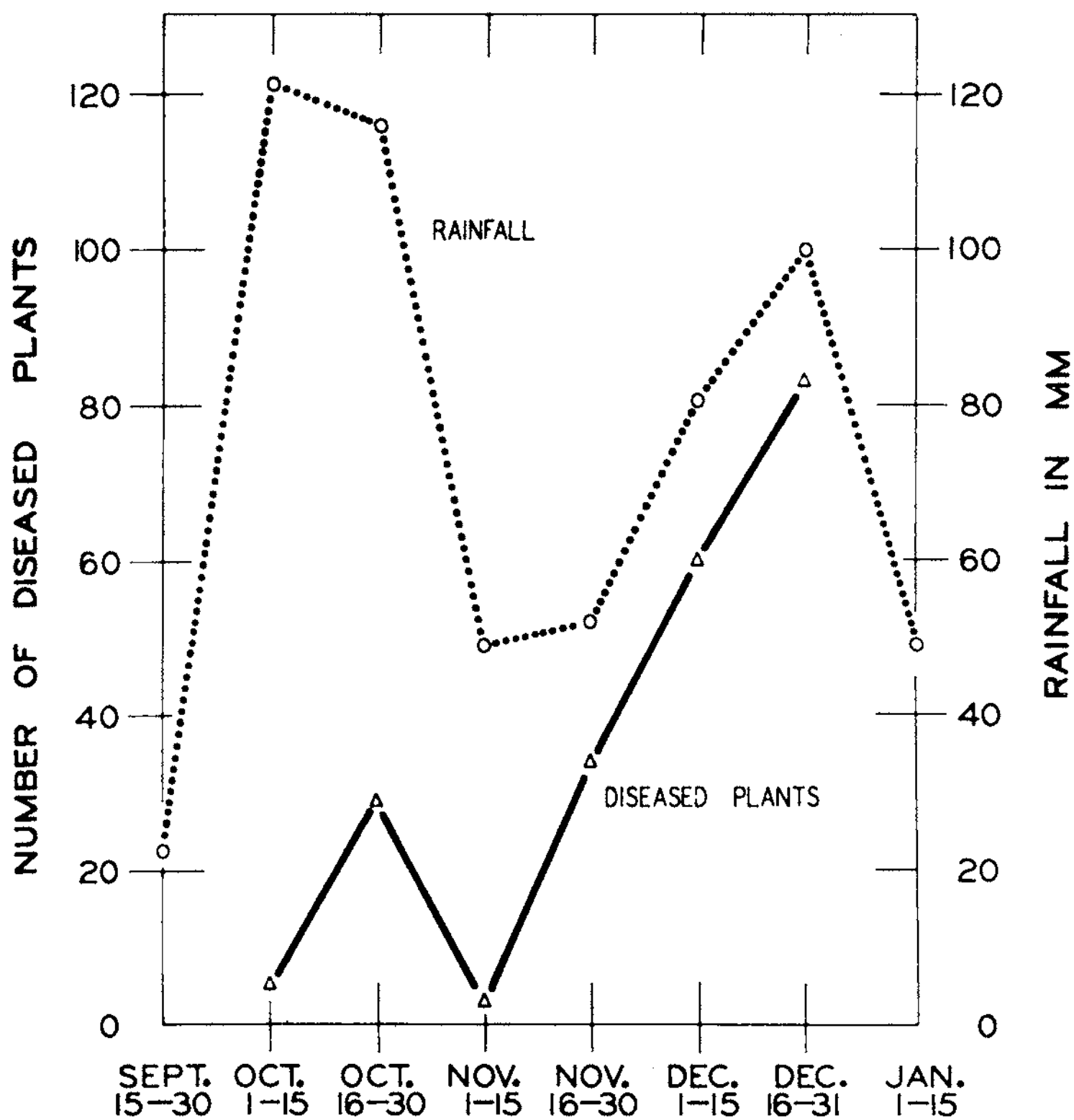


FIGURE 6. SPREAD OF CBB IN THE FIELD FROM INITIAL SOURCES OF INFECTION. RELATION OF TOTAL RAINFALL (MM) AND NUMBER OF DISEASED PLANTS IN EACH 15-DAY PERIOD (20).

During dry periods when disease development is slow little bacteria-containing gum is exuded, and hence the spread of the disease is halted. The bacteria, however, remain viable in the plant and become active during subsequent rainy periods.

CONTROL

Delaying the spread of the disease by pruning most of the above ground portions of infected plants has been reported^{11,18,19}. However, the success of this method depends on the susceptibility of the cultivar and the interval between initial infection and pruning. This method is most successful with mildly infected resistant and moderately resistant cultivars, and has little effect with severely infected susceptible cultivars as the new shoots rapidly become re-infected and so require regular and extensive pruning. Such extensive pruning must affect the productivity of the plant and quality as well as yield of roots. Although in certain circumstances this method may be useful to slow or break the spread of an epidemic, it can never give complete control and is incompatible with normal production of the crop.

For the complete avoidance of this disease where it does not yet occur, exclusion of the pathogen by the use of clean propagating material has been suggested^{9,13,15,16}. A successful means of producing bacteria-free cuttings has been developed by Wholey and myself at CIAT. We are able to root bacteria-free stem tips even from infected plants and can thus obtain clean stocks from infected cultivars and have provided certified bacteria-free cassava propagating material. (Fig. 7) Physical treatments, such as exposure to hot air and water, microwaves and ultraviolet light to inactivate bacteria in infected planting material have so far been unsuccessful. (Prada, Zarate, and Lozano unpublished).

Crop rotation has also been suggested as a means of control⁹. At CIAT we have found that if all infected plant debris is removed and destroyed by burning, an interval of six months between successive cassava crops is sufficient to prevent carry-over of the disease in the soil.

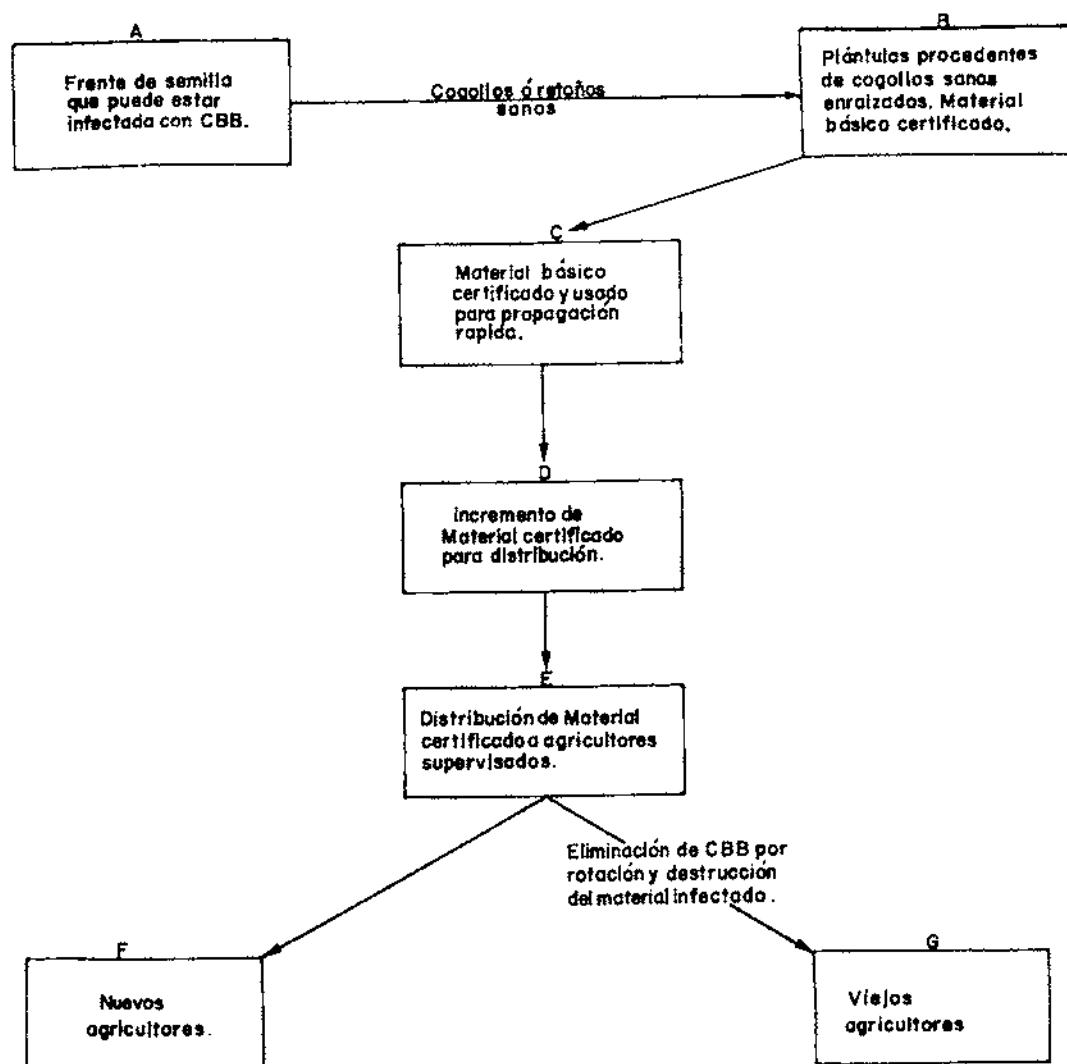


FIGURE 7. SUGGESTED SCHEME FOR A CBB-FREE "SEED" CERTIFICATION PROGRAM (LOZANA AND WHOLEY, UNPUBLISHED).

Control by the use of cultivars resistant to bacteria was first suggested by Gonçalves¹⁵. Numerous field resistant cultivars have since been reported^{9,14,20}. These field observations have been confirmed in greenhouse studies conducted by Lozano and Sequeira¹⁹. Their studies also revealed that three possible types of resistance exist in different cultivars; one type apparently limits penetration, another type limits systematic invasion and establishment, and the third type is apparently based on a hypersensitive response of the host¹⁹.

A combination of the use of rotation, resistant cultivars and the use of bacteria-free planting material appears to be a most promising means of controlling this important disease.

REFERENCES

1. Amaral, J.F. do (1972) Estudo do organismo causador da bacteriose da mandioca. *Arq. Inst. Biol., Sao Paulo* 11, 119-26.
2. ——— (1945) Doenças vasculares das plantas causadas por bacterias. *O Biologica, Sao Paulo*, 11, 250-3.
3. Amaral, J.F. do and Vasconcellos, L.G. (1945) Novos estudos do agente etiológica da bacteriose da mandioca. *Arq. Inst. Biol., Sao Paulo* 10, 361-8.
4. Bergey, D.H. (ed.) (1948) *Manual of determinative bacteriology*. 7th ed. The Williams & Wilkins Co., Baltimore, Md. 1529 pp.
5. ——— (ed.) (1957) *Manual of determinative bacteriology*. 7th ed. The Williams & Wilkins Co., Baltimore, Md. 1094 pp.
6. Bondar, G. (1912) Uma nova molestia bacteriana das hastes da mandioca. *Chacras e Quintaes, Sao Paulo* 5, 15-18.
7. Bondar, G. (1915) Molestia bacteriana da mandioca. *Bol. Agric. Sao Paulo* 16, 513-24.
8. Burkholder, W.H. (1942) Three bacterial plant pathogens: *Phytomonas caryophylli* sp. n., *Phytomonas alliicola* sp. n., and *Phytomonas manihoti*. *Phytopathology* 32, 146-8.
9. Carneiro, J.G. (1940) Doença bacteriana da mandioca. *Notas e Informacoes. Portaria do Min. Agric.* 573: 447.
10. Centro Internacional de Agricultura Tropical (CIAT). (1971) CIAT Annual Report. *CIAT, Cali, Colombia* 120 pp.
11. ——— (1972) CIAT Annual Report. *CIAT, Cali, Colombia* 192 pp.
12. Costa, R. (1940) Regioes infectadas pela bacteriose da mandioca. *Notas e Informacoes. Portaria do Min. Agric.* 573:446.
13. Drummond, O.A. and Hipolito, O. (1940-41) Notas sobre bacteriose da mandioca. *Escola Superior de Agric. Minas Gerais, Bol.* 4, 86-124.
14. Drummond, O.A. and Gonçalves, R. (1953) A bacteriose e a mandioca guazupe. *O Biologico, Sao Paulo* 19, 114-17.
15. Gonçalves, R.D. (1948) Bacteriose da mandioca. *Notas e Informacoes. O Biologica, Sao Paulo* 14, 145-6.
16. ——— (1953) A bacteriose e a mandioca quazupe. *Notas e Informacoes. O Biologico, Sao Paulo* 19, 114-17.
17. International Institute of Tropical Agriculture (IITA) (1972) Report of root, tuber and vegetable improvement programme. IITA, Ibadan, Nigeria. 43 pp.
18. Lozano, J.C. (1972) Bacterial blight of cassava (*Manihot esculenta* Crantz) in Colombia: etiology, epidemiology and control. Ph.D. Thesis, Univ. Wis. Madison. 114 pp.
19. Lozano, J.C. and Sequeira, L. (1974) Diseases of cassava (*Manihot esculenta* Crantz) *PANS* 20, 30-54.
20. Pereira, A.L.G. and Zagattia, A.G. (1967) Etiology of angular leaf spot of cassava (*Manihot utilissima*) *Arq. Inst. Biol. Sao Paulo* 34, 153-60.
21. Starr, M.H. (1946) The nutrition of phytopathogenic bacteria. I. Minimal nutritive requirements of the genus *Xanthomonas*. *J. Bacteriol.* 51, 131-4.
22. Viegas, A.P. (1940) Mofo dos afideos e aleriodideos. *Rev. Agric., Piracicaba* 15, 475-85.

ADVANCES IN YAM STORAGE RESEARCH IN NIGERIA

S.A. Adesuyi*

SUMMARY

A concise review of research findings from the Nigerian Stored Products Research Institute indicates in particular the importance of avoiding physical damage to yams during harvest and post harvest handling, and the great potential value, from a technical viewpoint, of the use of γ -radiation for sprout control, which effectively prolongs storage life maintaining excellent quality.

RESUME

Un aperçu concis des résultats de recherche obtenus par l'Institut Nigérien de Recherche sur les Produits en Stockage met en relief le fait qu'il est important de ne pas blesser l'igname pendant et après la récolte, de même que la grande valeur potentielle, du point de vue technique, de l'utilisation de radiation — y pour le contrôle des bourgeons, ce qui assure à l'igname une longue durée de conservation et une qualité excellente.

RESUMEN

Una revisión concisa sobre los aportes de la investigación del Instituto para la Investigación de Productos Almacenados de Nigeria, indica — en particular — la importancia de evitar daños físicos al ñame durante el manejo en la cosecha y en postcosecha, y el gran valor potencial, desde un punto de vista técnico del uso de radiación y para el control de retoños el cual, efectivamente, prolonga el tiempo de almacenamiento manteniendo una calidad excelente.

*Nigerian Stored Products Research Institute, Federal Ministry of Trade, P.M.B. 5044, Ibadan, Nigeria.

INTRODUCTION

Yams are the most important of any farm crop produced for home consumption in the internal economy of Nigeria, and they also earn foreign exchange⁵. The principal species is the white Guinea yam, *Dioscorea rotundata* Poir. Other species cultivated being the yellow Guinea yam, *D. cayenensis*, the Water yam, *D. alata* L., the Chinese yam, *D. esculenta* (Lond.) Burk and the Bitter or Cluster yam, *D. dumetorum* (Kunth) Pax. Nigeria is the world's largest producer of yams, producing 12.1 million long tons in 1970/71⁴, while global production has been estimated at 20-25 million tons per annum.¹²

Only one crop is grown per year, and it is therefore necessary to store yams for six months or longer. The yam barn is the most widely used structure for yam storage in West Africa. This consists of a vertical or nearly vertical wooden framework, to which the yams are tied individually by means of string or local cordage.

Very substantial losses in weight and quality occur during storage in the yam barn. Weight losses of 10-15 percent in the first three months, approaching 50 percent after six months' storage have been reported^{11, 12}. The factors responsible are as follows:

1. Physical losses, i.e. mechanical damage and dessication.
2. Metabolic losses due to respiration.
3. Losses due to microbiological attack.
4. Losses due to insect and nematode attack.
5. Losses caused by rodents and other mammals.

It has been found that smaller yam tubers are less susceptible to mechanical damage than larger tubers. In 1960 Coursey and Walker found that yams maintained a fairly constant moisture content at Port Harcourt during storage, losing only 4 percent moisture during 22 weeks storage, but in the drier climate of Ibadan, 24 weeks storage resulted in a moisture loss of 20 percent.

Work on the respiration of stored yams showed that the principal sources of weight loss in yams during storage could be attributed to the respiratory activity of the living tuber^{9, 14, 16}.

Storage rots caused by microorganisms are the second most important factor responsible for losses and deterioration. Weight losses are greatly increased when rotting of the tubers occurred, and several microorganisms have been isolated from rotten yams^{9, 10, 16, 22}.

Storage at low temperatures had been investigated in the hope of reducing the rate of respiration and controlling the microorganisms causing decay. However, yams suffer from chilling damage at temperatures of 10° C or below which are therefore unsuitable for their storage.¹³

The use of maleic hydrazide as a chemical sprout inhibitor at different concentrations was tried¹⁸ without any conclusive results, although it has been reported⁸ that methyl (alpha naphthyl) acetate (MENA) incorporated on paper carriers reduced sprouting in *D. alata*, while maleic hydrazide (MH-30), tetrachloronitrobenzene, pentachloronitrobenzene, and isopropyl phenyl carbamate failed to prolong the dormancy of *D. alata*.

Fungicides had been tried to control rotting of stored yams⁹; limewash proved to be more satisfactory for the first 10-12 weeks of storage, then borax or copper treatments tested on *D. cayenensis* and *D. rotundata*.

Walker²⁷ found that hermetic storage was unsuitable for yams. It has been claimed²⁶ that clamp storage was better than barn storage for yams but Olorunda and Adesuyi²⁴ found the reverse.

Attention has been paid to the two factors of sprouting and microbiological rot in relation to yam storage, during renewed research in the past four years in Nigeria. A report of the findings is presented here. *D. rotundata* has been used for most of these investigations.

REVIEW OF RECENT RESEARCH FINDINGS

Sprouting

Sprouting has been found to have many adverse effects in stored yams.

1. It reduces the food reserves in yams, through translocation of carbohydrate from the tuber into the sprouts.
2. It increases the rate of respiration and thus the rate of dry matter loss.
3. It causes an accelerated loss of moisture resulting in enhanced wilting. Adesuyi (unpublished work) reports that yams that sprouted lost 14 percent moisture content during six months' storage, 12 percent being in the last four months in which sprouting occurred; while yams that did not sprout lost only 6.5 percent moisture during the six months' storage.
4. It results in an enhanced loss of weight.
5. The vines produced during storage are a waste; vines of yams stored in the barn may be more than 180 cm long two months after sprouting, (i.e. about the fourth month of storage) and represent around 10 percent of the total weight.

6. It is associated with physiological rot in stored yam tubers. After some weeks the tubers become soft progressively from the bottom to the head, and become more susceptible to attack by microorganisms.
7. It reduces the quality and palatability of the tuber: the sprouting tuber is generally fibrous and bitter especially at the 'head' end.

Three methods for preventing sprouting in stored yam tubers of *D. rotundata* Gwaguzu have been investigated:

1. Storage at different temperatures, in rooms maintained at 15°C, 20°C, 25°C, and in the yam barn which was at ambient (27-35°C); only storage at 15°C was found to be effective in suppressing sprouting for six months.
2. Use of gamma radiation; tubers were irradiated to 2.5, 5.0, 7.5, 10.0, 12.5, or 15 krad four weeks after harvest, and stored with control tubers in a yam barn. Irradiation at 10 krad and higher doses effectively inhibited sprouting during six months storage, while 7.5 krad was found to be the critical dose for sprout inhibition.³
3. Use of chemical sprout inhibitors:
 - (a) Maleic hydrazide, MH-30, and 1-naphthylacetic acid as a pre-harvest foliar spray at various concentrations up to 10 percent.
 - (b) Aqueous solutions of MH-30, and 1-naphthylacetic acid as a dip at various concentrations.
 - (c) Methyl ester of 1-naphthylacetic acid (MENA) and 2,3,5,6, tetrachloronitrobenzene (TCNB) applied by brushing on the head region, where sprouting usually begins.
 - (d) Amyl and nonyl alcohols, to the vapours of which tubers were exposed in specially constructed air-tight cabinets for two weeks.

None of the chemical sprout inhibitors was found to be effective. The results of the successful methods of inhibiting sprouting in stored yam tubers for six months are presented in the Tables.

Radiation at doses of 15.0, 12.5, and 10.0 krad applied to yam tubers during dormancy and later stored in the yam barn, or alternatively storage of fresh tubers at 15°C, inhibited sprouting for six months as shown in Table 1. That there was a substantial reduction in weight loss in yams which did not sprout in storage is shown in Table 2. The weight loss in the controls, which sprouted, was approximately twice the weight loss in the treated tubers that did not sprout.

Table 3 shows that incidence of rot was reduced where sprouting was inhibited, presumably because there was no incidence of physiological rot. There was a high incidence of rot in one of the storage trials at 15°C when damaged samples were used, indicating that it is essential to store only sound tubers at this temperature.

Palatability and acceptability were very much enhanced in the treatments that inhibited sprouting as compared to the controls that sprouted in storage, as is shown in Table 4.

The successful inhibition of sprouting in stored yams for six months thus eliminated the adverse effects of sprouting enumerated earlier.

Decay

Two types of rot occur in stored yam tubers:

1. Physiological rot, which has already been mentioned in connection with sprouting.
2. Microbiological rot. This has the following effects on stored yams.
 - (a) It increases the rate of loss in weight of stored yams.
 - (b) It increases the rate of respiration and thus the rate of loss of dry matter.
 - (c) It adversely affects viability of the tuber.
 - (d) It can result in a total loss of the tuber.

Recent studies in Nigeria have led to the isolation of several fungi associated with storage rot of yams, *Aspergillus niger*, *Penicillium oxalicum*, *Fusarium moniliforme*, *F. poae*, *Trichoderma viride* and *Gliomastix convulata*^{1,20}

The pathogens responsible for soft rot in stored yams entered the host tissue through wounds, and mycelial growths developed at natural openings such as scars left by rootlets and lacerations on the tubers. No fungal penetration appeared through the unwounded surfaces of the yam tubers²⁰. This indicates that, apart from any natural openings, mechanical damage to tubers at harvesting, handling and transportation prior to storage provide the courts of infection. This in turn suggests that rotting in storage can be prevented by avoiding surface damage to the tubers during harvesting, handling and transportation prior to storage. Maximum attack by pathogens occurred at 90 percent R.H. and 26-30°C.

Anatomical studies on inoculated yam disks²⁰, revealed that the pathogens of yam causing storage rots penetrated the parenchyma cells of the tubers and established themselves within the cells. Infected cells were cleared of most of their starch grains and the cell walls disintegrated. The pathogens produced extra-cellular cellulolytic and pectic enzymes in culture.

Studies on yam nematodes⁶ showed that the yam nematode, *Scutellonema bradys*, feeds on the peri-

dermal and sub-peridermal cell layers of yam tubers causing destruction of the cells and the browning of cell walls, ultimately giving rise to a characteristic dark brown layer extending 1-2 cm into the tuber. This was described as the typical dry rot disease associated with nematodes. This differs from the views of Smit²⁵ that the nematodes only acted as incitants of the disease and the 'dry rot' was caused primarily by fungi such as *Fusarium* spp.

Ogundana²¹ reported that pre-harvest rot was greatly reduced in yam tubers produced from setts (or seed pieces) which had been treated with Benlate or Thiabendazole before planting. Both fungicides were more effective in controlling soft rot of stored yams than Captan when applied as a dip at either 500 ppm or 1000 ppm before storage, although all three could be recommended for tuber treatment prior to storage.

In studies on curing technique, Adesuyi² found temperatures of 25°C and R.H. of 55-62 for five days to be the most suitable for curing fresh yam tubers to control rot during storage. High humidities and higher temperatures were not suitable, because the microorganisms responsible for decay require high humidities for optimum growth¹⁹, while temperatures of 37°C and above cause damage to yam tissues¹⁵. Some pathogens can also survive temperatures up to 45°C, e.g. *Botryodiplodia theobromae*⁷ which is one of the major microorganisms associated with rot in yams.

REFERENCES

1. Adeniyi, M.O. (1970) Fungi associated with storage decay of yam in Nigeria. *Phytopath.* 60(4), 590-2.
2. Adesuyi, S.A. (1973) Curing technique for reducing the incidence of rot in yams during storage. Report Nigerian Stored Products Research Institute, 1971.
3. Adesuyi, S.A. and Mackenzie, J.A. (1973) The inhibition of sprouting in stored yams, *Dioscorea rotundata* Poir, by gamma radiation and chemicals. In *Radiation Preservation of Food*. International Atomic Energy Agency, Vienna.
4. Anon. (1972) *Rural Economic Survey of Nigeria. Consolidated results of crop estimation surveys, 1968-9, 69-70, and 70-71*. Agric. Statistics Unit. Federal Office of Statistics, Lagos.
5. Bell, J.K. and Coursey, D.G. (1971) Tropical vegetables in Britain. *Trop. Sci.* 13(4), 251-63.
6. Bridge, J. (1972) Nematode problems with yams (*Dioscorea* spp.) in Nigeria. *PANS* 18(1), 89-91.
7. Broadbent, J.A. and Oyeniran, J.O. (1973) Internal mouldiness of Nigerian cocoa caused by *Botryodiplodia theobromae* Pat. Rep. Nigerian Stored Products Research Institute, 1970.
8. Campbell, J.S., Chukwueke, V.O., Teriba, F.A. and Ho-A-Shu, H.V.W. (1962) Some physiological experiments with the white Lisbon yam (*Dioscorea alata* L.) in Trinidad. III. The effects of chemicals on storage. *Empire J. Expl. Agric.* 30(120), 335-44.
9. Coursey, D.G. (1961) Magnitude and origins of storage losses in Nigerian yams. *J. Sci. Fd. Agric.* 12(8), 574-80.
10. ——— (1963) Storage losses in yams. *Nigerian Grower and Producer* 2(3), 43-5.
11. ——— (1967) Yam storage. I. A review of yam storage practices and of information on storage losses. *J. Stored Prod. Res.* 2, 229-44.
12. ——— (1967) *Yams*. Longmans, London.
13. ——— (1968) Low temperature injury in yams. *J. Fd. Technol.* 3, 143-50.
14. Coursey, D.G., Fellows, L.E. and Coulson, C.B. (1966) Respiration in yam tuber tissue. *Nature*, 210(5042), 1292-3.
15. Coursey, D.G. and Nwankwo, F.I. (1968) Effects of insolation and of shade on the storage behaviour of yams in West Africa. *Ghana J. Sci.* 8, (1/2), 74-81.
16. Coursey, D.G. and Russell, J.D. (1969) A note on endogenous and biodeteriorative factors in the respiration of dormant yam tubers. *Int. Biodegr. Bull.* 5(1), 27-30.
17. Hayward, L.A.W. and Walker, H.M. (1961) The effect of pre-harvest foliar spraying with maleic hydrazide on the storage of yams. Ann. Rep. W. Afr. Stored Products Res. Unit. pp. 107-115.
18. Hayward, L.A.W. and Walker H.M. (1962) Yam storage in Nigeria. CTA/F.A.O. Symposium on Stored Food.
19. Ogundana, S.K., Naqvi, S.H.Z. and Ekundayo, J.A. (1970) Fungi associated with soft rot of yams (*Dioscorea* spp.) in storage in Nigeria. *Trans. Brit. Mycol. Soc.* 54(3), 445-51.
20. ——— (1971) Studies on soft rot of yams in storage. *Trans. Br. mycol. Soc.* 56(1), 73-80.
21. Ogundana, S.K. (1972) The control of soft rot of yams in Nigeria. *Int. Biodegr. Bull.* 8(2), 75-8.

22. Okafor, N. (1966) Microbial rotting of stored yams (*Dioscorea* spp.) in Nigeria. *Expl. Agric.* 2, 179-82.
23. Okigbo, P.N.C. (1962) Nigerian National Accounts, 1950-57. Lagos Federal Ministry of Economic Development.
24. Olorunda, O. and Adesuyi, S.A. (1973) A comparison between the barn and clamp methods of storing yams. Rep. Nigerian Stored Prod. Res. Institute, 1970.
25. Smit, J.J. (1967) Nematodes. In Coursey (1967) *Yams*. pp. 115-20.
26. Waitt, A.W. (1961) Review of yam research in Nigeria, 1920-61. Fed. Dept. Agric. Res./Nigeria. Memo 31.
27. Walker, H.M. (1961) The sealed storage of yams. Ann. Rep. W. Afric. Stored Products Res. Unit. pp. 103-6.

TABLE 1

Cumulative percentage of sprouting of yam tubers stored at 15°C and irradiated tubers stored in the yam barn for six months and their control

Period of storage in months	15.0 krad	12.5 krad	10.0 krad	con-trol	150C	con-trol
0	0	0	0	0	0	0
1	0	0	0	24	0	0
2	0	0	0	68	0	30
3	0	0	0	92	0	88
4	0	0	0	92	0	100
5	0	0	0	96	0	100
6	-	-	-	-	2	100

Irradiated tubers were treated one month after harvest and stored for another five months after treatment.

TABLE 2

Cumulative percentage loss in weight of yam tubers stored at 15°C and irradiated tubers stored in the yam barn for six months and their control

Period of storage in months	15.0 krad	12.5 krad	10.0 krad	con-trol	150C	con-trol
0	0.0	0.0	0.0	0.0	0.0	0.0
1	7.3	6.4	8.1	9.3	2.5	6.2
2	8.1	8.6	9.3	14.5	5.3	9.0
3	9.2	10.4	12.8	15.3	8.2	13.9
4	15.3	15.9	16.7	20.1	11.6	23.4
5	17.7	19.8	20.0	39.7	15.1	37.5
6	-	-	-	-	18.6	43.0

TABLE 3

Cumulative percentage of rotting of irradiated tubers stored in the yam barn for six months

Period of storage in months	15.0 krad	12.5 krad	10.0 krad	control
0	0	0	0	0
1	8	0	8	0
2	12	0	8	12
3	12	4	16	32
4	16	16	36	48
5	20	28	40	56

At 150C, 22 percent of the yam tubers were rotten by the sixth month of storage and 48 percent rotten in the control i.e. in the yam barn. The difference between the treated and the controls can be attributed to physiological rot.

TABLE 4

Palatability test results expressed as a percentage of assessments at the end of storage at 15°C and of irradiated yams stored in the barn and their unirradiated controls

Grading	15.0 krad	12.5 krad	10.0 krad	con- trol	15°C	control
A	85	95	45	-	75	20
B	15	5	55	-	25	20
C	-	-	-	15	-	40
D	-	-	-	85	-	20

A = very good
B = good
C = fair
D = poor

THE STORAGE OF FRESH CASSAVA ROOTS

R.H. Booth*

SUMMARY

Internal streaking and discolouration are the primary causes of the loss of acceptability of harvested cassava roots. Mechanical damage is a major cause of rapid post-harvest deterioration. Curing occurs in cassava roots stored in structures similar to potato clamps. These are inexpensive and easy to build using readily available materials. In such clamps unselected roots have been stored with acceptable levels of loss for up to two months under the conditions prevailing at Cali, Colombia during cool seasons. During storage internal quality changes included an increase in sweetness, and a softening of the root core. After successful curing, cassava roots had a longer shelf-life than freshly harvested roots.

RESUME

La pourridié interne et la décoloration sont les premières causes qui privent le manioc récolté de ses qualités. Les dégâts dus aux opérations mécanisées sont à la base de la détérioration rapide subie après la récolte. Le manioc stocké recouvre ses qualités dans des structures semblables aux silos à patate. On les construit aisément et à peu de frais en utilisant du matériel déjà existant. Dans ces silos on a stocké les racines rejetées pour leur niveau de perte, pendant environ deux mois en conditions prévalant au Cali, et en Colombie pendant les saisons fraîches. Pendant le stockage il y a eu changement dans la qualité interne du produit qui par ailleurs est devenu plus sucré et plus doux. Quand le traitement réussit, le manioc acquiert une durée de conservation plus longue que le manioc fraîchement récolté.

RESUMEN

El rayado interno y la decoloración son las causas primarias de la pérdida de aceptabilidad de las raíces de yuca cosechadas. El daño mecánico es la mayor causa de una deterioración rápida post-cosecha. El curado ocurre en las raíces de yuca almacenadas en estructuras similares a las prensas para papa las cuales son baratas y fáciles de construir, con materiales disponibles. En este tipo de prensas se han almacenado raíces no seleccionadas hasta dos meses, observándose pérdidas aceptables bajo las condiciones que prevalecen en Cali, Colombia, durante la temporada de frío. Durante el almacenaje la calidad interna cambia lo que incluye un incremento de dulzura y el ablandamiento de la parte central de la raíz. Después de un curado exitoso, las raíces de yuca tienen una vida de almacenaje mayor que la de las raíces recién cosechadas.

*Tropical Products Institute (T.P.I.), 56-62 Gray's Inn Road, London W.C. 1 England. The work was undertaken at the Centro Internacional de Agricultura Tropical (C.I.A.T.), Apartado Aéreo 67-13 Cali, Colombia, as a part of a joint TPI/CIAT Cassava storage project.

REVIEW

Cassava roots cannot be kept in the fresh state for more than a few days after harvest. This presents serious problems in the marketing and utilization of the crop and often results in heavy losses. Most of the literature on storage of cassava has been reviewed by Ingram and Humphries¹³. They concluded that "knowledge of techniques for preserving and storing fresh cassava is still rudimentary and few reliable data exist." Similarly, little reliable information is available about the nature of the rapid post-harvest deterioration in newly harvested cassava. This has been reported as decay or rotting, dark bluish or brownish discolouration, dark or vascular streaking and/or softening of the affected areas. Several workers^{1,6,10,17,21} have isolated and identified many microorganisms from deteriorated cassava and in some instances these organisms have in turn been shown to cause decay and discolouration. Other workers^{3,14,18,19,20} have suggested that both discolouration and softening result from enzymatic reactions. Ingram and Humphries¹³ concluded that "It appears that the spoilage arises from a combination of physiological and pathological factors."

Mechanical damage has recently been emphasized as a major factor in post-harvest loss of all tropical root crops⁵. Avere³ reported that vascular streaking of cassava roots commenced at cut surfaces and several workers^{4,24} have emphasized the need for careful handling of roots intended for storage. Montaldo¹⁸ reported differences between cultivars in the rate of development of vascular discolouration.

While extensive mechanical damage can only be reduced by improved harvesting and handling methods, a process of wound healing which occurs in several other root crops, such as potato⁷, sweet potato¹⁶ and yams^{11,23} has been shown to reduce storage losses of slightly damaged produce. This process, generally referred to as 'curing', is stimulated by conditions of relatively high temperature and humidity and involved suberisation which is followed by development of a wound periderm. This retards water loss and acts as a barrier against infection.

It has long been known that cassava roots can be preserved for a few days using several simple techniques such as reburial, placing under water and coating in mud. There are, however, few recorded instances, with the exception of the use of high cost systems, such as refrigeration^{9,21} and waxing^{14,22} of successful long term storage of fresh cassava roots. The normal practice in much of the tropical world is to leave cassava unharvested in the ground until required. However, it has been estimated that this practice occupies 0.75 million hectares of land unnecessarily¹³. While refrigeration and waxing techniques may be of use in some situations, they cannot be extensively applied to practical farm or local market storage.

There is an account in early ethnological literature¹² that Amazonian Indians successfully stored fresh cassava during the annual flood period by burying the roots in the soil. Also, in Mauritius in 1741², M. de Reine successfully stored fresh cassava roots in a trench resembling a European potato clamp for periods of up to twelve months. In the Philippines, Baybay⁴ showed that cassava roots could be stored for up to twenty-five days in a trench. It has also been reported^{2,22} that roots piled up and covered with straw alone, or with straw and soil, inside a building, could be stored for periods of one to two months. Similar structures have also been used to store sweet potatoes under tropical conditions¹⁵. Conditions of above-ambient temperature and relative humidity develop in potato clamps in Europe^{7,8}.

OBSERVATIONS ON THE DETERIORATION OF CASSAVA ROOTS

Post-harvest observations at CIAT have revealed two distinct phases in the deterioration of cassava roots.

Primary deterioration

The initial cause of loss of acceptability is internal discolouration which normally develops within one to five days after harvest. This internal discolouration is first evident as fine blue/black vascular streaks as reported by Avere³ and was described and illustrated by Montaldo¹⁸. This streaking increases in intensity with time and spreads to non-vascular tissue where a more diffuse brown discolouration, accompanied by dry white lesions, develops. This discolouration renders the roots unacceptable both for human consumption and for most industrial purposes. This is what will be called 'primary deterioration'. (Fig. 1).

Secondary deterioration

Later, pathogenic rotting, fermentation and/or softening of the roots occur. This type of root deterioration will be referred to as 'secondary deterioration'. However, in West Africa, softening can sometimes render cassava partially or completely unacceptable even when little or no primary deterioration has occurred (D.G. Coursey, private communication).

Occurrence of deterioration

In harvesting operations, cassava roots are always damaged and frequently severely so. Roots are often cut during digging, and the tips of the roots are commonly broken off and the 'shoulders' bruised as they

are pulled out of the ground. Cutting the roots from the plant creates a further lesion, while transport from the field can often result in additional mechanical damage by bruising. Only minor differences between cultivars have been found in susceptibility to primary deterioration. The importance of mechanical damage in post-harvest deterioration has been confirmed by artificial wounding.

Roots grown in sandy soils can be harvested with greater ease and with less damage and thus have a greater storage potential than roots produced in heavy soils. Cultivars of cassava differ widely in tuber shape, size, distribution through the soil and in the length of the 'neck' of non-storage root at the proximal end of the tuber. These factors, some of which may be modified by cultural practices, all influence the final amount of damage. Table 1 shows the effect of damage on water loss and deterioration of freshly harvested roots.

Nature of deterioration

The onset of primary deterioration was delayed when roots, portions of roots, or root slices were surface sterilized. For example, 10 mm thick transverse root slices untreated or dipped for thirty seconds in sterile distilled water and stored on moist filter paper in petri dishes became completely discoloured within twenty-four hours. Similar root slices dipped for thirty seconds in calcium hypochlorite (2.0%) or commercial alcohol (40%) showed no such deterioration for between two and four days, depending on the concentration of surface sterilant used (Table 2).

As a result of these observations and those on the effect of mechanical damage, it seems that the rapid primary deterioration that occurs after harvesting cassava roots may be due to colonization by epiphytic microorganisms naturally present on the root surface. While these organisms, at present uncharacterized, do not normally cause rotting or decay of undamaged roots, they may enter wounds produced by mechanical damage and stimulate the onset of discolouration which subsequently spreads throughout the root.

STORAGE OF CASSAVA ROOTS

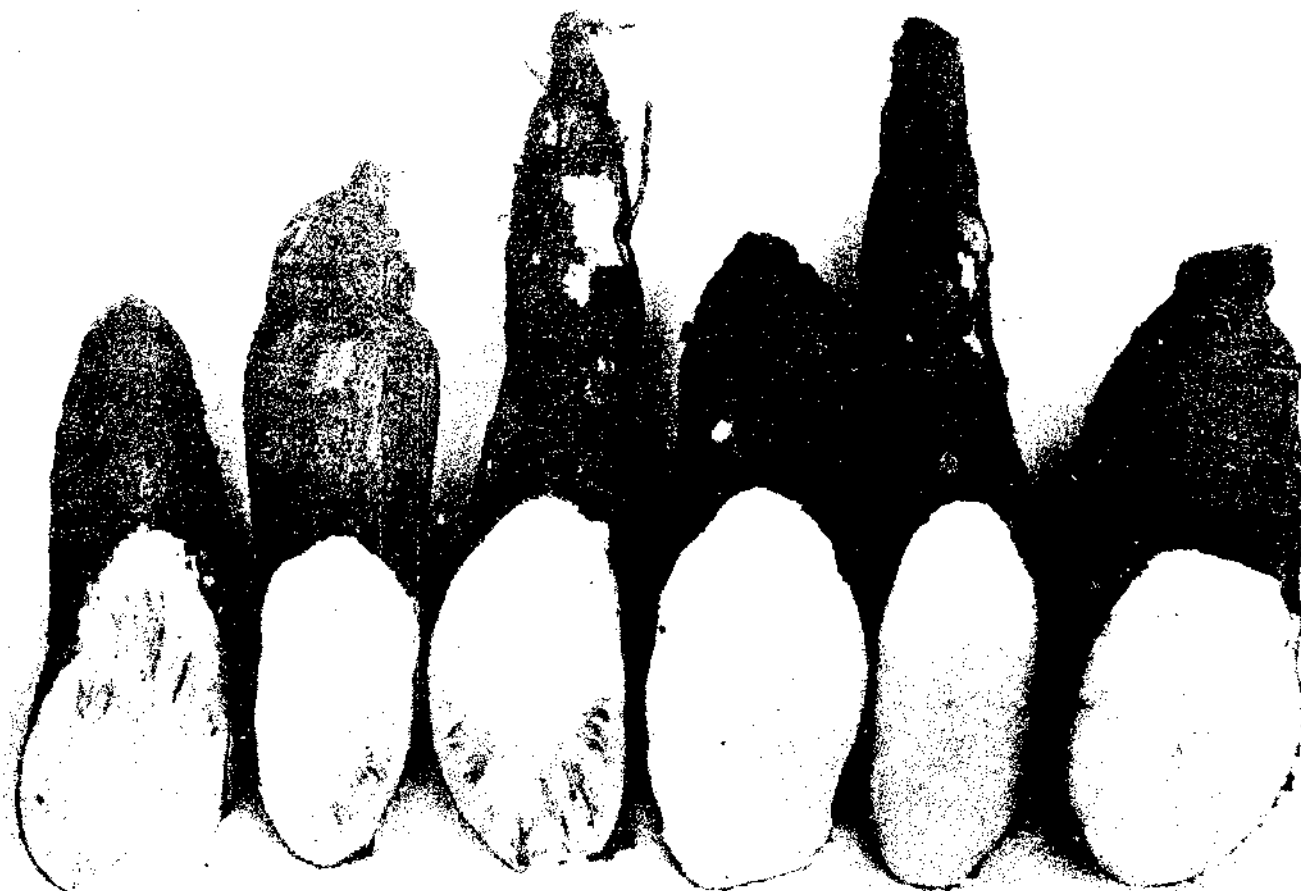
Storage in structures like potato clamps was re-investigated and several clamp units were built at C.I.A.T. from November 1972 to June 1973. Each clamp was built, on well-drained ground, by first placing a circular bed of rice straw of 1.5 m. diameter and of sufficient thickness so that, when later compacted, it was approximately 150 mm thick. Five hundred roots were heaped on this straw in a conical pile. These roots weighed approximately 300 kilos which is about the quantity one man can harvest in a day. Unselected roots were used, so that there was a large variation in root size and a substantial proportion of roots were mechanically damaged. The pile of roots was then covered with straw which compacted to a layer 150 mm thick. The whole clamp was then covered to a thickness of 100-150 mm with soil dug from around its circumference so as to form a drainage ditch. (Fig. 2).

Storage clamps were opened and the roots examined after periods of one, two and three months (Table 3). During cooler periods or during periods of frequent but light rainfall, the roots were successfully stored, with an acceptable level of loss, for two months. During such periods the temperature inside the clamps was between 30°C and 35°C. This temperature was found to remain constant throughout the storage periods, whereas the temperature of the soil cover fluctuated with the day and night temperature variations. A large proportion of the stored roots were successfully cured, and there was visible evidence of wound healing after one month in storage (Fig. 3). After two months storage, the bulk of the roots remained undeteriorated (Fig. 1). However, a few of the stored roots, although remaining undiscoloured, had softened in the centre. After three months storage, the percentage of unmarketable roots had increased considerably as there was some central softening in otherwise undeteriorated roots.

During long, hot and dry periods when the temperature of the stored roots inside the clamps rose to more than 40°C, high percentage losses had occurred by one month. Also, during periods of prolonged heavy rainfall when water penetrated the clamps, wetting the roots. There were heavy losses.

The main causes of loss were attributable to rots of pathogenic origin. Little loss attributable to primary deterioration was observed. On several occasions roots at harvest time were observed to be coated with hyphae of *Corticium rolfsii* Curzi which, during storage, rapidly invaded wounds before effective curing could take place and resulted in considerable decay. Other organisms associated with rotting and fermentation have not yet been identified.

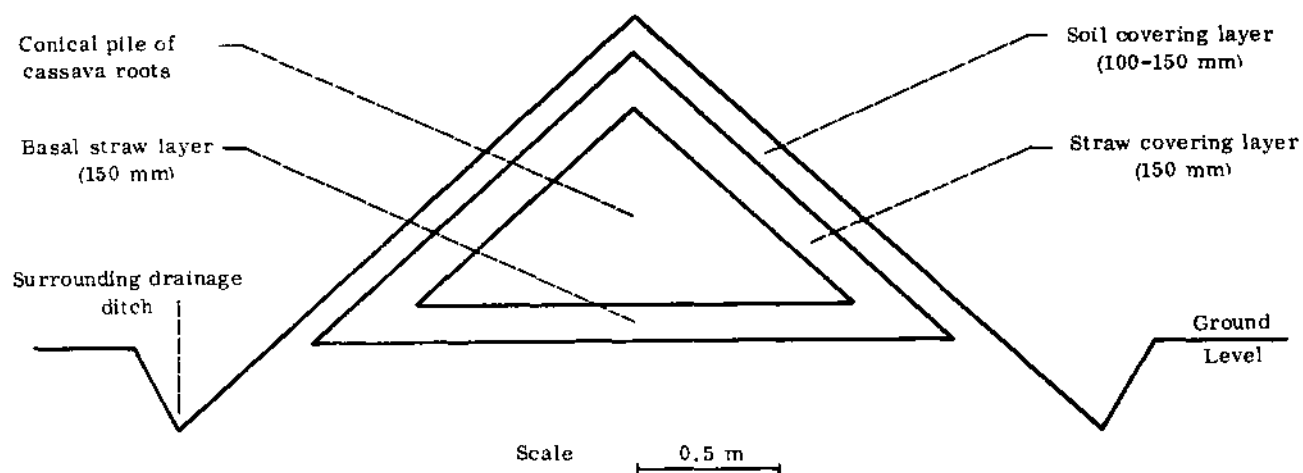
All the clamps in the main series of experiments were constructed using rice straw. However, some additional clamps were built using dry sugarcane leaves, dry maize stems and leaves, and dry grass. These gave similar results to the rice straw clamps. Also, two large clamps of similar cross-sectional design and size, but elongate instead of conical were built to accommodate one and two thousand roots respectively. These gave similar results to those obtained in the smaller clamps.



THE STORAGE OF FRESH CASSAVA ROOTS R. H. BOOTH

Figure 1. Three undeteriorated cassava roots after 8 weeks storage in a clump (right) compared with roots showing primary deterioration symptoms after 3 days storage at ambient (left).

FIG. 2 CROSS SECTION THROUGH CASSAVA CLAMP





THE STORAGE OF FRESH CASSAVA ROOTS R. H. BOOTH

Figure 3. Cured cassava root after 4 weeks storage in a clump, showing healed wounds (arrows).

QUALITY OF STORED ROOTS

Numerous root samples, after varying periods in storage, were tested for acceptability. Most visibly undeteriorated roots passed tests locally considered indicative of freshness, i.e. the skin was firm, the flesh moist and latex exudated after cutting.

Uncooked stored roots consistently tasted considerably sweeter than freshly harvested roots of the same cultivar, even after one month in storage. This sweetening was, however, less noticeable in cooked samples. Preliminary results indicate that there is a conversion from starch to sugar during storage.

In a few samples a longer cooking period was required to soften the stored roots than is normally required for freshly harvested roots. Roots which had softened internally during prolonged storage frequently regained an acceptable texture and edible quality during cooking. The biochemical changes that occur during storage and the effect of these changes on the eating quality of roots are being further investigated.

After successful curing, the shelf-life of roots removed from storage was longer than that of freshly harvested roots kept under the same conditions (Table 4). It is considered that during curing not only does the wound healing occur but also suberisation and/or thickening of the root skin. This slows down water loss and renders the roots more resistant to further damage. Individual, successfully cured roots have been stored for up to eight weeks under ambient conditions in the laboratory, at the end of which time they were still of an acceptable eating quality.

Thus, usually even after three months storage, undeteriorated roots were acceptable, despite the detectable quality differences between these and fresh roots. The effect of these differences on the marketability, human acceptability and animal feeding qualities of the stored roots is being investigated.

REFERENCES

1. Affran, D.K. (1968) Cassava and its economic importance. *Ghana Fmr.* 12(4), 172-8.
2. Anon. (1944) La conservation du manioc par le procede de reine. *Revue agric. Ile Maurice*, 23(3), 105-6.
3. Averre, C.W. (1967) Vascular streaking of cassava roots. *Proc. 1st Int. Symp. Trop. Root Crops, Trinidad* 2 (4), 31-5.
4. Baybay, D.S. (1922) Storage of some root crops and other perishable farm products. *Philipp. Agric.* 10(9), 423-40.
5. Booth, R.H. (1973) Control of deterioration of tropical root crops. *Proc. 2nd. Int. Congr. Plt. Path.* In press
6. Burton, C.L. (1970) Diseases of tropical vegetables on the Chicago market. *Trop. Agric. Trinidad.* 47,(4), 303-13.
7. Burton, W.G. (1966) *The Potato*. Veenman and Zonen 382 pp.
8. Crook, E.M. & Watson, D.J. (1950) Studies on the storage of potatoes. 11. The temperature conditions inside potato clamps. *J. Agric. Sci.* 40, 199-226.
9. Czyhrinciw, N & Jaffe, W. (1951) Modificaciones quimicas durante la conservacion de raices y tubercules. *Archos. Verez. Nutr.* 2(1), 49-67.
10. Doku, E.V. *Cassava in Ghana*. Ghana University Press, 44 pp. 1969.
11. Gonzalez, M.A. & Collazo de Rivera, A. (1972) Storage of fresh yam under controlled conditions. *J. Agric. Univ. P. Rico* 56, 46-56.
12. Hakluyt Society London (1922) *Journal of the travels and labours of Father Samuel Fritz in the River of the Amazons between 1686 and 1723*.
13. Ingram, J.S. & Humphries, J.R.O. (1972) Cassava storage, a review. *Trop. Sci.* 14(2), 131-48.
14. Instituto de Investigaciones Tecnologicas (1972) La Yuca Parafinada. *Rev. I.I.T.* 78, 47-148.
15. Keleny, G.P. (1965) Sweet potato storage. *Papua and New Agric. J.* 17 (3), 102-8.
16. Kushman, L.J. & Wright, F.S. (1969) Sweet potato storage. *Agric. Handb. U.S. Dep. Agric.* 358.
17. Majumder, S.K. (1955) Some studies on the microbial rot of tapioca. *Bull. Cent. Fed. Technol. Res. Inst. Mysore* 4 (6), 164.
18. Montaldo, A. (1972) Vascular streaking of cassava root tubers. *Trop. Sci.* 15 (1), 39-46.
19. Normanha, E.C. & Pereira, A.S. (1963) Cultura de Mandioca. *O. Agronomico, Sao Paulo, Brazil*, 15, (9), 9-35.
20. Pacheco, J.A. de C. (1952) Alteracoes de qualidade da fecula o armazenamento das raizes de mandioca. *Bragantia*, 12 (7/8), 297.

21. Singh, K.K. & Mathur, P.B. (1953) Cold storage of tapioca roots. *Bull. Cent. Fed. Technol. Res. Inst., Mysore* 2(7), 181-2.
22. Subramanyam, M & Mathur, P.B. (1956) Effect of a fungicidal wax coating on the storage behaviour of tapioca roots. *Bull. Cent. Fed. Technol. Res. Inst., Mysore* 5(5), 110-111.
23. Thompson, A.K. (1972) Storage and transport of fruit and vegetables in the West Indies. *Proc. Seminar Workshop on Hort. Devel. in the Caribbean. Assoc. of Caribbean Univ. and Res. Inst., Maturin, Venezuela, 12-15th March 1972.*
24. Tracy, S.M. (1903) Cassava. *Fmrs. Bull. U.S. Dep. Agric.* No. 167.

ACKNOWLEDGEMENTS

I wish to thank the Centro Internacional de Agricultura Tropical, in particular, members of the cassava production system team, and D. G. Coursey of the Tropical Products Institute for their assistance and encouragement throughout this project.

TABLE 1

Effect of severity of damage on fresh weight loss and deterioration of cassava roots stored at ambient conditions¹ in the laboratory.

Time in storage (days)	Fresh weight loss ² (%)		Deterioration Index ² (%)	
	Slightly ³ damaged	Severely ⁴ damaged	Slightly ³ damaged	Severely ⁴ damaged
1	2.9	3.5	2	15
2	7.4	10.1	27	32
4	12.4	15.9	62	65
7	17.9	21.5	57	67
11	22.1	34.2	72	75

1. Ambient conditions: temperature 20°C±4°C
2. 3 x 10 roots per sample
3. Roots with no obvious gross physical damage.
4. Roots with obvious physical damage.

NOTE

The deterioration index is the deterioration score expressed as a percentage of the total possible score for that treatment where, for any particular root, the score is 0 = no deterioration, 1 = $\frac{1}{4}$ deterioration, 2 = $\frac{1}{2}$ deterioration, 3 = $\frac{3}{4}$ deterioration and 4 = complete deterioration.

TABLE 2

Effect of calcium hypochlorite and commercial alcohol on the deterioration of cassava root slices.

Treatment ¹	Deterioration Index (%)				
	Days 0	1	2	3	4
Undipped control	0	100	100	100	100
30 sec. dip in sterile distilled water	0	100	100	100	100
30 sec. dip in 1.0% com. alcohol	0	100	100	100	100
" " " " 5.0% " "	0	75	100	100	100
" " " " 10.0% " "	0	50	75	100	100
" " " " 20.0% " "	0	25	50	75	100
" " " " 40.0% " "	0	0	12	25	30
" " " " 60.0% " "	0	0	0	0	2
30 sec. dip in 0.1% Ca.hypochlorite	0	81	100	100	100
" " " " 0.5% " "	0	25	50	75	100
" " " " 1.0% " "	0	0	12	50	60
" " " " 2.0% " "	0 ²	0 ²	0 ²	2 ²	12 ²
" " " " 3.0% " "	0 ²	0 ²	0 ²	0 ²	2 ²
" " " " 5.0% " "	0 ²	0 ²	0 ²	0 ²	0 ²

1. 4 x 4 slices per treatment

2. slight discolouration attributed to phytotoxicity

TABLE 3

Results of clamp storage at different temperatures.

Time in storage (months)	Undeteriorated roots ¹ (%)	
	Temperature of stored roots	
	30-35°C	40°C and above
1	85-90	5-25
2	70-75	0-5
3	40-60	0

1. Average of five clamps within each temperature range. Each clamp contained 500 roots which weighted approximately 300 kilos.

TABLE 4

Comparison of shelf-life of fresh uncured roots (A) with that of roots that had been cured and stored in a clamp for eight weeks (B)

Laboratory storage (weeks)	Deterioration Index ¹	
	A	B
1	45	10
2	80	7
3	100	20

1. 3 x 10 roots per sample.

REDUCTION OF WASTAGE IN STORED YAMS

A.K. Thompson, B.O. Been and C. Perkins*

SUMMARY

A combination of treatment with thiabendazole and storage of treated tubers in polythene bags in cool storage appears to be a practical possibility for yam storage in Jamaica.

RESUME

Une combinaison de traitement au thiabendazole et de stockage des tubercules traités dans des sacs de polythène en stockage frais semble être une possibilité pratique de stockage de l'igname en Jamaïque.

RESUMEN

Un tratamiento combinado de thiabendazole y el almacenamiento de los tubérculos así tratados en bolsas de polietileno bajo almacenaje refrigerado, parece ser una posibilidad práctica para el almacenamiento de ñame en Jamaica.

INTRODUCTION

Yams (*Dioscorea* spp.) are a major staple in many tropical countries⁷ and are also gaining importance as an export crop³. Storage, to extend periods of availability, is necessary but usually gives rise to high wastage. Weight losses arise from desiccation, respiration, necrosis caused by microorganisms^{1,2,6,10,13}, and parasitic nematodes¹⁷. Storage of yams below 12.5°C causes chilling injury⁹ but high levels of decay can occur at 15°C⁴. It was concluded⁷ that cold storage alone cannot be used as a method of reducing losses in yams although treatment of tubers with benomyl or thiabendazole fungicides can reduce wastage in cool storage^{14,15,18}. Curing undamaged yams before storage reduced weight losses and microbial infections^{11,16}. Waxing, which has been used commercially to improve the market appearance of sweet potatoes, has not apparently been used for yams. Premature sprouting (lack of dormancy) is a major cause of wastage, particularly in *D. cayenensis* Lam. However, attempts at chemical control of sprouting in ambient storage of yams has not been successful^{5,12} (an A.K. Thompson, unpublished data).

MATERIALS AND METHODS

Tubers were obtained from commercial harvests in the area of northern Manchester and southern Trelawny in Jamaica and were used for experiments one day after harvesting.

Experiment A used *D. cayenensis* and Experiments B and C used *D. rotundata* Polr. Tubers were cured for 25 hours in experiments A and B and 65 hours in experiment C at 36–40°C and 96–100% rh. or alternatively kept in ambient storage. Half the cured and uncured tubers were then stored at 12–13°C and 92–98% rh while the remainder were stored under ambient conditions (24–31°C and 56–92% rh).

Experiments D, E, G, H, I and J were on *D. rotundata* and experiment F was on *D. trifida* L. In each of these experiments half the tubers were wrapped individually in 150 gauge polyethylene bags secured with a rubber band while the remainder were left unwrapped. All storage was in 520 x 360 x 190 mm cardboard cartons under ambient conditions except in experiment H in which storage was at 12–13°C and 92–98% rh for 89 days, followed by ambient storage. All tubers in experiment H were cured for 24 h and then dipped for 3 minutes in 1000 ppm thiabendazole (2-(4-thiazolyl) benzimidazole) before storage. Tubers in experiment J were removed from storage at 11.7°C and 84% rh to ambient storage at weekly intervals. Tubers in experiments I, D and E were 'waxed' with the commercially available emulsion (Epolene E10 vegetable wax) diluted with water and air dried. In D and E waxing was combined factorially with polyethylene wrapping but no significant interaction was observed.

*Ministry of Commerce and Consumer Protection, 20, Hope Road, Kingston 10, Jamaica.

A.K. Thompson was seconded from the Tropical Products Institute, London.

Each tuber was weighed before storage and marked with an identifying number. At intervals (7–14 days) during storage each tuber was weighed, inspected for sprouting and scored for incidence of surface fungi according to the following scale:

- 0 = none
- 1 = negligible
- 2 = obvious
- 3 = severe
- 4 = very severe
- 5 = surface almost entirely covered

At the end of the storage period each tuber was cut open longitudinally and the percentage of internal necrotic tissue estimated.

Rates of loss in fresh weight were calculated for each tuber between each observation on the following basis:

$$S = \frac{(W_1 - W_2)}{(t_2 - t_1)} \times 1000$$

where S = storage loss range (g of fresh weight lost/kg of tuber present at day t_1 .) W_1 and W_2 = tuber fresh weight in g at t_1 and t_2 respectively. t_1 and t_2 = days in storage.

This approach to weight loss is derived from the formulae proposed to measure Crop Growth Rate and Relative Growth Rate.¹⁹

A.N.O.V., where appropriate, was on data transformed to logarithms but the results presented here refer to untransformed parameters. Significant 'fits' ($P = 0.05$) could be made to quadratic functions and these functions were plotted rather than the actual data to illustrate the effects.

RESULTS

Curing

Results are summarized in Table 1 with data from Experiment C presented graphically in Fig. 1 (curves derived from Experiments A and B were similar). Curing before storage reduced weight losses but the favourable effects of curing was less pronounced as storage progressed. Curing reduced the levels of fungal infections during cold storage and internal necrosis but hastened sprouting. Longer curing than 24 hours did not appear to produce a greater effect.

Temperature

Tubers in cold storage had a low and constant rate of weight loss throughout storage whereas under ambient conditions a rapid initial rate was followed by a lower rate which increased again at a time approximately coinciding with the appearance of sprouting (Fig. 1). Tubers in cold storage did not sprout at all during storage but high levels of fungal infection and internal necrosis were evident (Table 1). Storage at 11.7°C caused chilling injury symptoms of extensive necroses, high levels of fungal infection and high weight losses following removal to ambient conditions (Fig. 2).

Wrapping in polyethylene bags

Tubers in polyethylene bags lost little weight during storage (Table 2 and Fig. 3) but considerable levels of fungal growth occurred on tuber surfaces and also there appeared to be a proliferation of parenchyma around lenticels. This occurred within a few days of placing tubers in the bags, but quickly disappeared when they were removed. This phenomenon was entirely absent if tubers in bags were stored at 12.5°C. Tubers treated with thiabendazole prior to storage in polyethylene bags developed negligible incidences of surface fungi during storage.

Waxing

Waxed tubers had a very attractive appearance and this treatment could probably be used as an aid to marketing in those countries where the use of such treatment is permissible. Waxing however, had no effects on levels of fungal infections and the effect on weight loss was inconsistent.

DISCUSSION

The three *Dioscorea* spp used in these experiments all began to sprout early in the storage period and as no effective chemical suppressant has been found yet, reduced temperatures appear essential for prolonged storage*. Cold storage also prevents the build up of lesion-causing nematodes¹⁷ but increases mould

growth¹⁸ both of which can cause internal necrosis. The former is hard and dark brown in colour while that caused by fungi is generally soft and brownish purple¹. Levels of fungal infection were reduced by both curing and thiabendazole treatment; the latter being considerably more effective. The effect of curing was to hasten and enhance the formation of periderm tissues especially in areas of mechanical damage (B.O. Been, unpublished report).

The increase in mould growth on tubers stored in polyethylene bags was not associated with increases in necrosis, which in fact tended to be decreased. The high humidity inside the bags thus appears to be associated only with superficial mould growth. In isolated instances, bacterial rots were observed in tubers stored in polyethylene bags but this was rare and is considered of little importance. Although little weight loss occurred on tubers stored in polyethylene bags at ambient temperature, the high level of mould growth and the lenticel cracking would detract too much from appearance for this method to be suitable for practical storage for subsequent marketing. Combining an effective fungicidal treatment with storage in polyethylene bags in cool storage may well be practicable.

Figure 1. Effects of curing and storage temperature on weight losses of yam tubers in Experiment C.

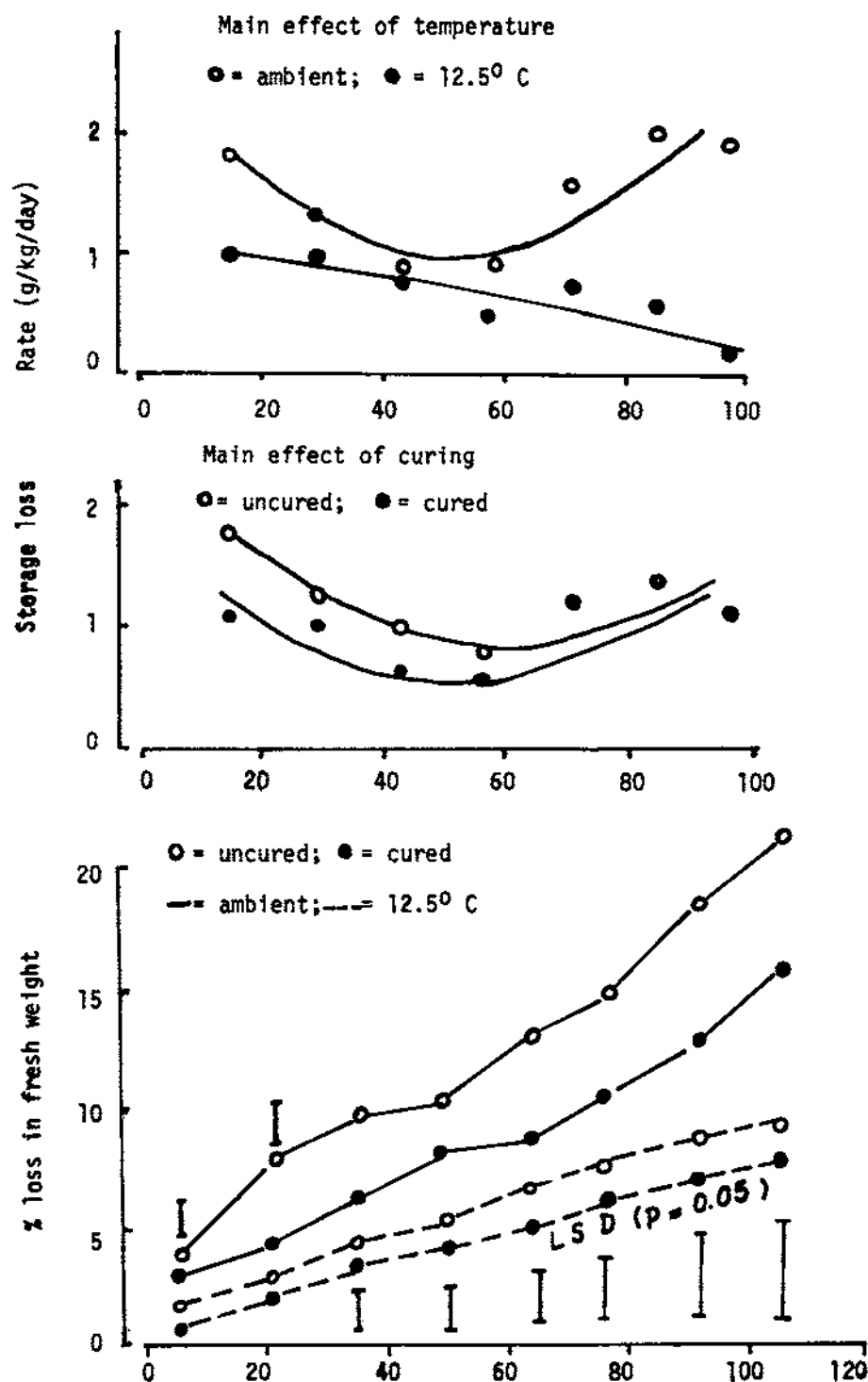


Figure 2. Effects of days at 11.7°C on loss in weight during ambient storage

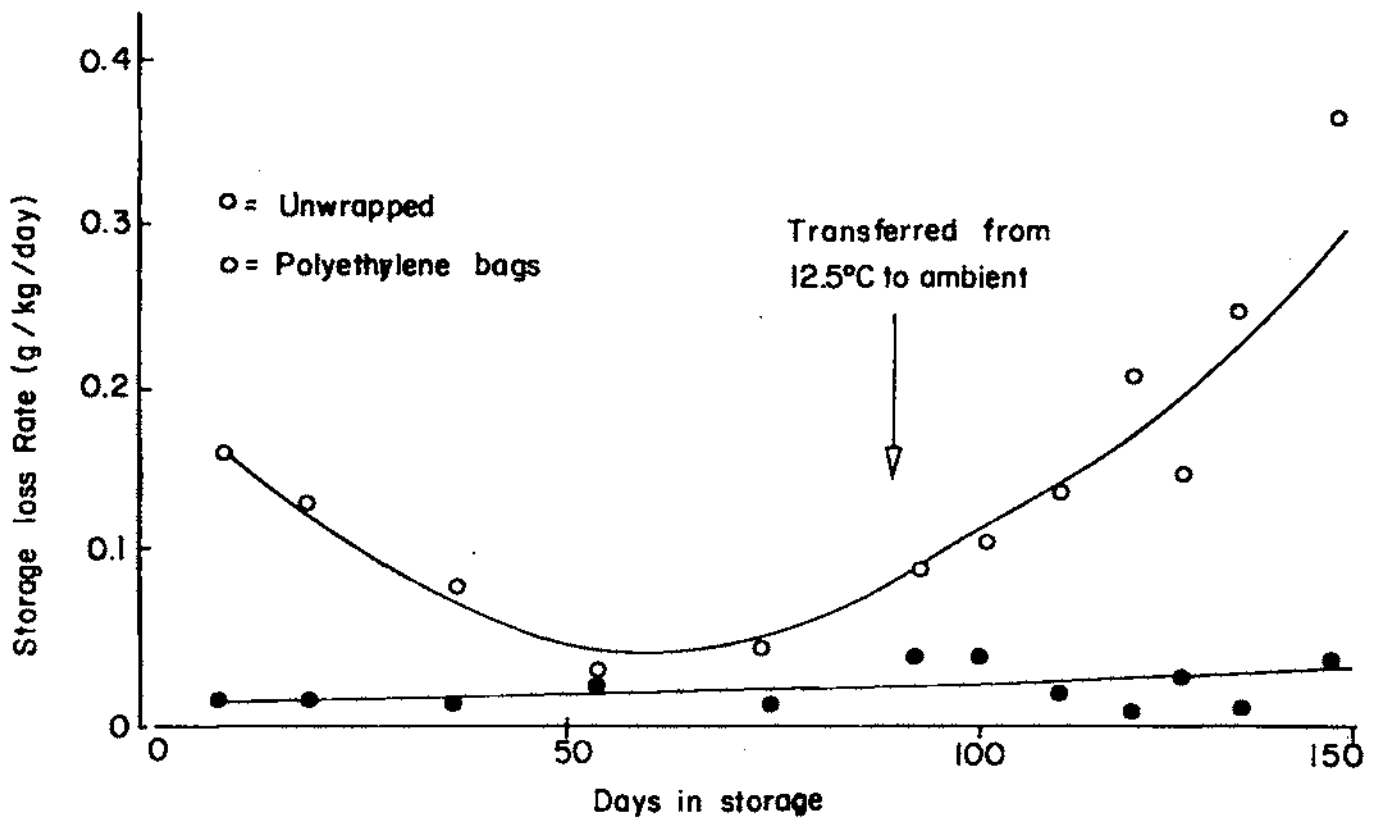
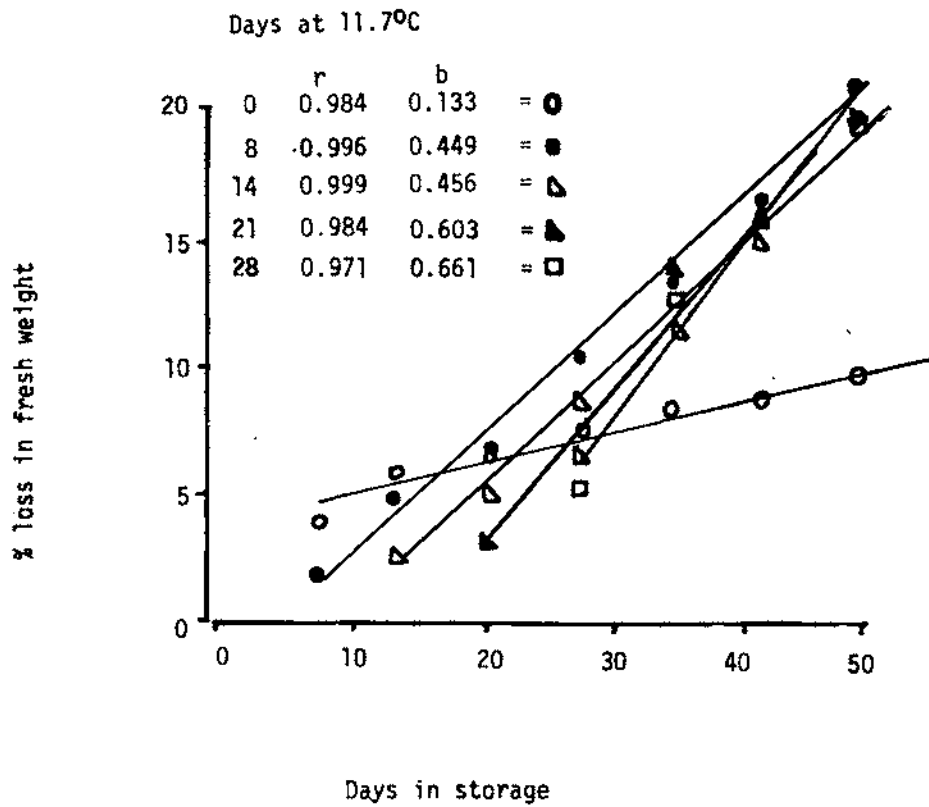


Figure 3 Effect of storage in polyethylene bags on loss in weight of yam tubers

Waxing of tubers appears to be of doubtful economic value since weight loss was inconsistent and the costs of application high.

ACKNOWLEDGEMENT

The authors thank the Agricultural Marketing Corporation Jamaica for provision of yams and storage facilities, Stanley Motta for a sample of Epolene E.10 vegetable wax, Merck Inc. for Thiabendazole and the Chief Food Storage Officer in Jamaica for facilities. Dr. Thompson was seconded from the Tropical Products Institute in London for this work.

REFERENCES

1. Adeniji, M.O. (1970a) Fungi associated with storage decay of yam in Nigeria. *Phytopath.* 60, 590-2.
2. ——— (1970b) Influence of moisture and temperature on yam decay organisms. *Phytopath.* 60, 1698-9.
3. Bell, J.M.K. and Coursey, D.G. (1971) Tropical vegetables in Britain. *Trop. Sci.* 13, 251-63.
4. Burton, C.L. (1970) Diseases of tropical vegetables on the Chicago market. *Trop. Agric. Trin.* 47, 303-13.
5. Campbell, J.S. et al. (1962) Some physiological investigations with White Lisbon Yam (*D. alata* L.) III. The effects of chemicals on storage. *Emp. J. Expt. Agric.* 30, 335-44.
6. Coursey, D.G. (1961) The magnitude and origins of storage losses in Nigerian yams. *J. Sci. Food Agric.* 12, 574-80.
7. ——— (1967a) *Yams*. Longmans, London.
8. ——— (1967b) Yams storage — 1: a review of yam storage practices and of information on storage losses. *J. Stored Prod. Res.* 2, 229-44.
9. ——— (1968) Low temperature injury in yams. *J. Fd. Technol.* 3, 143-50.
10. ——— and Russell, J.D. (1969) A note on endogenous and biodeteriative factors in the respiration of dormant yam tubers. *Int. Biodetn. Bull.* 5, 27-30.
11. Gonzales, M.A. and Collazo de Rivera, A. (1972) Storage of fresh yam (*Dioscorea alata* L.) under controlled conditions. *J. Agr. Univ. P.R.* 56, 46-56.
12. Hayward, L.A.W. and Walker, H.M. (1961) The effects of pre-harvest foliar sprays of maleic hydrazide on the storage of yams. *A.R. West African Stored Prod. Res. Unit, Tech. Report* 19, 107-115.
13. Ogundana, S.K. et al. (1970) Fungi associated with soft rot in yams (*Dioscorea* spp) in storage in Nigeria. *Trans. Br. Mycol. Soc.* 54, 445-51.
14. ——— (1972) The post harvest decay of yam tubers and its preliminary control in Nigeria. *Biodeterioration of materials* 2. Applied Science, London. 481-92.
15. Ricci, P. (1973) Storage decay of cush-cush yam tubers controlled by post-harvest fungicidal treatment. *Trop. Root Tuber Crops News.* 6, 39.
16. Thompson, A.K. (1972) Storage and transport of fruit and vegetables in the West Indies. *Proc. Seminar Ass. Carib. and Latin Amer. Univ. and Res. Inst.* 170-6.
17. ——— et al. (1973) Nematodes in stored yams. *Expl. Agric.* 9, 281-6.
18. ——— et al. (1974) Fungicidal treatments of stored yams. In preparation.
19. Watson, D.J. (1952) The physiological basis for variation in yield. *Adv. Agron.* 4, 100-2.

TABLE 1

Effects of curing on fungal growth, mean days to sprouting and % internal necrotic tissue in cold and ambient storage

Experiment*	A		B		C	
Storage conditions	amb.	cold	amb.	cold	amb.	cold
Mean fungal score						
uncured	0.2	2.9A	0.0	3.0A	0.0	1.4A
cured	0.3	2.3B	0.0	2.6B	0.0	1.2B
Mean % internal necrosis						
uncured	62AB	96A	17B	64A	4A	9A
cured	58AB	46C	2B	7B	3A	10A
Mean number of days to sprouting						
uncured	64A	-	72A	-	93A	-
cured	68A	-	57B	-	78B	-
Figures followed by the same letter were not significantly different (P = 0.05)						

TABLE 2

Effects of storing tubers either unwrapped or individually wrapped in 150 gauge polyethylene bags on surface fungal score, internal necrosis and loss in weight

Experiment	Days in storage	Fungal score		% internal necrotic tissue		% loss in fresh weight	
		0	Poly.	0	Poly.	0	Poly
D	80	1.4B	3.0A	2	1	48.6	1.4
E	91	0.8B	4.1A	26A	8B	52.1	4.0
F	64	0.3D	1.2A	43A	23B	35.7	6.9
G	72	0.0	1.9	22	12	30.0	3.1
H	148	0.3*	0.3	0	2	18.3	2.8
* Dipped in 1000 ppm TBZ prior to storage							

TABLE 3

Effects of waxing tubers on loss in fresh weight and fungal development

Experiment	Days in storage	% solids in wax				
		0	5	10	15	20
Fungal score						
I	140	1.2	1.1	1.3	-	1.3
D	80	2.4	-	-	2.3	-
E	91	2.5	-	2.4	-	-
I	140	53.8	42.8*	42.6*	-	49.6
D	49	16.4	-	-	16.4	-
E)	62	22.4	-	19.3*	-	-
)	91	29.7	-	26.3	-	-
* Significantly different from 0 (P = 0.05)						

THE UTILIZATION OF CASSAVA (TAPIOCA) IN LIVESTOCK FEEDING

R.I. Hutagalung, Phuah Chui Hing and Hew Voon Fong*

SUMMARY

Experiments have been carried out using cassava root meal and cassava leaf meal for partial to complete substitution of maize in chick and pig diets. Despite inclusion of supplementary methionine and extra energy sources, the cassava meals have given slower or reduced growth in comparison with isocaloric and equal protein standard diets. There appear to be as yet unexplained factors which are not fully overcome by amino acid, mineral or other additions. Nevertheless, cassava root meal can usefully be fed to broilers and finishing pigs. Cassava leaf meal has poor digestibility and despite its favourable 'proximate analysis', comparable to that of alfalfa, it cannot be regarded as a substitute. Further work on anti-nutritional factors in cassava meals is indicated.

RESUME

Des essais ont permis d'utiliser la farine de racines du manioc et la farine de feuilles du manioc pour la substitution partielle, puis totale du maïs dans l'alimentation des poussins et des porcs. Bien qu'on ait renforcé les farines du manioc de méthionine et d'autres sources d'énergie, elles ont ralenti ou contrarié la croissance comparativement aux régimes isocaloriques de teneur égale en protéine. Il existe probablement des facteurs encore indéterminés qui restent à surmonter par l'utilisation d'acides aminés, d'additions minérales et autres. Toutefois, la farine du manioc peut être utilisée pour l'entretien des poulets et des porcs en embouche. La farine des feuilles du manioc se digère difficilement et bien que son "analyse immédiate" soit favorable comparativement à celle de la luzerne, on ne peut pas en faire un substitut. Il y a lieu de poursuivre les travaux sur les facteurs anti-nutritionnels des farines du manioc.

RESUMEN

Se han conducido experimentos usando alimentos hechos de raíces y de hojas de yuca, para substituir — parcial hasta totalmente — la dieta de maíz de pollos y puercos. A pesar de la inclusión de metionina suplementaria y fuentes extras de energía, los alimentos de yuca han reducido el crecimiento en comparación con dietas isocalóricas con iguales estándares proteínicos. Parece haber factores no explicados que no han sido superados con la adición de aminoácidos y minerales, entre otras cosas. No obstante, los alimentos de yuca podrían ser útiles para alimentar pollos azaderos y cerdos para ceba. Los alimentos de hojas de yuca tienen digestibilidad pobre, y a pesar de sus favorables "análisis próximos", comparables a los de la alfalfa, no pueden ser considerados como sustituto. Es indicado realizar mas trabajos sobre factores antinutricionales de los alimentos de yuca.

*University of Malaya, Kuala Lumpur, Malaysia.

INTRODUCTION

Cassava (manioc, tapioca, yuca, *Manihot esculenta* (Crantz) is cultivated in many tropical regions for food and provides a major source of dietary carbohydrate for about 400 million people.⁷ Because the root is low in protein, minerals and vitamins and also because of recent findings that cyanogenic glucosides are associated with many chronic diseases, including tropical ataxic neuropathy⁴ and goitre¹¹, there has been anxiety over the use of cassava for food and feed in some areas. Nevertheless there is an increasing demand for the use of cassava, both to provide industrial starch and for animal feed. This is reflected in the world production of cassava which rose to 92.2 million tons in 1970³³.

At present, Malaysia depends heavily on imported feeds, amounting to approximately 70 million Malaysian dollars-worth per year for her livestock industry⁵³. With the recent world shortage of cereal grains resulting in high costs of imported feedstuffs, the expansion of the Malaysian livestock industry has been critically affected. A local supply of feedstuffs should therefore be explored in order to make the animal industry remain viable and profitable.

Cassava has many agronomic advantages over other staple food crops, including its relative ease of propagation, high energy-yielding potential, disease and pest resistance and its ability to tolerate drought and poor soils. Furthermore, it offers no storage problems as it can be harvested as required. These advantages made this crop a valuable famine reserve for subsistence farmers in tropical regions.

The yield of fresh cassava roots in Malaysia has been reported within the range of 20-40 tons/ha, although yields of more than 50 tons/ha have been recorded also under good conditions⁶.

The yield of cassava leaves has been estimated at 5-10 tons dry matter per hectare annually, depending on the soil and climatic conditions⁵⁹.

Many feeding trials with cassava roots have been conducted with poultry, pigs and laboratory animals^{4,17,24,58}, and it would be impractical to mention all these reports in this paper as most of these publications have been reviewed. Most of the investigators suggest that cassava root is a satisfactory replacement for maize in chicks^{13,38,39}, and pigs^{3,16,25,32,42}, without there being any evidence of acute cyanide toxicity. Performance using cassava root meal as an energy feed, with suitable protein sources, has been improved to the same level as that obtained from a maize-soybean control by supplementing the cassava with methionine and increasing the energy content of the diet.

Information on feeding cassava leaves to monogastric animals is rather limited, but in general the reports indicate that the use of cassava leaf meal at levels in excess of 10-20 percent in the diet will depress gain and feed efficiency of rats^{1,46,56}, chicks⁴⁶ and pigs²³. However, Lee and Hutagalung indicated that performance of pigs fed diets containing 20 percent cassava leaf could be greatly improved by increasing the methionine level and with the use of an additional energy source.

METHODS AND MATERIALS

Preparation of materials

Cassava materials used in these studies were a composite of several 'sweet' cultivars (e.g. Medan, Pulut, Jurai, Sakai), locally known as tapioca or 'ubi kayu' and were obtained from the University of Malaya Farm, the Federal Experimental Station and the surrounding farmers.

Fresh roots were harvested, cleaned, partially peeled in a rotary peeler, ground in a cutter grinder, then centrifuged to remove part of the liquid, and finally dried in a tunnel drier for 1-2 hours at approximately 90°C. The dried product, hereafter referred to as cassava root meal, was further ground in a hammer mill, and the resulting meals were stored in tightly sealed plastic containers before being analyzed or incorporated into the experimental diets.

Chemical analyses

Cassava leaf and root samples were subjected to proximate analysis according to the standard methods³. The amino-acid composition was determined by ion-exchange chromatography³¹ on an amino acid analyzer after acid hydrolysis. Since acid hydrolysis tends to destroy tryptophan and cystine, these were determined separately. The methods of Spies and Chambers⁵⁰ and Miller³⁰ were used to estimate tryptophan. Cystine was determined as cysteic acid after oxidation with performic acid and acid hydrolysis according to the method of Schram *et al.*⁴⁷. Mineral values were determined by using either a dry ashing or acid digestion procedure⁴³ on an atomic absorption spectrophotometer, with the exception of phosphorus which was analyzed by the A.O.A.C. procedure³. The combustible (gross) energy analysis of samples was carried out by an automatic ballistic bomb calorimeter.

The chemical composition of the cassava samples is summarized in Table 1. The proximate composition of cassava leaf is somewhat comparable to alfalfa leaf, being rather high in protein (25%), crude fibre

(15.9%) and about sufficient in calcium (1.4%) and iron (450 ppm) contents. Cassava root meal is low in practically all nutrients including protein (2.3%), fibre (2.7%), ash (1.6%) and fat (1.2%), but it is high in carbohydrates (81.2%). Mineral content is also low, particularly in copper and zinc which could not be detected during analysis. The vitamin composition of cassava leaf and root was not determined.

The amino acid profile of cassava leaf (Table 1) shows that the leaf is deficient in methionine, tryptophan and cystine, but quite sufficient in other essential amino acids, especially lysine. Similar low methionine content have been also reported by other workers^{45,56}. With reference to the amino acid pattern, cassava leaf protein is more or less similar to that of alfalfa meal, which suggests that this leaf could be utilized as a good protein source to substitute other proteins in livestock diets. Cassava root is clearly deficient in all amino acids, being very low in methionine, tryptophan and cystine, which is expected from its low protein content. Olson *et al.*³⁹ reported a similar amino acid pattern for cassava root.

FEEDING EXPERIMENTS

Chick feeding tests

Experiment 1:

One-day old crossbred chicks were used to determine the digestibility and metabolizable energy of cassava leaf and roots. All chicks were reared to 2 weeks of age on the reference diet. They were then assigned to groups of 10 chicks each on the basis of body weight, equalizing both mean weight and weight distribution among the groups. Each experimental diet was fed to triplicated lots of chicks 2-4 weeks of age. The metabolizable energy (M.E.) content of the cassava samples was determined by the methods recommended by Hill *et al.*¹⁸ using reference diet E-9. Since certain ingredients used in their reference diet were not easily obtainable and rather expensive to use for a large number of test materials, a semi-practical diet was formulated using ingredients found in commercial poultry diets in order to develop a more suitable local reference diet. The M.E. value of pineapple bran with this diet was found to be comparable to that of reference diet E-9²⁰. Cassava leaf and root meals were incorporated at 20% and 40% respectively of both reference diets either at the expense of glucose or maize. The composition of basal diets is presented in Table 2, with the chromic oxide addition at a level of 0.3% to serve as an index marker. Chromic oxide analyses were made on both feed and excreta samples according to the procedure outlined by Czarnocki *et al.*⁸. The M.E. values are the average of data obtained from the triplicate lots, expressed on a dry matter basis. M.E. values were corrected for nitrogen retention using a value of 8.22 kcal per gram of nitrogen retained. Digestibilities of dry matter, ether extract, energy and protein of the diets were also determined. All chicks were fed the experimental diets for 14 days for M.E. and digestibility determination, but the performance data was extended to 35 days.

The results of gross and M.E. values for cassava root and leaf are shown in Table 3. The average M.E. content of cassava leaf was calculated to be 1590 kcal/kg on a dry matter basis. This low M.E. result is somewhat similar to that of alfalfa meal⁴⁸. It appears that the high fibre content of other constituents of cassava leaves hindered digestibility of the diet and lowered the M.E. value. Digestibility results given in Table 4 support this finding in which chicks fed cassava leaf diet had lower digestion coefficients for dry matter, protein and energy than those fed the basal diets, indicating that young chicks have lower tolerance level for cassava leaf. Earlier work with chicks⁴⁶ and pigs²³ has shown that cassava leaf meal depressed performance. Since all our diets were formulated to contain equal protein and energy levels, and were adjusted to meet or exceed the minimum methionine requirement^{34,48}, it is possible that the high crude fibre content of the leaf may limit the nutrient density and voluntary feed intake.

The M.E. value for cassava root (3230 kcal/kg) compares favourably to that of maize^{18,44,49}, but it is lower than that reported by Olson *et al.*³⁸ and Maust *et al.*^{27,28}, for cassava meal, being 3440 kcal/kg and 4310 kcal/kg respectively. The lower M.E. value of the cassava root meal in this study could have been due to the difference in the processing method of the meal, the higher crude fibre content resulting from incomplete peeling, the cultivars of cassava used and possibly also due to the difference in the strains of chicks employed.

As shown in Table 4, the chicks fed dietary cassava leaf had lower digestion coefficients for dry matter, protein, fat and energy than those fed the basal diets. Apparent digestion of dry matter, protein, fat and energy was not consistently influenced by dietary cassava root.

An explanation for the low dry matter, protein, fat and energy digestibilities in chicks fed the cassava leaf diet is not readily apparent. It is possible that growth-suppressing factors are present in cassava leaves.

The average daily gain and feed/gain data of chicks fed experimental diets for 5 weeks are summarized in Table 5. The chicks fed cassava leaf had less average daily gain and required more feed per unit of gain than the chicks fed the basal diets, while gain and feed conversion of those fed cassava root diet were not consistently affected.

Experiment 2:

Two hundred and ten day-old chicks (Red Cornish x White Plymouth Rock) were used to study the influence of feeding graded levels of cassava leaf and root and their combination on the performance, body composition and on the mineral composition of tissues. The chicks were reared on the basal diet to 2 weeks of age. They were then distributed at random into 7 treatment groups of 10 chicks each on the basis of body weight, equalizing both mean weight and weight distribution among the groups. Each experimental diet was fed to triplicate pens of chicks from 2 to 10 weeks of age. The protein level of the dietary treatment was maintained isonitrogenous by the adjustment of the soybean and maize portion of the diets, while fish meal portion was kept constant.

Based on the performance and M.E. value of the cassava for chicks as determined in Experiment 1, vegetable oil (palm oil) was incorporated in increments to maintain the energy level isocaloric. The composition of the diets is shown in Table 6. The chicks were weighed and feed consumption was recorded at weekly intervals, throughout the 8 week experimental period. Four birds from each treatment were sacrificed after fasting for 12 hours. The whole carcasses of three birds were frozen, cut into sections with a saw, ground in a meat grinder and then samples taken for moisture, protein and fat analyses. The final moisture was obtained by drying the ground samples in a vacuum oven at 105°C for 16 hours. Samples for protein and fat analyses were weighed immediately after the samples were ground and were first dried in a vacuum oven for over 24 hours at 57°C and were then ground in a Wiley mill. Liver samples from the other birds were collected, frozen, dried and were then analyzed for moisture, protein and fat. Both dried samples of whole carcasses and livers were analyzed for mineral elements with the methods previously described. The average daily gain and feed efficiency and body composition data from this experiment are summarized in Table 7. The effect of increasing levels of leaf alone or in combination with graded levels of root caused a growth depression and poorer feed conversion as compared with those of the control diet. Gain and feed conversion of chicks fed root diets however were not significantly different from those of the basal group, although there was a reduction in gain of chicks fed diets containing 40% root. An explanation for the decline in gain and poor feed conversion of chicks from feeding leaf alone or in combination with root is not readily apparent. Since our diets were fortified with adequate methionine and energy supplements, it appears that either a reduction in nutrient density or incomplete elimination of growth depressing factors of cassava leaf diet are possible causes of the adverse effects of cassava leaf meal on growth performance and feed utilization.

Carcass composition of broilers fed cassava diets

Although much work has been done in feeding cassava leaf and root to chickens, there is little information available on the influence of cassava diets on carcass composition at time of marketing. It is becoming increasingly important to consider not only weight gain and feed efficiency of meat animals, but also their carcass composition resulting from feeding cassava products. With the recent findings on the incidence of tropical ataxic neuropathy and goitre in humans having high cassava intakes, public awareness of the possible health hazards from consuming meat animals fed high levels of cassava products is also increasing. This increases the need for an investigation of carcass characteristics and composition.

The average whole carcass and liver composition data are presented in Table 7. In general, cassava leaf and root diets did not exert any consistent effect on whole carcass and liver composition; however, there was a tendency for the birds fed diets containing a combination of leaf and root to have slightly less moisture and more fat in the whole carcass than for birds fed the basal diet. This difference is probably not due to the effect of cassava leaf and root but it may be related to the difference in the dry matter and fat contents of diets containing leaf and root meals compared with those of the basal diet. The observed increase in fat content with a concomitant decrease in moisture with increasing either fat or energy level supports the observations of several researchers^{9,10,22,54}.

A summary of the results of mineral contents of chicks fed cassava leaf and root diets is presented in Table 8. No consistent differences in the mineral content of the whole carcass and liver were observed between the cassava and the basal diets, although there was a slight reduction in the copper and zinc content of carcasses of chicks fed the diets containing leaf and root.

Experiment 3:

The objective of this experiment was to assess the performance response and the body composition of broiler chicks to protein increments in diets containing graded levels of cassava root when the energy value was maintained relatively constant for all diets. The combination of protein and cassava levels in the diet giving satisfactory performance then served as the basal diet for the subsequent experiments (Experiment 4, 5 and 6) in which the combination of supplemented minerals were studied. Commercial broiler chicks were reared from 1 day to 2 weeks of age as a group using standard brooding practices. One hundred and sixty two chicks were allocated at random to three replications of a 3 x 3 factorial arrangement of 9 dietary treatments to compare the effects of crude protein levels of 19, 22 and 25% at dietary cassava levels of 0,

20 and 40% from 2 to 6 weeks of age. All diets were calculated to contain a constant level of energy (3.00 kcal/g M.E.). Thereafter, the same chicks were changed to cassava diets containing 17, 20 and 23% protein formulated with a single M.E. value of 3.10 kcal/g. and these were fed to 10 weeks of age. Composition of the starter and grower diets is presented in Table 9A and 9B, respectively. At 10 weeks of age, the birds were individually weighed and fasted for 12 hours prior to sacrifice for carcass analyses. Two randomly selected birds from each replicate were ground and then pooled for analysis. Carcasses were analyzed for moisture, ether extract and protein in accordance with the previously described methods.

The results of this experiment are given in Table 10. No significant differences in performance were noted within the protein levels of the cassava diets, although there was a slight improvement in gain and feed/gain at higher dietary protein levels without cassava supplementation. This supports the conclusions of Spring and Wilkinson⁵¹ and Summers *et al.*⁵⁴ who showed no increased gain in weight of 8 week broilers when the protein of the diet was raised. Summed over all protein levels, chicks fed diets containing 40 percent cassava gained weight slightly slower and were less efficient than those fed diets containing 0 and 20 percent cassava, although the difference was not significant.

The carcass composition data (Table 10) showed some evidence of interdependence between dietary factors for carcass fat and protein content but not for carcass moisture content. As dietary protein increased there was a reduction in carcass fat and an increase in carcass protein.

Up to 20 percent increases in the cassava level of the diet significantly increased protein content and decreased fat content but at 40 percent level of cassava meal the fat and protein were inconsistently affected. These results of dietary protein level effects on carcass protein and fat content supports those of Donaldson *et al.*⁹ and Summers *et al.*⁵⁴.

Experiments 4, 5 and 6:

Three experiments were carried out to study the effects of varying levels of copper, iodine, iron and zinc added to cassava diets on the growth performance and body composition of chicks.

Preliminary observations showed that pigs fed diets containing high levels of cassava leaf (40-50%) and root (60-75%) developed clear health disorders such as diarrhoea, skin lesions in the stomach and hind quarters, localized swelling and weakness of the hind legs. Diarrhoea also occurred in chicks. In view of the low copper and zinc contents of carcass of chicks fed cassava leaf and root diets (found in Experiment 2), it appeared that some factors in the cassava diet may upset the availability of minerals. Maust *et al.*^{27,28,29} have already indicated that the disorders developed in animals fed high levels of cassava diet are due to zinc deficiency (parakeratosis).

Ekpechi *et al.*¹² and Osuntokun⁴ have also reported the incidence of skin lesions and goitre in human patients in Nigeria and have suggested that this may be associated with the long term high consumption of fermented cassava. Ekpechi¹¹ and Maner and Gomez²⁶ working independently have studied the effects of iodine supplementation in cassava diets and found that rats fed iodine-supplemented cassava diet gained more weight and utilized feed more efficiently than those fed cassava diets without added iodine.

In the view of the close nutritional interrelationships among copper, iodine, iron and zinc and the difficulty in identifying the factors involved in the resulting symptoms, we carried out three factorial experiments. Experiment 4 was a 3 x 3 factorial experiment to study the effects of three levels of zinc (0, 25, 50 ppm) and three levels of iron (0, 25, 50 ppm). Experiment 5 tested three levels of zinc (0, 25, 50 ppm) and three of iodine (0, 25, 50 ppm). Experiment 6 tested three levels of zinc (0, 25, 50 ppm) and three of copper (0, 25, 50 ppm). All these supplementations were made in diets containing 40 percent cassava root. Chicks were allotted at random to 3 replications of 9 treatments with 6 chicks for each replicate in all experiments. The compositions of basal diets is presented in Table 11. Each experiment was carried out for 8 weeks. At the end of the experiments, 4 birds from each replicate were randomly selected, fasted, sacrificed and analyzed as previously described.

The performance and body composition data of chicks in Experiments 4, 5 and 6 are summarized in Tables 12, 13 and 14 respectively. There are few significant differences. Nevertheless they contain some clear indications of real effects.

The effects of mineral supplementation in cassava diets on the performance and body composition can be summarized as follows:

1. Zinc supplementation regardless of its combination with copper or iodine resulted in improved weight gains and efficiency of feed utilization. Increments of iodine tended to cause an adverse effect on weight gains and feed efficiency. Performance of chicks was not consistently affected by incorporation of copper and iron.
2. Supplementation of zinc in combination with copper, iodine or iron had little overall effect on carcass moisture, nor on protein levels.
3. Regardless of zinc combination with iron, iodine or copper, liver copper levels were markedly reduced as the level of zinc increased. Dietary additions of zinc and iron significantly increased liver iron and zinc content. Within zinc levels, iodine additions gradually increased liver zinc levels. Copper addition

in increments increased liver copper levels. Dietary addition of zinc and copper significantly increased liver zinc level, being less apparent with copper supplementation experiments.

Pig feeding experiments

Hew and Hutagalung¹⁶ showed in pigs that weight gains and efficiency of feed utilization declined as increasing amounts of cassava root meal were incorporated into the diets. However, supplementation of high cassava diets with methionine, palm oil and glucose or molasses improved the performance of the pigs.

Although much work has been done in feeding cassava root meal to pigs, there is little information available on the influence of cassava root on carcass characteristics at time of marketing³². It is becoming increasingly important at this stage to consider not only weight gain and feed efficiency of pigs but also their carcass characteristics from feeding cassava.

Sixty crossbred weanling pigs of Landrace and Large White weighing approximately 20 kg were randomly allotted to five dietary treatments, each treatment being replicated three times. Cassava root was incorporated in place of maize at 0, 15, 30, 45 and 60 percent into conventional maize-soybean-fish meal diets. This experiment was undertaken to study the effects of levels of cassava root meal on performance and carcass characteristics of pigs. The composition of the basal diets is presented in Table 15. All diets were supplemented with vitamins and minerals to meet the estimated requirements for growing and finishing pigs³⁵. Although the cassava diets used in this experiment were deficient in methionine and lysine and also required fat and molasses supplementation in increments to satisfy the energy requirements, as well as increasing the palatability of cassava diets, these ingredients were deliberately omitted in order to compare effects of cassava substitution on the carcass characteristics of pigs. All pigs were fed 18 percent crude protein diets from 20 to approximately 45 kg weight, after which the pigs were shifted to the 15 percent protein diets on an individual basis and were retained on these diets until the termination of the experiment. Sex was balanced among treatments.

Individual pigs were removed from the test when they reached a weight of approximately 70 kg, which is the traditional market weight in this region. All pigs were slaughtered and processed in the commercial meat packer unit for determination of carcass characteristics. Feed, but not water, was withdrawn about 20 hr before slaughter. Carcass weight (24 hr chill), dressing percentage, length of carcass, averaged back-fat thickness and cross sectional area of the *longissimus dorsi* were obtained on carcass of all pigs.

During the first three weeks of the experiment, pigs fed diets containing the higher levels of cassava root (45 and 60 percent) developed diarrhoea and in a few cases they also developed skin lesions, and localized oedema. Treatments with drugs and antibiotics were ineffective in controlling these disorders in any of the pigs. Doubling the vitamin and mineral supplementation in all diets alleviated the skin disorder, but did not arrest the diarrhoea. Surprisingly, the diarrhoea gradually disappeared several weeks after the pigs had been on the cassava diets. An explanation for the cause and the subsequent recovery of pigs from this disorder was not apparent.

A summary of the gain, feed/gain and carcass data is presented in Table 16. The average daily gain decreased with an increase in dietary cassava level from 15 to 60 percent. Pigs fed diets containing 60 percent cassava reached the market weight approximately 36 days later than those fed the basal diet.

As is expected in pigs fed according to their live weight, differences in efficiency of feed conversion paralleled those in the rate of gain, with the highest levels of cassava giving efficiencies poorer than the diets without cassava supplementation. As is evident from the carcass data and the statistical analysis, neither of the cassava level feeding sequences exert a significant influence on carcass weight, dressing (killing-out) percentage and the carcass length, although the carcass weight and dressing percentage tended to decrease as the level of cassava in the diet increased from 15 to 60 percent. Carcass backfat and cross-sectional area of the *l. dorsi* were significantly affected by dietary cassava level. Carcasses from pigs fed the highest cassava diet had thicker backfat and smaller *l. dorsi* areas than those from pigs fed the low cassava diet and the basal diet.

Experiment 8:

Thirty-six pigs averaging 24 kg body weight, were allotted to three dietary treatments with twelve individual replicates. The treatments were (1) a basal maize-soybean meal diet; (2) a diet containing 15 percent cassava leaf meal and (3) a diet containing 40 percent cassava root. The objective of this experiment was to compare the performance of pigs fed the basal diet and diets containing either cassava root or leaf. All the diets were fed to pigs weighing up to approximately 44 kg and were supplemented with vitamins and minerals and contained 18 percent protein, after which a 16 percent protein diet was fed until the end of the experiment. The composition of the diets is presented in Table 17. Synthetic L-lysine was added in all diets, while DL-methionine was supplemented only in the cassava leaf and root diets. In balancing the diets, attempts were made to have approximately the same protein (isonitrogenous) and energy (isocaloric) levels.

Because of the difficulties experienced in obtaining adequate quantities of cassava materials the ex-

periment was able to be conducted for only 11 weeks.

The summary of the performance data is given in Table 18. There were no statistically significant differences for daily gains and efficiency of food utilization, although there was a trend in pigs fed dietary cassava leaf or root to have lesser gains and consume more feed per unit gained than those fed the basal diet.

DISCUSSION

Cassava leaf meal, as prepared for use in this study, was generally rich in protein and high in crude fibre content, slightly sufficient in calcium and iron levels, but low in metabolizable energy level. Terra⁵⁶ reported that cassava leaves are rich in B-complex, ascorbic acid and carotene vitamins, containing respectively 10, 190 I.U. carotene, 0.21 mg thiamine, 0.33 mg riboflavin, 1.85 mg niacin and 224 mg ascorbic acid per 100 g on a fresh weight basis (33.8% dry matter). Leaves are deficient in sulphur-containing amino acids, but quite sufficient in most other essential amino acids, particularly lysine. Our amino acid data supports those of Rogers and Milner⁴⁵ and Terra⁵⁶. Overall, cassava leaf meal is slightly superior to alfalfa meal in nutrient content* and compares favourably with soybean meal in amino acid composition. Cassava root meal is low in practically all nutrients, with the exception of carbohydrate. However, data of Oke³⁷ show that it contains reasonable amounts of ascorbic acid (35 mg/100 g), thiamine (0.06 mg/100 g), riboflavin (0.03 mg/100 g) and niacin (0.6 mg/100 g). The levels of these are affected by the method of sample preparation.

High levels of cassava leaf supplementation in the diet (Experiment 1) however, continued to depress growth and efficiency of feed conversion, even when methionine and energy contents are supplemented, thus it appears that either the levels of crude fibre or other growth depressing factors present in the cassava leaves, reduce or antagonise nutrient uptake of the animals. This finding for chicks and pigs supports work on rats^{1,66}.

Results of Experiment 2 support previous work with chicks and pigs in adding methionine, lysine, fat and molasses to the cassava root diet which improves feed efficiency¹³. Although chicks fed diets containing cassava leaf and root had no substantial differences in the moisture, fat, protein and mineral content of carcasses and livers, we have not ascertained whether there may be differences in the chemical composition of animals fed cassava rich diets and this warrants further investigation.

Mineral supplementation experiments indicate that zinc addition, regardless of its combination with copper, iodine or iron will improve rate of gain and feed efficiency. Maust et al.^{27,28,29} obtained similar results. An explanation for the relationship of zinc and cassava is not apparent but it has been suggested that zinc may enhance glucose uptake by adipose tissue, and conversely that zinc deficiency in animals is characterized by lack of normal adipose tissue⁵⁷.

In contrast with previous findings in rats^{11,26} iodine was not effective in improving gain and feed efficiency of chicks. However, we used lower levels of cassava and iodine in our diets. Maner and Gomez²⁶ suggested that supplementation with methionine and iodine in cassava diets might reduce toxic effects of cyanide.

Performance of pigs over the weight range of 20–70 kg (Experiment 7) showed that increased cassava content in the diet decreases daily weight gain compared with standard diets, especially in the range 30–60 percent cassava. This supports findings in rats²¹, chicks^{13,39,55,60}, and other recent work with pigs^{16,27}.

It is improbable that methionine was the limiting factor in affecting the performance of pigs on cassava diets as has been suggested by many investigators because methionine was unlikely to be deficient in our feeds in view of the adequate content of fish meal.

Cassava had no significant influence on carcass weight, dressing percentage and carcass length of pigs slaughtered at the standard 70 kg weight. However, there was a significant increase in backfat thickness and smaller loin eye (*l. dorsi*) area with increasing cassava content of diet. This may simply reflect the fact that pigs fed cassava were generally older at slaughter weight than pigs fed basal diets.

Long term experiments involving pigs fed on cassava products are required to assess further their carcass desirability.

CONCLUSIONS

Crudely processed cassava root meal can most suitably be fed to broilers or finishing pigs because of its higher fibre and lower energy content than maize. Special attention will have to be given to limiting factors, including essential amino acids, minerals and vitamins.

Because of the powdery nature of cassava meal attention should be given to formulation so that the

*If no account is taken of possible anti-nutritional factors. Ed

nutrient densities of cassava diets are made similar to those of other conventional diets.

Although cassava root has a potential for very high calorie production, its low protein content is disadvantageous. It is therefore necessary to find methods either for improving its own quality, notably in protein, or to find complementary high protein materials with which to enrich cassava meal^{2,36}. One such product might be produced by the microbial fermentation of cassava itself.

ACKNOWLEDGEMENTS

The authors are greatly indebted to Mr. Chang Chen Choo, Mr. Kok Kwai Weng, Mr. Yusof Ahmad, Mr. Mahathevan for the care of the experimental animals and chemical analyses. They are also grateful to Professor K.M. Graham and Dr. R.G. Lockhard for reading the manuscript of this paper and for their useful comments. Appreciation is also extended to Miss S. Saraswathy for typing the original manuscript. Acknowledgements are extended to Professor W.R. Stanton and Dr. C.N. Williams for cooperation in providing valuable information.

REFERENCES

1. Adrian, J. and Peyrot, F. (1971) Possible use of the cassava leaf (*Manihot utilissima*) in human nutrition. *Plant Foods for Human Nutrition*. 2, 61-5.
2. Akinrele, I.A. (1967) Nutrient enrichment of grain. *W. Afr. J. Biol. Chem.* 10, 19-23.
3. A.O.A.C. (1965) Official methods of Analysis (10 ed.) Association of Official Agricultural Chemists Washington, D.C.
4. Brannen, S.J. (1972) In *A literature review and research recommendations on cassava*. (Chap. X) Univ. of Georgia, Athens, Ga. USA.
5. Castillo, L.S., Aglibut, F.B., Javier, T.A., Gerpacio, A.L. Garcia, B.V., Puyaoan, R.P. and Ramin, B.B. (1963) Camote and cassava tuber silage as replacement for corn in swine growing-fattening rations. *Philippines Agric.* 47, 460-71.
6. Chan, Seak Khen, (1969) Tapioca (*Manihot utilissima*) Investigations at the Federal Experiment Station, Serdang, West Malaysia. October, 1969.
7. Coursey, D.G. and Haynes, P.H. (1970) Root crops and their potential in the tropics. *Wld. Crops* 22(4), 261-5.
8. Czarnocki, J., Sibbald, I.R. and Evans, E.V. (1961) The determination of chromic oxide in samples of feed and excreta by acid digestion and spectrophotometry. *Can. J. Animal Sci.* 41, 167-79.
9. Donaldson, W.E., Combs, G.F. and Romeser, G.L. (1956) Studies on energy levels in poultry rations. I. The effect of calorie-protein ratio of the ration on growth, nutrient utilization and body composition of chicks. *Poultry Sci.* 35, 1100-5.
10. Edwards, H.M., Jr., Denman, F., Abou-Ashour, A. and Nurgara, D. (1973) Carcass composition studies. I. Influences of age, sex and type of dietary fat supplementation of total carcass and fatty acid composition. *Poultry Sci.* 52, 934-48.
11. Ekpechi, O.L. (1973) Endemic goitre and high cassava toxicity: proceedings of an interdisciplinary workshop, London. Int. Develop. Res. Centre Monogr. IDRC-010e.
12. Ekpechi, O.L., Dimitriadou, A. and Fraser, R. (1966) Glutrogenic activity of cassava (a staple Nigerian food). *Nature* 210, 1137-8.
13. Enriquez, F.Q. and Ross, E. (1967) The value of cassava root meal for chicks. *Poultry Sci.* 46, 622-6.
14. — — — — (1972) Cassava root meal in grower and layer diets. *Poultry Sci.* 51, 228-32.
15. Greeley, M.G., Meade, L.J., Hanson, L.E. and Nordstrom, J. (1964) Energy and protein intakes by growing swine. II. Effects on rate and efficiency of gain and on carcass characteristics. *J. Animal Sci.* 23, 816-22.
16. Hew, Voon Fong, and Hutagalung, R.I. (1972) The utilization of tapioca root meal (*Manihot utilissima*) in swine feeding. *Mal. Agric. Res.* 1, 124-30.
17. Hill, D.C. (1973) Chromic cyanide toxicity in domestic animals, p. 105-111 in *Chromic cassava toxicity: Proceeding of an interdisciplinary workshop*, London. 29-30 Jan. 1972. Int. Develop. Res. Centre Monogr. IDRC-010e.
18. Hill, F.W., Anderson, D.L., Renner, R. and Carew, L.B. (1960) Studies of the metabolizable energy of grain and grain products for chickens. *Poultry Sci.* 39, 573-83.
19. Hutagalung, R.I. (1972) Nutritive value of tapioca leaf meal, tapioca root meal, normal maize and opaque-2 maize and pineapple bran for pigs and poultry. 17th Ann. Conf. Mal. Vet. Ass., University of Malaya.

20. Hutagalung, R.I., Webb, B.H. and Syed Jalaludin. (1973) Evaluation of agricultural products and by-products as animal feeds. I. The nutritive value of pineapple bran for chicks. *Mal. Agric. Res.* 2(2).
21. Jeffers, H.F. and Haynes, P.A. (1967) A preliminary study of the nutritive value of some dehydrated tropical roots. *Proc. Int. Symp. on Trop Root Crops, Univ W.I., St. Augustine Trinidad* 2(6), 72-89.
22. Kubena, L.F., Lott, B.D., Deaton, J.W., Reece, F.N. and May, J.D. (1972) Body composition of chicks as influenced by environmental temperature and selected dietary factors. *Poultry Sci.* 51, 517-22.
23. Lee, Kok Choo Thomas and Hutagalung, R.I. (1972) Nutritional value of tapioca leaf (*Manihot utilissima*) for swine. *Mal. Agric. Res.* 1, 38-47.
24. Maner, J.H. (1972) La Yuca en la alimentacion de cerdos. 1st Latin American Seminar on Swine Production systems. Cali, Colombia.
25. Maner, J.N., Buitrago, J. and Jimenez, I. (1967) Utilization of yuca in swine feeding. *Proc. Int. Symp. on Trop. Root Crops, Univ. W.I., St. Augustine, Trinidad* 2(6) 63-71.
26. Maner, J.N. and Gomez, G. (1973) Implications of cyanide toxicity in animal feeding studies using high cassava rations, p. 113-20 in *Chronic cassava toxicity*. Proc. of an interdisciplinary workshop, London. Int. Develop. Res. Centre Monogr. IDRC-010e.
27. Maust, I.E., Pond, W.G. and Scott, M.L. (1972a) Energy value of a cassava-rice bran diet with and without supplemental zinc for growing pigs. *J. Animal Sci.* 35, 953-7.
28. Maust, L.E., Scott, M.L. and Pond, W.G. (1972b) The metabolizable energy of rice bran, cassava flour and blackeye cowpeas for growing chickens. *Poultry Sci.* 51, 1397-401.
29. Maust, L.E., Warner, R.G., Pond, W.G. and McDowell, R.E. (1969) Rice-bran-cassava meal as a carbohydrate feed for growing pigs. *J. Anim. Sci.* 29, 140. (Abstr.)
30. Miller, E.L. (1967) Determination of the tryptophan content of feeding-stuffs with particular reference to cereals. *J. Sci. Fd. Agric.* 18, 381-7.
31. Moore, S., Stain, W.H. and Spackman, D.H. (1958) Automatic recording apparatus for uses in the chromatography of amino acids. *Anal. Chem.* 30, 1180-203.
32. Muller, Z., Chou, K.C., Nah, K.C. and Tan, T.K. (1972) Study of nutritive value of tapioca in economic rations for growing/finishing pigs in the tropics. U.N. Development Programme, FAO Singapore, 1972. UNDP/SF Project ISIN 67/505, p. 1-35.
33. Nestel, B. (1973) Current utilization and future potential for cassava, p. 11-26. In *Chronic cassava toxicity*. Proceedings of an inter-disciplinary workshop, London. ICRC-010e.
34. N.R.C. (1966) *Nutrient Requirements of Poultry*, No. 1345. National Research Council, Washington, D.C.
35. N.R.C. (1968) *Nutrient Requirements of Swine*, No. 1599. National Research Council, Washington, D.C.
36. Oke, O.I.L. (1966) Chemical studies on some Nigerian foodstuffs, 'gari'. *Nature (London)* 212, 1055-6.
37. — — — — — (1968) Cassava as food in Nigeria. *Wld. Rev. Nutr. Diet.* 9, 227-50.
38. Olson, D.W., Sunde, M.L. and Bird, H.R. (1969a) The metabolizable energy content and feeding value of mandioca meal in diets for chicks. *Poultry Sci.* 48, 1445-52.
39. — — — — — (1969b) Amino acid supplementation of mandioca meal chick diets. *Poultry Sci.* 48, 1849-53.
40. Osuntokun, B.O. (1971) The epidemiology of tropical nutritional neuropathy in Nigerians. *Trans. Roy. Soc. Trop. Med. Hyg.* 65, 454-79.
41. — — — — — (1973) Ataxic neuropathy associated with high cassava diets in West Africa. p. 127. 38. In *Chronic cassava toxicity*. Proceedings of an interdisciplinary workshop, London, IDRC.
42. Oyenuga, V.A. (1961) Nutritive value of cereal and cassava diets for growing and fattening pigs in Nigeria. *Brit. J. Nutr.* 15(3), 327-8.
43. Perkin-Elmer. (1971) I. Analysis of foodstuffs. II. Analysis of meat products. Perkin-Elmer Atomic Absorption Newsletter No. 10.
44. Potter, L.M. and Matterson, L.D. (1960) Metabolizable energy of feed ingredients for the growing chick. *Poultry Sci.* 39, 781-2.
45. Rogers, D.J. and Milner, M. (1963) Amino acid profile of manioc leaf protein in relation to nutritive value. *Econ. Bot* 17, 211-16.

46. Ross, E. and Enriquez, F.Q. (1969) The nutritive value of cassava leaf meal. *Poultry Sci.* 48, 846-53.
47. Schram, E., Moore, S. and Bigwood, E.J. (1954) Chromatographic determination of cystine as cysteic acid. *Biochem. J.* 57, 33-7.
48. Scott, M.L., Nesheim, M.C. and Young, R.J. (1969) *Nutrition of the Chicken*. M.L. Scott & Assoc., Hactra, New York, p. 511.
49. Sibbald, I.R. and Slinger, S.J. (1963) A biological assay for metabolizable energy in poultry feed ingredients together with findings which demonstrate some of the problems associated with the evaluation of fats. *Poultry Sci.* 42, 315-25.
50. Spies, J.R. and Chambers, D.C. (1949) Chemical determination of tryptophan in proteins. *Anal. Chem.* 21, 1259-66.
51. Spring, J.L. and Wilkinson, W.S. (1957) The influence of dietary protein and energy level on body composition of broilers. *Poultry Sci.* 36, 1159.
52. Stanton, W.R. and Wallbridge, A. (1969) Fermented food processes. *Process Biochem.* 4, 45-51.
53. Statistical Digest. (1973) Statistical Digest of West Malaysia In 1971: Economics and Statistics Section, Planning and Coordination Division, Ministry of Agriculture and Fisheries.
54. Summers, J.D., Slinger, S.J. and Ashton, G.C. (1965) The effect of dietary energy and protein on carcass composition with a note on a method for estimating carcass composition. *Poultry Sci.* 44, 501-9.
55. Tabayoyong, T.T. (1935) The value of cassava refuse meal in the ration for growing chicks. *Philippine Agric.* 24, 509-18.
56. Terra, G.J.A. (1964) The significance of leaf vegetable, especially of cassava, in tropical nutrition. *Trop. Geogr. Med.* 16, 97-108.
57. Underwood, E.J. (1971) *Trace elements in human and animal nutrition*. 3rd ed. Academic Press, N.Y.
58. Vogt, H. (1966) The use of tapioca meal in poultry rations. *Poultry Sci. J.* 22, 113-20.
59. Williams, C.N. (1972/73) Production and productivity of tapioca. Ph.D. Thesis. Univ. of Malaya, Malaysia.
60. Yoshida, M., Hoshii, H. Kosaka, K. and Morimoto, H. (1966) Nutritive value of various energy sources for poultry feed. IV. Estimation of available energy of cassava meal. *Japan Poultry Sci.* 3, 29-34.

TABLE 1

Proximate analysis and amino acid composition of cassava root and leaf

Item	Cassava leaf	Cassava root
Proximate analysis*		
Dry matter	90.00	89.00
Ash	5.50	1.60
Crude fiber	15.90	2.70
Ether extract	6.30	1.20
N-free extract	37.30	81.20
Protein (Nx6.25)	25.00	2.30
Gross energy (kcal/g)	5.30	4.20
Calcium	1.40	0.35
Phosphorus	0.25	0.40
Copper (mg/kg)	8	-
Iron (mg/kg)	450	8
Manganese (mg/kg)	46	18
Zinc (mg/kg)	28	-
Amino acids**		
Arginine	1.48	0.29
Histidine	0.66	0.07
Isoleucine	1.67	0.03
Leucine	2.72	0.31
Lysine	1.87	0.07
Methionine	0.36	0.03
Phenylalanine	0.92	0.03
Threonine	1.35	0.03
Tryptophan	0.24	-
Valine	0.99	0.04
Alanine	1.70	0.15
Aspartic acid	2.44	0.13
Cystine	0.21	0.01
Glutamic acid	1.99	0.15
Glycine	1.73	0.01
Proline	0.88	0.03
Serine	1.68	0.04
Tyrosine	1.89	0.01

* Expressed as percent or unit of 'as fed' sample

** Expressed as percent of air dry sample

TABLE 2

Composition of diets (Experiment 1)

Ingredients, %	Diets	
	Basal A*	Basal B
Maize, yellow	-	53.20
Glucose	43.10	-
Soybean meal	17.50	28.60
Ground wheat	9.00	-
Alfalfa meal	-	2.00
Dried yeast	2.50	2.50
Crude casein	10.50	-
Dried whey	2.00	-
Meat and bone meal	-	2.85
Fish meal	5.00	3.30
Dried fish solubles	1.00	-
Gelatin	2.50	-
Stabilized fat	2.50	3.00
Limestone	2.00	0.70
Dicalcium phosphate	1.00	1.40
Salt	0.50	0.50
Mineral mixture	0.40	0.30
Vitamin mixture	0.50	0.25
Vitamin mixture	0.50	0.25
DL-Methionine	-	0.20
L-Lysine	-	0.20
Chromic oxide mixture	1.00	1.00
Total	100.00	100.00

* Reference diet (E-9), Hill et al.¹⁸

TABLE 3

Energy values of cassava leaf and root for chicks (Experiment 1)

Item	Gross energy (kcal/g) ¹	Metabolizable energy (kcal/g) ¹
Glucose	4.85	3.622
Maize	4.57	3.30
Cassava leaf ³	5.30	1.59
Cassava root ⁴	4.20	3.23

¹ Expressed on a dry matter basis

² Values are the averages of triplicate lots fed each experimental diet

³ Cassava leaf was substituted for either glucose(Basal A) or maize (Basal B) on 'as fed' basis at 20% level

⁴ Cassava root was substituted for either glucose(Basal A) or maize (Basal B) on 'as fed' basis at 40% level

TABLE 4

Digestibility of dry matter, protein, fat and energy of basal and cassava diets (Experiment 1)

Items	*Diets- Basal A	Basal B	Cassava root	Cassava leaf
No. of chicks	30	30	30	30
Dry matter, %	80.6a	78.3a	77.5a	68.7b
Crude protein, %	76.6c	75.8c	74.7c	66.8d
Crude fat, %	60.4e	61.5e	60.3e	51.7f
Gross energy, %	73.4g	77.9g	76.4g	53.8h

* Means in the same row without a common superscript are significantly different ($P < 0.05$)

TABLE 5

Performance of chicks fed basal and cassava diets for 5 weeks (Experiment 1)

Items	Basal A	Basal B	Cassava root	Cassava leaf
No. animals	30	30	30	30
Length of trials, days.	35	35	35	35
Protein level, %	23	23	23	23
5-week gain, g	334a	413a	354a	280b
Avg. daily gain, g	9.55a	11.80a	10.11a	7.80b
Feed/gain	2.48a	2.28a	2.62a	3.61b

a,b Values with the same superscript are not significantly different ($P < 0.05$)

TABLE 6

Composition of diets (Experiment 2)

Ingredients, %	Diets						
	Basal	Leaf 10	Leaf 20	Root 20	Root 40	Leaf- root 10-20	Leaf- root 15-30
Maize	62.55	50.60	36.45	31.90	-	20.80	-
Soybean meal	25.50	22.65	20.20	30.25	35.40	27.10	28.25
Fish meal	4.25	4.25	4.25	4.25	4.25	4.25	4.25
Yeast	2.50	2.59	2.50	2.50	2.50	2.50	2.50
C. leaf meal	-	10.00	20.00	-	-	10.00	15.00
C. root meal	-	-	-	20.00	40.00	20.00	30.00
Molasses	-	2.50	5.00	3.00	6.50	4.00	6.00
Vegetable oil	1.75	4.00	8.00	4.50	7.75	7.75	10.40
Limestone	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Dical.phosphate	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mineral mixture	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin mixture	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.05	0.20	0.20	0.20	0.20	0.20	0.25
L-Lysine	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 7

Performance and body composition of chicks fed dietary cassava leaf and root (Experiment 2)

Items	Diets						
	Basal	Leaf 10	Leaf 20	Root 20	Root 40	Leaf- root 10-20	Leaf- root 15-30
No. animals	30	30	30	30	30	30	30
Length trials, days	56	56	56	56	56	56	56
Avg.daily gain,g	18.2	15.7	15.2	18.4	16.0	15.8	15.7
Feed/gain	3.12	3.36	3.81	3.14	3.24	3.64	3.81
Carcass*							
moisture	74.3	73.4	73.6	72.3	73.5	70.3	71.8
fat, % dry-wt.	34.8	35.8	35.8	37.0	35.2	37.9	36.1
protein %dry-wt.	51.6	52.0	51.4	51.9	52.5	51.0	52.3
Liver*							
moisture,%	75.1	74.0	74.0	73.9	73.2	72.7	73.8
fat, % dry-wt.	14.2	14.8	14.5	14.5	13.3	14.5	14.8
Protein,%dry-wt.	69.9	70.8	71.3	70.7	71.6	70.6	70.1

* Carcass and liver data based on 4 and 3 birds per treatment respectively.

TABLE 8

Effects of dietary cassava leaf and root on mineral contents of chick tissues (Experiment 2)

	Basal	Leaf 10	Leaf 20	Root 20	Root 40	Leaf- root 10-20	Leaf- root 15-30
Whole carcass							
Calcium, %	8.0	7.2	8.0	7.1	6.6	6.7	7.3
Phosphorus, %	3.4	3.4	3.4	3.3	3.7	3.6	3.3
Copper, ppm	23	22	21	19	13	15	16
Iron, ppm	160	550	500	550	460	550	460
Magnesium, %	0.46	0.46	0.46	0.46	0.54	0.48	0.48
Zinc, ppm	87	78	81	7.	81	58	64
Liver*							
Calcium, %	0.72	0.70	0.73	0.73	0.76	0.73	0.74
Phosphorus, %	1.05	1.03	1.04	1.04	1.16	1.10	1.28
Copper, ppm	29	25	22	21	26	25	29
Iron, ppm	621	630	607	608	617	637	648
Magnesium, %	0.90	0.82	0.83	0.80	0.86	0.89	0.90
Zinc, ppm	137	125	166	123	165	155	107

* Expressed on a dry matter basis

TABLE 9A

Composition of starter diets (Experiment 3)

Protein, %	Dietary variables								
	19			22			25		
Cassava, %	0	20	40	0	20	40	0	20	40
Cassava root	-	20.00	40.00	-	20.00	40.00	-	20.00	40.00
Maize	66.20	43.30	18.55	57.80	37.00	13.00	52.25	29.00	6.55
Soybean meal	15.50	15.50	23.50	23.90	15.55	21.35	20.40	22.55	20.60
Fish meal	12.35	15.25	12.00	12.35	21.50	20.70	21.40	22.50	27.00
Palm oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Trical.phosphate	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mineral mixture	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
L-Lysine	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 9B

Composition of grower diets (Experiment 3)

Protein, %	Dietary variables								
	17			20			23		
Cassava, %	0	20	40	0	20	40	0	20	40
Ingredients, %									
Cassava root	-	20.00	40.00	-	20.00	40.00	-	20.00	40.00
Maize	69.00	45.00	23.00	61.50	38.20	15.00	54.50	31.00	7.70
Soybean meal	16.00	17.00	18.00	20.50	22.80	24.00	23.50	26.00	28.30
Fish meal	8.00	10.00	12.00	11.00	12.00	14.00	15.00	16.00	17.00
Palm oil	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Trical.phosphate	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mineral mixture	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
L-Lysine	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Chromic oxide	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 10

Effects of dietary cassava and protein levels on performance and body composition of chicks for 8 weeks (Experiment 3)

Protein %	Dietary variables								
	19 - 17			22 - 20			25 - 23		
Cassava %	0	20	40	0	20	40	0	20	40
Avg.daily gain	18.0	17.5	16.8	18.6	16.6	16.1	18.1	17.6	16.7
Feed/gain	2.42	2.19	2.31	2.10	2.09	2.24	2.15	2.24	2.20
Whole carcass									
Moisture, %	65.3	68.3	67.8	68.7	69.6	70.4	69.2	69.8	68.4
Fat, % ^{1,2}	32.8	25.6	25.8	23.9	23.9	8.5	16.4	16.1	21.0
Protein, % ^{1,2}	52.1	57.4	57.5	59.4	60.7	61.0	64.3	67.1	63.2

1 Significant ($P < 0.01$) effect of cassava and protein2 Significant ($P < 0.01$) cassava x protein interaction

TABLE 11

Composition of basal diets (Experiment 4, 5 and 6)

Ingredients, %	Diets	
	Starter	Grower
Cassava root meal	40.00	40.00
Maize, yellow	16.25	22.25
Soybean meal	20.60	17.80
Fish meal	16.20	12.00
Palm oil	4.00	5.00
Tricalcium phosphate	1.75	1.45
Salt	0.50	0.50
Mineral mixture	0.30	0.30
Vitamin premix	0.10	0.10
DL-Methionine	0.20	0.20
L-Lysine	0.10	0.10
Chromic oxide	-	0.30
Total	100.00	100.00

TABLE 12

Effects of graded levels of zinc and iron in cassava diets on performance and body composition of chicks for 8 weeks (Experiment 4)

Dietary variables									
Zinc, ppm	0	25	50	0	25	50	0	50	50
Iron, ppm	0	25	50	0	25	50	0	25	50
Avg daily gain (g)	17.2	16.7	17.5	15.7	15.7	18.4	16.7	16.2	14.8
Feed/gain	3.27	3.16	3.33	3.25	3.17	3.07	3.08	3.02	3.02
Carcass data									
Moisture, %	65.8	64.4	62.7	64.4	63.4	63.7	62.1	65.8	64.4
Fat, %	33.3	36.1	38.9	33.1	35.9	31.0	37.2	37.8	33.5
Protein, % ^{1,5}	58.7	54.4	52.3	56.3	52.0	54.6	53.5	57.6	55.1
Copper, ppm	13.0	9.0	9.2	9.2	11.6	8.4	9.2	8.5	9.8
Iron, ppm ^{3,5}	240	256	273	253	276	313	233	274	314
Zinc, ppm ^{2,4}	163	168	168	193	168	186	238	173	173
Liver									
Copper, ppm ^{2,5}	34	33	37	24	28	26	19	17	17
Iron, ppm ^{2,4}	519	543	592	520	558	610	618	663	728
Zinc, ppm ^{5,6}	170	167	173	184	189	188	192	194	200

- 1 Significant effect of iron ($P < 0.05$), but not zinc
- 2 Significant ($P < 0.01$) interaction of zinc and iron
- 3 Significant ($P < 0.05$) effect of zinc and iron
- 4 Significant ($P < 0.01$) effect of zinc and iron
- 5 Significant ($P < 0.05$) interaction of zinc and iron
- 6 Significant effect of zinc ($P < 0.01$), but not iron

TABLE 13

Effects of graded levels of zinc and iodine in cassava diets on performance and body composition of chicks for 8 weeks (Experiment 5)

Dietary variables										
Zinc,ppm		0			25			50		
Iodine	0	25	50	0	25	50	0	25	50	
Avg.daily gain ^{1,2}	15.5	16.3	13.6	15.2	15.4	15.5	17.3	15.5	14.2	
Feed/gain ^{1,2}	3.12	3.12	3.53	3.30	3.27	3.15	3.12	3.13	3.41	
Carcass data										
Moisture,%	63.9	67.1	64.2	63.2	64.4	63.6	61.7	64.9	63.7	
Fat,% ^{2,3}	31.2	28.7	31.4	37.5	34.6	20.6	33.3	33.6	34.0	
Protein,% ^{2,3}	54.0	59.3	52.9	51.5	55.4	57.3	51.2	54.6	55.3	
Copper,ppm ^{1,2}	11.2	11.1	9.1	8.6	8.0	7.9	10.4	8.5	13.1	
Iron,ppm ^{2,5}	249	253	237	241	259	270	249	233	224	
Zinc,ppm ^{3,4}	160	189	177	179	199	198	158	169	204	
Liver										
Copper,ppm ^{2,3}	31	32	34	23	26	25	20	22	19	
Iron,ppm ^{4,5}	547	488	523	531	548	533	547	575	578	
Zinc,ppm ⁶	167	169	169	179	183	184	187	193	200	

1 Significant effect of iodine ($P < 0.05$), but not zinc

2 Significant ($P < 0.05$) zinc x iodine interaction

3 Significant ($P < 0.05$) effect of zinc and iodine

4 Significant ($P < 0.01$) zinc x iodine interaction

5 Significant effect of zinc ($P < 0.05$), but not iodine

6 Significant effect of iodine ($P < 0.05$) and zinc ($P < 0.01$)

TABLE 14

Effects of graded levels of zinc and copper in cassava diets on performance and body composition of chicks for 8 weeks (Experiment 6)

Dietary variables										
Zinc,ppm		0			25			50		
Copper,ppm	0	25	50	0	25	50	0	25	50	
Av.daily gain,g	17.3	16.4	18.7	17.7	18.2	17.7	19.9	17.6	19.9	
Feed/gain	3.24	2.96	3.06	2.78	2.87	2.89	2.85	2.80	2.82	
Carcass data										
Moisture,%	65.7	66.6	66.6	67.4	65.9	67.2	67.4	67.5	66.7	
Fat, %	29.2	21.6	27.7	21.6	27.8	22.9	23.6	27.5	28.6	
Protein,% ¹	55.9	58.1	54.7	62.3	61.2	59.9	60.5	56.9	59.9	
Copper,ppm ⁵	11.8	14.8	17.7	10.4	13.6	17.9	13.1	15.9	18.5	
Iron,ppm ^{1,3}	310	228	247	258	318	306	321	313	295	
Zinc,ppm ^{3,4}	194	212	225	229	229	188	232	212	165	
Liver										
Copper,ppm ^{2,3}	31	74	126	23	56	73	22	52	69	
Iron,ppm ^{3,5}	586	548	582	517	585	558	559	701	551	
Zinc,ppm ^{3,6}	167	159	155	171	169	174	185	204	205	

1 Significant effect of zinc ($P < 0.05$), but not copper

2 Significant ($P < 0.01$) effect of zinc and copper

3 Significant ($P < 0.01$) zinc and copper interaction

4 Significant effect of copper ($P < 0.05$), but not zinc

5 Significant effect of copper ($P < 0.01$), but not zinc

6 Significant effect of zinc ($P < 0.01$), but not copper

TABLE 15

Composition of diets (Experiment 7)

Ingredients, %	Basal	Diets			
		Cassava 15	Cassava 30	Cassava 45	Cassava 60
Maize	70.50	53.00	35.50	18.00	1.00
Soybean meal	20.30	22.30	24.30	26.30	26.00
Cassava root meal	-	15.00	30.00	45.00	60.00
Fish meal	6.00	6.50	7.00	7.50	9.80
Limestone	0.80	0.80	0.80	0.80	0.80
Dicalcium phosphate	1.50	1.50	1.50	1.50	1.50
Salt	0.50	0.50	0.50	0.50	0.50
Mineral mixture	0.30	0.30	0.30	0.30	0.30
Vitamin mixture	0.10	0.10	0.10	0.10	0.10

TABLE 16

Effects of dietary cassava root on performance and carcass characteristics of swine (Experiment 7)

Item	Basal	Diets			
		Cassava 15	Cassava 30	Cassava 45	Cassava 60
No. animals	12	12	12	12	12
Length of trials, days ^a	134	139	156	165	170
Performance data					
Avg. daily gain, kg ^b	0.55	0.52	0.48	0.43	0.42
Feed/gain ^b	3.52	3.57	3.68	3.82	3.90
Weight at slaughter, kg	69.8	70.0	70.4	70.2	69.9
Carcass data					
Weight, kg	55.0	55.5	54.8	52.6	52.7
Dressing, %	78.8	79.3	77.9	75.0	75.4
Length, cm	73.1	74.4	74.7	73.6	72.5
Backfat, cm ^b	3.24	3.30	3.47	3.69	3.78
Area of loin, cm ^{2b}	31.7	32.2	27.9	24.3	23.5

a Days required to reach an averaged slaughter weight of 70 kg from the weanling stage.

b Significant ($P < 0.01$) effect of cassava level

TABLE 17**Composition of diets (Experiment 8)**

	Diets		
	Basal	Cassava leaf	Cassava root
Maize	69.20	53.60	14.10
Soybean meal	27.50	21.40	35.90
Cassava meal	-	15.00	-
Cassava root meal	-	-	40.00
Molasses	-	3.50	3.50
Palm oil	-	3.00	3.00
Limestone	0.80	0.80	0.80
Dical.phosphate	1.50	1.50	1.50
Salt	0.50	0.50	0.50
Mineral mixture	0.30	0.30	0.30
Vitamin mixture	0.10	0.10	0.10
DL-Methionine	-	0.20	0.20
L-Lysine	0.10	0.10	0.10
Total	100.00	100.00	100.00

TABLE 18**Effect of dietary cassava leaf and root on the performance of pigs (Experiment 8)**

	Diets		
	Basal	Cassava leaf	Cassava root
No. animals	12	12	12
Length of trials, days	84	84	84
Protein level, %	18-16	18-16	18-16
Avg. daily gain, g	0.55	0.50	0.52
Feed/gain	3.72	3.88	3.93

EVALUATION OF TWO CASSAVA CULTIVARS FOR STARCH AND CHIP PRODUCTION

Seak Khan Chan*

SUMMARY

Black Twig, the current commercial cultivar of cassava in West Malaysia, has a lower fresh weight yield (though not significantly so) than the Thai cultivar Bangkok No. 1 but a much higher dry matter yield (significant at $P = 0.01$) on account of 45 percent dry matter in Black Twig in comparison with 28 percent dry matter in Bangkok No. 1. The protein content of Bangkok No. 1 may be slightly greater than that of Black Twig. For the production of animal feed or starch it is the dry matter yield that is important.

The planting of cassava in cleared old rubber plantations is analyzed in terms of man-days and financial cost.

RESUME

Le "Black Twig", cultivar commercial du manioc actuellement en cours en Malaisie occidentale, a un rendement en poids frais plus bas (bien qu'il ne soit pas tout à fait ainsi) que le cultivar Bangkok No. 1 du Thai, mais un rendement en matière sèche beaucoup plus élevé (important à $P = 0.01$) à raison de 45 pour cent de matière sèche dans le "Black Twig" comparés à 28 pour cent de matière sèche dans Bangkok No. 1. La teneur en protéine du Bangkok No. 1 est peut-être légèrement supérieure à celle du "Black Twig". Pour la production d'aliments du bétail ou de l'amidon, c'est le rendement en matière sèche qui est important.

La plantation du manioc sur terrain de caoutchouc défriché est analysée en termes de main-d'œuvre journalière et des coûts de l'exploitation.

RESUMEN

Black Twig, el cultivar comercial de yuca común en Malasia Occidental, tiene un rendimiento en peso fresco mas bajo (si bien que no significativamente) que el cultivar Thai, Bangkok No. 1, pero mucho mas alto rendimiento de materia seca (significativo a $P = 0.01$). Black Twig tiene 45% de materia seca y Bangkok No. 1 28%. El contenido proteínico de Bangkok No. 1, puede ser algo mas alto que el de Black Twig. El rendimiento de materia seca es lo importante para la producción de alimento animal o almidón.

Se analiza la siembra de yuca en lo que fueron plantaciones viejas de hule, en términos de días-hombre y costos financieros.

*Malaysian Agricultural Research and Development Institute, Malaysia.

INTRODUCTION

Of the thirty-five cultivars listed by Templeton³, one cultivar named 'Bangkok No. 1' was observed at the RRI Experiment station*, Sungei Buloh, to give as high a yield as 'Black Twig', which is currently planted in West Malaysia for starch and chip production. Little was known about 'Bangkok No. 1'. Its name implies that it was introduced from Thailand. Because it showed promising yield, it was selected for comparison of root yield and quality with Black Twig, which had been found to be the best yielding cultivar so far. The objective was to determine their relative suitability for the production of starch of tapioca chips in Malaysia.

MATERIALS AND METHODS

The two cultivars Black Twig and Bangkok No. 1 were each tested at two spacings, 90 cm x 90 cm and 90 cm x 120 cm. The harvested plot size was the same for each treatment, i.e. 720 cm x 720 cm, giving 48 plants per plot for spacing 120 cm x 90 cm and 64 plants for spacing 90 cm x 90 cm.

The trial was carried out at Serdang Estate, which was newly cleared from old rubber trees. The land is about 45 m above sea level and gently sloping. The soil type is sandy-clay-loam and pH 4.3. Total rainfall at Serdang in 1972 was 205 cm.

The land was ploughed, harrowed and rotavated. Stem cuttings, each 23 cm long, were planted in a flat position, about 2 cm – 3 cm below the soil surface. Twenty six days after planting, a fertilizer mixture of sulphate of ammonia, triple superphosphate and muriate of potash was applied around each plant at the rate of 66 kg N, 44 kg P₂O₅ and 88 kg K₂O per hectare. Twelve days later the plots were dressed with 85 kg of Kieserite (26% MgO) per hectare. About 26 weeks after planting the plots were manually weeded. The crop was harvested at fourteen months.

The weights of freshly harvested roots, stems and leaves, including leaf-stalks were separately determined for each plot. The number of roots per plot was also recorded. One root from each of twelve plants per plot was sampled from the first two rows (or replicates) of the Latin Square layout. The root samples were washed of dirt, dried superficially by the sun, and immediately sent to the laboratory. They were cut longitudinally into smaller pieces, and resampled for the determination of root composition in terms of moisture, starch, crude protein and crude fibre. The root samples taken from both the spacing treatments were bulked and analyzed only for differences between the cultivars.

RESULTS

The soil, where the two cassava cultivars were planted after the removal of old rubber trees, was observed in an adjacent maize crop to be deficient in some plant nutrients, particularly available phosphate, magnesium and zinc, despite the addition of fertilizers. Although the maize was severely stunted, the cassava appeared to grow normally.

The leaves of both cultivars were moderately attacked by small beetles, a fungal leaf spot disease caused by *Cercospora henningsii* and a bacterial disease, especially during a wet spell. No control measures were taken however.

Yield of freshly harvested roots (kg/ha)

At fourteen months the roots were harvested. Yields are given in Table 1.

The mean yields of fresh roots were high for both Black Twig and Bangkok No. 1, and between them the difference was not significant at 5%. There was slight evidence that Bangkok No. 1 produced higher yields at the spacing 90 cm x 90 cm than at the wider spacing.

Estimated dry matter yield of root and root composition

The dry matter yield of roots was estimated from the fresh root yield and the average dry matter content of each cultivar, which was sampled over the two spacings in each of the first two rows of the Latin Square. The dry matter contents of the roots are shown in Table 2.

Assuming that the difference in the dry matter content of the roots between the two spacing treatments is similar, the dry matter yields of Black Twig roots at 45.5% D.M. and Bangkok No. 1 roots at 28.1% D.M. were estimated as shown in Table 3.

Thus it appears that on a dry weight basis Black Twig yielded more than Bangkok No. 1.

The composition of starch, crude protein and crude fibre in the dry matter of root of the two cultivars

*The cassava collection at the Rubber Research Institute (RRI), later transferred to MARDI, Serdang.

is shown in Table 4. The root of Black Twig contained more starch and less fibre than the root of Bangkok No. 1.

Number of tuberous roots per hectare

The number of tuberous roots of each cultivar and spacing was recorded separately for these roots that exceeded 15 cm in length, and for those that were shorter. Table 5 shows the number of roots produced per hectare by Black Twig and Bangkok No. 1 at the two spacings.

The interaction between spacing and cultivar for root numbers was highly significant. Bangkok No. 1 at the spacing 90 cm x 90 cm, but not at the wider spacing, produced significantly more roots than Black Twig at either of the two spacings. Also, Bangkok No. 1, not Black Twig, produced significantly more roots at 90 cm x 90 cm than at 90 cm x 120 cm.

Table 6 shows a similar result, with the production of tuberous roots less than 15 cm long. Again Bangkok No. 1 at 90 cm x 90 cm produced significantly more roots than Black Twig at either spacing. There was also some evidence that Bangkok No. 1 produced more roots at 90 cm x 90 cm than at the wider spacing, when it was tested at 5% levels of significance.

Mean weight per freshly harvested root

Since Bangkok No. 1 produced numerically more roots than Black Twig without resulting in significant differences in total fresh weight, the mean weight per freshly dug root was analyzed for varietal difference. The result is shown in Table 7.

Black Twig produced heavier weight per fresh root than Bangkok No. 1. The difference between the spacings was not significant.

Comparison of total production of stems between Black Twig and Bangkok No. 1

The total production of stems by weight was compared between the two cultivars at the two spacings. Results are shown in Table 8.

There was no substantial evidence to suggest that Black Twig produced more stem materials than Bangkok No. 1. There was also no significant effect of spacing for either cultivar on the production of stem materials.

Varietal comparison of the total quantity of leaves remaining on the plants at fourteen months

Table 9 shows the total production of leaves and leaf-stalks by weight for the two cultivars planted at two spacings. Black Twig retained significantly more leaves and leaf-stalks than Bangkok No. 1 at fourteen months. The difference in total leaf harvest between the two spacings was not significant for either cultivar.

ECONOMIC ASPECTS OF GROWING CASSAVA AFTER OLD RUBBER

The expected cash returns from growing cassava after the removal of old rubber may be estimated from the result of this trial. The costs of production and returns from the sale of roots are estimated in Malaysian dollars (M\$) on the basis of one acre (0.4047 ha).

Costs of production

These include the costs of clearing old rubber on a contract basis, fertilizers, and employed labour. A casual labourer is currently paid \$4.33 per man day. One man day consists of 8 hours in which one hour is a break for a meal and seven are working hours.

Cost items	Man day	Cost in M\$
1. Clearing old rubber, ploughing and harrowing		100.00
2. Fertilizers:		
Sulphate of ammonia		24.00
Triple superphosphate		12.30
Muriate of potash		12.00
Kieserite		10.90
3. Application of fertilizer	2	8.66
4. Cutting sticks into 23 cm pieces for planting	1	4.33

5. Lining, holing and planting	12	51.96
6. Weeding: one round only	7	30.21
7. Harvesting:		
Cutting stems, pulling out roots and separating roots from stumps	22	94.26
Total cost of production:		M\$349.02

Price of roots

The current price of roots is \$2.80 per pikul at the starch content of 17-18%. Some major starch producers vary the price according to the change in the starch content of roots as determined by the specific gravity method. There is a 10 ct. difference in the price per pikul for each 1% difference from the above starch content. The chemical analysis of roots in this trial shows that Black Twig had 36.1% starch and Bangkok No. 1 had 19.7%. Thus one pikul of roots of Black Twig would fetch about 16 ct. more than that of Bangkok No. 1 if sold to quality-conscious buyers.

Expected returns

Since there is no significant difference between Black Twig and Bangkok No. 1 in the yield of freshly harvested roots, it would clearly be more profitable to grow Black Twig because of its higher starch content in the root. Therefore, only the yield of Black Twig is used to estimate the net income per acre. However, the starch content analyzed by the chemical method has not been correlated with that determined by the specific gravity method. Therefore it is not used to estimate the price of roots here. The prices used for estimating income from the sale of roots are based on the current price of \$2.00 per pikul and also on a conservative price of \$2.00 per pikul, as shown in Table 10.

The estimates in Table 10 show that it is economically feasible to grow cassava after felling rubber. It may be added that a greater profit margin is expected from the sale of rubber wood which can bring a return of \$30-\$40 per acre.

DISCUSSION

Although the cultivar Bangkok No. 1 appeared productive of tuberous roots, it was disappointing in its dry matter yield. Perhaps the roots at fourteen months were over-mature for Bangkok No. 1 as observed in the relatively high fibre content in the root and the significantly fewer leaves retained compared to those of Black Twig. Further work is needed to evaluate its performance at its optimum period of growth.

The income estimated from the yield of roots which were harvested at fourteen months may be taken as income for a crop which is harvested at twelve months, since previous studies have shown that the difference in yield between these two growing periods is not likely to be significant.

To the tapioca producer who makes starch or tapioca chips out of tuberous roots, the percentage of starch or dry matter in the root is very important. Because the roots can differ greatly in starch content, the specific gravity method has already been mentioned, but the subjective method of visually examining moisture in a broken root is also commonly used. How reliable these methods are in fixing a fair price of the root is a question. The fact remains, however, that roots of truly different starch or dry matter content do differ in value as their effects on the rate of production of starch or animal chips are concerned.

ACKNOWLEDGEMENTS

The writer is grateful to Mr. Anuwar Mahmud, Director of MARDI, for useful comments on the paper, Mr. Lee Chong Soon for statistical analysis and Miss Chia Joo Suan for chemical analysis.

REFERENCES

1. Chan, S.K. (1970) Notes on the growing of cassava at Serdang. Crop Diversification in Malaysia; Proc. of the Conf. held in 1969 and edited in 1970, 119-123, 145-146.
2. Jennings, D.L. (1970) Cassava in Africa. A review article.
3. Templeton, J.K. (1970) Identification and naming of tapioca varieties in West Malaysia. Crop Diversification in Malaysia. Proc. of the Conf. held in 1969 and edited in 1970, 139-140.

TABLE 1

Mean yields of fresh roots (kg/ha) of Black Twig and Bangkok No. 1 at two spacings

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	37,095	43,624	40,360
90 cm x120 cm	37,403	35,725	36,564
Mean	37,249	39,675	
L.S.D. (P = 0.05) between data in body of table = 7,036			
L.S.D. (P = 0.05) between data in margins of table = 4,976			
CV = 11%			

TABLE 2

Dry matter content of roots (%) of two cassava cultivars

<u>Replicate</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>
1	43.2	26.9
11	47.7	29.3
Average	45.5	28.1

TABLE 3

Estimated dry matter yield of roots in kg/ha for two cassava cultivars

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	16,879	12,259	14,569
90 cm x120 cm	17,068	10,060	13,564
Mean	16,974	11,160	
L.S.D. (P = 0.01) between data in body of table = 4441			
L.S.D. (P = 0.01) between data in margins of table = 3140			

TABLE 4

Content of starch, crude protein and crude fibre as % of dry matter of roots of two cassava cultivars

<u>Cultivar</u>	<u>Starch(%)</u>	<u>Crude protein</u>	<u>Crude fibre</u>
Black Twig	79.4	3.9	2.6
Bangkok No.1	70.2	4.1	4.1

TABLE 5

Number of tuberous roots per hectare (roots > 15 cm)

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	64,573	83,960	74,267
90 cm x120 cm	60,184	63,223	61,703
Mean	62,378	73,592	
CV = 7%			
L.S.D. (P = 0.01) between data in body of table	= 11,634		
L.S.D. (P = 0.01) between data in margins of table	= 8,228		

TABLE 6

Number of tuberous roots per hectare (roots > 15 cm)

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	29,996	44,415	32,206
90 cm x120 cm	30,430	34,963	32,697
Mean	30,213	39,689	
L.S.D. (P = 0.01) between data in body of table	= 13,652		
L.S.D. (P = 0.05) between data in body of table	= 9,010		
L.S.D. (P = 0.01) between data in margins of table	= 9,655		
CV = 15%			

TABLE 7
Mean weight in gm per fresh, undried root

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	394	344	369
90 cm x120 cm	413	363	388
Mean	404	354	
L.S.D. (P = 0.05) between data in body of table = 49			
L.S.D. (P = 0.05) between data in margins of table = 35			
CV = 8%			

TABLE 8
Total weight of freshly harvested stems in kg/ha

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	26,253	19,190	22,722
90 cm x120 cm	23,447	20,158	21,801
Mean	24,850	19,674	
L.S.D. (P = 0.05) between data in body of table = 7,780			
L.S.D. (P = 0.05) between data in margins of table = 5,502			
CV = 20%			

TABLE 9
Weight of freshly harvested leaves and leaf-stalks in kg/ha

<u>Spacing</u>	<u>Black Twig</u>	<u>Bangkok No.1</u>	<u>Mean</u>
90 cm x 90 cm	1,148	733	941
90 cm x120 cm	1,109	599	834
Mean	1,129	646	
L.S.D. (P = 0.01) between data in body of table = 322			
L.S.D. (P = 0.01) between data in margins of table = 228			
CV = 14%			

TABLE 10
Costs and returns from an acre of cassava grown after rubber

<u>Price of root</u>	<u>Yield of roots/ac</u>	<u>Gross return</u>	<u>Cost of production</u>	<u>Net return per acre</u>
\$2.00/pikul	248.6 pikul	\$497.20	\$349.02	\$143.18
\$2.80/pikul	248.6 pikul	\$696.08	\$349.02	\$347.06

HISTORY OF THE DEVELOPMENT OF THE FIRST MECHANIZED CONTINUOUS GARI MANUFACTURING PLANT

J.G. Purcell and D.H. Williams*

SUMMARY

After reviewing various endeavours to manufacture gari in factories, the main characteristics of a factory in Gambia are described. This is claimed to offer the best and most economic means available to produce this staple food of West Africa. The factory line comprises of an eccentric drum peeler, trays for hand sorting of peeled roots, and a horizontal hammer mill. The mash is then pumped into 1 ton, low-density polyethylene vats for fermentation. The fermented mash, contained in nylon bags, is dewatered in hydraulic presses and the dewatered mash is dried in a cascade type rotary drier. The process designers, Newell Dunford, are constantly improving their process and can offer complete systems.

RESUME

Après avoir passé en revue les divers efforts pour fabriquer du gari en usines, les grands traits d'une usine en fonction en Gambie ont été exposés. Celle-ci, pense-t-on, offre les meilleurs moyens économiques disponibles pour produire cette denrée propre à l'Afrique occidentale. L'usine se compose d'une éplucheuse excentrique à tambour, de plateaux pour dégager manuellement les racines épluchées et un moulin horizontal. Puis la pâte est versée dans un tonneau, des cuves polyéthylènes à basse densité pour la fermentation. La pâte fermentée, contenue dans les sacs en nylon est asséchée dans des presses hydrauliques et séchée dans une sorte de séchoir rotatoire à cascade. Newell Dunford, compagnie qui a mis au point le procédé, l'améliore constamment et peut en faire un système complet.

RESUMEN

Se describen las principales características de una planta de manufactura de gari en Gambia, después de revizar varios intentos hechos previamente. Se dice que ella ofrece los mejores y mas económicos medios para producir este alimento de consumo básico en Africa Occidental. La línea de operación de la fábrica incluye un tambor descortezador excéntrico, bandejas de clasificación manual de la raíces descortezadas y un molino horizontal de martillo. La masa es entonces bombeada a tinajas de fermentación de 1 ton, hechas de polietileno. La masa fermentado, contenida en bolsas de nylon se deshidrata en prensas hidráulicas y se seca en un secador rotatorio de tipo cascada. Los diseñadores del proceso, Newell Dunford, lo mejoran constantemente y pueden ofrecer sistemas completos.

INTRODUCTION

The original test work that led to the development of the gari plant was supervised by Mr. J.G. Purcell of Newell Dunford Engineering more than fifteen years ago. Roots were air freighted from Nigeria and the first preliminary tests were carried out at our Research and Development Department. The rapid deterioration of the roots made the work very difficult, but sufficient test information was obtained for a combined garifier/dryer of the rotary louvre type to be designed.

The first garifier/dryer was built and supplied to the Federal Institute of Industrial Research, Oshodi, Nigeria in late 1959, and after initial minor technical difficulties, an economic investigation was undertaken over a three month period in late 1961, running the plant on a semi-continuous basis.

In reports on this trial^(3,4,5) it was concluded that, although good quality gari had been produced, it had been difficult to obtain the quantity of cassava roots required at a reasonable price. It was suggested

*Newell Dunford and Co. Ltd., 143, Maple Road, Surbiton, Surrey, England.

that the minimum economic size of a factory would be ten tons of gari a day, at which size the price of the product should be able to be reduced from £30 per ton or less⁽⁶⁾.

However, those to whom gari samples were sent for opinion on quality had given a misleading verdict and it was later realized that the factory product did not compare favourably with gari produced by the traditional method. Another report issued by the F.I.I.R. in 1964⁽¹⁾ suggested that the garifier and dryer should be operated as separate units, and during the next few years they investigated the principles of garifying with different designs.

Based on the data obtained, Newell Dunford submitted a revised garifier design in 1967. A unit of this type was installed in mid-1969 and, after trials lasting some six months, gari of excellent quality was produced without problems of sticking which had occurred earlier.

Simultaneously, discussions were taking place regarding the installation of the first commercial plant in the Gambia. Since the new F.I.I.R. was not erected until 1969, the designs for the Gambia plant could not be based on the results obtained there. The equipment initially did not meet capacity and it took two years to modify it until it could produce 1000 lbs. per hour or two tons per day output of gari.

The development of the fully mechanized continuous gari plant was thus quite slow, but the problems were greater than originally envisaged, and the cost of solving them very discouraging. In the meantime however, the price of gari had risen to a much higher level which gave further impetus to the developments.

During this fifteen year development period, we have had to compete with the village method, where the capital expenditure is very low, resulting in a low price of gari. Consequently, designs have been limited to maintain the balance between plant efficiency and capital cost. For example: —

- (a) The root peeling section contains two batch peelers; proprietary continuous peelers using dry or steam methods would be about twice the price.
- (b) Hydraulic bag presses, although simple, have proved to be the most economic means of dewatering the cassava mash. Centrifuges, as used in the pilot plant, are too expensive.
- (c) The fermentation area could be more highly automated, but one of the simplest methods, using vats, pallet trucks and a cassava mash pump, has proved the least expensive.
- (d) The garifier is a specialized piece of equipment where costs cannot be reduced by using alternatives. Marginal savings have been made by interconnecting the garifier exhaust gasses to the dryer, reducing the heat wasted.
- (e) The dryer has been an item where considerable savings have been achieved. The substitution of a Cascade type dryer for the Rotary Louvre dryer has reduced costs.

There are, however, instances where cheaper equipment has been tried and proved unsuitable. Newell Dunford made a mistake in 1969 in trying to build the first commercial plant in the Gambia to an unrealistic target capital figure, and was eventually forced to subsidize it heavily to achieve success. However, an advantage of a simple low cost plant is that it should be reasonably easy to maintain by less skilled labour.

Due to the inflationary conditions in the United Kingdom, the present design has risen some 15% in price over the past year or so, but our policy is continually to re-appraise items of equipment with a view to reducing cost.

As mentioned earlier, the experimental pilot plant at F.I.I.R. Oshodi, has undergone considerable changes, and the present plant which is used for demonstrations, can be described as follows:

A pump delivers water to an eccentric drum type peeler. The peeled roots are then discharged onto wire sorting trays for hand sorting, and delivered via a ribbed belt conveyor into a vertical shaft grater. The grated cassava is discharged into an agricultural type mixer, has seed liquor added if necessary, and is discharged into 200 lbs capacity aluminum fermentation vats mounted on wheeled carriages. After two to three days fermentation, the cassava mash is transferred into press bags for dewatering in a hydraulic press. The dewatered cassava mash in the form of a cake, is fed into a sifter prior to entry into the single rotating drum garifier. After garifying, the gelatinized cassava is fed into a rotary louvre dryer. After drying, the product is stored in a bunker before being fed into a disc mill for grinding. The ground gari passes into a reciprocating two-stage sieve where the fines are removed and then the graded gari is weighed and packed into hessian bags for dispatch. This plant has now been running successfully for two to three years producing gari of an acceptable quality.

The garifier has proved to be a critical stage of the process, and so is worthy of more detailed discussion.

The garifier installed on the first pilot plant in 1959 was a combined garifier/dryer. The equipment consisted of a plain steel conical shaped garifying section heated externally by an oil fired air heater. Material fell onto this section and rolled in a spiral path into the remaining three quarters of the drum which consisted of a conventional rotary louvre dryer.

Although this followed the traditional idea where the garifying and drying are carried out in one operation by cooking the fermented mash in an open pan over a hot fire, the product from this plant was not of the same quality as the traditional gari. Further investigations revealed that two separate incompatible processes were occurring, namely (a) gelatinization which required high heat transfer and low mass

transfer and (b) drying which required low heat transfer and high mass transfer.

A later F.I.I.R. report¹ describes investigations into the use of separate garifiers, designed to increase heat transfer efficiency. Whilst these investigations were successful as far as product quality was concerned, only limited success was achieved in reducing the number of lumps formed as a result of sticking in the chamber. However, these studies led to the design of a separate rotary kiln garifier, externally heated by a baffled jacket of hot air. Sticking of the cassava on the drum surface was eliminated by using stainless steel material and fabricating small lifting devices in the drum.

This equipment proved satisfactory in the pilot plant, but when scaled up for the commercial plant in the Gambia, insufficient heat transfer occurred in the large garifier installed. It was therefore necessary to increase the surface area. As factory space was limited a compact triplanetary drum garifier was developed, the active portion of the garifier consisting of several planetary drums rotating around the central axis with a common inlet and outlet section, all enclosed in a heating chamber.

This design, together with other modifications such as three burners to give equal heat distribution; variable speed drive to compensate the differing feed inputs, and atmospheric conditions; and recovery of waste heat into the dryer air heater for more efficient operation, is the basis of the present garifier.

The commercial plant in the Gambia has undergone several alterations since being installed in 1969, but is basically the same as the Oshodi pilot plant:

Peeling takes place in eccentric drum units and the roots are discharged onto wire sorting trays where they are hand trimmed. The peeled roots are conveyed by an inclined ribbed belt elevator into a 20 h.p. horizontal hammer mill. The mash passes into an agricultural-type mixer with paddles, where seeding can take place, and is discharged into nylon bags for fermentation. The plant is also experimenting with fermentation vats. After fermentation, the cassava is transferred in bags to hydraulic presses for dewatering, the liquor extracted being used to seed the unfermented mash.

The resultant cake, after being broken by hand, is fed via a bucket elevator. The product from the dryer is discharged onto a trash screen where any large lumps are removed, and then elevated to a double deck screen and separated into three sizes. The undersize portion is bagged off separately as fines whilst the oversize portion is fed into disc mills and the resultant product returned for re-cycling through the screen. The middle cut of product passes into a hopper prior to weighing and bagging off.

Throughout its lifetime, the Gambia plant has suffered many technical problems, but we consider that these have been overcome and that the plant produces gari of quality acceptable for sale.

The fermentation of cassava is a crucial step in the gari process. Fermentation normally takes four to six days in the traditional process whereas, by seeding the mash with fermented liquor, this period can be halved.

Preliminary runs on the 1959 pilot plant at F.I.I.R. indicated that, due to imperfect stirring of mash in the bins, seeding produced unevenly fermented mash. This was overcome by using a mixer, which also acted as a holding hopper whilst the vats were being filled. However, seeding is often omitted in present production methods.

The fermentation containers used in the pilot plant were 2000 lbs capacity aluminum and stainless steel vats, but these proved too expensive for a commercial plant, and other systems were considered.

Traditionally, cassava mash was contained in hessian sacks. The Gambian plant uses nylon bags, holding 40–50 lbs each, but without strict hygiene control the bags soon develop fungal growth which contaminates the product.

Ferrous metals, apart from stainless steel, contaminated and coloured the product: in wooden barrels and formica-lined wooden vats, contamination again occurred, from the cracks and joints of the wood, while the cost of fabrication was not much less than for aluminum vats. Glass fibre vats were tested and have proved thoroughly acceptable: they are moulded and have no recesses where contamination can occur, and they are also relatively cheap. However, they tend to chip during constant handling. Vats moulded in polyethylene appear to have all the qualities of glass fibre vats but are less brittle and more robust for mechanical handling. Other ideas have included concentrate silos of 15–36 tons capacity, but although the cost appeared to be reasonable, until more tests were done, it was considered unwise to incorporate these in the commercial plant.

Thus, at present, fermentation is carried out in one ton capacity vats made of low density polyethylene, loaded and unloaded by a pump. This appears to be the most hygienic and cheapest system available.

Apart from the basic plant, Newell Dunford can offer the necessary ancillary equipment for an integrated process, including electricity generation systems for isolated sites; an effluent separation system; control laboratory equipment; and recommended maintenance equipment.

The areas in the gari process where future development can occur are the batch stages of peeling, fermentation and dewatering. Methods of making these continuous without increasing capital cost are currently being investigated.

In the peeling section, one, more continuous, machine would prove more desirable. There are several continuous peeling machines for such root crops as potatoes and carrots on the market: the basic problem is to modify these machines to peel the rather awkwardly shaped cassava roots.

Investigations have revealed the possibility of continuous fermentation in a column². As a result of these a pilot plant continuous fermentation column has been designed, although not yet constructed.

The original pilot plant contained laboratory basket-type centrifuge which dewatered the cassava mash successfully, but trials with large commercial sized machines proved unsuccessful as the moisture reduction was insufficient to enable gelatinization to occur in the garifier. Similar small reductions in moisture content have been found with single and twin screw continuous presses. It appears that the only continuous machines capable of dewatering the mash is a complicated pneumatic design, which for a commercial size unit would cost some £30,000–£40,000, over fifteen times the cost of the present hydraulic presses. A possible answer may lie in the use of continuous vacuum filters if a cheaper design is to be developed.

Other developments on the plant will no doubt arise as practical experience with commercial plants is gained and, naturally, efforts will be made to improve the plants. However, we feel that the plant now offered the best and most economic means of producing the staple diet of Nigeria and West Africa.

REFERENCES

1. Adeyinka, O. & Akran, C.D. (1964) Improvements on the 1 ton/day gari plant. Research Report No. 24 of Federal Institute of Industrial Research, Federation of Nigeria.
2. Akinrele, I.A. (1964) Fermentation of cassava. *J. Sci. Fd.* 15,(9), 589-4.
3. Akinrele, I.A., Collins, C., Cook, A.S., Holgate, R.A., Junaid, Y. & Baumer, G. (1962) Gari pilot plant (1 ton a day). Results of a 3 month trial run. Research Report No. 13 of Federal Institute of Industrial Research, Federation of Nigeria.
4. Akinrele, I.A., Cook, A.S. & Holgate, R.A. (1962) The manufacture of gari from cassava. Research Report No. 12 of Federal Institute of Industrial Research, Federation of Nigeria.
5. Banks, L. (1962) Background information on mechanized gari production as an aid to equipment manufacturers in development work. Technical Memorandum No. 12 of Federal Institute of Industrial Research, Federation of Nigeria.
6. Banks, L. & Cook, A.S. (1962) Estimates for a factory producing 10 tons a day of gari. Technical Memorandum No. 14. of Federal Institute of Industrial Research, Federation of Nigeria.

ACKNOWLEDGMENTS

The authors are indebted to the staff of Newell Dunford Engineering for their help in preparing this paper, and would also acknowledge the assistance given by Dr. I.A. Akinrele and the staff of the Federal Institute of Industrial Research, Oshodi, Nigeria.

GARI PROJECT REPORT

N.D. Wadhwa*

SUMMARY

Commercial factories have been designed in Ghana which are claimed capable of processing gari economically. All the machinery can be locally manufactured in Accra. A plant to process 8–10 tons of cassava per day working for 250 days a year, and another to process 2–3 tons of cassava per day are costed in detail. They give net returns (over 250 days) of £62,817 (53% capital cost and £11,625 (36% of capital cost) respectively. Plant is available from Agricultural Engineers Ltd., Accra, Ghana.

RESUME

Au Ghana, ont été installées des usines qui, pense-t-on, fourniront du gari rentable économiquement. Toutes les machines peuvent être fabriquées sur place à Accra. Une usine pouvant transformer 8 à 10 tonnes de manioc par jour de travail pendant 250 jours l'année, et une autre pouvant transformer 2 à 3 tonnes de manioc par jour ont été chiffrées en détail avec des bénéfices (pendant plus 250 heures) de £62,817 (53% du capital) et de £11,625 (36% du capital) respectivement. Le matériel pour l'installation de l'usine peut être obtenu auprès de la société "Agricultural Engineers Ltd", Accra, Ghana.

RESUMEN

Se han diseñado fábricas comerciales en Ghana de las que se dice procesarán gari económicamente. Toda la maquinaria puede ser manufacturada localmente en Accra. Se describen los costos de detalle y se dan las tasas de retorno neto de dos plantas; una para procesar de 8–10 toneladas de yuca por día trabajando 250 días al año y otra para procesar 2–3 ton. de yuca por día. Las tasas de retorno (sobre esos 250 días) son £62,817 (53% del costo del capital) para la primera planta y £11,625 (36% del costo del capital) para la segunda. La planta se encuentra disponible en Ingenieros Agrícolas Ltd., Accra, Ghana.

INTRODUCTION

It is estimated that Ghana produces nearly 1,350,000 tons of cassava roots per year from an area of 400,000 acres. Cassava root is consumed as human food, after it has been cooked, fried or processed. There are many uses of cassava in the world, but we in Ghana are interested in gari, kokonte (cassava chips) and cassava starch. Gari is one of the staple foods in Ghana, and in recent years has also become an export item.

The traditional methods of hand-grating, fermenting dough in sacks, pressing under stones and roasting in small frying pans are labour and time consuming, and the end product is not very attractive either for export or for the domestic market. The production capacity using the traditional method is inadequate to make it a profitable rural industry.

*Agricultural Engineers Ltd., Ring Road, Industrial Area, P.O. Box 3707, Accra, Ghana.

THE PRODUCTION PROCESS

Agricultural Engineers Limited, Accra, have been able to develop machines and techniques locally which make gari production a profitable rural industry. The 'Agrico' process for gari production involves weighing cassava, and then washing and peeling by the use of a rotating type of machine fitted with a pump and jet mechanism. Removal of outer cork and inner layer is done by hand.

Cassava is grated using a Wadhwa Cassava Grater which has a circular grating disc and grates nearly one ton of prepared cassava roots per hour.

Fermentation of the dough takes place in wooden tanks. In order to accelerate the bacterial action, some old dough is mixed with the fresh dough and this reduces the fermentation period by at least 24 hours.

The fermented dough is then pressed in an 'Agrico' cassava press to extract the water.

After the dough has been pressed, it is sieved and sifted using the 'Agrico' sieving and sifting machine before roasting.

The dough, after pressing and sieving, contains nearly 20-25% moisture. This moisture is taken off by roasting on a rotating pan.

The resulting gari is then graded, to obtain the uniform granules, using the 'Agrico' gari grader.

During the process of roasting, the cassava congeals into small lumps which are sorted by the grading machine and ground by a grinder or grinding mill.

At the end of the processing, gari is obtained of uniform size and of golden colour, and possesses the characteristic flavour of gari. The product is then weighed, packed and labelled.

LOCATION

A gari industry needs to be established in or near a cassava growing area of sufficient size as cassava root perishes quickly once out of the soil. It is estimated that a plant would work 250 days in a year, and hence that a plant of capacity to process 8–10 tons of cassava a day would need 2,000 to 2,500 tons of cassava per year which should be obtainable from 400–500 acres. A gari plant of 2–3 tons/day capacity is available which needs both less investment and is suitable for handling production from 100–125 acres.

In choosing a location preference should be given to the area where water and electricity is reliably available. The small plant can be run with a diesel engine; but for the large plant a generating set would be required if electricity is not already available.

RAW MATERIAL

The current cassava price is €35.00 per ton at the factory gate or €30.00 ex-farm.

MARKET

Gari is presently selling at 25 Ghana pesewas per pound in the retail stores. However, in this project we have based our ex-factory price on 12 pesewas a pound or C275.00 per ton. Schools, collage hospitals, army-messes, departmental stores and local markets are the main marketing outlets.

EMPLOYMENT

A minimum of 79 workers, 2 supervisors and one manager are required to man the 8–10 ton capacity factory. The smaller unit needs more workers per ton as less operations are mechanized.

ECONOMIC ANALYSIS

A. Factory of 8–10 tons of cassava processing capacity a day

Capital costs of the project

(a) Building (120 x 60 ft)	₹ 43,200.00
(b) Machinery, installation, commissioning	29,940.00
(c) Furniture and fittings	7,500.00
(d) Vehicle	5,000.00
(e) Tractor and trailer	8,900.00
(f) Other expenses — water supply, electricity	9,000.00
(g) Working capital	15,000.00

Total cost of the project	c 118,540.00

(In case electricity is not available at site, a provision of 1 60KVA generating set may be made which may cost nearly ₦17,500.00)

Labour requirements.

Recurrent costs (per day)

	No. of workers	Cost per day ₦
(a) Receiving and weighing	4	4.00
(b) Peeling and washing	36	36.00
(c) Grating and fermenting	10	10.00
(d) Pressing of cassava dough	6	6.00
(e) Sieving and sifting	2	2.00
(f) Roasting	12	12.00
(g) Sieving and grading	2	2.00
(h) Grinding	1	1.00
(h) Packing, labelling	6	6.00
Total	79	₦ 79.00

Direct costs per day

(a) * Raw material (₦35.00 per ton)	₦ 350.00
(b) Labour (without manager), including social security	89.00
(c) Cost of running the machines (fuel and oil)	10.00
(d) Firewood	15.00
(e) Repairs and spares, servicing of machines	9.00
(f) Running vehicle (car)	2.00
(g) Wages of tractor operator	1.75
(h) Maintenance of building etc.	3.00
Total	₦ 479.75

Indirect cost per operational day

(a) Manager's and supervisor's salary	₦ 16.00
(b) Interest on ₦120,000 @ 6% per annum	28.00
(c) Insurance (1% on fixed assets)	4.00
(d) Depreciation of building (20 yr life)	11.20
(e) Depreciation of machines (10 yr life)	18.00
(f) Vehicle and tractor trailer (5 yr life)	11.00
(g) Contingencies (and watchman etc.)	5.00

Cost of production per day

Total ₦ 573.75

* The cost of raw material has been taken at ₦35.00 per ton. If the factory tractor operator is used for carting, the cost of raw material should be based on ₦30.00 a ton. The difference in two costs (₦5.00) per ton would take care of maintenance and running of the tractor; only the tractor operator's wages have been taken into account.

RETURN

Gari from 10 tons of fresh cassava based on 25–33% recovery is equal to 2.5–3.3 tons. Basing average of 3 tons of gari from 10 tons cassava and minimum wholesale price of

₦ 275 per ton.,	₦ 825.00
Net return per day (₦825–₦573.73)	251.27
Net return in 250 days (₦251.27 x 250)	62817.00

(or 52% of capital costs)

NOTES

1. If cassava is available throughout the year and the plant can work 365 days, this would reduce the cost of production and further increase profitability. Working hours in this costing have been at 8 hours per day, but in peak season, the machines could also work much longer hours.
2. The return from the investment after paying interest is 52% per annum. Manufacturing of this plant in Ghana would create employment of 2500 man days.
3. Investment per direct worker is ₵1,400.00 and the project would employ nearly 85 persons.
4. The general economy and standard of living of the area would benefit as more than ₵100,000.00 would be injected by way of wage, salary and raw material costs per day.
5. The farming community would be assisted, as this project would assure farmers of sales of perishable fresh cassava roots.

B. Factory of 2–3 tons of cassava processing capacity per day

Capital costs of the project

	Qty	Cost(₵)
(a) Weighing machine		975.00
(b) Wadhwa cassava grater	1	905.00
(c) Wooden tanks	3	450.00
(d) Cassava press	1	1,250.00
(e) Sieving and sifting machine	1	1,350.00
(f) Rectangular frying pan	5	1,000.00
(g) Chimneys for smokeless over	5	300.00
(h) Gari grinder	1	1,100.00
(i) Misc. tools:		
wheelbarrows	2)	
bag carts,	1)	
shovels	2)	
rakes	2)	
hand trowel, etc.		220.00
(j) Packing, handling, insurance transport to site		250.00
(k) Supervision of installation, commissioning, (inc. of provision of mechanical staff)		950.00
	Total	₵ 8,750.00

Cost of project

Building cost 90 x 30 ft.	₵ 16,200.00
Machinery	8,750.00
Furniture and fittings	500.00
Other expenses (water supply etc.)	2,000.00
Working capital	5,000.00

Labor requirement.

Recurrent cost (per day)

	Qty	Cost
(a) Receiving and weighing	4	4.00
(b) Peeling and washing	12	12.00
(c) Grating and fermentation	4	4.00
(d) Pressing of dough	3	3.00
(e) Sieving, sifting and grading	4	4.00
(f) Frying	10	10.00
(g) Bagging	2	2.00
	Total	₵ 39.00

Direct costs per day

(a) Raw material (35.00/ton), 3 tons	105.00
(b) Labour (without manager) but including social security	44.00
(c) Cost of running machines	6.00
(d) Firewood	10.00
(e) Repairs and spare parts for machines	4.00
(f) Maintenance of building	1.50

Total ₦ 170.50

Indirect cost per day

(a) Manager and supervisor's salary	10.00
(b) Interest on ₦32,450.00	7.80
(c) Insurance	1.00
(d) Depreciation on building (20 yr life)	3.30
(e) Depreciation on machine (10 yr life)	3.40
(f) Contingencies (watchman etc.)	5.00

Total 30.50

Total cost of production per day ₦ 201.00

RETURN

Return from 3 tons of fresh cassava on 30% recovery
is equal to 9 tons of gari and wholesale price of

₦275.00 per ton per day ₦ 247.40

Net return (247.50 — 201.00) 46.50

Net return in 250 days ₦11,625.00

THE STATUS OF TROPICAL ROOT CROP PROCESSING RESEARCH AT THE UNIVERSITY OF THE WEST INDIES, TRINIDAD

G.M. Sammy*

SUMMARY

A flour produced from sweet potatoes that can be used at 15 percent substitution level for wheat flour in bread can be used at higher rates for other bakery products. The flour can be made from unpeeled sweet potatoes by the use of a mild bleaching with 1 percent sodium metabisulphite. Pan-loaf and butter-bread had a high consumer acceptability, and there is little obvious advantage in trying to produce the crusty type of loaf which is incompatible with the use of sweet potato flour without the additional use of other chemical additives. Yam flour can be used for production of acceptable bread at up to 25 percent substitution for wheat flour. Canning of sweet potatoes in brine can produce a very acceptable product. Pre-cooked yam flakes are another promising product.

RESUME

Une farine de patate douce pouvant être utilisée à 15 pour cent pour substituer la farine du blé dans le pain peut être employée à des taux plus élevés pour d'autres produits de boulangerie. On peut fabriquer la farine à partir de la patate douce non épluchée décolorée légèrement avec 1 pour cent métabisulfite de sodium. Le pain beurré cuit au moule est beaucoup apprécié par les consommateurs; il n'y a pas d'intérêt apparent à produire du pain ayant une forte croûte, ce qui n'est pas faisable sans avoir recours à d'autres produits chimiques additifs lorsqu'on utilise la farine de la patate douce. La farine d'igname peut être valablement utilisée pour la fabrication du pain et substituée jusqu'à 25 pour cent à la farine du blé. La mise en boîte de la patate douce contenant de l'eau salée peut donner un produit de conserve acceptable. Des flocons d'igname précuits offrent aussi des perspectives encourageantes.

RESUMEN

Una harina de camote que puede usarse como sustituto en un 15%, de la harina de trigo para pan, puede usarse en proporciones mayores en otros productos de panadería. La harina se puede hacer a partir de camote sin descascarar usando metabisulfito de sodio al 1% como blanqueador suave. El pan de barra y el de mantequilla tuvieron un alta aceptabilidad en el consumo, y habría muy pocas ventajas en tratar de producir el tipo de hogaza (con corteza dura) que es incompatible con el uso de harina de camote, sin el uso de otros ingredientes químicos adicionales. La harina de ñame se puede utilizar para una producción aceptable de pan substituyendo hasta en un 25% a la harina de trigo. El enlatado de camote en salmuera puede producir un producto bastante aceptable. Las hojuelas de ñame precocinado son otro prometedor producto.

*Department of Chemical Engineering, University of the West Indies, St. Augustine, Trinidad.

INTRODUCTION

Research on the processing of tropical root-crops was started at the University of the West Indies, Trinidad in 1969 through participation in the Root Crop Programme of the Faculty of Agriculture, financed at that time from the Rockefeller Foundation and now through the Canada International Development Agency (CIDA). Emphasis is placed on sweet potatoes (*Ipomoea batatas*) and yams (*Dioscorea* spp.), but some preliminary work is also being done with breadfruit (*Artocarpus communis*).

The object of the research is to study the processing potentials of tropical root-crops having possibilities for commercial utilization and thus of economic and developmental benefit to the Caribbean region. Work is being done on preparation of 'composite flours' for bread and baked goods, canning, 'instant' products and breakfast foods.

COMPOSITE FLOURS RESEARCH

The object is to study the baking characteristics of composite flours made from wheat flour mixed with varying quantities of root-crop flours, using the baking methods already in existence in Trinidad and Tobago. Any major changes in the baking industry is expected to be gradual. Because of this we are searching for composite flours that have baking properties and produce products essentially similar to those obtained from wheat flour. Products in the experiments described were considered 'acceptable' only when the taste panel recorded a 100 percent acceptance. Studies have been conducted using composite flours containing sweet potato, yam and breadfruit flours.

In the first study flour derived from sweet potato cultivar 049 had good baking properties when used for dilution up to 15 percent for bread, 20 percent for cakes and 30 percent for cookies, while flour from cultivar C9 had poor baking properties. (Tables 1 and 2). In the preparation of the sweet potato flour, peeling was found to be unnecessary, while treatment with one percent sodium metabisulphite improved the colour of the flour. Addition of one percent glyceryl monostearate or monopalmitate only slightly improved the baking properties. Addition of five percent fish protein concentrate or cotton seed flour had little or no effect on the baking properties.¹

In the subsequent study of seventeen different cultivars of sweet potato, bread-making potential varied greatly with cultivar and there seems to be an association between the higher crude protein content and better baking potential (Tables 3 and 4). After the laboratory studies, hundred pound batches of composite flour were given to local bakeries for baking trials. Bread of the pan-loaf and butter-bread types were readily produced, and proved to be highly acceptable by a consumer acceptance test. However, the preparation of 'hops' which is a crusty loaf, proved difficult at a 15 percent dilution. Addition of 0.5 percent of sodium and calcium Stearoyl-2 Lactylate, strengthened the dough and permitted the production of an acceptable 'hops'.²

Experiments have shown that yam composite flour produces an acceptable loaf at dilutions of up to 25 percent. The quality and storage life is better, for a loaf made with 25 percent dilution of wheat with yam flour, as compared to a loaf made with 100 percent white wheat flour (Table 5).

Bread made from breadfruit composite flour had poor baking qualities as compared with sweet-potato and yam. The highest acceptable dilution was 5 percent.

CANNING

Studies were carried out on the canning of sweet potato cultivar 049 and *D. alata* cultivars 'Lisbon', 'Coconut' and 'Oriental', Portuguese yam (*D. rotundata*), cush-cush yam (*D. trifida*) and Chinese yam (*D. esculenta*) in brine. Yams were canned as $\frac{1}{4}$ and $\frac{1}{2}$ inch cubes (diced) as well as chunks. Sweet potato was canned as small whole potatoes unpeeled.

The canned yam or sweet potato cubes and chunks showed considerable starch leaching and the sweet potato samples disintegrated. Leaching was so heavy that after one month of storage the total liquor in the can became a pasty mess.

Blanching of the cubes before can-filling, and the addition of 0.1 to 0.5 percent calcium chloride gave little improvement. The canning of small (2.0 — 4.0 cm dia.) whole, unpeeled sweet potato in brine gave a good product with little or no starch leaching. The canning liquor remained relatively clear after six months of storage. The skin on the potato posed no problem as it was easily removed before serving. This canned sweet potato product had a high acceptability on a random taste-panel of 150 consumers.

INSTANT PRODUCTS

The aim here was to prepare a precooked 'instant' product from yam similar to those marketed prepared from Irish potato. Tubers were cooked, mashed into a paste and drum-dried. The main problems en-

countered with yams were high blue-values (200 to 1,200) and difficulty in scraping the product cleanly off the drum. The high blue value was an indication of large numbers of ruptured starch cells. This was solved somewhat by passing the cooked yam pieces first through a meat-mincer and then mixing to the required consistency using a 'k' beater (Hobart). This reduced the amount of free starch from broken cells to an acceptable level. To assist the scraping of the product from the drum dryer, 0.1 to 0.5 percent glyceryl monostearate was added. With these modifications an acceptable product was achieved. There was some difficulty with discoloration of the final product. It is known that the head-end of cooked yam becomes discoloured, varying from light reddish brown to brown, while the tail-end remains white to off-white. This problem was overcome by judicious blending to give an acceptable off-white product.

Experimental results have shown that pre-cooked yam flake may be produced with equal facility from a variety of yams such as Lisbon, Coconut, and Oriental (*D. alata*), Portuguese (*D. rotundata*), Cush-Cush (*D. trifida*) and Chinese (*D. esculenta*). The flakes produced from the Chinese yam had poor texture on reconstitution, and developed a bitter taste after two weeks of storage. The flakes prepared from the other species were all acceptable.

Preliminary experiments have indicated that an 'instant' sweet potato, similar to the yam product is possible to make. Research is continuing to work out the various parameters affecting the final product. The results obtained thus far are encouraging.

BREAKFAST FOOD

The object of this research is to produce breakfast foods from root crops or with a root crop base as a replacement for imported convenience breakfast foods. Experiments are being carried out on two types of products, the flake type, similar to corn flakes and an instant porridge.

Preliminary work has indicated that both types of products are possible from sweet potato. The study includes fortifying the products with soya beans and other legumes in order to increase the protein content. Table 6 gives a summary of the formulations and process conditions.

Future research on the processing potential of root crops will be expanded on the breakfast foods to include puffed and milled products. High protein pre-weaning mixes for children using locally produced legumes and root-crops is also being considered. Other root crops to be included in the programme will be the aroids, dasheen, eddoes and tannia.

REFERENCES

1. Sammy, G.M. (1970) Studies in composite flour. I. The use of sweet potato in flour in bread and pastry making. *Trop. Agric. Trin.* 12(2).
2. — — — — (1972) The status of composite flour research at the University of the West Indies. Conference on the Production and Marketing of Composite Flour, Baking and Pasta Products, Bogota, Colombia.

TABLE 1

Effect of different proportions of sweet potato and wheat flour on characteristics of loaves baked under controlled conditions

		<u>Cultivar</u>								
		<u>049</u>					<u>C9</u>			
<u>Sweet potato</u>										
<u>Flour %</u>	0	5	10	15	20	25	5	10	15	
<u>Loaf volume</u>										
<u>ml/g bread</u>	4.6	4.2	4.3	4.3	3.7	2.8	4.0	3.8	2.7	
<u>ml/k.flour</u>	7429	7214	7286	7357	6333	5000	7000	6428	4571	
<u>Shape:</u>	stable	stable	stable	stable	some fall	fallen	stable	some fall	fallen	
<u>Colour:</u>										
<u>crust</u>	pale brown	pale brown	brown	brown	brown	brown	pale brown	brown	brown	
<u>crumb</u>	white	pale grey	pale grey	pale grey	pale grey	pale grey	pale grey	pale grey	pale grey	
<u>Texture:</u>										
<u>crust</u>	smooth	smooth	smooth	smooth	rough few cracks	rough many cracks	smooth	rough few cracks	rough many cracks	
<u>crumb</u>	cells even (good)	cells even (good)	cells even (good)	cells even (good)	cells un- even (very fair)	cells un- even (fair)	cells even (good)	cells un- even (very fair)	cells un- even (fair)	
<u>Taste:</u>	good	good	good	good	fair	poor	good	fair	poor	

TABLE 2

E Effect of 'composite flour' with sweet potato on pastry quality

<u>Product</u>	<u>% sweet potato flour</u>	<u>Cultivar</u>	
		<u>049</u>	<u>C9</u>
Roti (unleavened bread)	15	good	poor
Sponge cake	20	good	poor
Raisin bread	20	good	poor
Pancakes	20	good	poor
Doughnuts	20	good	poor
Sweet cream biscuits	15	poor	poor

Good means acceptable as compared with product made from wheat flour.
Poor means unacceptable.

TABLE 3

Comparative study of flour made from different sweet potato cultivars for bread making. Loaf properties of bread from 'composite flour' with 15 percent sweet potato flour and 85 percent wheat flour

Cultivar	Volume		Shape of loaf	Colour		Texture		Taste
	ml/kg flour	ml/g bread		crust	crumb	crust	crumb	
Wheat flour	5830	3.3	normal	brown	white	smooth	(even cells)	good
A 13/56/11	6380	3.6	normal	light brown	yellowish	smooth	good (cells even)	good
02/62	6270	3.5	normal	light brown	off-white	smooth	good (cells even)	good
08/58/9	6160	3.5	normal	brown	white	smooth	very good (cells even)	good
C9/9	6160	3.5	normal	brown	off-white	smooth	good (cells even)	good
02/59	5940	3.4	normal	brown	off-white	smooth	coarse (uneven cells)	good
Austin Canner	5940	3.4	normal	dark brown	pale yellow	smooth	good (cells even)	good
B 13/56/11	5885	3.3	normal	gold brown	gold yellow	smooth	coarse	slightly sweet
Centennial	5830	3.3	normal	dark brown	gold yellow	smooth	coarse (large uneven cells)	slight off flavour
049	5720	3.3	normal	brown	off-white	smooth	good (cells even)	good
28/59	5720	3.3	normal	brown	off white	smooth	fair (small cells, dense)	slight off flavour
A 7/63/22	5530	3.1	normal	brown	buff	smooth	coarse (few large cells)	good
A 16/15	5520	3.1	normal	brown	gold yellow	smooth	coarse (few large cells)	good
I 62	5500	3.1	normal	brown	off-white	smooth	fair (small cells, dense)	good
03/62	5060	3.0	normal	brown	greyish	rough	fair (small cells, dense)	off flavour
Sunny side	5060	3.0	some fall	brown	pale yellow	rough	coarse (soggy)	off flavour
								poor mouth feel
C9	4290	2.4	fallen	brown	pale grey	rough (many cracks)	coarse (uneven cells)	off flavour
A 28/7	3960	2.3	fallen	pale brown	off-white	rough (many cracks)	coarse (uneven cells)	off flavour

TABLE 4

Properties of sweet potato tubers and flour made from them

Cultivar	Tuber shape	Colour		Moisture		Flour bulk Density g/ml	Crude protein %	Total sugar %	Reducing sugar %	Fat %	Fibre %	Ash %
		Skin	Flesh	Tuber	Flour							
A 13/56/11	bulbous	yellow	pale orange	68	2.7	0.472	4.1	9.5	3.0	0.56	3.72	1.40
02/62	cylindrical	reddish	white	70	3.1	0.506	4.1	7.9	2.4	0.16	2.47	1.46
08/589	bulbous	white	white	71	3.2	0.618	3.8	8.2	1.0	0.60	1.46	2.07
C9/9	cylindrical	white	white	65	2.8	0.494	3.8	6.1	1.2	0.27	2.39	2.03
02/59	bulbous	reddish	white	67	2.5	0.542	3.6	7.9	1.2	0.61	2.85	1.62
Austin Canner	bulbous	yellow	orange	69	3.4	0.508	3.6	8.2	1.5	0.81	3.41	2.19
B13/56/11	bulbous	yellow	orange	68	2.3	0.442	3.1	12.0	3.0	0.90	4.31	2.07
Centennial	cylindrical	deep orange	deep orange	72	2.1	0.498	3.3	10.4	1.3	0.39	1.66	2.15
049	bulbous	reddish	white	70	3.9	0.486	3.0	6.3	3.2	0.41	1.82	1.71
28/59	bulbous	reddish	white	68	2.2	0.564	3.0	6.9	1.4	0.46	1.04	1.29
A 7/63/22	bulbous	dark red	pale yellow	69	2.3	0.548	2.9	7.9	3.0	0.17	1.64	1.94
A 16/15	bulbous	orange	orange	66	3.2	0.466	2.6	4.7	2.7	0.54	2.32	1.70
I 62	cylindrical	reddish	white	70	2.3	0.596	2.6	6.5	3.0	0.31	2.26	1.04
03/62	bulbous	white	white	71	2.5	0.518	2.4	5.6	2.9	0.52	2.35	1.64
Sunny side	bulbous	orange	pale orange	69	3.4	0.550	2.1	9.1	1.4	0.85	2.45	1.93
C9	cylindrical	white	white	68	3.2	0.494	2.8	7.1	0.7	0.62	1.62	1.74
A 28/7	bulbous	reddish	white	66	2.6	0.504	2.6	4.5	1.0	0.53	2.62	1.17

TABLE 5

Effect on baking properties of composite flour with different proportion of yam flour (baked under home conditions')

	% of yam flour in composite flour						
	0	5	10	15	20	25	30
<u>Loaf volume:</u>							
ml/g	3.3	3.4	3.5	3.6	3.5	3.3	3.1
ml/kg flour	5860	5940	6160	6380	6165	5850	5500
<u>Shape</u>	normal	normal	normal	normal	normal	slightly fallen	fallen
<u>Colour</u>							
crust	light brown	light brown	light brown	light brown	light brown	light brown	light brown
crumb	white	white	white	white	white	white	off-white
<u>Texture</u>							
crust	smooth	smooth	smooth	smooth	smooth	slightly rough	rough (few cracks)
crumb	good (cells even)	good (cells even)	good (cells even)	good (cells even)	good (cells even)	very fair (cells uneven)	fair (cells uneven)
<u>Taste</u>	good	good	good	good	good	good	good

TABLE 6

Formulation for flake-type breakfast foods using sweet potato flour as the base

Experiment No.	11	12	13	14	16	18	19
<u>Ingredients (% dry weight)</u>							
Sweet potato flour	94	82	13	50	50	50	50
Rice flour	-	-	-	44	34	22	12
Wheat flour (white)	-	-	-	-	-	20	35
Corn (maize) flour	-	12	-	-	10	-	5
Skim milk powder	4	4	4	4	4	-	-
Salt	2	2	2	2	2	3	3
Soya flour (whole)	-	-	12	-	-	-	-
Water (gms)	40	40	40	40	40	40	40
<u>Processing conditions</u>							
% dough moisture	range: 32 - 41%						
% moisture after drying	13 - 16%						
Roller spacing for pressing flakes (cold) (inches)	0.003						
Toasting temperature °C	210						
Moisture content of finished product	2 - 4						