BIOMASS PRODUCTION AND NUTRIENT UPTAKE OF TARO ROOTS

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ABSTRACT

*Information on biomass production and nutrient uptake of roots in tropical tuber crops is scarce. In this paper data are presented on nutrient uptake of taro roots (*Colocasia esculenta*) in relation to corm yield and above ground biomass on a Typic Tropofluvents in the humid lowlands near Lae. Fertilized (100-50-100 kg NPK ha^{-1}) and unfertilized plants (n=4 each) were harvested at 126 days after planting (126 DAP=mid-season) and 231 DAP (harvest). Root biomass at 126 DAP was 0.26 t ha^{-1} (15% of total biomass) in the unfertilized plots and 0.52 t ha^{-1} (13% of total) in the fertilized plots but at 231 DAP root biomass was similar (~0.50 t ha^{-1}). Root nutrient concentrations 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 but 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. Nutrient uptake by roots at harvest was 5 kg N, 1 kg P, 25 kg K, 5 kg Ca, and 3 kg Mg ha^{-1} for both fertilized and unfertilized conditions. The study has shown that taro roots contain considerable amount of nutrients 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*

INTRODUCTION

Root biomass production and nutrient uptake receive little attention in most field studies with food crops. The reasons for this omission are obvious: 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 (van Noordwijk *et al.* 1985). Much of the research on roots has been conducted in the temperate regions and information on root biomass and its nutrient content of tropical crops is limited. This is particular the case for tropical root and tuber crops (Goenaga and Chardon 1995; Jacobs and Clarke 1993).

Root and tuber crops are the major source of dietary energy for many people in the Pacific Islands countries (de la Peña 1996). In Papua New Guinea, sweet potato (*Ipomoea batatas*) is the main staple crop (Allen *et al.* 1995) although taro (*Colocasia esculenta*) is usually the first crop planted after the forest or fallow vegetation is cleared (Moles *et al.* 1984). It is generally grown under upland conditions and no irrigation or fertilizers are applied. Most smallscale farmers in Papua New Guinea grow taro for one season only because of an increase in the incidence of pests and diseases, weeds and/or the depletion of soil nutrients. These factors usually result in low yields in successive seasons. Inorganic fertilizers are a viable option to sustain and improve taro yields since taro commonly responds well to fertilizers (de Geus 1972; Kabeerathumma 1992). Smallscale farmers use little inorganic fertilizer because of low nutrient use efficiency (Noordwijk and de Willigen 1991) with the associated risk that investments in fertilizers will not be profitable (McIntire 1986). An important step to increase the efficiency of fertilizers in order to improve yields is an understanding of the nutrient uptake and

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allocation within the taro plant during a growing season. We therefore conducted an experiment which aimed to quantify root biomass production and nutrient 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 dug up.

MATERIALS AND METHODS

The site

The research took place on the experimental farm of the University of Technology in Lae. The experimental farm (6°41'S, 146°98'E) is located at an altitude of 65 m a.s.l. and annual rainfall is about 4400 mm y^{-1} which is fairly well distributed throughout the year. Average daily temperature is 26.3°C, with an average minimum of 22.9°C and an average daily maximum of 29.7°C. Annual evaporation (US Class A pan) is 2139 mm, and rainfall exceeds evaporation in each month (McAlpine *et al.* 1975). The climate is classified as Af (Köppen) i.e. a tropical rainy climate with driest month over 60 mm rain. During the experiment (23 March until 13 November 1996) 2605 mm of rain was recorded.

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). Airdried 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}, P-Olsen = 12 mg kg^{-1}, total N = 2.0 g kg^{-1}, CEC (1 *M* NH_4OAc, pH7) = 126 $mmol_c$ kg^{-1}, sand = 790 g kg^{-1}, and clay = 80 g kg^{-1}, bulk density = 1.10 t m^{-3}.

Experimental setup and management

The site at which the experiment was conducted had been under pasture for 8 years and was ploughed in January 1996. Four blocks each with two plots (5.6 x 9.5m) of taro (*Colocasia esculenta* (L.) Schott. var. *esculenta*) local cultivar Nomkoi were planted on 23/3/1996 at a spacing of 0.5 by 0.8 m (25,000 plants ha^{-1}). Planting material consisted of corm apical portions from main plants from which the petioles had been cut 0.25 to 0.30 m above the corm to remove the leaf lamina. In each block one randomly selected plot was fertilized with 100 kg N ha^{-1} (sulphate of ammonia) given in equal amounts at 49 and 79 DAP (=days after planting), and 50 kg P ha^{-1} (triplesuperphosphate) and 100 kg K ha^{-1} (muriate of potash) as a basal dressing at planting. 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 (*Phytophtera colocasiae*).

Sampling and nutrient analysis

In the mid-season (126 DAP) and at harvest (231 DAP) a row of four taro plants was randomly selected in both the fertilized and unfertilized plots to determine above and below ground biomass production and nutrient uptake. Due to the large amount of work involved in root washing and sorting, only 4 plants were sampled per treatment at the two sampling times. The plants were pulled up and divided into corms and leaves (including petioles). No distinction was made between main 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 ovendried at 70°C for 72h which after dry weight was recorded. The dried plant parts were ground (mesh 0.2mm) prior to nutrient analysis.

For the root biomass determination, an area equal to the plant spacing (0.5 x 0.8m) was pegged out around each taro plant which has been 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 to 0.18 m. All soil to a depth of 0.2 m (0.08 m^3) 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 whereafter the floating roots were handpicked the same day. After washing the roots with distilled water, they were immediately ovendried to avoid loss of nutrients (Misra 1994).

Nutrient analysis of root, 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 analyzed for P, K, Ca, Mg, S, B, Mn, Zn and Cu using inductively coupled plasma atomic emission spectrometry (ICP AES-Spectro Model P). A second subsample was digested according to the Kjeldahl procedure and analyzed 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 (123 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 and approximately 50 g m^{-2}. 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 taro. The CV% of dry root weight were 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 content of all plant parts increased from the mid-season to the end of season and was unaffected by fertilizer except for mid-season sampling when the roots of fertilized taro had a slight but significantly higher dry matter content (Table 1).

Nutrients

Nutrient analysis showed that the Ca concentration was significantly lower in taro roots ($p<0.001$) at the end of 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 from the mid-season 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. In the mid-season fertilizers increased the concentration of Mg, S, B, Mn and Cu but decreased the concentration of P and Zn. At harvest, there was no effect of the fertilizer applications on the nutrient concentration except for S which was 0.5 g kg^{-1} higher in fertilized roots.

The K, Ca, Mg, Mn and Cu concentration in the taro corms were all lower at the end of season than in the mid-season for both unfertilized and fertilized taro (Table 3). At harvest, the concentration of N and S was significantly lower in the corms of fertilized taro only. Fertilizers decreased the nutrient concentration of P and Zn in the mid-season, and N, K and Zn at harvest. Striking is the effect that fertilizer decreased P and Zn concentration in both roots and corms in the mid-season.

Table 1. **Biomass production and dry matter content of unfertilized and fertilized taro at 126 and 231 DAP.**

		mid-season (126 DAP)		at harvest (231 DAP)	
	plant part	unfertilized	fertilized	unfertilized	fertilized
dry weight (t 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

[1] **leaf biomass includes petioles**
,**, indicates significant difference between fertilized and unfertilized taro at $p<0.05$, 0.01 and 0.001 respectively.**

Table 2. Nutrient concentration in unfertilized and fertilized taro roots at 126 and 231 DAP

		Unferilized		Fertilized		Fertilizer effect[1]	
Nutrient	Unit	126 DAP	231 DAP	126 DAP	231 DAP	126 DAP	231 DAP
N	g kg^{-1}	13.0	11.4*	14.1	10.6	ns	ns
K	"	2.1	2.2	1.8	2.2*	-	ns
K	"	52.7	48.9	47.7	46.3	ns	ns
Ca	"	14.0	10.7***	14.4	11.0**	ns	ns
Mg	"	5.9	5.9	7.1	6.0*	+	ns
S	"	1.2	1.5*	2.3	2.0	+++	ns
B	mg kg^{-1}	12	30**	25	25	+	ns
Mn	"	77	84	120	94*	++	ns
Zn	"	91	105	63	114**	--	ns
Cu	"	42	39	62	29**	+	ns

*****,**,* indicates significant difference at p<0.001, 0.01 and 0.05 between mid season (126 DAP) and at harvest (231 DAP)**
[1] indicates level of significant difference between fertilized and fertilized taro at 126 and 231 DAP;
+++,++,+ indicates fertilizers increased nutrient concentration significantly at p<0.001, 0.01 and 0.05 respectively;
--, - indicates fertilizers decreased nutrient concentration significantly at p<0.01 and 0.05 respectively;
ns = not significant.

Table 3: **Nutrient concentration1 in unfertilized and fertilized taro corms at 126 and 231 DAP**

		Unferilized		Fertilized		Fertilizer effect[1]	
Nutrient	Unit	126 DAP	231 DAP	126 DAP	231 DAP	126 DAP	231 DAP
N	g kg^{-1}	8.3	5.8	14.5	4.5**	+	-
K	"	2.6	2.1**	1.9	1.8	--	ns
K	"	20.9	17.0*	19.0	13.0**	ns	-
Ca	"	5.8	3.6*	4.9	3.1*	ns	ns
Mg	"	1.4	0.8**	1.3	0.8**	ns	ns
S	"	0.5	0.4	0.8	0.4***	+	ns
B	mg kg^{-1}	4	16**	13	17	ns	ns
Mn	"	40	24*	43	21*	ns	ns
Zn	"	68	37**	28	27	---	-
Cu	"	18	11*	19	9***	ns	ns

*****,**,* indicates significant difference at p<0.001, 0.01 and 0.05 between mid season (126 DAP) and at harvest (231 DAP)**
[1] indicates level of significant difference between fertiliezed and fertilized taro at 126 and 231 DAP;
+++,++,+ indicates fertilizers increased nutrient concentration significantly at p<0.001, 0.01 and 0.05 respectively;
--, - indicates fertilizers decreased nutrient concentration significantly at p<0.01 and 0.05 respectively;
ns = not significant.

Although variation was large, it was found that roots of fertilized taro at 126 DAP had taken up significantly larger ($p<0.01$) amounts of all major nutrients (Table 4). This was due to the greater biomass (Table 1) and higher concentration of most nutrients (Table 2). The total nitrogen content in the corm was higher 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 expressed as a proportion of 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

Table 4. **Nutrient content (kg ha^{-1}) of roots, corms and leafs of unfertilized and fertilized taro at 126 and 231 DAP**

	plant part	unfertilized taro			fertilized taro		
sampling period		N	P	K	Ca	Mg	S
mid-season	roots	3	<1	13	4	2	<1
(126 DAP)	corms	5	2	17	4	1	<1
	leaves[1]	19	5	46	8	1	1
	total	27	9	76	16	4	2
at harvest	roots	6	1	25	5	3	1
(231DAP)	corms	13	5	42	8	2	1
	leaves[1]	34	10	80	21	3	2
	total	53	16	147	35	8	4

,**, indicates significant difference between fertilized and unfertilized taro at *p*<0.05, 0.01 and 0.001 respectively**
[1] leaf biomass includes petioles

Table 4. **contd.**

	Plant part	fertilized taro					
sampling period		N	P	K	Ca	Mg	S
mid-season	roots	8**	1***	25**	8***	4***	1**
(126 DAP)	corms	14**	2	22	6	2	1
	leaves[1]	63	9	119	29*	5*	4
	total	85*	13	166	42*	10*	5*
at harvest	roots	5	1	23	5	3	1
(231DAP)	corms	31*	12*	86*	23	5*	3**
	leaves[1]	55	18	106	46	6	4
	total	91	31	215	74*	15*	8*

,**, indicates significant difference between fertilized and unfertilized taro at *p*<0.05, 0.01 and 0.001 respectively**
[1] leaf biomass includes petioles

K, Ca and S uptake was present in the roots at 126 DAP. The amount of Mg in the roots accounted for 36 to 38% of the total Mg in the taro plants in both treatments.

At the end of 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 was similar for unfertilized taro at 126 DAP 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, notably for Ca (from 18 to 7%) and Mg (from 36 to 20%).

DISCUSSION

Fertilized taro produced twice as much biomass than 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 about 0.50 t ha^{-1}. This root biomass is much larger than that recorded by Goenaga and Chardon (1995) who found between 0.14 to 0.31 t ha^{-1} for fertilized and drip-irrigated taro in Puerto Rico. Goenaga and Chardon (1995) also found that root biomass accumulation was complete within 120 DAP and did not change thereafter. Our 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 our data confirmed. As whole plants were dug up variation in root biomass measurements was relatively low (CV%<24) compared to other destructive sampling techniques like core samples and pinboards (Noordwijk *et al.* 1985; Taylor *et al.* 1991).

It was found that fertilizers reduced the concentration of P and Zn in both corms and roots at the mid-season whereas it increased the level of S. The increase in S concentration may be due to an increased S availability due to the addition by the sulphate of ammonia (114 kg S ha^{-1}). The significant decrease in P concentration may be caused by dilution in the plants which occurs when the rate of uptake is slower than the rate of biomass accumulation. The same may hold for the decrease in Zn concentration.

In our experiment we found that large amounts of nutrients are taken up by the roots and only small 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 found by Gliessman (1982) who recorded 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 (Goenaga and Chardon 1995; Jacobs and Clarke 1993) and the growing conditions. Very little P was found in the roots ($\leq$ 1 kg ha^{-1}) and the majority of the P 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 24% loss of K. Magnesium was not taken up in large quantities in taro roots under unfertilized conditions (3 kg ha^{-1} at harvest) but it accounted for about 36% of the total Mg in the taro plants. In fertilized taro, about 20% of the total Mg taken up was found in the roots at harvest. In the mid season, the proportion of Mg in taro roots was highest (36-38% of total uptake). These data are much higher than those found by Kabeerathumma *et al.* (1985) who found 5% of the total Mg in the taro roots.

CONCLUSIONS

Root biomass in fertilized taro was fully developed by the mid-season whereas only half of the final root biomass was formed in unfertilized taro at this time. At harvest root biomass of fertilized and unfertilized taro was 0.50 t ha^{-1}. The amounts of nutrients in the roots of fertilized and unfertilized taro was similar at harvest: 5 kg N, 1 kg P, 25 kg K, 5 kg Ca, and 3 kg Mg ha^{-1}. The study has shown that considerable amounts of nutrients are allocated to the roots of taro but that the proportion of nutrients in the roots was much larger for unfertilized taro.

ACKNOWLEDGEMENTS

The authors are indebted to Spencer Poloma and Maquin Maino of the University of Technology in Lae for technical assistance. The research was partly funded through ACIAR Project 9101 (Diagnosis and correction of mineral nutrient disorders in root crops of the Pacific) and support from Drs F.P.C. Blamey and J.N. O'Sullivan of The University of Queensland in Brisbane is kindly acknowledged.

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