Proceedings of the 13th ISTRC Symposium, 2007
pp. 240 - 247

Soil nutrient and cassava yield variations under continuous cultivation of three-crop mixtures in Eastern Nigeria

Asadu C.L.A.[1] and Dixon A.G.O.[2]
[1]Department of Soil Science, University of Nigeria, Nsukka (UNN), Nigeria
[2]International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

Abstract. A research farm at UNN which was under cultivation for >25 yrs before it was fallowed for 8 yrs, was cleared in 1998 and grown to three common crop mixtures for four years. The aim was to assess the performance of the cassava component under continuous cultivation relative to soil nutrient variations. The crop mixtures were cassava + pigeon pea, cassava + pigeon pea + maize, and cassava + pigeon pea + maize + yam. Incorporation of crop residues from each of the respective plots into the soils and the use of a legume (pigeon pea) served as means of restoring soil fertility. The experimental design was a randomized complete design (RCBD) replicated thrice each year. Changes in eight selected soil fertility indicators were monitored for the period. An analysis of the nutrient contents in the soils under the crop mixtures indicated narrow variations over the four years except in the cases of exchangeable cations where coefficients of variations of ≥25% were obtained. Comparatively, year-to-year variations were more substantial though not consistent. This is because in some years some nutrients decreased while others increased relative to the values obtained in the preceding year. Except in 1999 when cassava root yields from all the crop mixtures decreased substantially (>60%) relative to their 1998 respective values, the trends in other years were not consistent in all the crop mixtures. The mean yields obtained were generally below the expected mean yield for the same cassava variety in the area. The study also showed that all the soil parameters selected contributed to the variations in cassava yields though they were not consistent in each year and in each crop mixture. Thus, adequate management of these soil factors is required to enhance the performance of cassava in the crop mixtures.

Introduction

Intercropping (polyculture) is a well-known cropping system practised by most farmers in South Eastern Nigeria (SEN) for the production of most staple crops. The most popular crops found in mixtures are yam (*Dioscorea rotundata*), cassava (*Manihot esculenta*), maize (*Zea mays*) and pigeon pea (*Cajanus cajan*). The farmers generally adopt the intercropping (mixed cropping) system, with no special sequence of planting the crops. More than 70% of the food grown in the humid tropics, especially in Africa, comes from intercropping (IITA, 1984). In SEN about 80% of the farmers grow their crops in mixtures (Okigbo, 1978; Okorji, 1986). The numerous advantages of the system over sole cropping are well documented (Andrew, 1972; Finlay, 1974; Okigbo, 1978; Kantor, 1999) and appreciated by the farmers of SEN (Okorji, 1986; Asadu, 1997). Generally, yam- and cassava- based systems are the most popular among the farmers in SEN (Asadu, 1989). The importance of mixed cropping in the zone is hampered by shortened fallow periods or no fallow due to increasing population (Nweka *et al.*, 1994). The need for more and closer studies of the system especially with respect

to improving the soil management component for optimal yields and poverty alleviation is therefore imperative.

Most studies in the past on mixed cropping system have emphasized their advantages and constraints over sole cropping using yield parameters from component crops without due analysis of yield response to soil nutrient variations in the crop mixtures. The lack of information is more acute with respect to where continuous cultivation of the crop mixtures is practiced. The objectives of the study were to examine the yields of cassava from three crop mixtures under continuous cultivation as related variations in soil nutrients in the crop mixtures.

Materials and Methods

Study Location. The study was at the University of Nigeria, Nsukka (UNN) research farm fallowed for 8 years before the establishment of the trials in 1998. The soil has been classified as an alfisol (Asadu, 1990). Nsukka is located on Lat. 06° 52'N, Long. 07° 24'E within the derived savanna zone of SEN. It is on an average elevation of 447m above sea level. It usually has two seasons namely rainy and dry seasons. Average annual rainfall is about 1550 mm with more than 85% of this falling in the rainy season. The average minimum and maximum temperatures are about 22 and 30 °C respectively while the average relative humidity is rarely below 60%.

Crop mixtures and experimental design. Three crop mixtures were selected based on prior knowledge of the most common staple food crops grown by the local farmers in SEN: cassava + yam + maize + pigeon pea, cassava + maize + pigeon pea and cassava + pigeon pea. These crop treatments were arranged in a randomized complete block design and replicated three times for the four years beginning from 1998. Control sole crops were not included in this analysis because farmers in this area normally grow their crops in mixtures. The cassava variety used was TMS 30572, other crops were the local bests namely Nwopoko for yam Western Yellow for maize and *ogam-gam* for pigeon pea.

The trials were established between 15 and 18 May each year. Cassava and yam were planted at a spacing of 1m x 1m on the tip of the ridges on May 15 and 16 while maize and pigeon pea were planted by the sides of the ridges at the same spacing on May 17 and 18 respectively. However, two seeds of maize and two seeds of pigeon pea were planted per hole following the local farmers' practice. The ridges were made with local hoes. In each location, an area of 20 m^2 at the centre of each plot was harvested for the analysis following the elimination of discards at the edges. Cassava yield parameters analyzed were root yield and harvest index (HI).

Soil sampling and analysis. During the four years of the experimentation loose soil samples were collected from each of the three replicate plots at 0-20 cm depth before cultivation commenced. These loose soil samples were air-dried gently, crushed and sieved with a 2-mm sieve. The samples were analysed to determine chemical properties. The soil pH was determined in duplicate in water using Beckman's zeromatic pH meter and in a soil: liquid suspension of 1:2.5. Exchangeable bases were extracted with neutral, 1N ammonium acetate (NH_4OAc) while Ca and Mg were determined by atomic absorption spectroscopy. Potassium (K) and Sodium (Na) were determined using flame photometry. Total nitrogen was determined by the macro-Kjedahl wet oxidation method (Bremner, 1965). Organic carbon was determined by the method of Walkley and Black (1934), and this was converted to soil organic matter (SOM) by multiplying the percentage carbon by 1.724. Available P was determined by Bray 2 method (Bray and Kurtz, 1945).

Data analysis. The percentage changes (p) in soil and cassava yield parameters between two-crop years were calculated from $p = 100 (Y_2-Y_1)/Y_1$

where Y_1 = value of soil or cassava yield parameter in year 1

Y_2 = value of soil or cassava parameter in year 2 (year 1 precedes year 2 chronologically)

Results and Discussion

Soil Nutrient Variations. In cassava + pigeon pea (C+P) mixture, soil pH did not change substantially throughout the four year period. There was only a slight increase of about 2% (Table 1). There were increases in total N, SOM, exchangeable K, Ca and Mg in 1999 relative to the original values in 1998. On the other hand, available P and Na diminished in the reference years. All the fertility indicators except available P increased in 2000 relative to the 1999 values. Virtually all the nutrients except available P decreased in 2001 relative to the 2000 values. For the four years, only the exchangeable cations namely K, Ca, Mg and Na had coefficients of variation above 35%.

Table 2 also shows that in cassava + maize + pigeon pea mixture, soil pH did not vary substantially over the years. There was a slight decrease of 2% in 1999 relative to 1998 value while in 2000 and 2001 a slight increase of 2% each was obtained relative to the preceding years. Relative to the 1998 values, in 1999 there were increases in total N (H"10%), SOM (H"26%), exchangeable Mg (H" 86%) and exchangeable Ca (> 150%). Available P and exchangeable Na decreased by at least 30% while exchangeable K did not change (Table 2). In 2000 all the nutrients had increases except total N and available P which decreased by about 4% and 22% relative to the 1999 values respectively. Relative to the 2000 values, in 2001 there were increases in total N (H" 6%), SOM (H" 13%) and available P (H" 20%). All the exchangeable cations decreased by at least 8% relative to the 2000 values (Table 2). For the four years, variations over 25% were obtained for all the exchangeable cations and available P (Table 2).

Table 1: Mean ± SD of soil fertility indicators obtained from 0-20 cm soil depth in C+ P mixtures and relative changes over four years (1998-2001) in eastern Nigeria.

Soil fertility indicators	Mean ± SD				Relative changes (%)				Overall mean (cv)
	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs2000	2001 vs1998	
pH	4.6 ±0.26	4.7±0.20	4.8±0.06	4.9±0.00	+2.2	+2.1	+2.1	+6.8	4.8 (3)
Total N (%)	0.075±0.02	0.092±0.01		0.092±0.01	+22.7	+4.3	-4.2	+18.5	0.089(11)
SOM (%)	1.22±0.38	1.74±0.08	2.09±0.35	1.86±0.14	+42.6	+20.1	-11.0	+52.5	1.73(21)
Avail. P (mg kg^{-1})	7.0±2.00	6.7±0.58	5.3±0.58	6.1±0.00	-4.3	-20.9	+15.1	-12.9	6.3(12)
Exc K (cmol kg^{-1})	0.06±0.01	0.08±0.03	0.13±0.02	0.13±0.01	+33.3	+62.5	0.0	+116.7	0.1(36)
Exc Ca (cmol kg^{-1})	0.67±0.21	2.10±0.17	2.97±0.85	1.93±0.12	+213.4	+41.4	-35.0	+188.1	1.92(49)
Exc Mg (cmol kg^{-1})	0.57±0.21	1.37±0.60	1.60±0.36	1.27±0.46	+140.4	+16.8	-20.6	+122.8	1.20(37)
Exc Na (cmol kg^{-1})	0.15±0.03	0.08±0.03	0.26±0.04	0.19±0.02	-46.7	+223.0	-26.9	+26.7	0.17(44)

Note: SD = standard deviation, cv = coefficient of variation (%), (+) = increase, (-) = decrease in the preceding year except in 2001vs 1998

Table 2: Mean ± SD of soil fertility indicators obtained from 0-20 cm soil depth in C+ M + P mixtures and relative changes over four years (1998-2001) in eastern Nigeria.

Soil fertility indicators	Mean ± SD				Relative changes (%)				Overall mean (cv)
	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs2000	2001vs 1998	
pH	4.8±0.15	4.7±0.15	4.8±0.1	4.9±0.00	-2.1	+2.1	+2.1	+2.1	4.8(2)
Total N (%)	0.082±0.02	0.090±0.01	0.086±0.01	0.091±0.00	+9.8	-4.4	+5.8	+11.0	0.087(5)
SOM (%)	1.41±0.38	1.77±0.15	1.79±0.07	2.02±0.08	+25.5	+1.1	+12.8	+43.3	1.75(14)
Avail. P (mg kg^{-1})	8.7±3.51	6.0±1.00	4.7±0.58	5.6±0.46	-30.0	-21.7	+19.1	-35.6	6.3(28)
Exc K (cmol kg^{-1})	0.07±0.00	0.07±0.01	0.13±0.02	0.12±0.00	0.0	+85.7	-7.7	+71.4	0.10(33)
Exc Ca (cmol kg^{-1})	0.70±0.20	2.03±0.75	3.27±1.62	1.97±0.15	+190	+61.1	-39.8	+181.4	1.99 (53)
Exc Mg (cmol kg^{-1})	0.70±0.20	1.30±0.52	1.47±0.72	1.27±0.50	+85.7	+13.1	+13.6	+81.4	1.19(28)
Exc Na (cmol kg^{-1})	0.14±0.04	0.07±0.03	0.26±0.02	0.18±0.00	-50.7	271.4	-30.5	+28.5	0.16(48)

Note: SD = standard deviation, cv = coefficient of variation (%), (+) = increase, (-) = decrease in the preceding year except in 2001vs 1998.

From Table 3, soil pH also exhibited the least variation both between years and across the four years in the cassava + yam + maize + pigeon pea mixtures. In 1999 available P and exchangeable Na decreased by 17 % and 39 % respectively relative to the 1998 values. Except exchangeable K that did not change, there were increases in other nutrients ranging from about 22% in total N to > 200% in exchangeable Ca (Table 3). Relative to 1999 values, in 2000 all the exchangeable cations had substantial increases ranging from about 50% in exchangeable Mg to >200% in exchangeable Na. On the other hand, total N and SOM had slight decreases while exchangeable K did not change. Relative to 2000 values, in 2001 total N did not change whereas there were increases in SOM (about 13%) and exchangeable K (about 8%). Other nutrients decreased by at least 24% (Table 3). For the four years only exchangeable cations had variations of up to 30% the highest being 56% exhibited by exchangeable Ca.

Generally, the mean soil pH values in both 1998 and 1999 were acid (4.5 <pH< 5.0) based on the USDA-SCS (1974) classification. These values are generally below the range (5.2-7.0) recommended for cassava by the FAO (1998).

The mean values of total N in each year appeared to be low and below the critical levels for cassava (Metson, 1961; Enwezor *et al.*, 1989) irrespective of some observed increases. Similarly, the contents of SOM and available P appeared to be inadequate for the good performance of cassava each year based on the recommendation by Howeler (1996). The mean exchangeable K values obtained were generally below 0.2 cmol kg^{-1}, the critical level below which most crops will respond to K application (Meredith, 1965). The increases in exchangeable K obtained in 2000 under each crop mixture could be due to the incorporated crop residues since organic materials are also sources of K in soils (Asadu and Nweke, 1999). The mean values of exchangeable Ca obtained in each year appeared to be adequate since all are well above 0.2 cmol kg^{-1} , the critical level that will elicit Ca response by most crops (Meredith, 1965). Similarly all the values of

Table 3: Mean ± SD of soil fertility indicators obtained from 0-20 cm soil depth in C+ M + P +Y mixtures and relative changes over four years (1998-2001) in eastern Nigeria.

Soil fertility indicators	Mean ± SD				Relative changes (%)				Overall mean (cv)
	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs2000	2001vs1998	
pH	4.6±0.35	4.6±0.12	4.8±0.06	4.9±0.00	0.0	+4.3	+2.1	+6.5	4.7(3)
Total N (%)	0.076±0.01	0.093±0.01	0.092±0.01	0.092±0.00	+22.4	-1.1	0.0	+21.1	0.088(9)
SOM (%)	1.31±0.23	1.91±0.08	1.77±0.21	2.00±0.21	+45.8	-7.3	+13.0	+52.7	1.75(16)
Avail. P (mg kg^{-1})	9.3±2.51	7.7±1.15	7.7±1.15	5.8±0.46	-17.2	0.0	-24.7	-37.6	7.6(19)
Exc K (cmol kg^{-1})	0.07±0.03	0.07±0.02	0.12±0.00	0.13±0.00	0.0	+71.4	+8.3	+85.7	0.10(33)
Exc Ca (cmol kg^{-1})	0.63±0.06	2.07±0.75	3.52±0.71	2.33±0.42	+228.6	+70.5	-34.0	+269.8	2.14(56)
Exc Mg (cmol kg^{-1})	0.47±0.12	1.27±0.46	1.93±0.11	1.23±0.35	+170.2	+52.0	-36.3	+161.7	1.23(49)
Exc Na (cmol kg^{-1})	0.13±0.03	0.08±0.03	0.24±0.04	0.18±0.00	-38.5	+200.0	-25.0	+38.5	0.16(43)

Note: SD = standard deviation, cv = coefficient of variation (%), (+) = increase, (-) = decrease in the preceding year except in 2001vs 1998.

exchangeable Mg were $\geq$ 0.5 cmol kg^{-1} the critical level that will elicit Mg response by most crops (Landon, 1991). The increases in exchangeable Ca in 1999 and 2000 may also be attributed to the incorporated organic material from crop residues. The exchangeable Na contents in the soils were not high enough (>15% ESP) to induce deleterious effects on the crops (Landon, 1991).

The analysis of the cumulative variation (2001 vs 1998) shows that the order of enrichment of total N, exchangeable Ca, Mg and Na among the crop mixtures is C+M+P+Y>C+P>C+M+P (Tables 1-3). The order of SOM enrichment is almost the same, C+M+P+Y=C+P>C+M+P while that of exchangeable K is in the order C+P>C+M+Y+P>C+M+P. Only available P decreased over the four year comparison in the order C+M+Y+P>C+M+P>C+P. It is clear that the soil nutrient variations in the crop mixtures except in the cases of exchangeable K and available P were related to SOM dynamics, a relationship very much well known.

Cassava yields and soil nutrient variations. The root yields obtained from the crop mixtures were not significantly affected by the number of crops in each mixture. The highest mean values obtained were at the beginning of the trials in 1998 (Table 4). These were the only values fairly close to that obtained using the same cassava variety (TMS 30572) in Nsukka environment (Nnodu *et al.*, 1995). The highest yield depressions (about 62-81%) occurred in 1999. The soil nutrient that might have accounted for these depressions was a decrease in the available P (Tables 1-3). The soil under C+M+P mixture with the highest decrease (30%) in available P (Table 2) produced the highest (80%) decrease in root yield (Table 4). The decrease in available P could have caused some negative nutrient interaction among other nutrients leading to a decreased root yield since available P is one of the major nutrients required by cassava in large amounts (Howeler, 1996).

The slight increases in cassava root yields (4%) in 2000 (Table 4) relative to the observations recorded in 1999 from C + P mixture might be attributed to slight increases in total N, SOM and all the exchangeable bases (Table 1). In the case of C + M + P mixture the observed yield increase (40%) is surprising because there was a substantial increase in exchangeable cations and only slight increase in SOM (Table 2). The 30% decrease in root yield obtained in C + M + P + Y mixture (Table 4) is also surprising because there were only slight decrease in total N and SOM in the reference years (Table 3).

The slight decrease in root yield in 2001 (Table 4) in C+P mixture is evident from the slight decreases in total N and SOM as well as decreases in exchangeable Ca, Mg and Na (Table 1). On the other hand, the slight decrease in yield (about 9%) obtained from C+ M + P mixture might be associated with the observed decreases in all the exchangeable cations (Table 2). The increase in yield in C + P + M + Y mixture might be associated with the observed increases (Table 3) in total N (about 13%), and exchangeable K (about 8%).

In general, the results of the regression analyses between the relative root yields of cassava and the different changes in soil fertility indicators over the four years (Table 5) show that the most significant indicators

Table 4: Summary of cassava root yields and harvest index from the three crop mixtures and relative changes over four years (1998-2001) in eastern Nigeria.

Crop mixtures	Fresh root yield (t ha^{-1})				Relative changes (%)		
	1998	1999	2000	2001	1999 vs 1998	2000 vs 1999	2001 vs 2000
C + P	10.0	2.4	2.5	2.4	-76.0	+4.2	-5.1
C + M + P	11.9	2.3	3.2	2.9	-80.7	+39.1	-9.1
C + M + P +Y	8.4	3.1	2.2	4.0	-61.7	-29.0	+84.3
Harvest index							
C + P	0.67	0.63	0.55	0.61	-6.0	-12.7	+10.9
C + M + P	0.67	0.53	0.57	0.61	-23.2	+7.5	+7.0
C + M + P +Y	0.66	0.58	0.60	0.64	-12.1	+3.4	+6.7

Notes: C = cassava, M = maize, P = pigeon pea, Y = yam; (+) = increase, (-) = decrease in the preceding year.

Table 5: Regression parameters obtained between the relative root yields of cassava and relative changes in soil nutrients.

Soil parameter	Intercept	Slope	R^2 /significant level
pH	-37.1	13.4	0.19^{ns}
Total N (%)	8.1	-3.7	0.51^{*}
SOM (%)	7.9	-1.4	0.28^{ns}
Avail. P (mg kg^{-1})	-17.6	-0.3	$<0.01^{ns}$
Exc K (cmol kg^{-1})	-24.5	0.3	0.05^{ns}
Exc Ca (cmol kg^{-1})	15.5	-0.4	0.61^{**}
Exc Mg (cmol kg^{-1})	16.0	-0.6	0.69^{***}
Exc Na (cmol kg^{-1})	-22.5	0.1	0.13^{ns}

Note: $^{ns, *, **, ***,}$ = not significant, significant at 0.05, 0.01 and < 0.001 probability levels respectively.

($p \leq 0.05$) are total N, exchangeable Ca and Mg as indicated by the R^2 values.

The changes in harvest index (HI) were generally small. However, there were consistent decreases between 1999 and 1998, and consistent increases between 2001 and 2000 (Table 4). The former may be associated with slight decrease in available P in C+P mixture, decreases in total N and available P in the C+M+P mixture and decreases in total N and SOM in the C+P+Y+Y mixture (Tables 1-3). The 13% decrease in HI in C + P mixture in 2000 could be due to the decrease in available P (Table 2). The slight increases in HI in 2000 relative to 1999 in the other two crop mixtures could be due to observed increases in all the exchangeable cations (Tables 2 and 3). Again the slight increases in HI in all the crop mixtures in 2001 relative to 2000 values (Table 4) could be due to an increase in available P in the case of C+P mixture (Table 1), increases in total N, SOM and available P in the case of C+P+M mixture (Table 2) and increases in SOM and available P in the case of C+P+M+Y mixture (Table 3).

Conclusion

An analysis of the variations in eight soil fertility indicators over four years in three crop mixtures in eastern Nigeria indicates that only the exchangeable cations namely K, Ca, Mg and Na varied substantially with cvs ranging from about 25% to 56%. However, year-to-year comparison indicated more substantial but inconsistent variations.

Cassava root yields decreased substantially (>60%) in all the crop mixtures in 1999 relative to the 1998 values. In 2000 there were slight increase (<5%) in C + P and large increase (about 40%) in C + P + M mixtures and up to 29% decrease in C + P + M + Y mixture relative to the 1999 values. On the other hand, the 2001 yields from C + P and C + P + M mixtures were above 90% of the respective yields obtained in 2000 indicating slight deceases where as there was an increase of about 80% in the C + P + M + Y mixture relative to the 2000 yield. The harvest index decreased in all the crop mixtures in 1999 relative to the 1998 values and in the C+P mixture in 2000. There were slight increases in both C+M+P and C+M+P+Y mixtures in 2000 and in all the crop mixtures in 2001. Generally, the variations in cassava yields over the four years appeared to be associated with all the fertility indicators implying clear evidence of interactions among the nutrients. Thus these indicators need to be adequate in the soils for cassava to perform well in the crop mixtures.

References

Andrew, D.J. 1972. Intercropping with sorghum in Nigeria. Exptl. Agric. 13: 139-150.

Asadu, C.L.A. 1989. A Comparative Study and Evaluation of Yam-zone Soils and the Performance of six Cultivars of white Yam (*D. rotundata*) in Southeastern Nigeria. *Ph.D. Thesis* University of Nigeria, Nsukka.

Asadu, C.L.A. 1990. A Comparative Characterization of two foot-slope soils in Nsukka area of Eastern Nigeria. Soil Sci. 150: 527-534.

Asadu, C.L.A., 1997. The optimum time of yam-mound remoulding for cassava introduction in yam fields in eastern Nigeria. Trop. Agric. (Trinidad) 74(4): 308-312.

Asadu, C.L.A. and F.I. Nweke. 1999. Soils of Arable Crop Fields in sub-Saharan Africa: Focus on cassava-growing Areas. Collaborative Study of Cassava in Africa Working Paper No 18. IITA, Ibadan, Nigeria. 182 pp.

Bray, R.H. and L.T. Kurtz. 1945. Determination of total organic and available forms of phosphorus in soil. Soil Sci. 59: 39-45.

Bremner, J.M. 1965. Total nitrogen. In Methods of Soil Analysis, Agronomy No 9 Part 2. C.A. Black (ed.) American Society of Agronomy, Madison, Wisconsin.

Enwezor, W.O., E. J. Udo, N.J. Usoroh, K.A. Ayotade, J.A. Adepetu, V.O. Chude and C.I. Udegbe. 1989. Fertilizer Use and Management Practices for Crops in Nigeria

Series No. 2. Bobma Publishers, U.I. P.O. Box 9555, Ibadan.

Finlay, R.C. 1974. Intercropping soybeans with cereals. In. Proceedings Regional Soybean Conference, Addis Ababa, Ethiopia.

FAO (Food and Agriculture Organization). 1998. World Soil Resources Report, Agroecological Zone Projects vol. 1 Methodology and Results for Africa. FAO, Rome, Italy.

Howeler, R. 1996. Mineral nutrition in cassava. Pp 110-116 in Mineral nutrient disorders of root crops in the Pacific (E.T. Cranwell, C.J. Asher and J.N. O'Sullivan, Eds). Proceedings of the Workshop on mineral Disorders in Root Crops. Nukualofa, Kingdom of Tonga, 17-20 April 1995.

IITA (International Institute of Tropical Agriculture)., 1984. Maize plant "architecture", important factor in intercropping with cassava. In. Farming Systems Program Research Highlights 1981-1984. IITA, Ibadan, Nigeria.

Kantor, S. 1999. Intercropping. Agricultural and Natural Resources Fact Sheet. Washington State University, Cooperative Extension King County. #531: Pp1-2.

Landon, J. R. (Ed.) 1991. Booker Tropical Soil Manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. John Wiley and Sons Inc., 605 Third Avenue, New York. USA. 474p

Meredith, R.N. 1965. A review of the responses of fertilizer of the crops of Northern Nigeria. Samaru Misc. Papers. No. 4. Zaria, Nigeria.

Metson, A.J. 1961. Methods of chemical analysis for soil survey samples. New Zealand DSIR Soil Bulletin 12. Government Printer, Willington, New Zealand.

Nnodu, E.C., J.E. Okeke, and A.G.O. Dixon. 1995. Evaluation of newly improved cassava varieties for Nigerian ecologies. Pp207-216 In: Root Crops and poverty Alleviation, Proceedings Sixth Triennial Symposium. Intern. Soc. Trop. Root Crops- AB, 22-28 Oct 1995, Lilongwe, Malawi.

Nweke, F.I., A.G.O. Dixon, R. Asiedu, and S.A. Folayan. 1994. Cassava varietal needs of farmers and potentials for production growth in sub-Saharan Africa. COSCA Working Paper No. 10 Collaborative Study of Cassava in Africa. International Institute of Tropical Agriculture Ibadan, Nigeria.

Okigbo, B.N. 1978. Cropping Systems and Related Research in Africa. Association for Advancement of Agricultural Sciences in Africa (AAASA)., Occasional Publication Series OTI, 81 p.

Okorji, E.C. 1986. Productivity of yam under alternative cropping systems adopted by small-holder farmers of southeastern Nigeria. Agric. Syst. 22, 231-241.

USDA-SCS. 1974. Definition and Abbreviation for Soil Description. West Technical service Center, Portland, Oregon.

Walkley, A. and I. A. Black. 1934. Determination of organic carbon in soil. Soil Sci. 37: 29-39.