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Growth rates of three cassava varieties (*Manihot esculenta* Crantz) under varying population densities

By B. A. C. ENYI*

Faculty of Agriculture, University of Dar es Salaam, Morogoro, Tanzania

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SUMMARY

The effect of variety and spacing on growth, development and yield of cassava and the relationship between growth, development and yield in three cassava varieties were investigated during the 1971 and 1972 growing seasons. Msitu Zanzibar outyielded Aipin Valenca and these two varieties in turn outyielded Amani 4026/16. The varietial effect was associated with differences in the rate of bulking. Increase in plant density led to an increase in the yield of tubers per hectare, the mean increase with increasing plant density being greater in Aipin Valenca than in either Amani 4026/16 or Msitu Zanzibar. Increase in plant density from 12000 to 18000 plants/ha led to a decrease in root tuber yield in Amani 4026/16. The calculated optimum density for maximum yield was 6·7, 6·4 and 5·6 plants/m² respectively for Msitu Zanzibar, Aipin Valenca and Amani 4026/16. The spacing effect on tuber yield was associated with differences in the rate of bulking. Aipin Valenca was usually taller than the other varieties and, in general, increase in plant density increased the height of the plants.

Final total dry matter/m² was greater in Aipin Valenca and Msitu Zanzibar than in Amani 4026/16 and, with the exception of the last variety, total dry matter/m² increased with increasing plant density. Total dry matter produced per plant was greater in Msitu Zanzibar than in Aipin Valenca and these two varieties had greater dry weight per plant than Amani 4026/16. In the three cassava varieties, the dry weight per plant increased with decreasing plant density.

A greater proportion of the total dry matter was diverted into the root tubers of Aipin Valenca and Msitu Zanzibar than in Amani 4026/16. Generally, increase in plant density decreased the proportion of total dry matter diverted into the root tubers. Mean crop growth rate increased with increasing plant density while mean net assimilation rate and relative growth rate decreased with increasing plant density. Amani 4026/16 and Aipin Valenca had a greater mean crop growth rate and a greater net assimilation rate than Msitu Zanzibar. Mean relative growth rate was greater in the latter than in the former two varieties.

Leaf area index and leaf area duration were greater in Msitu Zanzibar than in the other two varieties and these tended to increase with increasing plant density.

There was a close and positive relationship between rate of bulking and root tuber yield and the lack of a positive relationship between leaf area duration and tuber yield is discussed.

INTRODUCTION

Williams & Ghazali (1969), working on high-, medium- and low-yielding clones of cassava, found that the lowest yielding variety had the greatest leaf area per stem. They showed that the leaves of the highest yielding variety possessed attenuated lobes with a more vertical midday orientation, while the lowest yielding variety possessed large broad-lobed leaves with a more horizontal orientation. Bremner & Taha (1966) compared the growth and yield of two varieties of Irish potato and found that total tuber yield of Majestic was greater than that of King Edward. The superiority of Majestic over King Edward was attributed to earlier tuber initiation and a greater persistence of tuber bulking of the former than of the latter variety. Enyi (1972*a*) showed that the superiority of large seeds of the lesser yam (*Dioscorea esculenta*) over small seeds in tuber yield

* Change of address. Faculty of Agriculture, University of Papua, New Guinea.

was brought about by the greater number of tubers, leaf area duration and bulking rate of the former than of the latter.

Various experiments on root crops have shown that tuber yield increases with increasing plant density (Bremner & Taha, 1966; Findlay & Sykes, 1938; Enyi, 1972*a*). However, Enyi (1967) showed that the yield of corms of *Xanthosoma sagittifolium* Schott increased with decreasing plant density.

This paper is concerned with the growth rates of three cassava varieties, grown in Tanzania, and the relationship between growth, development and tuber yield and how these are affected by variation in spacing.

MATERIALS AND METHODS

The experiment was conducted at the Morogoro Faculty of Agriculture Farm in Tanzania during the 1971 and 1972 growing seasons. The experimental design was à 3^2 factorial with four replications in randomized blocks. The spacing treatments were 90×60 cm (S_1), 90×90 cm (S_2) and 90×120 cm (S_3) and the three cassava varieties were Amani 4026/16 (V_1) Aipin Valenca (V_2) and Msitu Zanzibar (V_3). The soil is a clay loam and had carried maize the previous year. The setts (30 cm long), obtained from 12-month-old matured stems were planted on ridges 30 cm high and 90 cm apart on 8 January 1971. Each plot, which was about 0·04 ha received basic dressing of 336 kg/ha of sulphate of ammonia, 280 kg/ha of double superphosphate and 224 kg/ha of sulphate of potash. The fertilizers were placed in small furrows 3·5 cm deep and about 3 cm wide and covered up immediately after application. The plots were weeded four times during the 1971 growing season and once during the 1972 growing season. Enyi (1972*c*) showed that single-shoot plants of cassava outyielded multi-shoot plants, and so all the shoots except one of the cassava setts in the present experiment were removed 2 weeks after planting. The plots were inspected at regular intervals to remove shoots that developed after the first shoot removal operation.

Seventy-two days after planting an assessment of the plants was made so as to ascertain the proportion of the total number of plants in each plot showing symptoms of mosaic.

Sampling began 113 days after planting and continued at 4-weekly intervals until 4 December in 1971 and between 5 February and 29 April in 1972. Each sample consisted of four adjacent plants taken from each plot in a random fashion. Plants were pulled out from the ridges, soil washed out of their root tubers and then separated into leaf blades, petioles, root tubers and stems for fresh-weight determination. Subsamples of the weighed fresh materials were dried in an ov and the dry weight of various organs determined by proportion. For leaf-area measurements, the disk method was used and the cross-sectional area of the punch used was 2·23 cm^2. Only whole disks were used in calculating the area–weight relationship of the subsamples. Usually 100 disks were taken.

On 27 May 1972 plants from 1080 dm^2 of land were harvested from each plot for the determination of yield of root tubers.

RESULTS

The rainfall data for 1971 and 1972 are shown in Table 1. The expected annual rainfall for this area is between 875 and 1000 mm and most of this falls between December and May. The total rainfall for 1971 was therefore below, while that for 1972 was slightly above, the expected rainfall in this area. In both years most of the rain fell between December and May. The heaviest rainfall in 1971 occurred in April and after this month it declined and between August and November the amount of rainfall was negligible. For most months the amount of rainfall in 1972 was greater than that in 1971.

Seventy-two days after planting, the percentages of plants showing symptoms of mosaic in Aipin Valenca, Msitu Zanzibar and Amani 4026/16 were respectively 10·7, 6·1 and 4·0.

Plates 1 and 2 show the foliage characteristics of the three cassava varieties. The leaves of Amani 4026/16 and Msitu Zanzibar possessed narrower individual lobes than those of Aipin Valenca. The results of measurements of leaf angle showed that the angle of orientation of the leaves from the horizontal at midday was approximately 45, 50 and 25° respectively for Amani 4026/16, Msitu Zanzibar and Aipin Valenca.

Root tuber yield at harvest and yield components

The three varieties of cassava mature within a period of 15 months from the time of planting. In Aipin Valenca and Msitu Zanzibar root tuber yield per hectare increased with increasing plant density, but in Amani 4026/16 there was a reduction in tuber yield within an increase in plant density from 12 to about 18 thousand plants/ha. On average, increase in the plant population from 9000 to 12000 and 18000 plants/ha increased tuber yield by 91 and 84% respectively. In Amani 4026/16 increase in plant population from 9000 to 12000 and 18000 plants/ha increased tuber yield by 129 and 33% respectively. In Aipin Valenca increase in the plant population from 9000 to 12000 and 18000 plants/ha increased tuber yield by 99 and 122% respectively and in Msitu Zanzibar increasing the plant population from 9000 to 12000

Table 1. *Mean monthly rainfall (mm) at the Faculty Farm in 1971 and 1972*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
124·6	37·6	63·9	227·0	58·6	22·0	21·8	0·0	3·9	6·0	3·7	34·5	603·6–1971
109·3	116·4	177·0	165·9	152·9	0·0	26·1	14·2	22·8	83·0	71·3	107·2	1046·1–1972

Table 2. *Root tuber yield per hectare and per plant*

Spacing	Plant population/ha	Variety (t/ha)				Mean	Variety (kg/plant)				Mean
		Amani 4026/16	Aipin Valenca	Msitu Zanzibar			Amani 4026/16	Aipin Valenca	Msitu Zanzibar		
90 × 60 cm (S_1)	18500	37·2	78·1	84·6	±7·2	66·6	2·6	4·2	4·6	±0·68	3·8
90 × 90 cm (S_2)	12346	63·9	70·1	73·2		69·0	4·5	5·6	5·9		5·3
90 × 120 cm (S_3)	9259	27·9	35·2	45·3		36·1	4·8	8·0	10·3		7·7
Mean		43·0	61·1	67·6		±4·8	4·0	5·9	6·9		±0·45

Table 3. *Effect of variety and spacing on bulking rate*

Spacing	Plant population/ha	Variety (kg/ha/week)				Mean	Variety (g/plant/week)				Mean
		Amani 4026/16	Aipin Valenca	Msitu Zanzibar			Amani 4026/16	Aipin Valenca	Msitu Zanzibar		
90 × 60 cm (S_1)	18500	8250	15510	11520	±728	11760	37·9	65·4	79·2	±11·3	60·8
90 × 90 cm (S_2)	12346	7730	11890	11310		10310	63·7	72·0	100·5		78·7
90 × 120 cm (S_3)	9259	3230	5680	4770		4560	78·5	119·7	129·2		109·1
Mean		6400	11030	9200		±485	60·0	85·7	102·9		±7·5

and 18000 plants/ha increased tuber yield by 62 and 87% respectively.

In Amani 4026/16 plant population of about 12000 plants/ha gave significantly greater tuber yield than plant population of about 9000 plants/ha. Aipin Valenca and Msitu Zanzibar significantly outyielded Amani 4026/16 at a population of about 18000 plants/ha and Msitu Zanzibar outyielded Amani 4026/16 at a population of about 9000 plants/ha. A plant population of 12000 plants/ha gave significantly greater root-tuber yield than 9000 plants/ha in all three cassava varieties. In Aipin Valenca and Msitu Zanzibar the difference between tuber yield/ha at a population of about 12000 and 18000 plants/ha was not significant, but in Amani 4026/16 an increase in population from 12000 to 18000 plants/ha significantly reduced root tuber yield.

In the three cassava varieties decrease in plant density increased root-tuber yield per plant, the difference between populations of 9000 and 12000 plants/ha being significant in Aipin Valenca and Msitu Zanzibar and between populations of 12000 and 18000 plants/ha in Amani 4026/16 (Table 2). Tuber yields per plant in Aipin Valenca and Msitu Zanzibar were significantly greater than that of Amani 4026/16 at populations of 18000 and 9000 plants/ha. Tuber yield per plant of Msitu Zanzibar was significantly greater than that of Aipin Valenca only at a population of 9000 plants/ha.

The effects of the treatments on bulking rates are shown in Table 3. In all three cassava varieties mean bulking rate/ha for the experimental period increased with increasing plant density, the difference in the bulking rate between plants at populations of 9000 and 12000 plants/ha being significant in the three varieties and between plants at populations of 12000 and 18000 plants/ha in Aipin Valenca. The effect of spacing on bulking rate is in accordance with the findings of Enyi (1972*a*) for lesser yam and Bremner & Taha (1966)

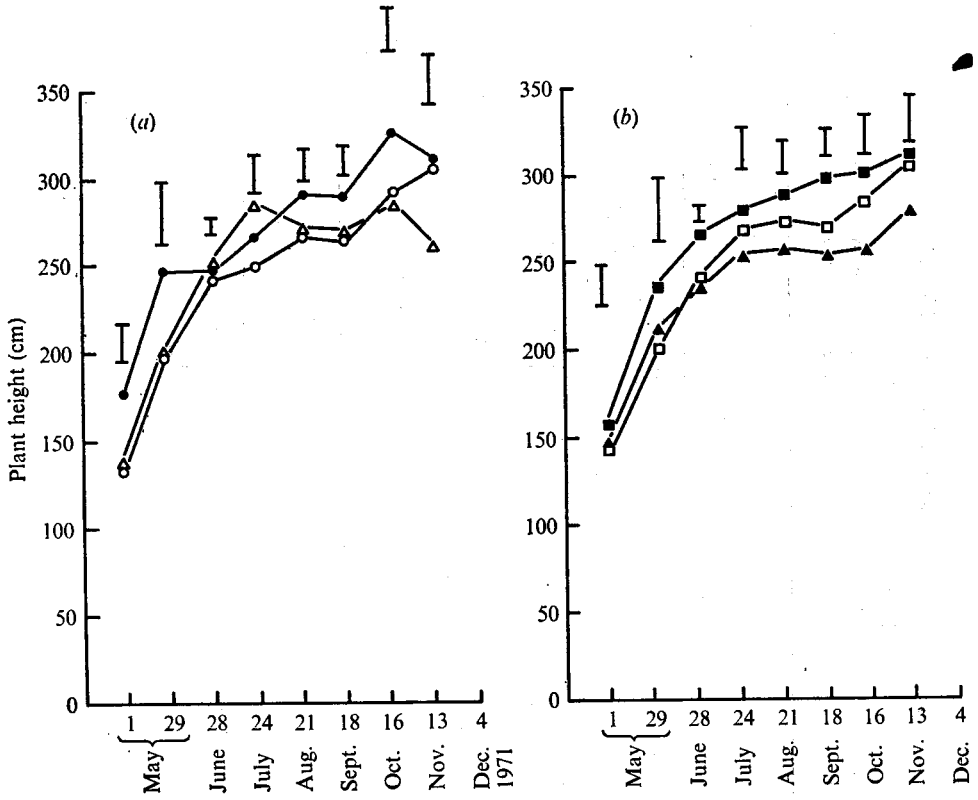

Fig. 1. Effect of (*a*) variety and (*b*) spacing on changes with time in plant height. ○——○, Amani 4026/16; ●——●, Aipin Valenca; △——△, Msitu Zanzibar; ■——■, 90 × 60 cm; □——□, 90 × 90 cm; ▲——▲, 90 × 120 cm. In this and other graphs vertical lines indicate least significant difference ($P = 0{\cdot}05$).

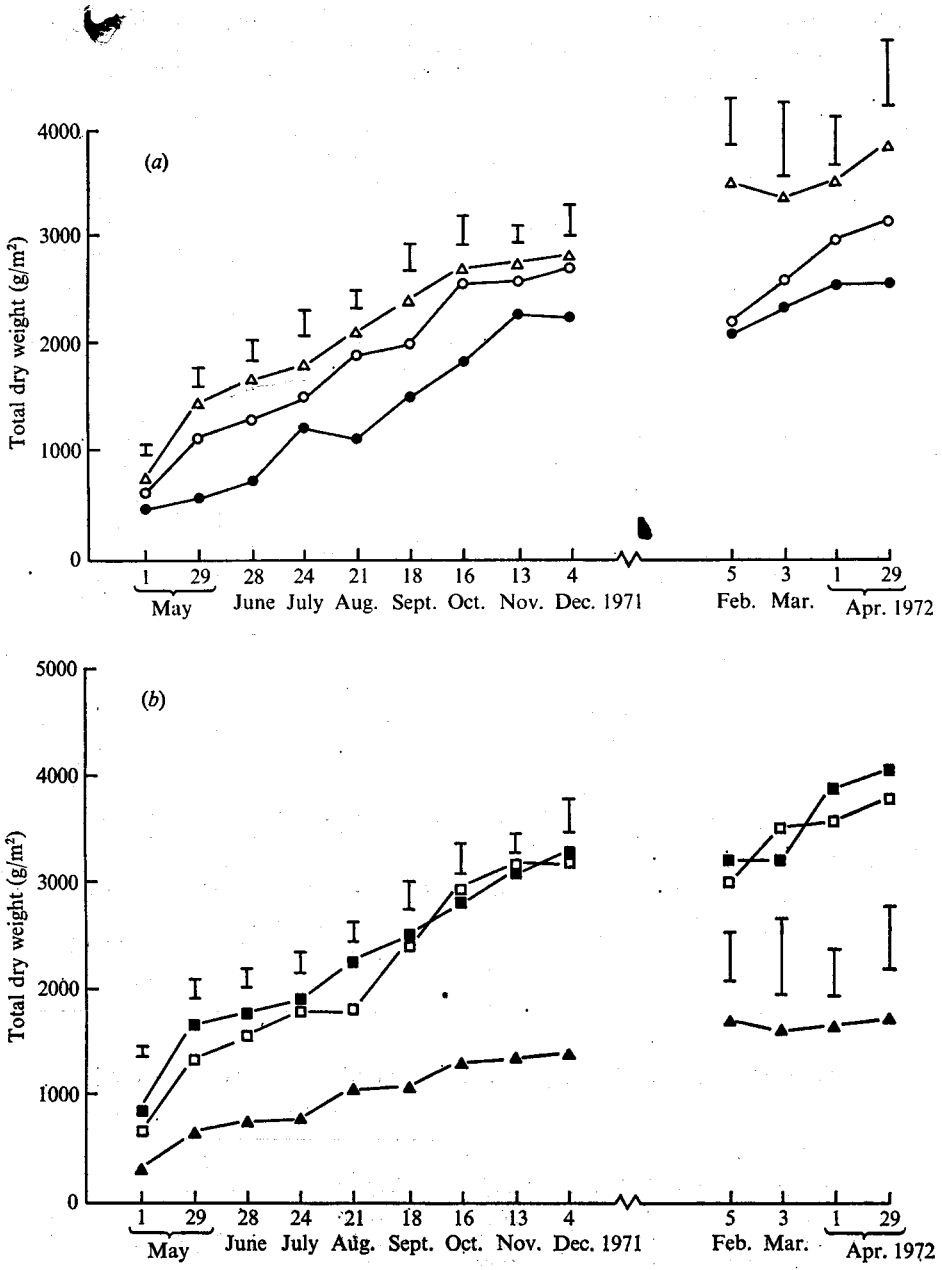

Fig. 2. Effect of (*a*) variety and (*b*) spacing on changes with time in total dry weight. ○——○, Amani 4026/16; ●——●, Aipin Valenca; △——△, Msitu Zanzibar; ■——■, 90 × 60 cm; □——□ 90 × 90 cm; ▲——▲, 90 × 120 cm.

for Irish potato. Mean bulking rates/ha for Msitu Zanzibar and Aipin Valenca were significantly greater than that of Amani 4026/16 at populations of 12000 and 18000 plants/ha. At a population of 9000 plants/ha mean bulking rate was significantly greater in Aipin Valenca than in Amani 4026/16. Msitu Zanzibar had significantly greater bulking rate than Aipin Valenca at a population of 12000 plants/ha, while Aipin Valenca had significantly greater bulking rate/plant than Amani 4026/16 at populations of 9000 and 18000 plants/ha. Msitu Zanzibar had significantly greater bulking rate/plant than Amani 4026/16 at all the population densities.

Plant height

Aipin Valenca plants were taller than the other two varieties (Fig. 1) and the height of the plant increased with increasing plant density.

Accumulation and distribution of dry matter

Total dry-matter accumulation was greater in Aipin Valenca and Msitu Zanzibar than in Amani 4026/16 and the accumulation in Msitu Zanzibar greater than that of Aipin Valenca (Fig. 2). Significant differences in the total dry-matter accumulation between Aipin Valenca and Msitu Zanzibar occurred between 1 May and 16 November in 1971 and between 5 February and 29 April in 1972. Significant differences in total dry-matter accumulation between Msitu Zanzibar and Amani 4026/16 occurred throughout the sampling period and with the exception of 5 February, 3 March and 29 April the differences in the total dry-matter accumulation between Aipin Valenca and Amani 4026/16 were statistically significant throughout the sampling period.

The final total dry weights in Aipin Valenca and Msitu Zanzibar were significantly greater than that of Amani 4026/16 at a population of 18000 plants/ha and total dry weight in Msitu Zanzibar significantly greater than that of Amani 4026/16 at a population of 12000 plants/ha (Table 4).

Plants at populations of 12000 and 18000 plants/ha had significantly greater dry weight/m² than those at a population of 9000 plants/ha throughout the sampling period (Fig. 2).

With the exception of Amani 4026/16 increase in plant density increased the final total dry matter produced by the cassava varieties, the differences being significant in all the varieties when the population was increased from 9000 to 12000 plants/ha (Table 4). In all the varieties final total dry matter/ha produced at a population of 18000 plants/ha was greater than that produced at 9000 plants/ha (Table 4).

On average, increase in the plant population from 9000 to 12000 and 18000 plants/ha increased total dry-matter content in the plants by 118 and 136 % respectively. In Amani 4026/16 increase in plant population from 9000 to 12000 and 18000 plants/ha increased dry-matter yield by 145 and 128 % respectively. In Aipin Valenca the increase was 100 and 139 % respectively and in Msitu Zanzibar the increase was 114 and 138 % respectively.

At the final sampling there was little or no difference in the stem dry weight of Amani 4026/16 and Aipin Valenca and the effect of spacing on stem dry-weight changes was similar to its effect on total dry weight. Table 4 shows that in all varieties final stem dry weight increased with increasing plant density. The decrease in total dry

Table 4. *Effect of variety and spacing on final total, stem and root tuber dry weights* (g/m^2)

			Variety			
	Spacing	Plant population/ha	Amani 4026/16	Aipin Valenca	Msitu Zanzibar	Mean
Total dry weight	90 × 60 cm (S_1)	18500	3088	4190	4981	4082
	90 × 90 cm (S_2)	12346	3318	3504	4477 ± 446	3763
	90 × 120 cm (S_3)	9259	1354	1756	2089	1731
	Mean		2584	3147	3845	± 297
Stem dry weight	S_1	18500	1529	1510	1682	1572
	S_2	12346	1491	1440	1618 ± 83	1516
	S_3	9259	550	607	757	637
	Mean		1189	1186	1351	± 55
Root tuber dry weight	S_1	18500	1370	2524	3074	2323
	S_2	12346	1612	1883	2640 ± 293	2043
	S_3	9259	738	1094	1197	1009
	Mean		1240	1832	2301	± 195

weight of Amani 4026/16 when the population was increased from 12000 to 18000 plants/ha cannot therefore be attributed to changes in the dry weight of the stem since this increased with increasing plant density.

Table 4 shows that in Amani 4026/16 increase in plant population from 12000 to 18000 plants/ha led to a decrease in final root tuber dry weight, therefore the decrease in final total dry weight, with increasing plant density from 12000 to 18000 plants/ha can be attributed to the decrease in root dry weight with increasing plant population. In Aipin Valenca, a population of 12000 plants/ha gave significantly more root tuber dry weight than 9000 plants/ha. Significant difference between Msitu Zanzibar and Aipin Valenca occurred at a population of 12000 plants/ha, between Msitu Zanzibar and Amani 4026/16 at populations of

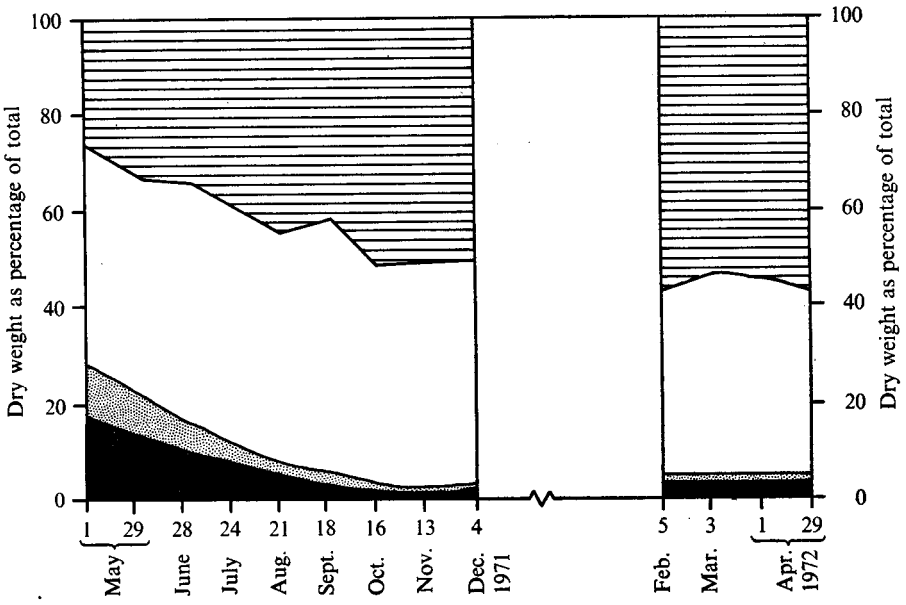

Fig. 3. Dry matter in the plant parts as percentages of the total. ⊟, Root tubers; □, stems; ▦, petioles; ■, leaf blades.

Table 5. *Effect of variety and spacing on mean crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR), throughout the sampling period*

	Spacing	Plant population/ha	Variety: Amani 4026/16	Variety: Aipin Valenca	Variety: Msitu Zanzibar		Mean
CGR (g/m² of land surface/week)	90 × 60 cm (S_1)	18500	60·9	90·0	63·6	±13·0	71·4
	90 × 90 cm (S_2)	12346	71·8	85·9	65·1		74·2
	90 × 120 cm (S_3)	9259	26·0	32·0	18·1		25·3
	Mean		52·8	69·2	48·9		±8·6
NAR (g/dm²/week)	S_1	18500	0·286	0·276	0·151	±0·080	0·237
	S_2	12346	0·325	0·304	0·189		0·272
	S_3	9259	0·425	0·515	0·215		0·385
	Mean		0·345	0·365	0·185		±0·053
RGR (g/g/week)	S_1	18500	0·036	0·040	0·035	±0·009	0·037
	S_2	12346	0·047	0·046	0·031		0·041
	S_3	9259	0·038	0·041	0·080		0·053
	Mean		0·040	0·042	0·049		±0·006

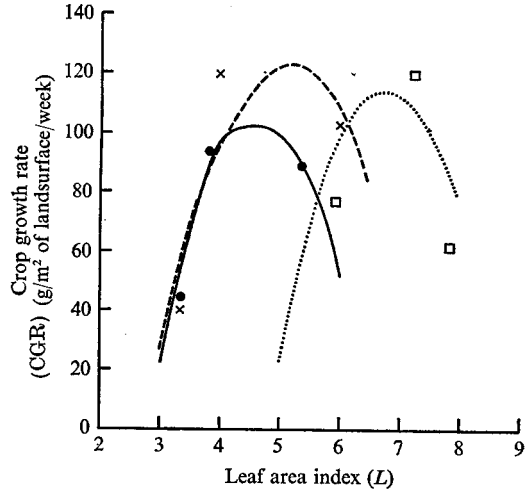

Fig. 4. Relationship between crop growth rate and leaf area index between samplings 1 and 3. × - - - ×, Aipin Valenca; ●——●, Amani 4026/16; □....□, Msitu Zanzibar.

9000 and 12000 thousand plants/ha and between Aipin Valenca and Amani 4026/16 at a population of 18000 plants/ha (Table 4).

The dry-matter distribution (Fig. 3) showed that most of the dry matter produced was diverted into the root tubers and stems. The proportion of the dry matter diverted into the leaf blades and petioles decreased with time, while the proportion diverted into the root tubers increased with time. Generally increase in plant density decreased the proportion of dry matter diverted into the root tubers, the reverse applying with regard to the proportion diverted into the stems. This finding is in accordance with that reported by Taha & Bremner (1966) for Irish potato but contrary to that reported by Enyi (1972*a*) for lesser yam. In the early stages of growth the proportion of dry matter diverted into the leaf blades and petioles increased with increasing plant density.

The proportion of the dry matter diverted into the root tubers of Aipin Valanca and Msitu Zanzibar was greater than that diverted into the root tubers of Amani 4026/16, the reverse applying with regard to the proportion of dry matter diverted into the stems. On average, the proportion of dry matter diverted into the root tubers of Aipin Valenca was greater than that diverted into the root tubers of Msitu Zanzibar, the reverse applying with regard to the proportion of dry matter diverted into the stem.

In crop plants the rate and the duration of dry-matter accumulation in the economic organ are of considerable importance to agricultural yields and the greater the proportion of the total dry matter diverted into these organs the greater will be their yield at harvest. In the present investigation 49·3, 58·8 and 59·4% of the total dry matter produced were diverted into the root tubers of Amani 4026/16, Aipin Valenca and Msitu Zanzibar respectively. In comparison, Enyi (1972*c*) showed that in lesser yam about 50% of the total dry matter produced was diverted into the tubers, and Enyi (1968) showed that about 70% of the total dry matter produced by *Xanthosoma sagittifolium* was diverted into its corms.

Mean crop growth rate CGR tended to increase with the increase in plant density (Table 5) but there was no significant difference in the mean CGR of plants at populations of 12000 and 18000 plants/ha. Mean CGR of Aipin Valenca was greater than that of either Amani 4026/16 or Msitu Zanzibar, the difference between Aipin Valenca and Msitu Zanzibar being statistically significant at a population of 18000 plants/ha. Mean CGR between samplings 1 and 3 for the three varieties were plotted against their mean leaf area index (L) (Fig. 4). The results show that in the three varieties CGR increased with an increase in L reaching a maximum at the L value of 3·9 in Amani 4026/16, 4·1 in Aipin Valenca and 7·3 in Msitu Zanzibar. The quadratic regression lines fitted to the points have the equations $CGR = 259{\cdot}8L - 27{\cdot}8L^2 - 505{\cdot}5$ for Amani 4026/16, $CGR = 215{\cdot}8L - 21{\cdot}0L^2 - 431{\cdot}1$ for Aipin Valenca and $CGR = 363{\cdot}1L - 26{\cdot}5L^2 - 1129{\cdot}3$ for Msitu Zanzibar. The calculated optima L for maximum CGR based on the above quadratic equations were 4·67, 5·14 and 6·84 for Amani 4026/16, Aipin Valenca and Msitu Zanzibar, respectively.

Fig. 5 shows the changes in net assimilation rate (NAR) with time for the three cassava varieties. Amani 4026/16 had significantly greater NAR than Msitu Zanzibar between 29 May and 28 June, between 21 August and 13 November in 1971 and between 5 February and 3 March in 1972, the reverse applying between 24 July and 21 August, 13 November and 4 December in 1971 and between 1 and 29 April in 1972. Aipin Valenca had greater NAR than Amani 4026/16 in 1972 and in 1971 between 24 July and 21 August, 18 September and 16 October and between 13 November and 4 December. Results of the mean NAR for the entire sampling period (Table 5) show that there was no significant difference between the mean NAR of Amani 4026/16 and Aipin Valenca but both were significantly superior to Msitu Zanzibar. NAR decreased with increasing plant density, plants in a population of 9000 plants/ha being significantly superior to the plants in a population of either 12000 or 18000 plants/ha.

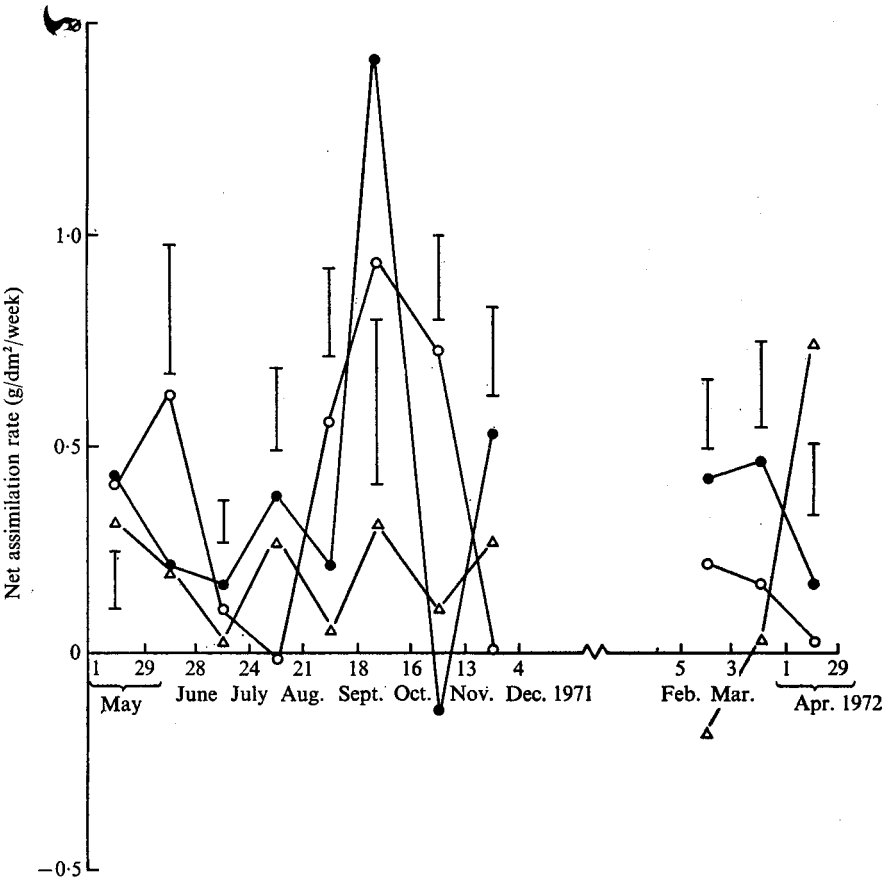

Fig. 5. Changes with time in net assimilation rate in the three cassava varieties. O——O, Amani 4026/16; ●——●, Aipin Valenca; △——△, Msitu Zanzibar.

Results of the mean relative growth rate (RGR) (Table 5) show that there was no significant difference in the mean RGR of the three cassava varieties but the interaction results show that at a population of 9000 plants/ha Msitu Zanzibar had significantly greater RGR than either of the other two varieties. Mean RGR tended to increase with decreasing plant density.

Leaf data

Msitu Zanzibar had significantly greater leaf area index (LAI) than the other varieties almost throughout the sampling period, and between 28 June and 16 November 1971 there was little or no difference in the LAI of Aipin Valenca and Amani 4026/16, but the latter had greater LAI than the former between 13 November and 4 December in 1971 and throughout the sampling period in 1972 (Fig. 6).

On average, increase in the plant density tended to increase the LAI, differences between treatments being significant between 1 May and 24 July in 1971. Maximum LAI was attained on 29 May 1971 for the three varieties but then the LAI declined rapidly and continuously until 13 November. The decline in LAI after March was probably due to the decrease in the amount of rainfall (Table 1). The growth of leaves resumed in 1972 with the onset of rainy season but leaf area development was not as high as in the first growing season. Relative leaf area duration (Msitu Zanzibar and 90 × 60 cm = 100·0) (Table 6) tended to increase with the increase in plant density, plants in a population of 18000 plants/ha being significantly superior to those in populations of either 9000 or 12000 plants/ha. The results show, however, that the increase in leaf area duration with increasing plant density occurred only in Amani 4026/16 and Aipin Valenca. Msitu Zanzibar had significantly greater leaf area duration than the other two

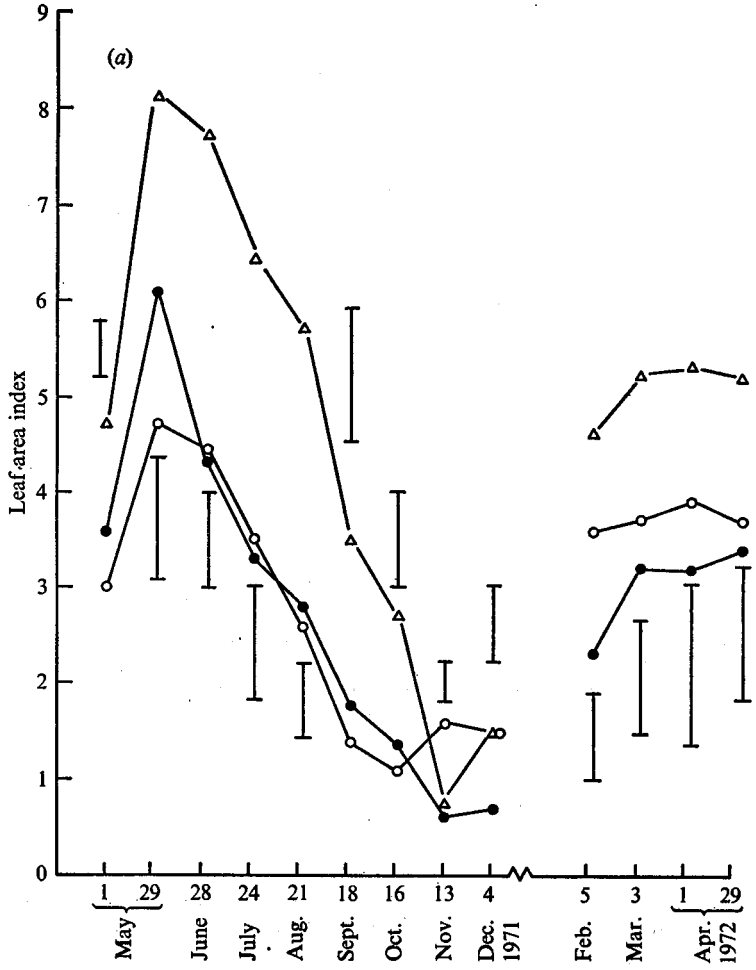

Fig. 6(*a*). For legend see opposite.

varieties and, although Amani 4026/16 had greater leaf-area duration than Aipin Valenca, the difference was not significant. Since the period of leaf growth in the three varieties did not differ the difference in their leaf area duration may therefore be attributed to the differences in the LAI.

DISCUSSION

Williams & Ghazali (1969) reported that in the three cassava varieties studied by them the lowest yielding variety had the highest leaf area per stem. In the present study, however, the highest yielding variety had the highest leaf area per plant. These workers also showed that the leaves of the highest yielding variety possessed attenuated lobes with a more vertical midday orientation. In the present study although Amani 4026/16 possessed narrower individual lobes its root tuber yield was lower than that of Aipin Valenca, which possessed broad-lobed leaves, and also the mean angle of orientation of the leaves from the horizontal was greater in Amani 4026/16 than in Aipin Valenca. In the present study, therefore, there is no definite relationship between size of lobes, mean angle of orientation of the leaves from horizontal and root tuber yield.

Although Msitu Zanzibar possessed narrow individual lobes of leaves and had greater mean angle of orientation than Aipin Valenca the photosynthetic efficiency of the leaves, estimated as net assimilation rate, of the former variety was considerably lower than that of the latter. However, when mean net assimilation rate was plotted against mean LAI (Fig. 7) the results showed that

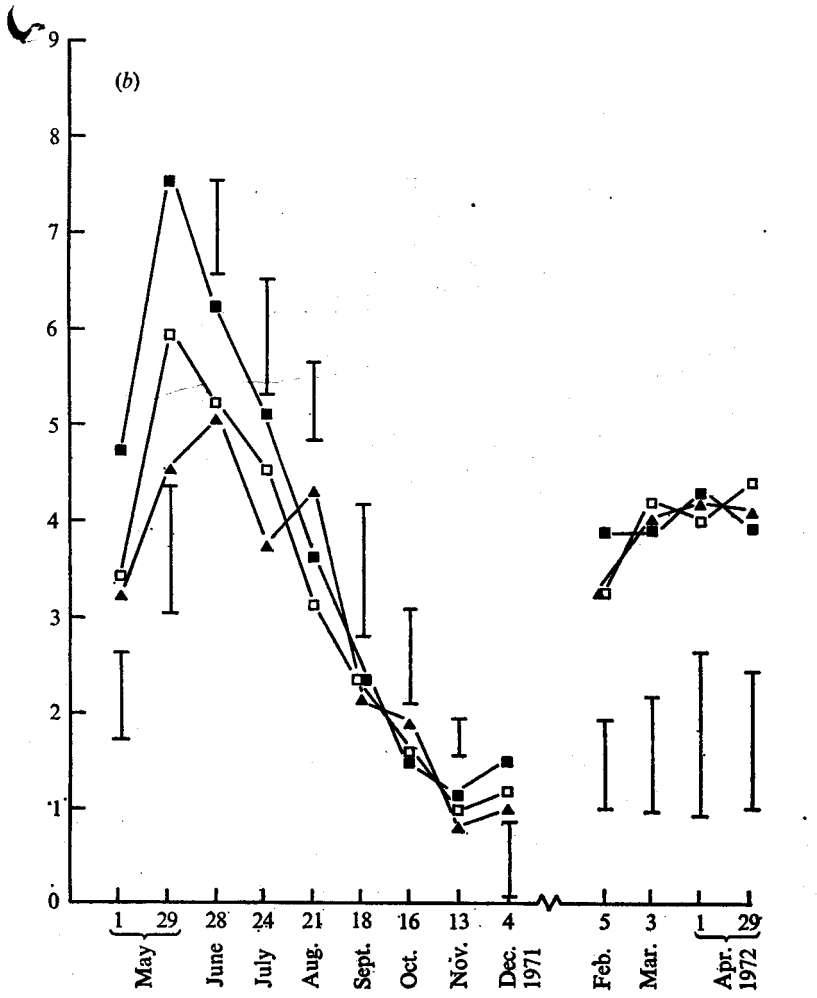

Fig. 6. Effect of (*a*) variety and (*b*) spacing with time in leaf area index. O——O, Amani 4026/16; ●——●, Aipin Valenca; △——△, Msitu Zanzibar; ■——■, 90 × 60 cm; □——□, 90 × 90 cm; ▲——▲, 90 × 120 cm.

Table 6. *Effect of variety and spacing on relative leaf area duration*

S_1 Msitu Zanzibar plants = 100·0

Spacing	Plant population/ha	Variety: Amani 4026/16	Variety: Aipin Valenca	Variety: Msitu Zanzibar		Mean
90 × 60 cm (S_1)	18500	69·6	68·3	100·0		79·2
90 × 90 cm (S_2)	12346	64·8	52·1	95·2	±6·5	70·6
90 × 120 cm (S_3)	9259	52·5	50·2	99·6		67·4
Mean		62·2	56·8	98·2		±4·3

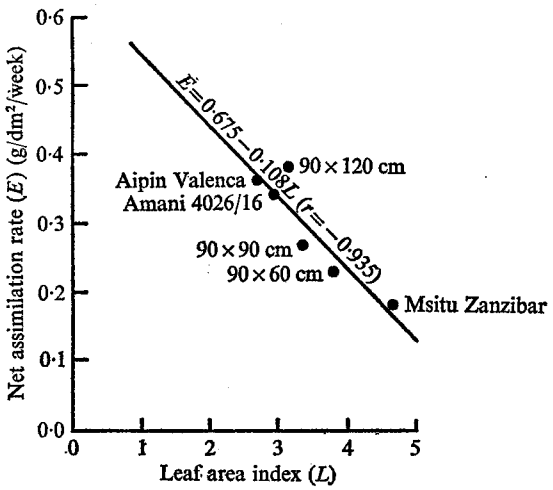

Fig. 7. Relationship between mean net assimilation rate and leaf area index.

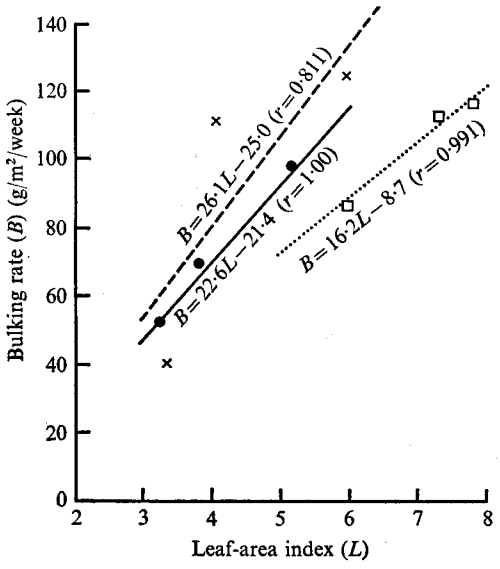

Fig. 8. Relationship between bulking rate and leaf-area index between samplings 1 and 3. × - - ×, Aipin Valenca; ●——●, Amani 4026/16; □. . . □, Msitu Zanzibar.

NAR was linearly but negatively related to LAI Watson & French (1958) and Enyi (1965) have also reported a decrease in NAR with increase in LAI. Since Msitu Zanzibar had greater mean LAI its lower NAR can therefore be attributed to its greater leaf area development, which resulted in increased shading of the lower leaves. The greater NAR of the other two varieties can be attributed to their lower mean LAI rather than to the differences in size of lobes of their leaves or the angle of orientation of their leaves from the horizontal.

Bremner & Taha (1966) showed that tuber yield in Irish potato was highly and positively correlated with leaf area duration. Similarly, Enyi (1972*a*, *b*, *c*) showed that in lesser yam, tuber yield was highly and positively correlated with leaf area duration. Enyi (1972*d*) also showed that in multi-shoot plants of cassava the product of leaf area duration and mean net assimilation rate was also positively and highly correlated with root tuber yield. In the present investigation root tuber yield was poorly correlated with leaf area duration, the calculated correlation coefficient between root tuber yield and leaf area duration being 0·44. The reasons for the poor correlation between tuber yield and leaf area duration was due to the fact that although the leaf area duration of Msitu Zanzibar was about 42 % more than that of Aipin Valenca its root tuber yield was only 10 % more than that of the latter and although the leaf area duration of Amani 4026/16 was about 9 % more than that of Aipin Valenca the tuber yield of the former was about 30 % less than that of the latter. In Msitu Zanzibar the spacing treatment did not cause any significant differences in leaf area duration but had significant effect on root tuber yield and in Amani 4026/16 the leaf area duration of plants in the population of 18000 plants/ha was about 7 % more than that in a population of 12000 plants/ha, but the tuber yield of the former plants was about 42 % less than that of the latter treatment plants. In the present investigation also root tuber yield was negatively correlated with the

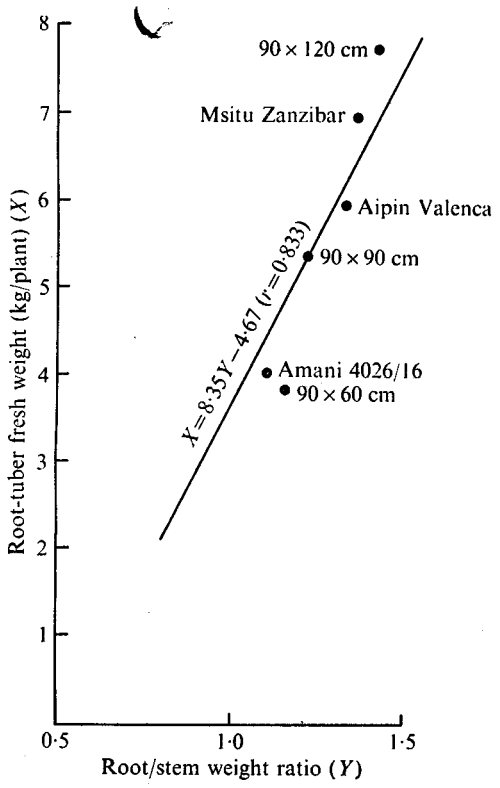

Fig. 9. Relationship between root/stem weight ratio and fresh-weight yield of root tuber per plant.

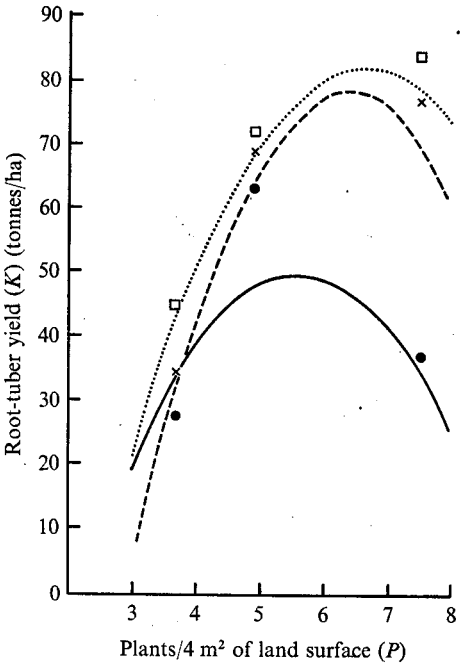

Fig. 10. Relationship between plant population and yield of root tubers. × - - - ×, Aipin Valenca; ●——●, Amani 4026/16; □. . . .□, Msitu Zanzibar.

product of relative leaf area duration and mean net assimilation rate, the correlation coefficient being −0·886.

In most root crops final tuber yield is determined by two factors, bulking rate and duration of bulking. Bremner & Taha (1966) showed that the greater yield of Majestic potato over King Edward was due to longer period of bulking of the former than of the latter variety. They also showed that the difference in the yield of large and small seed was due to the difference in the length of bulking of plants produced from the former type of seeds. Enyi (1972*a*) also showed that greater tuber yield in lesser yam was associated with higher rate of bulking. In the present study root-tuber yield was positively and highly correlated with the rate of bulking and the regression equation showing the relationship between tuber yield (t/ha) (Y) and bulking rate (kg/ha/week) (B) is $Y = 0{\cdot}0053B + 10{\cdot}3$ ($r = 0{\cdot}866$).

Variation in B therefore accounted for about 75% of the variation in Y between treatments. Since in the present investigation there was no difference in the period of bulking, differences in root-tuber yield between treatments can therefore be attributed to the differential effects of the treatments on the rate of bulking. Enyi (1972*a*) showed that in lesser yam the rate of bulking increased with increasing leaf area but declined at higher leaf area. In the present investigation mean bulking rate for the three varieties of cassava between samplings 1 and 3 were plotted against their mean leaf-area index (Fig. 8), and the results show that in all the varieties bulking rates increased linearly with increasing LAI It appears that optimum LAI for maximum bulking rate is above 7·8, 6·0 and 5·3 respectively in Msitu Zanzibar, Aipin Valenca and Amani 4026/16.

The relationship between plant top and tuber weight is very important to cassava producers, a high root/stem ratio being desirable for production of tubers. Krochmal & Samuels (1969) showed that the production of tubers per plant in cassava was inversely related to top/tuber weight ratio. In the present investigation root/stem weight ratio for the main treatments were plotted against their root-tuber yield/plant (Fig. 9) and the results show that root-tuber yield/plant increased linearly with the increase in root/stem weight ratio. In Amani 4026/16, Aipin Valenca and Msitu Zanzibar the correlation coefficients between root-tuber

weight/plant and root tuber/stem weight ratio were 0·986, 0·777 and 0·555 respectively.

With the exception of Amani 4026/16 increase in plant density from 9000 to 12000 and 18000 plants/ha led to increase in the root-tuber yield, but the increase was linear only when the population was increased from 9000 to 12000 plants/ha. Plant population/4 m² (P) was plotted against root-tuber yield/ha (K) at final harvest for each variety (Fig. 10) and the quadratic regression lines fitted to the points have the equations $K = 622{\cdot}5P - 46{\cdot}6P^2 - 1249{\cdot}2$ for Msitu Zanzibar, $K = 833{\cdot}5P - 64{\cdot}7P^2 - 1896{\cdot}8$ for Aipin Valenca and $K = 492{\cdot}4P - 43{\cdot}6P^2 - 886{\cdot}1$ for Amani 4026/16. The optima populations of plants/4 m² for maximum root-tuber yield as calculated from the quadratic equations were 6·7, 6·4 and 5·6 for Msitu Zanzibar, Aipin Valenca and Amani 4026/16 respectively. The figures given above correspond to populations of 16297, 15568 and 13622 plants/ha respectively.

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