

Root biomass and nutrient uptake of taro in the lowlands of Papua New Guinea

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Data are presented on nutrient uptake of taro [*Colocasia esculenta* (L.) Schott] roots in relation to corm yield and above-ground biomass on a Typic Tropofluvents in the humid lowlands of Papua New Guinea. Fertilized (100:50:100 kg NPK ha⁻¹) and unfertilized plants ($n = 4$ each) were harvested 126 days after planting (DAP) (mid-season) and 231 DAP (harvest). Rooting depth at both sampling times was <0.2 m and a unit soil area equivalent to the planting distance (0.5 m × 0.8 m) was removed from the field whereafter roots were washed on a 0.5-mm sieve. Root biomass at 126 DAP was 0.26 Mg ha⁻¹ (15% of total biomass) in the unfertilized plots and 0.52 Mg ha⁻¹ (13% of total) in the fertilized plots, but at 231 DAP root biomass was similar (0.50 Mg ha⁻¹). Root nutrient concentration at 126 DAP was similar in both plots but N, Ca, and S significantly declined in the unfertilized plots at 231 DAP whereas B increased with 18 mg kg⁻¹ ($P < 0.01$). In the fertilized plot, P, K, Mg, Mn, and Cu had decreased at 231 DAP whereas Zn had significantly ($P < 0.01$) increased. Nutrients in the root biomass as a fraction of the total nutrient uptake were similar at 126 DAP for both treatments. At 231 DAP, however, the fraction of nutrients in the root biomass was considerably lower in the fertilized plots. There was a high uptake of Mg by taro roots in the unfertilized plots at 126 DAP (38% of total) and at 231 DAP (36% of total). This study has shown that the amount of nutrients taken up by roots of fertilized and unfertilized taro was similar at harvest, but that a much larger proportion of plant nutrients is allocated to the roots under unfertilized conditions.

Keywords: Taro; Roots; Nutrient uptake; Nutrient concentration; Fertilizer

In most field studies with food crops, root biomass production and nutrient uptake receive little attention, because the root system is hidden from direct observation and the quantification of roots is tedious and difficult because of problems in extracting roots from the soil. It is also complex because of the spatial and temporal variability of roots in the soil matrix. Despite these problems, various destructive and advanced non-destructive methods have been developed to study roots of field crops (Taylor *et al.*, 1991) in addition to sampling schemes for their quantification (Noordwijk *et al.*, 1985). Much of the research on roots is conducted in the temperate regions and information on root biomass and its nutrient content of tropical crops is limited. This is particularly the case for tropical root and tuber crops (Jacobs and Clarke, 1993; Goenaga and Chardon, 1995).

Root and tuber crops are the major sources of dietary energy for many people in the Pacific Islands countries (de la Peña, 1996). In Papua New Guinea sweetpotato [*Ipomoea batatas* (L.)] is the main staple crop (Allen *et al.*, 1995), although taro [*Colocasia esculenta* (L.) Schott] is usually the first crop to be

planted after the forest or fallow vegetation is cleared (Moles *et al.*, 1984). It is grown under upland conditions and no irrigation or fertilizers are applied. Most small-scale farmers in Papua New Guinea grow taro for one season only, because pests and disease, weed infestation, and (or) the depletion of soil nutrients usually result in low yields in successive seasons. To sustain and improve taro yields, inorganic fertilizers are a viable option and taro responds well to fertilizers (De Geus, 1972; Kabeerathumma, 1992). Small-scale farmers use little inorganic fertilizers because of low nutrient-use efficiency (Noordwijk and Willigen, 1991) with the associated risk that investments in fertilizers are not profitable (McIntire, 1986). An essential step to increase the efficiency of fertilizers in order to improve yields is an understanding of the nutrient uptake and allocation within the taro plant during a growing season.

An experiment was therefore conducted which aimed to quantify root biomass production and nutrient concentrations and total uptake of fertilized and unfertilized taro. In order to make an accurate estimation of root dry weight, destructive measurements were made whereby whole taro plants were harvested.

Materials and Methods

The site

The research was conducted on the experimental farm (6°41' S, 146°98' E) of the University of Technology in Lae, Papua New Guinea, located in the humid lowlands with mean rainfall of about 4400 mm yr⁻¹ which is fairly well distributed throughout the year. Average daily temperatures are 26.3°C with a daily minimum of 22.9°C and a maximum of 29.7°C. Annual evaporation (U.S. Class A pan) is 2139 mm, and rainfall exceeds evaporation in each month (McAlpine *et al.*, 1975). The climate classifies as Af (Köppen) i.e., a tropical rainy climate with the driest month having over 60 mm rain. During the experiment (23 March to 13 November 1996) 2605 mm of rain was recorded.

The farm is located at an alluvial plain with an altitude of about 65 m above sea level (asl). The soil at the farm is well drained and classified as a sandy, mixed, isohyperthermic Typic Tropofluvents (USDA *Soil Taxonomy*) or Eutric Fluvisol (FAO-*Unesco*). Air-dried and sieved (2 mm) topsoil (0–0.23 m) had the following properties: pH (1:5 soil:water suspension), 5.9; organic C, 23.8 g kg⁻¹; Olsen P, 12 mg kg⁻¹; total N, 2.0 g kg⁻¹; cation exchange capacity (CEC) (1M NH₄OAc, pH 7), 126 mmol_c kg⁻¹; sand, 790 g kg⁻¹; and clay, 80 g kg⁻¹; $r_b = 1.10 \text{ Mg m}^{-3}$.

Experimental setup and management

The site at which the experiment was conducted had been under pasture for eight years and was ploughed in January 1996. Two plots (5.6 m × 9.5 m) of taro [*C. esculenta* (L.) Schott. var. *esculenta*] local cultivar Nomkoi were planted on 23 March 1996 at a spacing of 0.5 m × 0.8 m (25 000 plants ha⁻¹). Planting material consisted of corm apical portions from main plants from which the petioles were cut 0.25–0.30 m above the corm to remove the leaf lamina. One plot was fertilized with 100 kg N ha⁻¹ (sulphate of ammonia) given in split applications at 49 and 79 days after planting (DAP), and 50 kg P ha⁻¹ (triple superphosphate) and 100 kg K ha⁻¹ (muriate of potash) were given as a basal dressing at planting. The N fertilizers were broadcast over the plot and slightly incorporated into the topsoil. The other plot was not fertilized. Weeding was done manually at regular intervals and weeds were not removed from the plots. Biocides were used to control hawkmoth (*Hippotion celerio* L.) and taro leaf blight (*Phytophthora colocasiae*).

Sampling and nutrient analysis

In the mid-season (126 DAP) and at harvest (231 DAP) four taro plants were selected in both the fertilized and unfertilized plots to determine total biomass production and nutrient up-

take. The plants were harvested and divided in corms and leaves (including petioles). No distinction was made between main plants and sucker plants and for each plant, corms or leaves of the main plants and suckers were combined into one sample. The samples were washed with distilled water and oven-dried at 70°C for 72 h after which dry weight was recorded. The whole plant part (i.e., corms and leaves) was ground (mesh 0.2 mm) for nutrient analysis.

For the root biomass, an area equal to the spacing (0.5 m × 0.8 m) was pegged out around each taro plant which is called the 'unit soil area' by Noordwijk *et al.* (1985). Pits were dug to observe the rooting depth of the taro, and in the mid-season and at the harvest the taro had not rooted deeper than 0.15–0.18 m. All soil to a depth of 0.2 m (0.08 m³) was collected in plastic bags and taken to the laboratory. The roots were washed from the soil with pressurized water on a 0.5-mm sieve. The sieved root and organic debris material were put in plastic trays filled with water after which the floating roots were handpicked the same day. After washing the roots with distilled water, they were immediately oven-dried to avoid loss of nutrients (Misra, 1994).

Nutrient analysis on roots, corm, and leaf biomass samples was conducted at the laboratories of the Department of Agriculture of the University of Queensland. One subsample was digested in 5:1 nitric:perchloric acids and analysed for P, K, Ca, Mg, S, B, Mn, Zn, and Cu using ICP AES (Spectro Model P). A second subsample was digested according to the Kjeldahl procedure and analysed for N on an Alpkem Rapid Flow Analyser Series 300.

Results

Biomass

Fertilized taro had significantly ($P < 0.05$) more total biomass than unfertilized taro at both sampling times which in the mid-season (126 DAP) was due to the larger root and leaf biomass (Table 1). There had been little corm development in the mid-season and differences in the corm weight of fertilized and unfertilized taro were not significant. At harvest (231 DAP), however, the difference in total biomass was due to the greater corm and leaf biomass in the fertilized taro. The root biomass was similar for both fertilized and unfertilized plants at harvest. In fertilized taro, maximum root biomass was achieved by the mid-season (52 g m⁻²), whereas, root development was still occurring in the mid-season unfertilized taro (26 g m⁻²). At 126 DAP, root biomass was 15 and 13% of the total biomass in the unfertilized and fertilized taro, respectively. At harvest, the proportion of roots of the total biomass was 10% in the unfertilized taro and 4% in the fertilized

Table 1 Biomass production and dry matter content of unfertilized and fertilized taro

Plant part	Mid-season (126 DAP)		At harvest (231 DAP)		
	Unfertilized	Fertilized	Unfertilized	Fertilized	
Dry weight (Mg ha ⁻¹)	Roots	0.26	0.52***	0.51	0.50
	Corms	0.82	1.21	2.53	6.99*
	Leaves ¹	0.67	2.13*	2.00	3.64*
	Total	1.75	3.86*	5.04	11.13*
Dry matter content (%)	Roots	4	5***	12	11
	Corms	21	19	30	30
	Leaves ¹	8	7	16	16

¹Leaf biomass includes petioles*, ***, indicates significant difference between fertilized and unfertilized taro at $P < 0.05$ and $P < 0.001$, respectively

taro. The coefficient of variation of dry root weight was between 6 and 24% at 126 DAP and between 1 and 14% at 231 DAP. The variation in root measurements was larger in fertilized taro.

The dry matter (DM) content of all plant parts increased from the mid-season to the end of the season, and was unaffected by fertilizer except for mid-season sampling when the roots of fertilized taro had a slight but significantly higher DM content (Table 1).

Nutrients

Nutrient analysis showed that the Ca concentration was significantly lower in taro roots ($P < 0.001$) and corms ($P < 0.05$) at the end of the season compared to the mid-season for both unfertilized and fertilized taro (Table 2). At harvest, B and Zn concentrations had significantly ($P < 0.01$) increased in unfertilized and fertilized taro roots, respectively. Potassium concentration in the roots were similar at 126 DAP and 231

DAP and not affected by fertilizer. The K, Ca, Mg, Mn, and Cu concentration in the taro corms were all lower at the end of the season than in the mid-season for unfertilized and fertilized taro. The concentration of N and S decreased significantly in the corms of fertilized taro only. Overall, it appeared that fertilizers had little effect on the nutrient concentration in taro roots, whereas, in the corms of fertilized taro, the concentration of most nutrients was slightly lower.

Roots of fertilized taro at 126 DAP had taken up significantly higher ($P < 0.01$) amounts of all major nutrients (Table 3) which may be due to the greater biomass (Table 1). The total N uptake in the corm was larger in fertilized taro (14 kg ha⁻¹) than in unfertilized taro (5 kg ha⁻¹). Overall, in the mid-season, fertilized taro had taken up significantly more N, Ca, Mg, and S. The fraction of nutrients taken up by the roots from the total uptake was, however, not different between fertilized and unfertilized taro at 126 DAP. The uptake of N and P in roots was about 7 to 12% of the total uptake whereas 13 to 22% of the total K, Ca, and S uptake had occurred in the roots at 126 DAP. The Mg uptake in the roots accounted for 36 to 38% of the total Mg uptake in both treatments.

At the end of the season, there were no differences in the amount of nutrients taken up by the roots of fertilized and unfertilized taro. On a whole-plant basis, however, fertilized taro took up significantly ($P < 0.05$) more Ca, Mg, and S than unfertilized taro. The proportion of nutrients taken up by the roots were similar for unfertilized taro at 126 and 231 DAP. However, nutrient uptake in the roots as a proportion of the total uptake decreased between 126 and 231 DAP for both fertilized and unfertilized taro, especially for Ca (from 18 to 7%) and Mg (from 36 to 20%).

Table 2 Nutrient concentration¹ in unfertilized and fertilized taro roots and corms

Nutrient	Unfertilized				Fertilized			
	Roots		Corms		Roots		Corms	
	126 DAP	231 DAP	126 DAP	231 DAP	126 DAP	231 DAP	126 DAP	231 DAP
N	13.0	11.4*	8.3	5.8	14.1	10.6	14.5	4.5**
P	2.1	2.2	2.6	2.1**	1.8	2.2*	1.9	1.8
K	52.7	48.9	20.9	17.0*	47.7	46.3	19.0	13.0**
Ca	14.0	10.7***	5.8	3.6*	14.4	11.0***	4.9	3.1*
Mg	5.9	5.9	1.4	0.8**	7.1	6.0*	1.3	0.8**
S	1.2	1.5*	0.5	0.4	2.3	2.0	0.8	0.4***
B	12.0	30.0**	4.0	16.0**	25.0	25.0	13.0	17.0
Mn	77.0	84.0	40.0	24.0*	120.0	94.0*	43.0	21.0*
Zn	91.0	105.0	68.0	37.0**	63.0	114.0**	28.0	27.0
Cu	42.0	39.0	18.0	11.0*	62.0	29.0**	19.0	9.0***

¹N, P, K, Ca, Mg, and S in g kg⁻¹, other nutrients in mg kg⁻¹*, **, ***, indicates significant difference at $P < 0.05$, $P < 0.01$, and $P < 0.001$ between mid-season (126 DAP) and at harvest (231 DAP)

Table 3 Nutrient uptake (kg ha⁻¹) in roots, corms, and leaves of unfertilized and fertilized taro

Sampling period	Plant part	Unfertilized taro						Fertilized taro					
		N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Mid-season (126 DAP)	Roots	3	<1	13	4	2	<1	8**	1***	25**	8***	4***	1**
	Corms	5	2	17	4	1	<1	14**	2	22	6	2	1
	Leaves ¹	19	5	46	8	1	1	63	9	119	29*	5*	4
	Total	27	9	76	16	4	2	85*	13	166	42*	10*	5*
At harvest (231 DAP)	Roots	6	1	25	5	3	1	5	1	23	5	3	1
	Corms	13	5	42	8	2	1	31*	12*	86*	23	5*	3**
	Leaves ¹	34	10	80	21	3	2	55	18	106	46	6	4
	Total	53	16	147	35	8	4	91	31	215	74*	15*	8*

¹Leaf biomass includes petioles* ** *** indicates significant difference at $P < 0.05$, $P < 0.01$, and $P < 0.001$

Discussion

Fertilized taro produced twice the biomass of unfertilized taro. Differences were already pronounced in the mid-season when fertilized taro had three times more leaf biomass and two times more root biomass. At harvest, however, root biomass was not different and was about 0.50 Mg ha⁻¹. This root biomass was much larger than that recorded by Goenaga and Chardon, (1995) who found between 0.14 to 0.31 Mg ha⁻¹ for fertilized and drip-irrigated taro in Puerto Rico. Goenaga and Chardon (1995) also found that root biomass developed within 120 DAP but did not change thereafter. The present research suggested the same for fertilized taro but showed that unfertilized taro had not fully developed its root system by 126 DAP. The advantages of the rapidly developed root system are obvious and can be simplified as the more roots, the better shoot growth (Noordwijk and Willigen, 1991) which the present data confirmed. As whole plants were dug up, variation in root biomass measurements were relatively low ($1 < CV\% < 24$) compared to other destructive sampling techniques like core samples and pinboards (Noordwijk *et al.*, 1985; Taylor *et al.*, 1991).

In the present experiment, it was found that large amounts of nutrients are taken up by the roots and little differences were found between fertilized and unfertilized taro at harvest. Some caution is, however, needed in the interpretation of the nutrient data of the roots as traces of soil may have adhered to the roots and nutrients may be washed from the roots with separation (Misra, 1994). Nitrogen in the roots at harvest was 8 kg ha⁻¹ (9% of total uptake) and 5 kg ha⁻¹ (6%) for fertilized and unfertilized taro, respectively. This is much higher than that reported by Gliessman (1982) who found only 0.5 kg N ha⁻¹ in the taro roots at harvest which was 2% of the total uptake. The difference is large and may be partially explained by differences in taro cultivars (Jacobs and Clarke,

1993; Goenaga and Chardon, 1995) and the growing conditions. Very little P was found to be taken up in the roots (≤ 1 kg ha⁻¹) and the majority of the P uptake was in the leaves (including petioles). Potassium was found in large quantities in taro roots and up to 25 kg ha⁻¹ was recorded. This may be an underestimation as K is easily lost from roots with washing. Misra (1994) found that wet separation (washing) of *Eucalyptus* roots resulted in a K loss of 24%. Although Mg was not taken up in large quantities in taro roots under unfertilized conditions (3 kg ha⁻¹ at harvest), it accounted for about 36% of the total uptake, whereas Mg uptake in roots of fertilized taro was 20% of the total uptake. In the mid-season, the proportion of Mg in taro roots was even higher (36–38% of total uptake). These data are much higher than those found by Kabeerathumma *et al.* (1985) who found only 5% of the total Mg to be taken up by taro roots.

Conclusions

Root biomass in fertilized taro was fully developed at the mid-season whereas only half of the root biomass was formed in unfertilized taro. At harvest, root biomass of fertilized and unfertilized taro was 0.50 Mg ha⁻¹. Nutrient uptake by roots of fertilized and unfertilized taro was similar at harvest and about 5 kg N, 1 kg P, 25 kg K, 5 kg Ca, and 3 kg Mg ha⁻¹ were taken up.

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