RESPONSE OF TARO, *COLOCASIA ESCULENTA* (L) Schott TO WATER MANAGEMENT PLOT PREPARATION AND POPULATION

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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 défaillants, le rendement des tiges bulbleuses 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 facon 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 atribuíbles 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.[15] 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 suggested[10]. This study was undertaken to determine the effects of some cultural adjustments on taro. Enyi[8] 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. Milthorpe[13] 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 taro[16]. 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.

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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 months[4]. Maturity is indicated by specific gravity[2]. 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 Chapman[3]. 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(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 (AI) to 2.8 and declined with further increase to LAI. The equation of this relationship was $Y=128x^{½}-39.9x-67.0$ ($R^2=0.64$) 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 $Y=4.5x^2-0.56x^3-22.0x^{½}+54$. 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: $Y=210x^{½}+0.25x^3 65.6x-120.6$ ($R^2=0.87^{**}$).

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 nutrients 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 growth[14]. 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 lead 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. Statior

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 selectec 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

	Months after planting					
	7	10	13	7	10	13
Irrigation method	Tons per ha* Total yield			Kg per plant* 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)

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 corm 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 corm 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 corm yield of taro — main and sucker corm 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		
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 Main	Six months Sucker	Nine months Main	Nine months Sucker	Twelve months Main	Twelve months 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, 1967[5]

TABLE 9

Nutrient content of taro petioles under different water treatments: sprinkler (SP), furrow (FU), flood or paddy (PA) irrigation

Element	SP	FU	PA	LSD 0.05	
	Treatment				
	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	%	7-21	%	Total
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.