Mineral Nutrition of Cassava

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Abstract

Although cassava (*Manihot esculenta* Crantz) is more productive than most other crops when grown on acid infertile soils, it is also very responsive to better soil fertility and may require high levels of fertilisation to reach its yield potential. In moderately acid soils, cassava generally does not respond to the application of lime except as a source of calcium and/or magnesium. High rates of liming often induce zinc deficiency. When grown on infertile soils cassava seldom shows clear symptoms of nitrogen, phosphorus or potassium deficiencies, but instead produces small and weak plants while root yields are reduced. Diagnosis of major nutrient deficiencies is best done through soil or plant tissue analysis.

The paper therefore describes both deficiency (or toxicity) symptoms as well as critical levels or ranges of each nutrient in soil and in cassava leaves. When grown on light textured and low organic matter soils, cassava tends to respond mainly to N application; however, due to the relatively large removal of K in the root harvest, continuous cassava cultivation on the same soil may lead to K exhaustion, and K will eventually become the most limiting nutrient. Under normal soil conditions cassava roots become readily infected with mycorrhizal fungi, which help the plant absorb P even at low external P concentrations in soil solution. Thus, in most cassava soils in Asia the crop does not respond much to P application.

BECAUSE cassava is well adapted to poor soils and is relatively tolerant of drought, the crop is usually grown under marginal soil and climatic conditions and often with very limited inputs of fertilizers and pesticides. Under these conditions cassava can still produce reasonably good yields where most other crops would fail. However, like any other crop, cassava only realises its high yield potential when it is supplied with adequate light, nutrients and water. Thus, when grown on infertile soils cassava responds well to the application of chemical fertilizers and manures or to the incorporation of green manures.

Symptoms of nutrition disorders in cassava, especially the deficiencies of nitrogen (N), phosphorus (P) and potassium (K), are often not readily recognised and farmers are unaware that their crop may be suffering from nutrition stresses leading to reduced yields. This makes the diagnosis of nutrition disorders rather difficult, and in some cases the diagnosis can be made only after soil and/or plant tissue analyses. For that reason, the most common symptoms of various nutrition disorders and critical levels for nutrition deficiencies or toxicities in the plant tissue (Table 1) and soil (Table 2) are given. The values can be used as a general guide for the interpretation of leaf or soil analysis results.

Since nutrient concentrations in the plant vary among the different tissues and change during the growth cycle, it is important to standardise the sampling of plant tissue for diagnosing nutrition disorders. It is recommended to sample the blades (without petioles) of youngest fully expanded leaves (YFEL) at 3–4 months after planting.

Soil Acidity and Aluminium Toxicity

Cassava is well adapted to acid soils because of its tolerance to high levels of aluminium (Al) in soil solution. However, in very acid soils with high levels of exchangeable Al and/or low levels of calcium (Ca), cassava can suffer from Al toxicity. This has been observed mainly in very acid Oxisols with a soil pH of 4.2–4.5 and an Al saturation of about 85%. However, in peat soils of Malaysia, with little

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exchangeable Al but high levels of exchange acidity, cassava produced very well in areas with a pH of 3.4, but showed severe nutrition disorders in areas with pH 3.1 and 6.5 cmol exchange acidity/kg.

Symptoms of Al toxicity are not very clear. In some varieties the lower leaves show interveinal yellowing and necrosis, but in most varieties there are few recognisable symptoms; plants are small and lack normal vigour. In nutrient solution culture with high concentrations of Al, cassava plants were found to be small with a short and stubby root system. Both Al toxicity and soil acidity stress can be prevented by the application of lime, which will decrease the Al saturation and raise soil pH. Rates of 0.5–2.0 t/ha of calcitic or dolomitic lime are generally required to obtain maximum yields in very acid mineral soils, while 3 t/ha of hydrated lime are required for maximum yield on peat soils. Higher rates of liming may result in the induction of micronutrient deficiencies (Spain et al. 1975).

Salinity and alkalinity

Cassava is seldom grown on saline alkaline soils because it is not well adapted to these conditions. The crop is rather sensitive to high pH and the associated problems of salinity, alkalinity and sometimes poor drainage. Moreover, at high pH there are often problems of micronutrient deficiencies, especially that of zinc (Zn).

Cassava plants suffering from salinity problems show a uniform yellowing of leaves, which starts at the top of the plant but quickly proceeds downward. Under moderate salinity stress the symptoms are similar to those of Fe deficiency. Under severe stress, the lower leaves become necrotic and fall off and plant growth is severely affected, sometimes leading to plant death.

Soil salinity can be improved by leaching out the salts through flooding and draining, while alkalinity can be reduced by the application of elemental sulfur (S) or gypsum; however, this is a long and expensive process. Since cassava varieties differ markedly in their tolerance to salinity problems it is more practical to select adapted varieties and apply micronutrients when necessary.

Nitrogen deficiency

Nitrogen deficiency is commonly observed when cassava is grown on light-textured soils with low organic matter content or in very acid soils with a low rate of N mineralisation. Nitrogen deficiency seems to be more common in Asia than in Latin America.

Some varieties show no symptoms of N deficiency, but plants remain small and weak while root yields are markedly reduced. Other varieties show clear symptoms of N deficiency: plants are uniformly chlorotic and leaves have a uniform light green or yellowish colour. Although N-deficiency symptoms first appear in the bottom leaves, they rapidly spread throughout the plant, leading to a generalised chlorosis. Nitrogen-deficient leaves are smaller and may have less lobes and shorter petioles than normal leaves.

The critical level for N deficiency in youngest fully-expanded leaf (YFEL) blades at 3–4 months after planting is about 5.3% N, while the sufficiency range is about 5.1–5.8% N (Table 1). (In this paper the critical level is defined as that concentration corresponding to 95% of maximum yield, while the sufficiency range is the concentration corresponding to 90–100% of maximum yield.)

To control N deficiency in cassava, an application of 50–100 kg N/ha in the form of urea or as a compound fertilizer during the first 2–3 months after planting is recommended. In light-textured soils, in which N may be lost through leaching, two applications are recommended, at planting and at 3 months. Nitrogen can also be applied in the form of animal manure (5–10 t/ha), or by the incorporation of or mulching with green manures or cover crops.

Phosphorus deficiency

Phosphorus deficiency is the most limiting nutrition factor for cassava grown on many acid infertile Oxisols, Ultisols and Inceptisols in Latin America, but it is less common in Asia. Phosphorus-deficient cassava plants are generally short and spindly with thin stems, small and narrow leaves and short petioles. During periods of drought the upper leaves tend to droop down from the petioles. The leaves are generally dark green while one or two lower leaves may be dark yellow to orange and in some varieties purplish with necrotic white spots. These lower leaves often drop off, leaving the plant without any recognisable symptoms.

The critical level for P deficiency in YFEL blades is about 0.41% P (Howeler and Cadavid, 1990) and the sufficiency range is calculated to be 0.38–0.50% P (Table 1). The critical level of available P in the soil is about 4–6 µg/g Bray II-extractable P (Howeler 1990). In some soils having only 2–4 µg/g available P there is still no response to P application due to a highly efficient mycorrhizal association (Howeler et al. 1987), which enables the plant to absorb soil P from a greater soil volume.

To control P deficiency it is recommended to band-apply near the stake 25–50 kg P/ha as highly soluble P-sources such as single or triple superphosphate or compound fertilizers; alternatively, P can be applied by broadcasting and incorporating less soluble sources such as basic slag, rock phosphate or thermophosphate. The latter are good sources of P in acid soils. All P should be applied at or shortly after planting to enhance early growth and plant vigour.

Potassium deficiency

Cassava extracts large amounts of K in the root harvest and long-term fertility trials have shown that sooner or later K deficiency becomes the most limiting nutrition factor if it is grown continuously without adequate K fertilisation.

Potassium-deficient plants are generally short, highly branched and with a prostrate growth habit. In many varieties the upper internodes are very short and prematurely lignified resulting in a 'zigzagging' of the upper stem. In some varieties, the upper leaves are small and chlorotic, while in others a few lower leaves are yellow with black spots and border necrosis. During periods of drought leaf borders may curl upward, while during wet periods there may be severe die-back of shoot tips due to K deficiency-induced anthracnose (*Colletotrichum* spp.). In many cases, however, there are no clearly recognisable symptoms and plants are simply shorter and have smaller leaves than those well supplied with K.

The critical level for K deficiency in YFEL blades at 3–4 months after planting is about 1.5% K, while the sufficiency range is 1.4–1.9% K (Table 1). The critical level of exchangeable K in the soil was found to be 0.15–0.17 cmol/kg (Howeler 1985a; Howeler and Cadavid 1990).

Potassium deficiency in cassava can be controlled by the application of 50–100 kg K/ha as potassium chloride. Potassium can also be applied as a compound fertilizer or in the form of wood ash. In soils where P deficiency is not a serious problem, compound fertilizers with an N-P_2O_5-K_2O ratio of about 2:1:3 or 2:1:4 are recommended in order to supply enough K to prevent K exhaustion of the soil. Most K fertilizers are highly soluble and should be band-applied near the stake during the first two months after planting. In light-textured soils they should be applied in two smaller doses to prevent losses by leaching.

Calcium deficiency

Calcium deficiency symptoms are easily produced in nutrient solution culture, but are seldom seen in the field; significant responses of cassava to Ca application are also rather rare. Still, in very acid soils with high levels of Al and low levels of Ca, cassava does respond to liming, which is thought to be mainly a response to the application of Ca and/or magnesium (Mg).

Since Ca is not very mobile in the phloem, there is little Ca translocation from the older to the younger tissue. When the Ca supply is inadequate, symptoms of Ca deficiency develop in the growing points of both shoots and roots. Upper leaves are deformed with leaf tips burned and curling either up or down. The growing points of fibrous roots die back, resulting in excessive root branching. In the field, Ca deficiency is characterised mainly by deformation and burning of leaf tips in the upper part of the plant, but these symptoms cannot be seen in all varieties.

The critical concentration for Ca deficiency in YFEL blades at 3–4 months after planting was found to be 0.56% Ca and the sufficiency range calculated to be about 0.50–0.72% Ca (Table 1). However, Ca concentrations in YFEL blades can vary markedly among different varieties.

Calcium deficiency is generally controlled by the application of 200–400 kg Ca/ha in the form of calcitic or dolomitic limestone, as calcium oxide or hydroxide, or as gypsum. Gypsum is a more soluble source, which supplies Ca as a nutrient but without affecting soil pH or exchangeable Al. All these Ca sources should be broadcast and incorporated before planting.

Magnesium deficiency

Magnesium deficiency symptoms are often found in acid infertile soils such as Oxisols, Ultisols and certain Inceptisols.

Magnesium deficiency is characterised by interveinal chlorosis of the lower leaves, which starts out as slight yellowing of leaf margins and may eventually develop into necrosis of leaf tips and margins. Symptoms appear first at the lowest leaves and progressively move up the plant.

Critical concentrations for Mg deficiency in YFEL blades at 3–4 months after planting were found to be 0.25% Mg and the sufficiency range was calculated as 0.24–0.29% Mg (Table 1). No critical levels for soil exchangeable Mg have been reported, but Mg deficiency symptoms and a response to Mg application were found in soils with less than 0.2 m-equiv. Mg/kg (Table 2).

Magnesium deficiency can be controlled by the application of 40–60 kg Mg/ha in the form of magnesium oxide, dolomitic limestone or magnesium sulphate. The first two sources are relatively insoluble and should be broadcast and incorporated before planting. Magnesium sulphate is a soluble source, which may be band-applied near the stake shortly after planting. It has no effect on soil pH or exchangeable Al, but can be used as a source of S.

Sulfur deficiency

Sulfur deficiency in cassava is easily produced in nutrient solutions, but is not often found in the field.

Table 1. Nutrient concentrations in youngest fully-expanded leaf blades of cassava at 3–4 months after planting, corresponding to various nutrition states of the plants. Data are the average results of various greenhouse and field trials.

	Nutritional states[a]					
Nutrient	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1–4.8	4.8–5.1	5.1–5.8	>5.8	[b]
P (%)	<0.25	0.25–0.36	0.36–0.38	0.38–0.50	>0.50	—
K (%)	<0.85	0.85–1.26	1.26–1.42	1.42–1.88	1.88–2.40	>2.40
Ca (%)	<0.25	0.25–0.41	0.41–0.50	0.50–0.72	0.72–0.88	>0.88
Mg (%)	<0.15	0.15–0.22	0.22–0.24	0.24–0.29	>0.29	—
S (%)	<0.20	0.20–0.27	0.27–0.30	0.30–0.36	>0.36	—
B (µg/g)	<7	7–15	15–18	18–28	28–64	>64
Cu (µg/g)	<1.5	1.5–4.8	4.8–6.0	6–10	10–15	>15
Fe (µg/g)	<100	100–110	110–120	120–140	140–200	>200
Mn (µg/g)	<30	30–40	40–50	50–150	150–250	>250
Zn (µg/g)	<25	25–32	32–35	35–57	57–120	>120

[a] Very deficient = <40% maximum yield
Deficient = 40–80% " "
Low = 80–90% " "
Sufficient = 90–100% " "
High = 100–90% " "
Toxic = <90% " "

[b] — = no data available.

Table 2. Approximate classification of soil chemical characteristics according to the nutrition requirements of cassava.

Soil parameter	Very low	Low	Medium	High	Very high
pH	<3.5	3.5–4.5	4.5–7	7–8	>8
Org. matter	<1.0	1.0–2.0	2.0–4.0	>4.0	
Al-saturation (%)			<75	75–85	>85
Salinity (mS/cm)			<0.5	0.5–1.0	>1.0
Na-saturation (%)			<2	2–10	>10
P (µg/g)	<2	2–4	4–15	>15	
K (me/100g)	<0.10	0.10–0.15	0.15–0.25	>0.25	
Ca (me/100g)	<0.25	0.25–1.0	1.0–5.0	>5.0	
Mg (me/100g)	<0.2	0.2–0.4	0.4–1.0	>1.0	
S (µg/g)	<20	20–40	40–70	>70	
B (µg/g)	<0.2	0.2–0.5	0.5–1.0	1–2	>2
Cu (µg/g)	<0.1	0.1–0.3	0.3–1.0	1–5	>5
Mn (µg/g)	<5	5–10	10–100	100–250	>250
Fe (µg/g)	<1	1–10	10–100	>100	
Zn (µg/g)	<0.5	0.5–1.0	1.0–5.0	5–50	>50

pH in H_2O; OM by method of Walkley and Black;
Al-saturation = 100 × Al/(Al+Ca+Mg+K) in cmol/kg;
P in Bray II; K, Ca, Mg and Na in 1N NH_4-acetate; S in Ca-phosphate
B in hot water; and Cu, Mn, Fe and Zn in 0.05 N HCl+0.025 N H_2SO_4.

It is characterised by a uniform chlorosis or yellowing of leaves (similar to N deficiency) in the upper and middle part of the plant. Eventually the whole plant becomes chlorotic. Leaves are small and plant height may be reduced, but leaves are not deformed.

The critical concentration for S deficiency in YFEL blades was found to be about 0.31% S, while the sufficiency range was calculated to be 0.30–0.36% S (Table 1). Critical levels in the soil have not been determined, but S responses were obtained in soils with 25–30 µg/g phosphate-extractable S.

Sulfur deficiency can be controlled by the application of 10–20 kg S/ha as elemental sulfur or as sulfates of ammonium, potassium, calcium or magnesium. The latter four sources are relatively soluble and can be band-applied near the stake at planting, while elemental sulfur should be broadcast and incorporated before planting.

Boron deficiency and toxicity

Symptoms of boron (B) deficiency are not commonly observed in the field, but are easily produced in nutrient solution. Since B is a phloem-immobile element, deficiency symptoms are mainly found in the growing points of shoots and roots. Thus extremely B-deficient plants have small and deformed leaves in the upper part of the plant with, in some cases, exudation of a brown gummy substance from the upper petioles. Root tips often die, resulting in a small and excessively branched root system (Asher et al. 1980). In the field these symptoms are seldom observed. Boron deficiency in the field is generally characterised by white or brown speckles on leaves in the middle part of the plant. Some varieties are much more susceptible than others, but in general cassava is quite tolerant of low levels of available B in the soil.

Symptoms of B toxicity have been found only when B was applied at too high rates. In that case, lower leaves are deformed with yellow or brown spots and necrosis of leaf tips and margins. Since B is not translocated to the growing points, plants generally recuperate from an initial B toxicity.

The critical concentration for B deficiency in YFEL blades, as determined in two nutrient solution experiments, were found to be 21 and 35 µg B/g, while those for B toxicity were 50 and 100 µg B/g (Howeler et al. 1982; J.M. Portieles, pers. comm.). However, B concentrations of less than 10 µg B/g were found in YFEL blades of apparently normal field-grown plants. A sufficiency range was calculated to be about 18–28 µg B/g (Table 1). Symptoms of B deficiency and some response to B application have been found in soils with 0.2–0.3 µg/g of hot water-soluble B. A normal range of B in the soil is about 0.5–1.0 µg/g (Table 2).

Boron deficiency can be controlled by the application of 1–2 kg B/ha in the form of sodium borates, such as Borax or Solubor. These sources are rather soluble and can be band-applied near the stake at planting. Alternatively, stakes can be dipped in a solution of 1% Borax before planting; however, concentrations above 1% may result in B toxicity.

Copper deficiency

Symptoms of Cu deficiency in cassava have been produced in nutrient solution culture but are seldom seen in the field. Severe symptoms and yield reductions due to Cu deficiency were found only on the peat soils of Malaysia, where high levels of organic matter result in the complexing of Cu with humic acids, making the Cu unavailable to plants.

Copper deficiency in cassava is characterised by chlorosis, deformation and wrinkling of upper leaves with necrosis of leaf tips and margins; leaf tips curl either up or down. Leaves in the middle and lower part of the plant are rather large and suspended on long and bent-down petioles.

A critical concentration for Cu deficiency in YFEL blades after 9 weeks of growth in nutrient solution was reported to be 6 µg/g, while that for Cu toxicity was about 15 µg/g (Howeler et al. 1982). The sufficiency range was calculated to be about 6–10 µg Cu/g (Table 1). However, high yields on peat soils in Malaysia were obtained with Cu concentrations of 14–15 µg Cu/g in YFEL blades (Chew et al. 1978). Critical levels of available Cu in the soil have not been determined, but about 0.3–1.0 µg/g double-acid extractable Cu is considered a normal range for cassava (Table 2).

Copper deficiency can be controlled with the application of 2.5-3.5 kg Cu/ha as $CuSO_4.5H_2O$, band-applied near the stake at planting. Copper deficiency can also be controlled by foliar application of 0.05% $CuSO_4.5H_2O$; higher concentrations resulted in reduced yields (Chan and Ramli, 1987).

Manganese deficiency and toxicity

Manganese (Mn) deficiency is found mainly in high pH calcareous soils or in acid soils treated with excessive amounts of lime. Its symptoms are similar to those of Mg deficiency, but are found mainly in the middle part of the plant. Manganese-deficient plants have leaves with interveinal chlorosis, in which the green veins stand out in a 'fishbone' pattern on a yellow background. Under severe conditions the whole leaf may turn almost uniformly yellow (similar to Fe deficiency), while plant height is reduced. Leaves usually maintain their normal size and are not deformed.

Manganese toxicity is usually found in very acid soils, especially under conditions of excess water resulting in the reduction of higher oxides of Mn to the more soluble Mn^{2+} form.

However, Mn toxicity may also occur during the dry season when stagnated growth can lead to excessive accumulation of Mn in the lower leaves. It is characterised by brown or black speckling along the veins of lower leaves. These leaves are initially green, but later turn yellow to orange. They may be hanging flaccid on the petioles before they fall off. Manganese toxicity may also severely reduce root growth.

The critical concentration for Mn deficiency in YFEL blades was found to be about 50 µg Mn/g, while that for Mn toxicity was about 250 µg Mn/g (Howeler et al. 1982). The sufficiency range was estimated at 50–150 µg Mn/g. Critical levels of available Mn in the soil have not been determined, but about 10–100 µg/g of double-acid extractable Mn may be considered a normal range for cassava (Table 2).

Manganese deficiency can be corrected by soil application of manganese oxide or sulfate, by a foliar spray with Mn chelates or a 1–2% solution of $MnSO_4.4H_2O$, or by dipping the stakes in a 5% solution of $MnSO_4.4H_2O$ for 15 minutes before planting. Manganese toxicity can be controlled by the application of lime in acid soil and by providing better internal drainage by loosening compacted soil.

Iron deficiency

Iron (Fe) deficiency is quite common when cassava is grown on calcareous soils. It has also been observed when cassava is grown on levelled-off termite hills; these soils have high concentrations of Ca, Mg and K and an elevated soil pH. Iron deficiency can also be induced by high applications of lime and/or P in acid sandy soils of low Fe content, as well as by excessive absorption of Mn.

Iron-deficient plants have a uniform chlorosis of the upper leaves including the veins. Under severe conditions the upper leaves may turn completely white, while lower leaves become increasingly chlorotic. Plant height may be reduced and seriously affected plants may die. Symptoms of Fe deficiency are most serious during the dry season and may completely disappear again during the following wet season.

The critical concentration for Fe deficiency in YFEL blades could not be clearly established (Howeler et al. 1982), but a sufficiency range was estimated to be 120–140 µg Fe/g (Howeler 1983). Concentrations of over 400 µg/g may result in a reduction in plant growth, but no symptoms of Fe toxicity nor a reduction in root yield have been observed. Critical levels of available Fe in the soil have not been determined, but about 10–100 µg Fe/g is a normal range for cassava (Table 2).

Iron deficiency is best controlled by a foliar spray of iron chelates or a 1–2% solution of $FeSO_4.7H_2O$. Dipping stakes in a solution of 5% $FeSO_4.7H_2O$ for 15 minutes before planting had no adverse affect on germination, but its effectiveness in controlling Fe deficiency still needs to be determined.

Zinc deficiency

Zinc deficiency is a rather common nutrition disorder in cassava and is observed both in high pH soils, due to a reduced availability of Zn, and in low pH soils, due to their low levels of total Zn.

In cassava it is characterised by white speckling or striping in the interveinal region of upper leaves. These leaves may become chlorotic, they are usually small in size and have narrow leaf lobes which tend to point away from the petiole and stem. Under more severe conditions the leaves in the growing point become increasingly chlorotic and deformed, while in some varieties the lower leaves have white necrotic spots or generalised chorosis in the interveinal areas. Zinc deficiency is often observed when plants are young, but they may grow out of it once the root system is better developed. Under severe Zn deficiency stress, shoot tips die back or the whole plant may die.

The critical concentration for Zn deficiency in YFEL blades was found to be 40 µg Zn/g, while the sufficiency range was calculated to be 35–57 µg Zn/g. A critical level for soil-available Zn has been reported as 1 µg/g of double-acid extractable Zn (Howeler 1985b); a Zn level of 1–5 µg/g can be considered as a normal range for cassava (Table 2).

Zinc deficiency can be controlled by band-application of 5–10 kg Zn/ha as $ZnSO_4.7H_2O$ or by broadcast-application of 10–20 kg Zn/ha as ZnO. In high pH soils, in which applied Zn soon becomes unavailable to plants, it is more effective to make foliar applications of 1–2% solutions of $ZnSO_4.7H_2O$ or to dip stakes for 15 minutes in a solution of 2–4% $ZnSO_4.7H_2O$ before planting. The latter is a very cheap and effective method of preventing serious Zn deficiency in alkaline or calcareous soils (CIAT 1985).

References

Asher, C.J., Edwards, D.G. and Howeler, R.H. 1980. Nutritional Disorders of Cassava. Department of Agriculture, University of Queensland, St Lucia, Qld, Australia. 48 p.

Centro Internacional de Agricultura Tropical (CIAT). 1985. CIAT Annual Report for 1982 and 1983. Cassava Program, Cali, Colombia.

Chan, S.K. and Ramli, K. 1987. Evaluation of three methods of copper fertilization for cassava on peat. In: Lim, K.H. and Talib, J., ed., Recent Advances on Soil and Water Management in Malaysian Agriculture, Proceedings National Seminar, Kuala Lumpur, Malaysia, March 20, 1986. 69–78.

Chew, W.Y., Joseph, K.T. and Ramli, K. 1978. Influence of soil-applied micronutrients on cassava (*Manihot esculenta*) in Malaysian tropical oligotrophic peat. Experimental Agriculture, 14. 105–111.

Howeler, R.H. 1983. Analisis del tejido vegetal en el diagnostico de problemas nutricionales de algunos cultivos tropicales. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 28 p.

— 1985a. Potassium nutrition of cassava. In: Potassium in Agriculture. International Symposium held in Atlanta, Ga, USA, July 7–10, 1985. ASA, CSSA, SSSA, Madison, Wisc., USA. 819–842.

— 1985b. Mineral nutrition and fertilisation of cassava. In. Cassava: Research, Production and Utilization. UNDP-CIAT Cassava Program. Cali, Colombia. 249–320.

— 1990. Phosphorus requirements and management of tropical root and tuber crops. In: Proceedings Symposium on Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania. IRRI, Los Banos, Philippines, March 6–10, 1989. 427–444.

Howeler, R.H. and Cadavid, L.F. 1990. Short- and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. Fertilizer Research, 26. 61–80.

Howeler, R.H., Edwards D.G. and Asher, C.J. 1982. Micronutrient deficiencies and toxicities of cassava plants grown in nutrient solutions. I. Critical tissue concentrations. Journal of Plant Nutrition 5. 1059–1076.

Howeler, R.H., Sieverding, E. and Saif, S. 1987. Practical aspects of mycorrhizal technology in some tropical crops and pastures. Plant and Soil, 100. 249–283.

Spain, J.M., Francis, C.A., Howeler, R.H. and Calvo, F. 1975. Differential species and varietal tolerance to soil acidity in tropical crops and pastures. In: Bornemisza, E. and Alvarado, A., ed., Soil Management in Tropical America. North Carolina State University, Raleigh, NC, USA. 308–329.

Mineral Nutrition of Root Crops in Fiji

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Abstract

Root crops, in particular ginger, taro and sweet potato, have a place in commercial and smallholder Fijian agriculture, and they fit readily into crop rotations involving other vegetables. As population pressure in the Fiji Islands and elsewhere increases, root crops may assume a more significant role in both local and export markets due to their ease of cultivation, short growth duration habits, high yields, and good eating and keeping qualities. Opportunities exist to study these and other root crops in both commercial and smallholder farming systems. An understanding of their mineral nutrition and the ability to cost-effectively diagnose any nutrition limitations (by soil test, foliar analysis or pictorial representation) will be vital as Fiji aims for greater export earnings, greater acceptance of a wider variety of root crops on local markets and more sustainable agricultural production in the future.

ROOT crops in Fiji, although of less economic importance than sugar, remain the staple diet of about half Fiji's population. In 1993, sugar alone accounted for 41% of total agricultural GDP in Fiji, whereas all other crops including root crops accounted for 14%. The main root crops are ginger, cassava, taro (dalo), sweet potato and yams. Root crops are generally grown by semi-subsistence farmers principally for their own use, although there are significant commercial plantings of ginger and Samoan Pink taro for export plus local Fijian varieties of taro for local markets. Ginger and taro are the next most important export crops after sugar ($F300–400 million annually), each valued at $F4–6 million annually ($F1.00 = $A1.046 approx.), and with expanding export markets. The major production areas for ginger, taro and sweet potato in Fiji are shown in Figure 1.

Research is currently being conducted by Fiji's Ministry of Agriculture, Fisheries and Forests (MAFF) on root crops in the following areas: (1) ginger nutrition and management; (2) taro for early maturing, drought-tolerant and high-yielding varieties; (3) sweet potato for scab and weevil resistant varieties; and (4) cassava and yams for high yielding varieties. Although the mineral nutrition of root crops has been little studied in the past, MAFF recognises the importance of understanding their nutrition requirements if production levels and quality are to be improved through the adoption of better varieties. This paper provides an overview of production systems, soils and their limitations, and the current direction of mineral nutrition research in Fiji on ginger, taro and sweet potato.

Ginger

Ginger was introduced to Fiji a century ago as a spice crop. Today, it is an important export crop marketed in immature unprocessed, or immature processed (crystallised ginger) forms or as a fresh mature vegetable. Immature ginger is processed in Fiji and sold in New Zealand, the United Kingdom, Germany and Australia. Fiji also exports over $F2 million worth of immature and mature fresh ginger to North America including Los Angeles, San Francisco, Seattle and Vancouver. An industry-based Ginger Growers Council of Fiji was established in 1993 specifically to support growers, exporters and others involved in Fiji's ginger export industry.

Ginger Production

Ginger is grown mainly in the south-eastern provinces of Viti Levu, along the Rewa River (Davuilevu, Naisoqo and Waibau areas), Navua and

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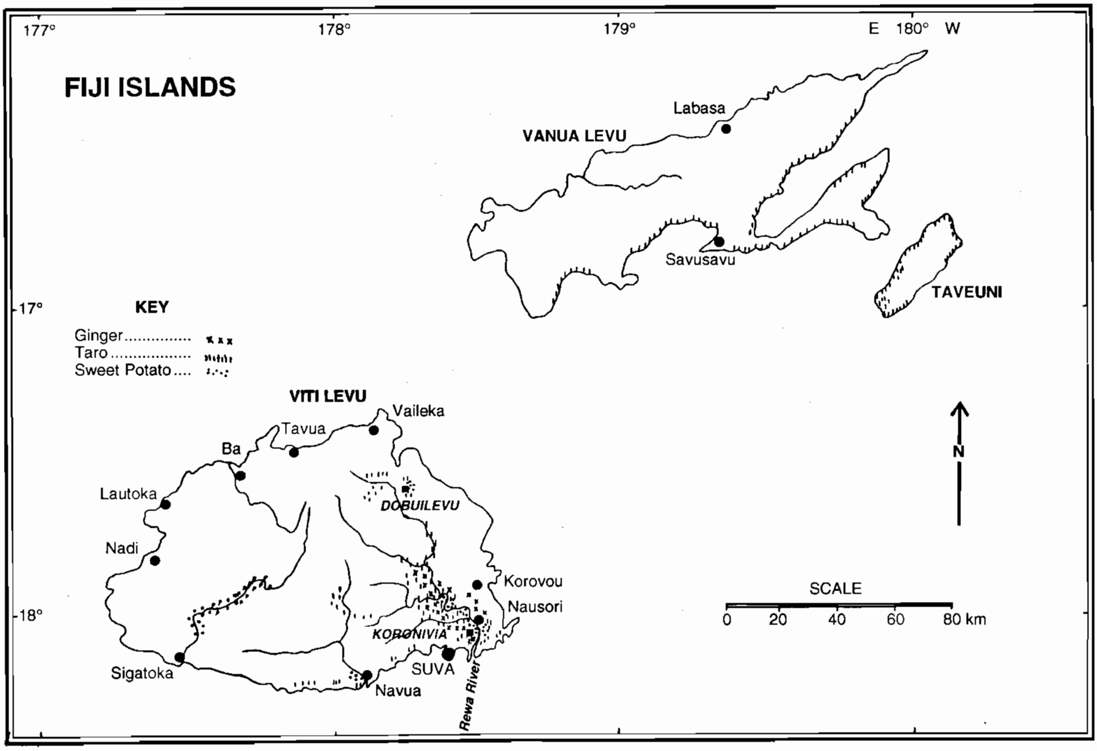

Fig. 1. Ginger, taro and sweet potato growing areas in Fiji.

Tailevu, areas of suitable climate with annual rainfall more than 3000 mm. Sloping lands, possibly prone to erosion, are preferred to flatter lands to minimise disease risks. On sloping lands, natural vegetation is removed and the land prepared using digging forks. Shallow furrows are made for planting down the slope to allow drainage. Land preparation is costly and laborious. As the area and production of ginger in Fiji are increasing and there is potential for increasing erosion on sloping lands, research on the mechanised cultivation of ginger on flat lands using raised beds to facilitate drainage is being undertaken.

Due to nematode and disease problems, ginger is usually planted on newly cleared land. Failing this, a four year rotation of ginger-taro-cassava-fallow-ginger is recommended. Immature ginger is harvested at 5-6 months and mature ginger at 10 months. Soil conservation measures (e.g. contour planting) are not usually applied. Weeds are usually controlled chemically. Farmers can modify this rotation by planting vegetables or sweet potato during the fallow period, and the use of both organic and inorganic fertilizers can be high. This rotation has helped reduce pests and diseases, minimise tillage operation, maintain soil fertility and increase production of taro and cassava, and allow better utilisation of available on-farm resources.

Likely Soil Limitations

Ginger requires well-drained, deep loamy soils. Newly cleared lands with high amounts of organic matter and a gentle slope are most suitable. Ginger is grown mainly on Humic Latosols, particularly on hilly areas of Waidina clay, Waimaro clay, Sote clay and Lobau clay. It is also grown on nigrescent soils, particularly Samabula clay and Wailoku clay on the Suva Peninsula. According to some farmers, ginger performs better on these 'darker', neutral to alkaline soils than on 'redder', more acidic soils. But yields on darker soils tend to decline rapidly over time. Consistently high yields can be obtained on red soils with adequate fertilisation and good management. Lime can be used to correct acidity problems.

From a series of fertilizer trials during the early 1980s, fertilizers are typically recommended for both immature and mature ginger as follows: (1) poultry manure (10 t/ha) applied during land preparation to help control root-knot nematodes; (2) N–P–K (13:31:21) mix at 1 t/ha, half at planting and half three months after planting; and (3) urea (300 kg/ha) in three split applications for immature ginger and four applications for mature ginger. Leaf samples taken from farmers' fields suggest few limitations (Table 1) except occasionally for N, P and Ca deficiencies. Low levels of Ca uptake are a concern, given the high rates of K fertilizer applied and a possible cation (Ca to K ratio) imbalance. Cation imbalances due to use of mixed N–P–K fertilizers containing very high K levels may be occurring. In the Sigatoka area, for example, high K fertilizers are often used and blossom end rot is common in tomatoes. Ca deficiency is suggested but soil Ca levels are high (Table 2). Hence the problem may lie in the oversupply of K.

Directions of Research on Ginger

As part of the Farming System Research and Development (FSRD) approach to the ginger industry initiated in 1994, an exploratory Rapid Rural Appraisal (RRA) was conducted, and farmers' problems identified and research devised to solve these problems. For example, soil analyses suggested most farms had soil pH levels of 4.1–5.6 and low P availability (Olsen-P levels of 8–10 mg/kg). As a result, ginger trials at nine sites (treatments: control; lime; P; and lime+P) were planted in September 1994. Observations suggest the combined lime+P treatment was out-performing those receiving lime or P alone. Another trial was planted at Koronivia Research Station to describe ginger responses to 100–400 kg/ha N, 150 and 250 kg/ha K, and 0 and 10 t/ha poultry manure on a Fluventic Eutropept

Table 1. Foliar analyses for ginger, taro and sweet potato growing areas in Fiji.

Area		N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
				(%)					(mg/kg)		
Ginger											
Davuilevu	Mean	3.66	0.31	3.71	0.43	0.47	210	506	10	33	nd
(n=5)	CV%	8	10	7	5	9	9	47	30	6	
Naisoqo	Mean	3.44	0.38	3.80	0.47	0.42	261	949	16	40	nd
(n=5)	CV%	6	5	7	11	10	44	22	25	32	
Waibau	Mean	3.47	0.44	4.12	0.40	0.44	169	375	14	35	nd
(n=4)	CV%	4	9	12	20	14	5	23	36	23	
Taro											
Nausori	Mean	3.26	0.36	3.05	1.31	0.42	nd	nd	nd	nd	nd
(n=17)	CV%	30	4	8	9	5					
Sweet potato											
Baulevu	Mean	2.35	0.32	4.03	0.84	0.44	696	47	11	19	34
(n=9)	CV%	20	22	22	31	22	67	40	30	20	15
Sigatoka	Mean	2.28	0.29	3.27	1.56	0.50	164	45	20	19	35
(n=5)	CV%	14	32	28	39	19	32	31	51	13	20

nd: not determined

Table 2. Soil analytical data for taro and sweet potato growing areas in Fiji.

Area		pH	Olsen-P (mg/kg)	Ca	Mg	K	Na	B (mg/kg)
					(cmol (+)/kg)			
Taro								
Nausori	Mean	5.9	5	16	6.6	0.54	nd	nd
(n=6)	CV%	6	28	13	12	4		
Sweet potato								
Baulevu	Mean	6.3	10	14	5.3	0.49	0.20	0.2
(n=13)	CV%	5	34	22	30	56	20	87
Sigatoka	Mean	6.2	13	12	4.0	0.66	0.17	nd
(n=4)	CV%	9	58	91	58	72	56	

nd: not determined

(Rewa soil series). Soil analysis indicated 8–10 mg/kg Olsen-P and 0.25–0.40 (cmol(+)/kg) exchange K. Best growth was observed in treatments receiving higher rates of N only.

Also at the International Board for Soil Research and Management (IBSRAM) PACIFICLAND site in Fiji, MAFF is involved in determining rates of soil loss and land degradation under the recommended ginger-taro-cassava-fallow rotation with the inclusion of pineapple or vetiver grass on the contour. This study aims to develop improved technologies and farming systems to enable farmers to better manage their sloping lands. Data from 1991–92 suggest less soil loss from areas under ginger with vetiver or pineapple planted along the contour. With better land management and less erosion, downstream effects of siltation and flooding should be less severe.

As ginger is an important export crop, MAFF has recognised the need to develop farmer-driven and problem-driven research programs to improve ginger production in Fiji. Areas targeted include: (1) pest and disease management; (2) development of more effective farming systems involving using raised beds on flat lands and more appropriate conservation practices on sloping lands; and (3) identification and correction of nutrient deficiencies.

Taro (dalo)

Taro has long been grown in Fiji as a staple food crop. Socially, it is important and its presentation, with yam, is often essential at traditional functions. In local markets, taro is often preferred to cassava as its leaves can be used as a green vegetable ('rourou'). Recently, demand for taro varieties with characteristics similar to Tausalsa ni Samoa (Samoan Pink) for export has increased. Export earnings in 1994 were A$5.27 million. Sales on export and local markets make taro an important source of income to many farmers.

Taro production

In Fiji, taro is grown in wet and intermediate rainfall (>2500 mm) zones. The main growing areas are on the island of Viti Levu in the Rewa Delta area, in Ra Province near Vaileka, in Cakaudrove Province on Vanua Levu in Taveuni, and in the outer eastern islands. Taro is typically grown under rain-fed conditions on either flat or sloping lands. Fijian varieties including Samoan hybrid are grown mainly on older volcanic soils in eastern Viti Levu for local markets. Samoan Pink taro is grown mainly on younger volcanic soils in Taveuni and other eastern islands.

Traditionally, taro is planted manually in a hole made in the ground using a stick or narrow spade. Organic manures are occasionally used. Inorganic fertilizers are seldom applied. In some cases, chemicals are used for weed control. Mechanised and semi-mechanised methods may be used on flat lands with taro planted in furrows. Land preparation, furrow-making, and later tillage operations are carried out by animal- or tractor-drawn implements. Traditional methods are more costly than mechanised or semi-mechanised systems. Also, there is little difference in corm yield in manual relative to mechanised systems. Further, taro is grown under a variety of farming systems. In subsistence and semi-subsistence systems, it is grown for food, with any surplus sold locally. Soil fertility is maintained through the practice of shifting cultivation, and a number of taro varieties are typically grown together to ensure continuous production. Other vegetables may be intercropped with it.

Taro can also be grown as a cash crop, and different farming systems have been adopted for sloping and flat lands. On sloping lands, it may be rotated with high-value crops such as ginger, but labour inputs for land preparation, planting and weeding are high since mechanisation isx often not feasible. A single taro variety is usually grown and often fertilizer is used. However, on flat lands, fertilizers and mechanisation are commonly used and the normal practice is to grow a single taro variety with a ready market.

Likely soil limitations

During the 1970s, a series of N–P–K trials was conducted and responses to N and P recorded. Current N-P-K recommendations are: (1) 100 kg/ha N plus 25 kg/ha P and/or 100 kg/ha K (if P and /or K levels are low), or (2) in the absence of soil analysis, 400 kg/ha NPK (13:13:21) plus 50 kg/ha N. Poultry manure at 10 t/ha is also used. MAFF is currently undertaking NPK trials to reassess fertilizer requirements of taro. Recent soil and foliar analyses from the Nausori area (Koronivia Research Station) suggest few limitations except for P where Olsen-P levels were low (Tables 1 and 2). As mentioned earlier, consideration should also be given to a possible cation (Ca/K) imbalance when using the high K fertilizer mix in soils with high K levels.

Research directions

Current research focuses on developing taro varieties with characteristics similar to Samoan Pink, and improving drought, pest, and disease tolerance, corm quality, and yield. Government policy focuses on export-led growth in taro production. A taro germplasm collection is maintained at Koronivia Research Station.

Taro is best suited to poorly drained soils. With the decline of the rice industry, many 'rice-growing' soils with minor amelioration may be suitable for taro. MAFF is currently considering management options for these soils.

Sweet Potato

Sweet potato is produced largely for on-farm consumption. Over the past five years, pests and diseases, high transportation costs and low market prices have led to an annual decline in production per farmer from 1.2 (1990) to 0.6 t (1994), but the number of farmers growing sweet potato has increased from 2514 to 7100 over the same period.

Although sweet potato is consumed by a majority of Fiji's people, very few plant nutrition studies been completed or published. There were some inconclusive fertilizer trials at Koronivia during 1949 and 1950, but yields were generally low (relative to local averages) and treatment effects were not significant. Most research work to date has concentrated on developing sweet potato varieties with resistance to scab and weevil attack. Currently, MAFF is not undertaking studies on the mineral nutrition of sweet potato.

Sweet potato production

Sweet potato is grown commercially along the Baulevu, Nasi, and Muaniweni alluvial flats of the Rewa River on Fluventic Eutropept soils, and in the Sigatoka valley on mainly Ustic Humitropept and Cumulic Haplustull soils. Elsewhere, it is grown mainly for subsistence purposes and not on a large scale. Sweet potato is typically grown in rotation with legumes and other vegetables. Vines are planted on ridges, fertilizer is rarely used, and little or no weeding occurs during the growing season. Commercial tuber yields are typically 10–15 t/ha in the Sigatoka area and 7–8 t/ha in the Baulevu area.

Likely soil limitations

For the major commercial sweet potato producing areas of Baulevu and Sigatoka, soil and foliar samples were collected on farms growing sweet potatoes during January 1995. Data are summarised in Tables 1 and 2. Except for low levels of available soil P (Olsen-P) and low foliar N, which may act to limit sweet potato growth in the field, the nutrition status of these soils appears adequate for reasonable growth. However, symptoms of B (boron) deficiency have been observed on paw paw grown under low rainfall in the Sigatoka area. Also, P deficiency is suggested by soil analysis but not supported by foliar data, suggesting another factor, e.g. VAM fungi, may be acting to enhance P uptake in these soils.

Review of Some Fertilizer Research on Root and Tuber Crops and Farmer Adaptive Strategies to the Short Fallow Systems in Lowland Papua New Guinea

L.M. Kurika[1]

Abstract

In Papua New Guinea (PNG) while rice continues to assume greater significance as a staple food within rural communities, root and tuber crops are still important staples. The root and tuber crops grown are sweet potato (*Ipomoea batatas*), lesser yam (*Dioscorea esculenta*), greater yam (*Dioscorea alata*), taro (*Colocasia esculenta*) and Chinese taro (*Xanthosoma sagittifolium*), cassava (*Manihot esculenta*) and, to a lesser extent, giant taro and swamp taro.

Root and tuber crops in lowland PNG are still primarily produced by subsistence farmers under the traditional method of shifting cultivation. In the past this traditional system of cultivation with its long forest fallow (more than 15 years), could reliably sustain soil fertility lost through leaching, erosion and gardening. In the latter half of this century, however, in many lowland areas of the country, there has been a rapid shift away from the long forest fallow system toward a more sedentary and unstable short bush and grass fallow system. This change has come about due to a shortage of land caused by population pressure and in some areas the allocation of good arable land to plantation crops. The short fallow system with almost continuous cultivation of crops and meagre restorative measures has resulted in declining yields corresponding to declining soil fertility. This paper briefly discusses results of some fertilizer research conducted in lowland PNG and some adaptive strategies that have been adopted by subsistence farmers in response to declining food crop yields.

THE PNG lowlands include regions of the country that are within 0–500 metres above sea level. There are two distinct climatic environments, the wet lowlands, which represent the major environment, and the seasonally dry lowlands which represent only a small proportion of the region. Annual rainfall in the wet lowlands is over 2000 mm and fairly well distributed. In the seasonally dry lowlands, rainfall is 1000–2000 mm annually. Soil water deficits occur for at least four months of the year in the seasonally dry areas.

The vegetation is tropical forests in the wet lowlands and man-induced grasslands and savanna in the seasonally dry areas. Temperatures in the lowlands are constantly high with mean minimum and maximum readings of 28–34°C and 20–25°C, respectively, with a daily fluctuation of about 7°C (Bourke and Bull 1983).

Landform on the mainland is mainly characterised by alluvial plains and fans, flood plains and swamplands. The islands region comprises a belt of active volcanoes and associated plains and raised coral islands (Bleeker 1983). Soil fertility ranges from less fertile soils developed on old rocks as part of the Australian continental plate in the southwest of the country to red loams derived from limestone on New Ireland to extremely fertile recent volcanic ash-derived sandy loams on New Britain and in the Popondetta area (Bourke et al. 1981).

Overall, the environment is conducive to all-year-round production of root and tuber crops. However, a number of inherent characteristics could aggravate soil fertility problems, for example, the soils are deficient in two essential elements, potassium (K) and nitrogen (N). Potassium, essential for tuber formation in root and tuber crops, is widely deficient on limestone-derived soils while N deficiency occurs on all soil types, to some degree attributed to the

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farming systems practiced. The minor element magnesium (Mg) is widely deficient on recent volcanic ash-derived soils. In the coral atolls and also in certain areas under grassland and savannah vegetation there is a general lack of topsoil. In high rainfall and steep areas nutrient losses occur through erosion and leaching. Other climatic constraints include the inundation of garden lands in many low-lying areas during the wet season, and the effect of drought in the seasonally dry areas during the dry period. In low population density areas where land is still abundant these constraints are avoided or minimised by farmers selecting good arable sites for gardening.

Root and Tuber Crops

Root and tuber crops are widely distributed throughout the lowlands. Their importance is influenced to some extent by the prevalent agro-ecological conditions. The sweet potato is rapidly becoming the most important staple crop in the lowlands. This is because it is adaptable to a wide range of soil and climatic conditions. Taro has in general declined in importance except in specific places such as the Bainings in East New Britain, Suau in the Milne Bay and other similar areas where cultivation is still practised under the long forest fallow system. Some cultivation of taro also occurs in fertile grassland soils. Yams are always a co-staple with other (staple) crops and are important in areas with marked seasonal rainfall or where rainfall is highly variable. They are a co-staple with sweet potato and taro where rainfall is not so marked, and with bananas in very dry areas. *Xanthosoma* grows in the same broad ecological zone as taro but it is shade-tolerant and produces well under lower soil fertility than taro. Cassava is considered a minor crop but is gaining greater significance in areas with strongly seasonal rainfall where it sometimes attains the status of co-staple. It is important in subsistence gardens in the dry Port Moresby areas and also in certain islands in Milne Bay (Bourke and Kesavan 1982).

Research

The imminent problems associated with the short-fallow system — e.g. declining food crops yields and a build-up of pests and diseases — were realised by researchers as early as the first half of this century. This prompted the establishment of two long-term trials: the three course rotational trial and the soil exhaustion trial at the Lowland Agricultural Experiment Station (LAES) at Keravat in the Islands region. Both trials were aimed at devising alternative cropping systems to the long forest fallow system. Besides these, other soil fertility-related trials included one to assess the suitability of a number of leguminous green manure cover crop and shrub species planted as fallows and, more recently, agroforestry studies. These studies have been documented by Bourke (1977), Leng (1982), Brook (1992) and Brook and Humphrey (1992). As far as individual root and tuber crops are concerned, mainly sweet potato, because of its rapid expansion in the country and its prospects as a saleable commodity and a crop for such institutions as schools, corrective institutions and health centres, has received some notable fertilizer research. The studies were mainly to determine response of sweet potato to various levels of both inorganic and organic fertilizers.

From the literature available, two on-farm fertilizer trials were also carried out on taro because of declining yields and its renown for response to high fertility conditions. The research findings are briefly discussed below.

Sweet potato fertilizer trials — Keravat

These trials consisted of a total of 17 field and six pot trials between 1954 and 1976 on a young volcanic soil at LAES, Keravat, and at various locations in the Gazelle Peninsula (reported by Bourke (1977)). They were conducted to determine the influence of various levels of N, P, K and eight minor elements on two varieties of sweet potato. Seven were conducted in grassland and former forest sites with various cropping histories, the remaining 10 incorporated in the long-term soil exhaustion and rotation trials at the station.

Results showed that nitrogen had the greatest effect on sweet potato yield, especially at grassland sites. However, in the soil exhaustion trial which involved continuously cropping with sweet potato, N depressed yield in three plantings, which was attributed to the use of a variety for which a fertilizer response favoured increased top growth at the expense of tuber production. Phosphate improved top growth and yield in a few trials. In the soil exhaustion trial there were negative responses to residual P in most plantings but large yield responses to applied and residual potash fertilizer.

Potash increased tuber number. There was a response to residual magnesium (Mg) in two plantings and in the pot trials, top growth responses to N, P, K and manganese (Mn).

Fertilizer (N–P–K or N–K) gave large yield increases in the rotation trial. A significant negative relationship was found between the magnitude of fertilizer responses and control yields.

Conclusions from the trials were that in grassland areas nitrogen should be applied at 150 kg N/ha as urea and accompanied by 100 kg K/ha in areas intensively cropped with root crops. In the former forest areas, after a number of years cropping, the application of a moderate level of N (50 kg/ha) was recommended, and where cropping has intensified, both N and K should be applied at 100 kg/ha.

Residual effect of chicken manure on sweet potato at UPNG, Port Moresby

This trial was conducted at the Agriculture faculty garden, Port Moresby, as part of a study to assess yield responses by various food crops to organic wastes. It was conducted to assess the residual effect of chicken manure on sweet potato which followed a fertilised wing bean crop. Rates of chicken manure used in the preceding crop were: 0, 5, 10, 15 and 20 t/ha. Results showed that the optimum level of chicken manure in the trial was 10 t/ha. It produced a maximum yield of 24.86 t/ha of sweet potato which was significantly higher than yields from the other rates, which were not significantly different from each other (Thiagalingam et al. in Bourke and Kesavan 1982).

Effect of applied nutrients on sweet potato at Laloki

This trial was conducted on a silty clay loam soil at the Laloki Agricultural Experiment station near Port Moresby to assess the effect of soil native nutrients and applied nutrients on sweet potato. Fertilizer treatments tested included four levels of nitrogen (0, 20, 40, 60 kg N/ha), two levels of phosphate (0, 40 kg P_2O_5/ha), four levels of potash (0, 20, 40, 60 kg K_2O/ha) and two levels of chicken manure (0, 15 t/ha). N, P and K concentration of the leaf petiole at a specific growth stage was studied to determine in sweet potato yield any relationship between these and any response to the applied nutrients.

Results showed that, except for the effect of N on the percentage of small-size tubers, sweet potato did not respond to any of the applied nutrients in either organic or inorganic forms. Chemical analysis of soil as well as leaf petiole revealed that the soil was fertile and produced a mean yield of 41.6 t/ha. The uptake of nutrients appeared independent of the level of nutrients applied (Velayutham et al. in Bourke and Kesevan 1982).

Fertilizer trials on taro at Lae

These consisted of two researcher-managed trials on a farmer's field at Tikeling village in the Lae district of mainland PNG. This is an area where low and declining soil fertility has been identified as a primary constraint to taro production. The trial objectives were to quantify the response of taro yield and quality to combinations of N, P and K. The rates used included zero to 100 kg N/ha applied in combination with 0, 50 and 100 kg/ha of P and K and conducted over two seasons.

Results showed that treatments that included N at 100 kg/ha had higher yields, i.e. above 13 t/ha. There were clear differences among treatments with other nutrients and between the control and these treatments (DAL 1989).

Farming systems and agroforestry trials at Keravat

The three-course rotational trial

This trial was the long-term rotation trial conducted at LAES Keravat. Food crop yields were used to compare the effects of two rotational treatments, wide and narrow. The wide rotations involved alternating food cropping with a three-year green manure cover crop fallow, the narrow rotation of almost continuous food cropping except for a short-term legume fallow. Results over 19 years (reported by Bourke, cited by Brook (1992)), showed that the sweet potato and taro yields declined markedly over the period. None of the rotations tested offered any promise as an alternative to the traditional long forest fallow system. It was also suggested that in tropical rain forest zones with a high population density and land shortages, recourse to inorganic fertilizers might be necessary.

Alley cropping

The alley cropping trials conducted so far at Keravat have been reported by Brook (1992). The results indicate that, despite the potential of the mulch produced to provide large quantities of nutrients, the use of leguminous hedges failed to improve significantly yields of sweet potato plantings. There were in fact yield decreases recorded in these trials. Some suggested explanations were: (i) yields were impaired by a shading effect in some species; (ii) possible competition from the leguminous hedges for water and nutrients; (iii) the timing of coppicing and subsequent nutrient release from organic matter decomposition did not coincide with the peak period of sweet potato demand; and (iv) the high intensity of rainfall and low Cation Exchange Capacity (CEC) of the soil may have been responsible for rapid leaching of the nutrients after release. Indications were also that alley cropping was labour-intensive, which shed some doubt on its relevance to subsistence farmers.

Adaptive Strategies of Farmers to the Short Fallow System

In villages the conditions forced upon farmers by the intensification of agriculture, subsistence and commercial, have necessitated that they adopt various adaptive strategies to sustain food supplies and to accommodate their increasing cash-crop activities. These adaptive strategies are wide-ranging and include social as well as economic adaptations. Of the agricultural adaptations in the lowlands, perhaps the most notable have been those that have involved modification to the cropping system followed by adoption of some soil fertility improvement techniques, which crudely conform to scientific rationale. However, they still require thorough investigation and confirmation of success before they can be transferred to other areas with similar constraints and agro-ecological conditions. These agricultural adaptations are discussed below.

Change in the cropping system

Modification to the traditional cropping system is probably one of the most significant adaptations that village farmers in stressed areas have undertaken. For root and tuber crops it has involved increased cultivation of the more adaptive and productive crops such as sweet potato, *Xanthosoma* and cassava in place of taro, diploid bananas and yams. The latter are traditional staples in various parts of the lowlands.

In high population density areas as in the Gazelle Peninsula in New Britain, the robust and perennial triploid and tetraploid bananas and *Xanthosoma* have gained prominence as the staples most adaptable to cropping conditions under cocoa and coconut plantings. They are interplanted together with various fruits and nuts species under mature cocoa and coconuts, and provide a continuous source of food supply to households (Ghodake et al. 1995). *Xanthosoma* is also occasionally used as shade for new cocoa plantings. In the grassland areas sweet potato is the main crop. In drier stressed areas as around Port Moresby, bananas and cassava are the main staples. In a number of small islands in Milne Bay they are also the main staples grown to supplement the bulk of food obtained through trade with the mainland and the bigger islands.

From a soil fertility perspective, the adoption of more adaptive and productive crops in the farming system has meant that the expression of nutrition disorders or yield declines has become less apparent or further delayed in the system, especially on the rich volcanic soils.

Composts

Unlike in the highlands, composting is less frequently practised in the lowlands except in the outer atoll islands of Nuguria and Tauu to the north of mainland PNG. The islands are inhabited by a mixture of Polynesians, Melanesians and Micronesians. Their method of composting has been reported by Lefroy (1981). They mainly use composting for the cultivation of swamp taro, the main staple on these islands.

For the islanders, the compost technique overcomes problems of poor soil structure, poor soil fertility, salt spray and lack of fresh water. It involves digging pits down to freshwater level and leaf litter from several species of trees repeatedly added to the pits to produce a rich dark soil at the bottom. Swamp taro is then planted in the pits. During growth leaf litter is regularly added at the base of plants. It takes two to three years for the plants to produce edible tubers.

Rooney (in Bourke and Kesavan 1982) has also reported that taro cultivation by the Nali-speaking people of Manus Province in the past involved no burning and that the branches of felled trees were trimmed and the debris reorganised to ensure continuous ground cover.

Integration of livestock and food plants

In the lowlands a system involving the integration of livestock and food plants is probably at best represented by free-range chickens and feral pigs in villages. The contribution of such a system towards soil fertility improvement is thought to be insignificant because of the open space on which the animals are allowed to forage.

However, in the coral islands such as Paneati in Milne Bay there exists what appears to be a fairly organised system. It involves alternating pigs with food plants. The pigs are confined by fences constructed from coconut trunks. They are fed kitchen scraps or coconut meal till the time they are either sold or slaughtered for a feast. After the pigs have been removed the remaining animal wastes are allowed to decompose fully before the fenced area is planted to food crops. Crop growth observed was fairly vigorous, which seemed to suggest that the decomposed animal wastes were an effective source of plant nutrients.

Legume species in fallows

Results from studies in which the performances of a number of small fast-growing leguminous tree species were tested for suitability as planted fallows have not been promising. They are often difficult to establish due to weed competition, and much labour is required to incorporate the mulch into the soil.

However, indications are that in some places in the lowlands one or two species are able to establish well under the prevalent agro-ecological conditions. The eastern end of Paneati Island in Milne Bay is one such place, where a considerable number of at least one species of a small fast-growing leguminous tree locally known as Kasiu was noticed. It has yet to be identified, but it was probably either *Schleinitzia novo-guineesis* or *Adenanthera pavonina* (Hide et al. 1994). These trees are killed during clearing after a 10–15 year fallow. Those that remain standing give a distinctive appearance to gardens. The leguminous vines (*Pueraria* and *Centrosema*) are also very common in fallows.

Conclusion

In spite of the threat that soil fertility decline poses to the maintenance of food supply in the country, it is only recently that significant research input via agroforestry studies has occurred.

This can be partly blamed on the nature of the problem itself. It often builds up slowly over the years and is not immediately apparent. Indicators such as low yields or food shortages are often marred by certain adaptations, e.g. the use of adaptive and productive crops or imported foods already in place in the farming system. Farmers therefore rarely perceive the problems as critical, and so receive little political and scientific interest.

The country to date lacks the necessary resources and expertise to implement a comprehensive program on nutrition disorders of food crops.

Any successful cropping system that involves agroforestry practices will probably be location-specific and will, to a large extent, be dependent on the existing biological as well as social and economic environments. The use of high-labour input practices such as alley cropping and composting are doubtful, especially among commercially oriented farmers who may not wish to share time or labour between fertility enhancing practices and cash cropping activities.

However, some headway toward addressing soil fertility problems has been achieved through the following:

(i) the participation of DAL research stations in PNG in the ACIAR 9101 project on 'Diagnosis and correction of mineral nutrient disorders in the Pacific';

(ii) the adoption of a farming systems approach to research — while research is being hampered by limited resources at present, it is nevertheless being slowly extended to farmers' fields. Nutrition disorders of root and tuber crops are site-specific and far more likely to be detected on farm than in station plots where remedial measures such as chemicals (fertilizers, fungicides and insecticides) are often applied in order to maintain reasonable yield levels;

(iii) the mapping 'Agricultural Systems of Papua New Guinea' which is being jointly done by the Australian National University, the Department of Agriculture and Livestock and the University of Papua New Guinea, and includes among others such variables as important crops, cultivation intensity, fallow period and type, should reveal many areas within the lowlands that are likely to suffer from soil fertility related problems; and

(iv) there is now an abundance of information available in the literature that could be used to formulate future research strategies.

References

Bleeker, P. 1983. Soils of Papua New Guinea. CSIRO. Australian National University, Canberra, Australia.

Bourke, R.M. 1977. Sweet Potato (*Ipomoea batatas*) fertilizer trials on the Gazelle Peninsula of New Britain: 1954–1976. Papua New Guinea Agricultural Journal, 28. 73–96.

Bourke, R.M. and Bull, P.B. 1983. The lowlands environment. Harvest, 9. 63–67.

Bourke, R.M., Gamble, W.K. and Brookson, C.W. 1981. Executive summary. In: Country Report – Papua New Guinea. South Pacific Agricultural Research Study. Consultants' report to the Asian Development Bank.

Bourke and Kesavan, 1982. Proceedings of the second Papua New Guinea Food Crops Conference. Parts 1 and 2, DPI, Port Moresby.

Brook, R.M. 1992. Sustainable Agriculture Research at LAES Keravat: Report for period June 1990 to March 1992. LAES Technical Bulletin 3/92.

Brook, R.M. and Humphrey, W. 1992. Sustainable Agriculture: A Review of Research in Papua New Guinea up to 1989. LAES Technical Bulletin 4/92.

DAL. 1989. Annual Research Report, Agricultural Research Division, Department of Agriculture and Livestock (DAL), Papua New Guinea.

Ghodake, R.D., Cook, K.E., Kurika, L., Ling, G., Moxon, J.E., and Nevenimo, T. 1995. A rapid rural appraisal of the cocoa and coconut based farming systems in the north east lowlands of the Gazelle Peninsula of East New Britain Province. Technical report 95/1, Department of Agriculture and Livestock, Port Moresby, Papua New Guinea.

Hide, R.L., Bourke, R.M., Allen, B.J., Betitis, T., Fritsch, D., Grau, R., Kurika, L., Lowes, E., Mitchell, D.K., Rangai, S.S., Sakiasi, M., Sem, G. and Suma, B. 1994. Agricultural systems of Papua New Guinea: Milne Bay Province. Working Paper No. 6, Australian National University, Canberra, Australia.

Lefroy, E. 1981. Growing food on coral atolls. Department of Primary Industry, Port Moresby, Harvest, 7. 7–13.

Leng, A. S. 1982. Maintaining fertility by putting compost into sweet potato mounds. Department of Primary Industry, Port Moresby, Harvest, 8. 83–84.

Nutrient Disorders of Root Crops Growing on Raised Coral Reef Landforms Near Madang, Papua New Guinea

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Abstract

Root crops growing in soils on raised coral reef landforms near Madang show interveinal chlorosis of the young mature leaves which extends into new and/or old leaves, depending on the root crop species. Observations and preliminary work indicate that the nutrient disorder observed may be manganese deficiency. The severity of the visual signs of the nutrient disorders varied depending on the root crop species. The yam *Dioscorea esculenta* appears to be the species most severely affected, and taro and sweet potato appear least affected.

RAISED coral reefs make up a significant proportion of landforms in Papua New Guinea (PNG) accounting for 1.5% of its total area (Keig et al. 1987). These areas generally are regarded as fertile (Anon. 1986) and support up to 7% of the PNG population (Keig et al. 1987). There is a considerable area of raised coral reef along the coastal strip west of Madang. The main crops grown along this coastal strip are subsistence root crops and the cash crops cocoa, coconuts and coffee. The yam *Dioscorea esculenta* is the main staple of the people of this region. Cooking banana, taro (*Colocasia esculenta*), tannia (*Xanthosoma sagittifolium*), and the yam *Dioscorea alata* are also important subsistence crops. Sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*) are also grown but are of only minor importance.

This paper describes the preliminary examination of a mineral nutrient disorder observed in the root crops growing on the raised coral reef landforms of the Madang region.

Field Observations

Soil

The soils of the raised coral landforms where the nutrient disorders were observed are Rendolls as described by Bleeker and Healy (1980). Rendolls are shallow, dark, weakly acid to neutral soils formed on calcareous parent materials. Although these soils are shallow, they are generally regarded as fertile (Anon. 1986). Bleeker and Healy (1980) found the Rendolls they examined were very well drained with a pH (1:5 H_2O) from 6.6–7.9 and of moderate to high chemical fertility. The Rendolls have a high cation exchange capacity (>25 meq%), a high base saturation (>60%), a high nitrogen (N) content (>0.5%), high phosphorus (P) (>20 ppm) and moderate exchangeable potassium (K) (0.2 to 0.6 meq%) and no problems with anion ixation or salinity (Bleeker and Healy 1980).

The pH (1:5 H_2O) of the soil where the nutrient disorders were observed ranged 7.1–7.6 and had a conductivity (1:5) of <0.2 dS/m.

Crop Growth and Symptoms

Yams

The visual signs of the nutrient disorders were most pronounced on the yam *Dioscorea esculenta* and included interveinal chlorosis which was more pronounced towards the leaf margin. Except for the extreme cases, the symptoms first occurred in the young fully expanded leaves. The interveinal areas ranged from pale green to yellow in colour. The transition between the chlorotic interveinal areas and the dark green veinal regions was not distinct and appeared fuzzy. These symptoms persisted in the

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older leaves in which the small veins remained dark green, giving a netted appearance. Other visual symptoms included leaves which were smaller than normal, 'leathery' and very pale with green blotches either side of the main veins. Other leaves were pale yellow–green throughout. Necrotic areas often occurred on the leaf margins and, in severe cases, most of the leaf laminar was necrotic. In plants showing extreme deficiency symptoms, the new leaves and growing tips showed symptoms resembling iron (Fe) deficiency. These leaves were small, very chlorotic or nearly white and often had necrotic margins.

The women of the local village claim that they obtain very little yield from the yams growing where these deficiencies occur.

The yam *Dioscorea alata* did not show symptoms as severe as *D. esculenta.* The only symptom observed in *D. alata* was interveinal chlorosis of mature leaves.

Taro

Taro is grown as an intercrop within the yam gardens. Taro also did not show symptoms as severe as *D. esculenta.* The plants generally had a pale and dull appearance. The mature leaves had pale green to yellow interveinal chlorosis which was more pronounced towards the margins. This is similar to the description of magnesium (Mg) deficiency in taro described by O'Sullivan and co-workers (1995) which may also be characteristic of Mn deficiency which often shows similar visual symptoms to Mg deficiency.

Local women claim that they get adequate taro yield in these areas.

Tannia

The nutrient disorders were observed in tannia as light green to yellow chlorotic interveinal areas contrasting with the dark green veins and surrounding tissue. The interveinal chlorosis was observed in all leaves of the plant but was more pronounced in the younger leaves.

The women of the villages state that tannia yields well in these soils.

Cassava

Cassava is only a minor crop in this region and is generally grown outside the main garden area as a border or along roads, and is used as an emergency food supply. In cassava plants the nutrient disorder was observed as interveinal chlorosis of leaves in the middle region of the plant. The chlorotic areas were more distinct towards the leaf margin. The disorder first appeared as a light green mottling within the darker green veinal regions. The symptoms observed are similar to the Mn deficiency symptoms of cassava reported by Asher and colleagues (1980).

Sweet potato

There is very little sweet potato grown in the area where the nutrient disorders were observed. This may be because it may not be productive in these soils, although the villagers claim that they do not grow it because the village pigs eat it all.

As no sweet potato could be observed growing in these areas, cuttings of the *Ipomoea batatas* cv. Wanmun (a cultivar extensively grown in PNG that has a high level of anthocyanin pigmentation) were planted within a yam garden and observed 38 days after planting. At this time the plants were still relatively small, and the leaves were a pale green colour with little anthocyanin pigmentation. They did not show any of the severe deficiency symptoms described by O'Sullivan and co-workers (1993). The pale green colour, lack of vigour and reduced anthocyanin pigmentation fits the description of N deficiency or the first signs of Mn deficiency (O'Sullivan et al. 1993).

Leaf painting

Leaves of yam, tannia and taro showing nutrient disorder symptoms were painted with a solution of one of the following nutrients: K, copper (Cu), Fe, boron (B), Mg or Mn. Although the results are not conclusive, only Mn appeared to green the leaf tissue. However, the greening was only slight, possibly because observations were made only three days after application.

Future Investigations

Further work is being carried out to identify the nutrient disorders observed. This includes tissue analysis and omission pot trials which will be followed up with field trials to test the validity of the results. It would be interesting to measure the relative reduction in yield of the different root crops due to the nutrient disorder. If the local village women are correct in their assessment of the yield obtained, it may be more beneficial for them to grow taro or tannia than to grow yam.

Conclusion

A nutrient disorder was observed in root crops growing in the Madang region of PNG. Although the disorder has not been positively identified, it is likely that it is a Mn deficiency, for the following reasons: Mn is usually deficient in soils with a high pH; the symptoms observed generally occurred in the young mature leaves and were similar to the visual Mn deficiency symptoms described in the literature; and Mn was the only nutrient to cause leaves to green when applied as a leaf paint to chlorotic leaves.

The severity of the visual signs of the nutrient disorders varied depending on the root crop species. The yam *Dioscorea esculenta* appears to be the species most affected, and taro and sweet potato appear to be the least affected.

References

Anonymous. 1986. Notes from Land Utilisation Section DPI. Harvest, 21(1). 18.

Asher, C.J., Edwards, D.G. and Howeler, R.H. 1980. Nutritional Disorders of Cassava, Department of Agriculture, University of Queensland, St Lucia, Queensland.

Bleeker, P. and Healy, P.A. 1980. Analytical Data of Papua New Guinea Soils. Division of Land Use Research, Technical Paper No. 40. Vol. 2. CSIRO, Melbourne, Australia.

Keig, G., Cuddy, S.M., McAlpine, J.R. and Freyne, D.F. 1987. The Papua New Guinea Resource Information System (PNGRIS). A software package. PNG Department of Agriculture and Livestock, Port Moresby.

O'Sullivan, J.N., Asher, C.J., Blamey, F.P.C. and Edwards, D.G. 1993. Mineral nutrient disorders of root crops in the Pacific; preliminary observations on sweet potato (*Ipomoea batatas*). In: Barrow, N.J. ed., Plant Nutrition — From Genetic Engineering to Field Practice. Kluwer Academic Publishers. 293–297.

O'Sullivan, J.N., Asher, C.J. and Dowling, A.J. 1995. Diagnosis of mineral nutrient disorders in taro. In: Jackson, G. ed., Proceedings of the Second Taro Symposium, Cenderasih University, Irian Jaya and selected papers from the First Taro Symposium. Unitech, Lae (in press).

Mineral Nutrition of Root Crops in Cook Islands

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Abstract

Mineral nutrition of some selected root crops in Cook Islands showed significant response to nitrogen fertilizer. The use of organic fertilizer (azolla) and intercropping legumes indicated some influence on the growth of taro on Mangaia and Atiu Islands. The traditional and sustainable systems of yam in the Cook Islands yield higher than those using chemical fertilizer, but the differences are not statistically significant.

THE Cook Islands comprise 15 islands scattered over a million square kilometres of ocean. There are two distinct types of islands: (i) the Northern Group — all coral atolls; and (ii) the Southern Group — of mainly volcanic origin, with two atolls.

The population of the Cook Islands is approximately 20 000, of whom 9678 live on Rarotonga, the biggest island, latitude 21°–21′S and longitude 150°–46′E. It has a humid tropical climate during the warmer part of the year (October to May) and a subtropical climate during the cooler months (June to September).

Root Crops

The nine root crops grown in the Cook Islands are taro (*Colocasia esculenta*), kumara (*Ipomoea batatas*), tarua (*Xanthosoma sagittifolium*), yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), puraka (*Cyrtosperma chamissonis*), kape (*Alocasia macrorrhiza*), pia (*Tacca* spp.) and teve (*Amorphophallus campanulatus*). Of these, the first five are the most popular in local food production. Puraka and pia are also rated important in the Northern Cook Islands.

Taro, kumara and cassava are the staple food on almost all the islands, and therefore play an important role in the daily lives of the people of the Cook Islands.

Soil and Growth

Most root crops are grown on the following soil types:

Southern Group — Avana — stony silty clay loam, Matavera — clay loam, Matavera — clay loam, stony phase, Vaikai — clay loam, Vaikai — clay loam, buried soil phase, Tikioki — clay loam, Arorangi — clay loam, Tamarua — clay loam (Mangaia, Mauke and Atiu islands), Rangimotia (Mangaia island), Nuata (Mauke island), Te Autua (Atiu island), Mangarei (Mitiaro island), and Tautu, Nikaupara, Tongarutu, Rakautai and Vaipeka (Aitutaki island).

Root crops grown on these soil types show few mineral nutrition problems except occasional nitrogen or potassium deficiencies, especially with the dryland taro varieties such as Niue Matie. Only rarely are deficiencies of this sort found in puraka. Overall, root crops in the Cook Islands perform reasonably well on these soils.

Northern Group — The only soil type on the atolls in the Cook Islands is known as Muri sand. This is young soil formed from comminuted reef coral on the constructional beach ridge that fringes the island between the flood plains and lagoon. It has no subsoil and the parent material (white coral sand) is within 25 cm of the soil surface. The parent material is loose, structureless and coarse sand-textured. There being no other soil type, the residents of these islands have no option but to try to grow crops in this soil type.

Root crops such as tacca thrive well on this sandy soil. Puraka and taro are two other root crops that

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produce amazingly well in this soil in low-lying areas close to the water table.

Taro growing on Muri sand often shows yellowing of the leaf blade. Sometimes plant growth is reduced and often the plants die prematurely. Other root crops such as kumara, cassava and tarua also show yellowing symptoms.

Mulching and composting are common practices for this soil to minimise mineral deficiencies and to ensure food crops yield well.

Crop Response

A number of experiments comparing yields from different fertilizer rates and agronomic treatments have been conducted in the Cook Islands. The results of these experiments are summarised below.

Nitrogen fertilisation, lowland taro

Nitrogen fertilisation resulted in tall plants with big leaves, though its effect on the number of shoots per plant was not apparent in the study. Niue Po and Niue Matie were responsive to fertilisation in terms of all growth characters except shoot number per plant. With Niue Po, highest corm yield was obtained with 100 kg N/ha. With Niue Matie, the highest yield was obtained with 200 kg N/ha (Table 1). Veo did not respond to N applications.

Table 1. Effects of different levels of nitrogen on corm yield (t/ha) of different varieties of taro grown under lowland conditions.

	Nitrogen rate (kg/ha)					
Variety	0	50	100	150	200	250
Niue Po	8.7	10.7	15.3	11.7	12.4	10.6
Niue Ma	7.1	9.5	10.2	8.7	10.3	10.2
Veo	6.4	5.5	6.0	5.2	6.5	6.3

Green azolla fertilisation, upland taro

The incorporation of azolla, irrespective of method, resulted in tall plants with large leaves and plenty of shoots but lower dry matter content. Niue Matie was the most responsive variety to azolla fertilisation when determined on the basis of plant height, leaf area and dry matter content. Veo produced the most shoots or suckers.

Intercropping taro with legumes

The effects of four intercrops, mungbean, blackgram, horsegram and cowpea, on raised bed swamp taro, were measured. The taro–mungbean combination gave the highest gross return without significant reduction in taro yield. Mungbean and cowpea were quick and vigorous in growth. Reduction in taro yield was dependent upon the period of time in which there was competition between the taro and intercrop (Table 2).

Table 2. Yield of taro with and without legume intercrops (values followed by the same letter are not significantly different (P=0.05)).

Treatments	Yield t/ha	
	Taro	Intercrop
Taro (mulched)	25.4 a	—
Taro + mungbean	23.8 a	1.23
Taro + blackgram	19.8 b	0.61
Taro + horsegram	17.6 bc	0.56
Taro + cowpea	15.9 c	1.34
Taro (non-mulched)	16.5 bc	—

Yam, organically grown and with artificial fertilizer

The treatments were as follows:—

1. Dug pits plus 600–700 kg fresh organic matter (banana stumps, leaves, etc);
2. NPK (11:2:15) at 300 g/6m^2;
3. NPK plus organic matter in a dug pit as in treatment 1; and
4. Control.

Two yam varieties, locally known as Toka and Etene, were grown. The experimental design was a 2×4×3 split plot, i.e. (2 varieties, 4 treatments and 3 replications) at the following dimensions: subplots, 6 m × 1 m; plots, 12 m × 1 m; and blocks, 12 m × 8.5 m.

Results of the experiment are summarised in Table 3 and show the Toka yams in the NPK plus organic matter treatment and the organic matter alone treatment gave significantly higher yields than the control. There was no significant difference between the control and the NPK treatments.

The Etene yams tended to yield higher than Toka in most treatments but there were no significant effects between the treatments. As with Toka, the NPK plus organic matter treatment gave the highest yield.

Table 3. Yields of yams kg/plot supplied with combinations of organic matter and chemical fertilizer (values in the same column followed by the same letter are not significantly different at P=0.05).

Treatments	Toka	Etene
Organic matter	91.5 a	91.5 a
NPK	72.2 ab	79.2 a
NPK plus o/matter	93.0 a	108.3 a
Control	51.7 b	94.0 a

LSD = 34.8 kg within the same variety.

Research Needs

Research into the following aspects of root crop production is needed:

- Root crop mineral nutrients application systems for atolls;
- The application of organic fertilizer to root crops via bi-wall drip irrigation systems;
- Fertilizer requirements for certain root crops grown on the hill slopes of Rarotonga;
- The effects of azolla on the yield of paddy taro; and
- A root crop network for the region is needed.

Bibliography

Bhatt and Makakea 1992. Root Crop Research Report, Atiu Island. Ministry of Agriculture, Cook Islands.

Juanito, L., San Pedro, Vivia Tangatataia, Ngarangi Tuakana, Teinakore George, Itimanga Tereapii, Taokia and Teremanuia Tangianau 1992. Root Crop Research Report, Mangaia Island. Ministry of Agriculture, Cook Islands.

Purea, M. 1982. Evaluation of the performance of 36 Nuiean taro varieties under Rarotonga conditions. Research Bulletin, Research Division, Ministry of Agriculture, Cook Islands.

Totokoitu Research Station Annual Report 1992 and 1993. Ministry of Agriculture, Cook Islands.

The Agronomy of *Cyrtosperma chamissonis*, *Colocasia esculenta* and *Ipomoea batatas* in Kiribati

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Abstract

Root crops are the major staple foods on the 33 atolls that constitute Kiribati. Babai or giant swamp taro (*Cyrtosperma chamissonis*), taro (*Colocasia esculenta*) and sweet potato (*Ipomoea batatas*) are the principle edible root crops grown.

Babai is the most important crop and it is grown using traditional methods of cultivation, handed down in secret from generation to generation. This crop is culturally significant and can produce corms up to 100 kg in weight. Island people cultivate the crop in pits dug to water table depth and amended with compost made from local plants. Production is very labour intensive.

Where possible taro and sweet potato are cultivated in trenches dug in deep soils with high organic content. Most of the coral soils are deficient in nitrogen, potassium and trace elements such as iron, manganese, zinc and copper. As for the giant swamp taro, compost is the main amendment used. Rusty crushed tins may be added to combat iron deficiency. Small additions of a complete fertilizer give good crop responses, but care must be taken to avoid over-fertilising that pollutes the fresh water lens in the atoll.

KIRIBATI islands are low-lying atolls, scattered astride the equator, over 3 million km^2 in the Central Pacific, 33 islands divided into three main groups: the Gilbert group (17 islands), Phoenix group (8 islands) and the Line group (8 islands). Tarawa, in the Gilbert group, is the capital of Kiribati. According to the 1990 census, the total population was 72 335.

Root crops are considered the major food groups in atolls. The principal edible root crops commonly grown in Kiribati are babai or giant swamp taro (*Cyrtosperma chamissonis*), taro (*Colocasia esculenta*) and sweet potato (*Ipomoea batatas*). Their agronomy is discussed.

Culturally babai is by far the most important root crop in Kiribati. The traditional methods of babai cultivation have been developed over many generations and are generally kept within the family, revealed only to immediate members of the family. The size of the babai corm grown indicates worth as a farmer and social standing.

Taro (*Colocasia esculenta*) is less important in Kiribati but of considerable importance in Tuvalu, Cook Islands, Tokelau and parts of Micronesia. However, a small amount is grown on most islands.

Sweet potato (*Ipomoea batatas*) is occasionally grown on a small scale in home-gardens in Kiribati. Yields are often disappointingly low. Sweet potatoes are considered to have advantages over the edible aroids, giving high yield within a short time. Most cultivars reach maturity in three to five months.

Varieties

Cyrtosperma chamissonis

Since no systematic work is being carried out on the agronomy of *Cyrtosperma chamissonis*, there is no certainty about the actual number of different cultivars of this crop, but Ali (1987) collected 24 cultivars and reported their characteristics. The varieties described vary considerably in eating quality, time to maturity, and morphology.

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Colocasia esculenta and Ipomoea batatas

Taro and sweet potato cultivars have been distributed to Kiribati by the former Fellow Agriculture, USP Atoll Research and Development Unit and the Pacific Regional Agricultural Programme (PRAP). According to PRAP the following (Table 1) are the recommended varieties for taro and sweet potato in Kiribati.

Table 1. Recommended varieties and spacing of taro and sweet potato for Kiribati.

Crop	Spacing	Varieties
Taro	10.3	Samoa hybrid, Tausala ni mumu, Alafua sunrise, Intelpelyar, Samoa
Sweet potato	10.5	L329, TIB 2, Funafuti white

Botany

Cyrtosperma chamissonis

Cyrtosperma chamissonis is the largest plant that produces an edible corm. The height of some cultivars, e.g. 'te ikaraoi' may reach three to four metres. It lives a long time, some cultivars up to 15 years, but 10 years is quite common.

Corm size is variable, weighing from 2–100 kg, although 50 kg is more common. The corm is the stem of the plant and suckers arise from it. The leaves grow directly from this, the roots growing from its sides and lower end. The shape of the corm may vary from conical to an almost perfect sphere. Some cultivar corms are branching, e.g. Natutebubua.

Fibrous roots emerge from the corm side as well as from the base. The true roots have air spaces in the cortex which enable them to exchange gases in the swamp. These roots are usually found in the compost basket, have a poorly developed root cap and are known to have no hairs.

Cultivation

Much effort is required in the cultivation of babai (*Cyrtosperma*). Babai is usually grown in pits where water is always available, and is the only plant cultivated carefully in Kiribati. The only source of water for the crops is the fresh water found floating at a variable depth on the salt water. The freshwater lens varies in depth below ground surface, depending on the island's height at sea level. The size of the water lens is in proportion to the width of the raised part of the atolls. In narrow islands, there are few babai pits because the islands have no good water reserves; the wider islands have many babai pits because of wider and thicker water lens and therefore greater water reserves of better quality (Webb 1994).

Pits are dug to the water table with an average width of seven metres, the length of any size, 5–20 metres or more. Planting procedures vary, and most islanders have secret methods not known to others except their own families. However, one typical planting method includes making the pit the required size. Further digging is carried out to make a hole in accordance with the size of the planting material, approximately 30–50 cm in diameter. The hole is then backfilled with prepared dry and chopped green leaves, topped with a thin layer of black soil rich in organic matter. The placement of black soil at the top is important because it assists in the prevention of burning the young plant from heat generated during fermentation of the leaves. A young seedling or a set (top of the plant from which the corm has been cut) is planted in the middle of the hole (Ali 1987).

Cyrtosperma growers devise their own special materials for compost mixtures. They collect the readily available compost material on their islands, e.g. *Artocarpus altilis* (te mai), *Guetarda speciosa* (te uri), *Tournefortia argentea* (te ren), *Scaevola taccada* (te mao), *Hibiscus tiliaceus* (te kiaiai), *Sida fallax* (te kaura), *Cordia subcordata* (te kanawa), *Pisonia grandis* (te buka), *Pandanus tectorius* (te kaina), *Triumfetta procumbens* (te kiaou), *Vigna marina* (te kitoko), *Morinda citrifolia* (te non), *Cassytha filiformis* (ten tanini) or *Cocos nucifera* (te ni).

Some cultivars are early maturing like 'katutu'. This cultivar does not require a lot of labour but requires minor work like topping up the base of the plant with mud, whereas late-maturing cultivars such as 'ikaraoi' involve a lot of labour. The work involves making a basket out of pandanus or coconut leaves and backfilling it with prepared compost either dry or in its fresh stage. According to *Cyrtosperma* growers, the plant is composted quarterly. For a grower to know the time of composting application, he or she has to observe closely the emergence of new leaves that come out approximately every month; after the third leaf comes out, it is time for the planter to apply compost.

Colocasia esculenta and Ipomoea batatas

Taro and sweet potato cultivation in Kiribati also involves much input for a successful crop. Recommended cultivars are tolerant to local soils and conditions. However, they will not thrive on any site. It is therefore important when selecting digging grounds for taro and sweet potato to avoid areas with a shallow soil on top of a hard pan, rocky ground or gravelly soils, areas where ground water is known to become brackish during drought or areas which flood for extended periods during the rainy season (Webb 1994). Other factors to consider are exposure to salt-laden winds, availability of space and sunlight, and competition from other plants. The ideal location is preferably close to the household water-drawing area on the protected lagoon side, with good quality water. A site with a good topsoil layer, because of its high organic matter content, also helps ensure good results (Webb 1994).

The methods of production briefly described below are applicable to the cultivation of taro and sweet potato.

Tree crops research method of production

The trenches are dug 30 cm wide and 30 cm deep, at 1 metre spacing, length depending on the size of the garden. Because of the highly permeable nature of the soil and the variable rains, sunken beds are advisable in order to concentrate and retain as much water as possible.

The constituents of the compost may vary with location and availability of material. A list of potential backfilling materials is modified from Webb 1994:

green leaves of any common species (te uri, te mao, te ren),
dead leaves (te uri, te buka, breadfruit),
rinsed seaweed,
manure and/or topsoil from chicken or pig pens,
any rusting metal, e.g. crushed tins (rusty steel has been used in cultivation in Kiribati for many years to combat iron deficiency in plants),
other materials, e.g. fish and animal waste, such as ground and pond algae, sea cucumber, rotten breadfruit, telapia, any organic waste,
rotten coconut logs, husks and coconut root peat,
crushed pumice or soil from a guano outcrop,
black soil.

The trench is then backfilled with as wide a range of materials as possible. The bottom layer is usually made up of coconut husks mixed with rusty tins, as these take a long time to decompose and could pose a problem to root development if too close to the surface. Ingredients are placed in thin layers with a layer of black soil and manure between each, then the trench overfilled so that it is raised above ground level by about 30 cm. Sufficient water is added to moisten each layer to hasten decomposition of the compost. The final layer should be heavily mulched soil to avoid drying out. Because of the large amount of unrotted material used in backfilling, the trench takes considerable time to be ready for planting. A period of 6–7 weeks is considered the minimum but it depends on how often the hole is aerated and watered, and the quality of the materials used (Webb 1994). Generally the trench is ready when it has sunk to the level of or just below the surrounding soil due to the decomposition processes.

PRAP

The trench size is as described above. The backfilling technique is different, i.e. the compost mix is decomposed before applying to the trench. The compost mix has the following components:

25% dead leaves of te uri, te mao, te ren and other species especially leguminous and nitrogen-fixing trees such as *Sophora tormentosa* or *Vigna marine,*
25% well-rotted coconut log broken into small pieces,
25% soil or sand, and
25% manure (chicken and/or pig).

These ingredients (a rough measure could be a bucket or a bag of each type) need to be mixed thoroughly. If well-rotted leaves and the matured manure (old, not fresh, to prevent burning of plants) are applied, then the compost can be used immediately.

Either one of these two methods can be used in accordance with the availability and stage of decomposition of the compost ingredients.

Plant Nutrient Requirements

Cyrtosperma

Very little is known about plant nutrition requirements. The only plant nutrients applied are in the form of organic matter — plant leaves. According to Ali (1987), no accurate data on the quantity of composting material applied to a single plant are available. It is estimated that 60-70 kg of dry or green leaves may be required to grow a single plant over 4–5 years.

Sweet potato and taro

Kiribati coral soils are shallow, well-drained and deficient in nitrogen, potassium and trace elements, especially iron, manganese, zinc and copper. In addition, because of the naturally high pH, even if nutrients are added as fertilizers they may not benefit the crops planted, as many important nutrients are not available to plants in such alkaline conditions. The preparation of a planting hole or trench with compost, and later the addition of organic matter, can make the pH of the soil more neutral, thus increasing the ability of plants to utilise any nutrients present in the soil (Webb 1994).

Table 2. Fertilizers recommended for use in Kiribati (Trewren 1986).

Kiribati general mix			
Fertilizer	Quantity (kg)	Element in mixture	(%)
I.B.D.U.	31.0	N	(9.9)
Triple superphosphate	27.0	P	(5.1)
Potassium chloride	30.0	K	(12.0)
Iron sulphate	9.0	Fe	(1.8)
Manganese sulphate	1.8	Mn	(0.41)
Zinc sulphate	0.8	Zn	(0.184)
Copper sulphate	0.4	Cu	(0.10)
Total	100.0		

Addition of small amounts of complete fertilizer mix (Table 2) to the compost is helpful and sometimes necessary to bring about the successful growth and maturity of the plant (Trewren 1986). Low rates of fertilizer are used to make applications affordable by the majority of growers and also to pose lower risks of pollution of the water lens. The fertilizer rate used in planting trenches has been a single dose of 100g of General Mix incorporated in a 3-metre trench, but satisfactory results have also been obtained without inorganic fertilizer addition.

References

Ali, A. 1987. The agronomy of *Cyrtosperma chamissonis* Schott in Kiribati. Alafua Agri. Bull.

Trewren, K. 1986. Charcoal: a useful additive to fertilizer for coral soils — an experiment in Tuvalu. Harvest (Papua New Guinea) 12: 16–18.

Webb, A.P. 1994. Tree and Perennial Crop Introduction and Extension in Kiribati 1991-1994. Ministry of Environment and Natural Resources Development, Kiribati.

The Incidence of Taro Leaf Blight (*Phytophthora colocasia*) in Relation to Rainfall in Western Samoa: a Progress Report

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Abstract

An investigation is being conducted on taro leaf blight (*Phytophthora colocasia*) in relation to rainfall in Western Samoa. The preliminary results showed a positive relationship for taro leaf blight disease to rainfall and plant age. A negative relationship appeared to exist between the disease damage and the eating quality of the corm. A possibility of growing taro as a seasonal crop is suggested in order to minimise cost of production.

IN Western Samoa, taro (*Colocasia esculenta*) was the main staple food and also a major export crop. Success in efforts to realise this potential depends largely on the capacity to overcome the many constraints while intensively exploiting the various systems of taro cultivation. The effects of natural hazards can be a major constraint, as demonstrated by the highly destructive taro leaf blight (TLB) disease, which has been infecting taro in Western Samoa since July 1993. A recent report released by the Central Bank of Western Samoa showed a marked decrease in taro export in 1994. It dropped from an annual average of about 184 000 cases during 1988–1993, to about 2000 cases in the first nine months of 1994 (Anon. 1993, 1994).

A major task for the Ministry of Agriculture, Forests, Fisheries, and Meteorology (MAFF&M) in the immediate term is to revitalise the taro industry. Work has centred on the use of chemicals and sanitation technologies, in an integrated control package to combat the disease. This approach has been quite successful, but such a recommendation must have some degree of flexibility in order for the resource-poor farmers to maintain production at a sustainable level.

For certain diseases, such as downy mildew of hops, a 'weather index' can be used to determine the time and number of spray applications for its control (Solarska 1991). Similarly, this approach might be applicable in establishing a 'flexibility index' for the control of TLB in Western Samoa. This is particularly important because of the differences in rainfall at the various sites on Upolu and Savaii Islands. According to Wright (1963), the southern side of Upolu is relatively rainy, with an annual average rainfall of 4063 mm. The northern rainshadow area has an annual average of about 2813 mm. This difference in rainfall has been observed to be related to the incidence of TLB, and affects the frequency of chemical applications (personnal communication with farmers). The implications for production cost are assumed to be quite significant, considering an unsubsidised price of about WST50.00 (approx. $A26.50) for one litre of Foschek, which is currently used for the chemical control of TLB.

The objective of this paper is to present some preliminary findings on the interrelationships among rainfall, incidence of TLB, frequency of spray applications, growth, yield, and eating quality of the corm.

Materials and Methods

The experiment is being conducted on Upolu Island in Western Samoa (latitude 13°–51′ and longitude 171°–47′W) by the Research Division of MAFF&M. The planting treatments were administered in August, October, December of 1994, and February, April and June of 1995 (time of planting), in four replicates (sites): Siumu, Nuu, Saleimoa and Faleolo.

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The trial layout is a randomised complete block design.

The plots measuring 43 m × 11 m gross (528 plants) and 19 m × 9 m × 2 net (400 plants) have been planted with taro headsets (cultivar Niue) at 1 × 1 m spacing, and harvested at seven months maturity.

Thirty-two plants per plot have been used for the assessment of growth and TLB. Every leaf is numbered at emergence, and the accumulative total during the period from planting to harvesting is a measure for growth. For TLB assessment, each leaf is monitored regularly for number of lesions and disease severity. The assessment of the latter is based on a diagramatic scale (1 = no infection; 6 = severe infection) of Gollifer and Brown (1974).

A systemic fungicide, Foschek, has been used to control the disease, at 200 mL per 10 litres of water. Spraying has been done using a mistblower when the disease severity reaches a score of about 2.5 at the different sites.

Fresh corm weight was measured for each plot at seven months maturity.

Rain gauges were installed at Siumu and Saleimoa for the daily recording of rainfall by the farmers. Information for Nuu and Faleolo is being made available at the Station and the Meteorological Centre, respectively.

Results

The parameters (disease severity, growth, yield, and eating quality of the corm) were similar between the rainy (Siumu) and rainshadow (Saleimoa) blocks, except for the amount of rainfall and number of spray applications (Table 1). During this investigation, the average monthly rainfall at the wet area (Siumu) was roughly twice the amount of that at the dry area (Saleimoa). At the same time, the number of spray applications in the wet area had at least doubled the amount applied to the dry area.

The TLB infection was minimal during the first two months after planting. An increasing trend was observed parallel to plant age, and it appeared to be most prominent beginning at about four months of maturity. This pattern coincided with enhanced leaf senescence. Out of 21 leaves observed between planting and harvesting for a seven-month-old taro, about four functional leaves had been maintained by the plant at any one time of the investigation.

The corms from the two distinct rainfall sites were relatively small, compared to a good marketable-sized corm normally at the market before TLB. Close to 3000 kg/ha was the average yield, and generally of good eating quality.

Table 1. Characteristics observed on taro grown on rainy (Siumu) and rainshadow (Saleimoa) areas during the wet season months.

Observations	Wet area	Dry area
Rainfall monthly average (mm)	531	281
Disease severity		
- 12 days maturity	1.0	1.1
- 75 days maturity	1.7	1.5
- 130 days maturity	1.8	2.4
- 201 days maturity	2.0	2.4
Number of spray applications at about 2.5 disease severity (from planting to harvesting)	12	5
Growth (leaves per plant) average from planting to harvesting	22	20
Yield (kg/ha) at 9880 plants/ha, 0.3 kg average corm weight and 7 months maturity	2964	2964
Eating quality of the corm Score (4 = top quality; 1 = poor) (boiled then tasted)	3.6	2.9

Discussion

The results confirm the positive relationship between the amount of rainfall and the level of TLB infestation. This was reflected in a more frequent number of spray applications at the wet area. This kind of relationship is quite common with fungal diseases (Gambrah-Sampaney, 1990; personal experience with banana leaf spot). An increase in the frequency of spray application in a wet area was useful in maintaining the severity of the disease between the two rainfall zones at equivalent levels. The same concept of disease control would be applicable in relation to plant age, due to a high risk associated with increasing levels of inoculum.

By maintaining the severity of the disease between Siumu and Saleimoa at equivalent levels, their actual yields were similar in both quantity and eating quality. However, the latter appeared to be more sensitive, with greater negative reponses in relation to TLB. As indicated in the eating quality of the corm, the slightly lower quality of the Saleimoa taro could be attributed to a corresponding higher incidence of the disease.

It should also be noted that this part of the experiment was implemented during the wet season months, when the amount of rainfall for the dry area is expected of the wet area during the dry season months (Wright 1963). Therefore taro could be grown on the wet side of the island during the dry season months, with a significant reduction in spray applications. This warrants further studies on taro growing as a wet season crop in the north and as a dry season crop in the southern part of the island. This might minimise the use of chemicals without sacrificing yield.

Acknowledgments

The consultancy assignment of Dr Liyanage on TLB is appreciated. The Assistant Director of Research, Dr Semisi and other colleagues have been assisting with this work. The Australian International Development Assistance Bureau (AIDAB) assists with funding through the Western Samoa Farming System Project.

References

Anonymous, 1993. Central Bank of Samoa Bulletin, June 1993.

Anonymous, 1994. Central Bank of Samoa Bulletin, December 1994.

Gambrah-Sampaney, G. 1990. Aggregate Supply Response of the Cocoa Industry of Trinidad and Tobago; 1952–1986. University of the West Indies (Trinidad).

Gollifer D. E. and Brown J. F. 1974. Phytophthora leaf blight of *Colocasia esculenta* in the British Solomon Islands. Papua New Guinea Agricultural Journal 25(1:2), 6–11.

Solarska E. 1991. Forecasting and signalling of downy mildew of hop — results of practical application in 1986–1988.

Wright A. C. S. 1963. Soils and Land Use of Western Samoa. New Zealand Department of Scientific and Industrial Research.

Use of Leguminous Trees to put N into Pacific Farming Systems:
Solution in Search of a Problem?

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Abstract

Leguminous trees have the potential to provide large amounts of nitrogen-rich biomass to Pacific Island farming systems. This paper reviews the use of leguminous tree species in root crop production systems, outlines some of the factors which may affect nitrogen fixation capacity, and comments on the choice of appropriate tree species and management from a farming systems perspective. It is concluded that in root crop systems N-fixation will not be the primary characteristic used by farmers in tree selection.

THE use of leguminous trees to provide nitrogen and other benefits to farming systems has been popularised and promulgated since the major work on alley cropping at the International Institute for Tropical Agriculture (IITA) in the early 1980s (Kang et al. 1981). Leguminous plants can produce large amounts of biomass, which can release nutrients to increase soil fertility, reduce fertilizer needs (Yamoah et al. 1986), and increase crop yields (Hussain et al. 1988).

Early alley cropping experiments were concerned mainly with nitrophilic crops such as maize that respond readily to nitrogen (N) inputs provided by prunings from leguminous hedgerows (Kang et al. 1981). However, the principal staple foods in most Pacific Island countries are root crops, and reports of positive benefits from tree legumes in root crop production systems are more difficult to find. Indeed, high N levels in newly cleared forest soils or applications of N fertilizer can result in vigorous top growth with low tuberisation in crops such as sweet potato and cassava (Van Wijmeersch, pers. comm.).

The capacity to fix N might be expected to convey a distinct advantage in the choice of a hedgerow species. However, interactions between hedgerow species, the crop and the soil are complex, there being numerous factors besides N-fixation that impinge upon the interactions in these systems (Garrity and Mercado 1994). This paper reviews information on the use of leguminous tree species in root crop production systems in Pacific Islands, outlines some of the factors which may affect N-fixation capacity, and comments on choice of appropriate tree species and management from a farming systems perspective.

Empirical Evidence

Direct attempts to relate soil N supplied from tree prunings to root crop production in the Pacific Islands are limited. Brook (1993), reporting on an alley cropping trial conducted at the Lowlands Agricultural Experiment Station in Papua New Guinea, concluded that all hedgerow species tested provided N in quantities greater than the intercropped sweet potato requirements, which resulted in greater vine growth at the expense of tuber formation. This worker also considered shade from the hedgerows detrimental to crop yield and concluded that the prospects of this land-use system for sustaining sweet potato yields were not promising. In Solomon Islands studies have indicated that the yields of both sweet potato and cassava are low in alley-cropped plots (Hancock 1989).

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In contrast, Weeraratna and Asghar (1992) demonstrated increased available nitrogen (NH_3-N and NO_3-N) during weeks 2–6 after the application of 30 and 60 t/ha of Dadap (*Erythrina* spp.) mulch to taro (*Colocasia esculenta* L. Schott) plots, with a subsequent significant increase in dry matter yield of corms compared to non-mulched control plots. Rogers (1995) reported positive effects of alley cropping on taro yield only after five years of continuous cropping and mulch application with prunings from *Calliandra calothyrsus* or *Gliricidia sepium* on a Typic Humitropept in Western Samoa. In the first four years of this trial there was no significant difference in crop yield between the alley plots and the no-tree control plots (Rosecrance et al. 1992).

Yield data from an on-farm trial established at Poutasi in Western Samoa in September 1990, to evaluate *Erythrina subumbrans* interplanted at 2 × 2 m spacing with taro and to compare this system with a *Glyricidia sepium* alley treatment with trees planted in hedgerows spaced at 5 m and a no-tree control, are shown in Figure 1. The data indicate advantages in the tree plots from year two onward, with the *Erythrina* plots being the most productive. In year four the plots were planted with a mixture of *Colocasia* and *Xanthosoma* taro because of the outbreak of taro leaf blight in Samoa. The overall lower yields in this year are due to blight infection of the *Colocasia*. Positive effects of both tree species on crop production and sustainability of yield are evident in this trial.

No published data on the effects of leguminous tree mulch in yam production systems in the Pacific Islands could be found in the literature. Yams are high demanders of soil N (Young 1976) and are frequently the first crop grown in freshly cleared forest soil. In Western Samoa farmers use mature *Erythrina subumbrans* trees as live support for yams; about 5–6 setts *(Dioscorea nummularia)* are planted in a circle 2–3 m from the base of the tree and allowed to climb up bamboo stick buttresses to the bole of the tree. The growing yam vines eventually cover the canopy and suppress the tree growth over the growing period. Green leaf prunings from the *Erythrina* are used as mulch at the time of planting the yams. Further work to validate the benefits of this system and

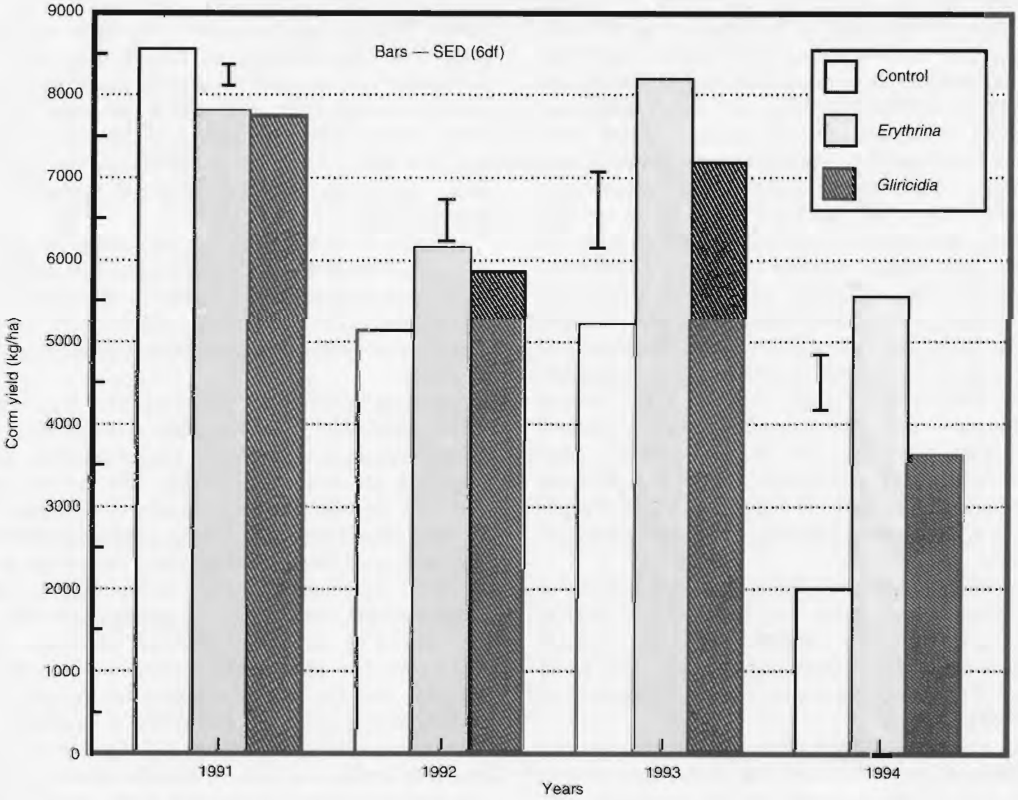

Fig. 1. Taro yields at Poutasi over four consecutive years.

to tune the management is being carried out by the Pacific Regional Agricultural Programme (PRAP) farming systems project in Western Samoa.

Nitrogen Fixation

Many small farmers in developing countries cannot afford to buy chemical fertilizers, or the supply is erratic and fertilizers are not available when needed. From both the ecological and economic standpoints the advantages of in situ N-fixation by the components of the agricultural system are attractive (Garrity and Mercado 1994). Addition of N to the system, however, is not guaranteed simply by planting a leguminous tree species. Not all these species have the ability to nodulate and fix atmospheric N.

Several workers in the Pacific Islands have reported levels of biomass production from coppiced leguminous tree species and leaf N content (Brook 1992, 1993; Tekle-Halmanot et al. 1991; Rogers 1995). Estimates of possible N additions from the leaf prunings have ranged from 29 to over 300 kg/ha per year, but no records could be found of direct measurements of N-fixation of levels of active nodulation of the trees in the trials. It is difficult, therefore, to know how much of this is N-accretion in the system and how much is recycling. Ladha and co-workers (1993) working in the Philippines, estimated N-fixation in *Gliricidia sepium* may account for 30–60% of plant N uptake, but because a leguminous tree is reported to fix N somewhere does not mean that it will always be able to do so. The presence of suitable rhizobia is essential to N fixation. In fields that have not been successfully planted to a given N-fixing tree (NFT), it is likely that the introduction (inoculation) of suitable bacteria will be beneficial (MacDicken 1994). Furthermore, any factor in the environment that affects the growth of the host plant is likely also to affect nodule development and function (Dixon and Wheeler 1983). Low pH (below 5.5), low soil P levels, water stress, reduced oxygen levels, salinity and shortage of micronutrients such as cobalt, iron and molybdenum, are all factors that may reduce or inhibit N-fixation.

Garrity and Mercado (1994) pointed out that a high demand for P to service the N-fixation process may result in severe competition for this nutrient between NFTs and annual crops. This may be of special significance on some of the P-fixing soils in the Pacific Islands.

Few studies have been carried out to evaluate tree management on nodulation and N-fixation. Nygren and Ramirez (1993) reported on the phenology of N-fixing nodules in pruned clones of *Erythrina poeppigiana* in Costa Rica. Dramatic changes in nodule biomass were observed during a six-month pruning cycle. Nine weeks after pruning nodule biomass was almost nil but had increased to above the pre-pruning level by 17 weeks after pruning. They linked the nodule phenology of pruned *Erythrina poeppigiana* to availability of photosynthate. Clearly, further studies to investigate the effects of rigorous pruning in hedgerow systems on nodulation and N-fixation are required.

The rate of release and supply of nutrients from decomposing prunings also needs to be carefully considered. Synchronising the release of nutrients with crop demands is important, particularly in high rainfall areas where leaching can rapidly remove nutrients from the root zone. When prunings are applied to the soil surface as mulch, N may also be lost by volatilisation. Knowlege of the rates of litter decomposition offers opportunities to manipulate the timing of nutrient release and improve the efficiency of the system (Young 1989).

Farming Systems

Leguminous trees have been used extensively in Pacific Islands farming systems as shade for cocoa and coffee. *Gliricidia sepium*, *Albizia chinensis* (syn. *A. stipulata*), *Leucaena leucocephala* and *Erythrina subumbrans* are commonly used in this way. The primary function of these trees is to provide shade to the tree crop, but they undoubtedly add organic matter and some N to the system through leaf fall and loppings.

Farmers in Western Samoa also recognise *Erythrina subumbrans* as a valuable tree in root crop systems. As mentioned above, they use this tree as live support for yams, but also to enrich fallow periods and, intercropped, to improve taro yields (Rogers et al. 1993).

However, attempts to introduce new leguminous tree species into food cropping systems have frequently resulted in increased labour demand and a change in the labour use profile. The systems have therefore proved unpopular and/or unadoptable by resource-poor farmers. Trials in Samoa demonstrate that, with appropriate management, labour use in the tree plots can be similar to or less than that in no-tree plots after the initial input to establish the trees in year one (Fig. 2a,b). Furthermore, the main work task in the tree plots changes from weeding to tree pruning, and the shady environment in the early months of crop establishment makes a more pleasant work environment. Experience with farmers suggests that they prefer, and are better able, to carry out a pruning regime than control persistent weeds such as para grass (*Brachiaria mutica*).

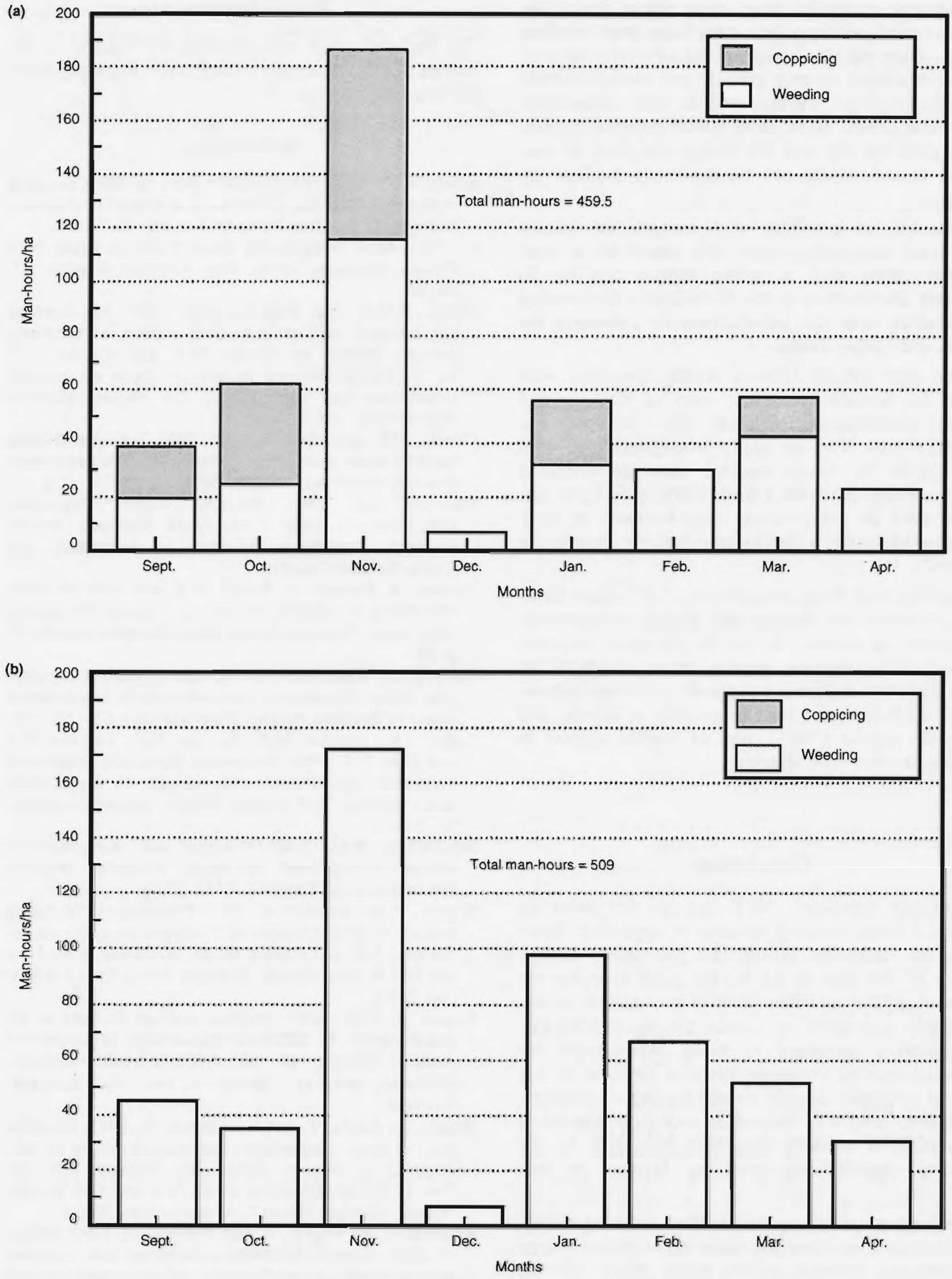

Fig. 2. Labour use profile 1993–94 season for (a) *Erythrina* and (b) no-tree plots.

Farmers generally have clear ideas about the products and services they want from trees on their farms. They are also aware of the adverse effects of tree competition on crop growth, and identify certain species which do not mix well in close association with food crops. Also, trees which produce prolific seed, grow rapidly, and are hard to cut, such as *Leucaena leucocephala*, can be positively disliked by farmers.

Attempts to introduce such competitive species into food cropping systems can result in, at best, farmer apathy and, at worst, serious conflict. In Western Samoa there is still ill-feeling in the farming community over the introduction of *Leucaena* for cocoa and coffee shade.

The tree species farmers readily associate with crops for service functions, such as shade, weed control and support, frequently share the following characteristics: they are easily propagated from stem cuttings or by direct seeding; they are softwood species easily cut with a bush knife; they have soft roots; they do not produce large amounts of seed; and they are easily killed by ring-barking close to the ground.

Species with these characteristics offer great flexibility because tree density and spatial arrangements can easily be adjusted to suit the particular cropping situation. Furthermore, pruning management of the trees does not require hard labour. *Erythrina subumbrans* used in food cropping systems in Samoa, and *Jatropha curcas* ('fiki') used as vanilla support in Tonga, are two such species.

Conclusion

Identifying candidate NFT species for roles in Pacific Islands farming systems is appealing; however, tree selection should not rest solely on the ability of the tree to fix N, but must consider the other attractive qualities already recognised in traditionally used trees. In Samoa the leguminous tree *Adenanthera pavonina* is being investigated for potential use in cropping systems because it has several products already valued by the community, but it does not fix N. Indeed, in root crop systems, it is considered unlikely that N-fixation will be the primary characteristic used by farmers in tree selection.

Perhaps of more importance than N-fixing ability, leguminous trees have the capacity to produce large amounts of biomass which make them valuable fallow species to put carbon (C) into Pacific Islands farming systems.

Acknowledgment

The authors' posts and research are funded by the European Union as part of the Pacific Regional Agricultural Programme.

References

Brook, R.M. 1992. Early results from an alley cropping experiment in the humid lowlands of Papua New Guinea. Nitrogen Fixing Tree Research Reports, 10. 73–76.

— 1993. Alley cropping for sweet potato in Papua New Guinea. Nitrogen Fixing Tree Research Reports, 11. 35–39.

Dixon, R.O.D. and Wheeler, C.T. 1983. Biochemical, physiological and environmental aspects of symbiotic nitrogen fixation. In: Gordon, W.C. and Wheeler, C.T. ed. Biological nitrogen fixation in forest ecosystems: foundations and applications. The Hague, Martinus Nijhoff/Junk. 108–172.

Garrity, D.P. and Mercado, A.R. 1994. Nitrogen fixation capacity in the component species of contour hedgerows: how important? Agroforestry Systems, 27. 241–258.

Hancock, I.R. 1989. Terminal Report, September 1985–February 1989. Dodo Creek Research Station, Research Department, Ministry of Agriculture and Lands, Solomon Islands.

Hussain, A., Hussain, A., Hayee, M.A. and Nasir, M. 1988. The leaves of leguminous trees as nutrients for agricultural crops. Nitrogen Fixing Tree Research Reports, 6. p. 20.

Kang, B.T., Wilson, G.F. and Sipkens, L. 1981. Alley cropping maize (*Zea mays* L.) and leucaena (*L. leucocephala* Lam.) in Southern Nigeria. Plant and Soil, 63. 165–179.

Ladha, J.K., Peoples, M.B., Garrity, D.P., Capuno, V.T. and Dart, P.J. 1993. Estimating dinitrogen fixation of hedgerow vegetation using the nitrogen-15 natural abundence method. Soil Science Society American Journal, 57. 732–737.

MacDicken, K.G. 1994. Selection and mangement of nitrogen fixing trees. Mortilton, Arkansas, Winrock International and Bangkok, FAO. 272 p.

Nygren, P. and Ramirez, C. 1993. Phenology of N_2-fixing nodules in pruned clones of *Erythrina poeppigiana*. In: Westley, S.B. and Powell, M. ed., *Erythrina* in the New and Old Worlds. Hawaii, Nitrogen Fixing Tree Association. 358 p.

Rogers, S. 1995. Alley cropping and agroforestry in the South Pacific. In: IBSRAM Proceedings of the Second Annual Meeting of the *PACIFICLAND* Network. IBSRAM Network Document No. 10. Bangkok, Thailand.

Rogers, S., Iosefa, T. and Rosecrance, R. 1993. Development of an *Erythrina*-based agroforestry system for taro cropping in Western Samoa. In: Westley, S.B. and Powell, M., ed. *Erythrina* in the New and Old Worlds. Hawaii, Nitrogen Fixing Tree Association. 358 p.

Rosecrance, R., Rogers, S. and Tofinga, M. 1992. Effects of alley cropped *Calliandra calothyrsus* and *Gliricidia sepium* hedges on weed growth, soil properties, and taro yields in Western Samoa. Agroforestry Systems, 19. 57–66.

Tekle-Halmanot, A., Weeraratna, C.S. and Doku, E.V. 1991. Evaluation of three tree legume species in Western Samoa. Nitrogen Fixing Tree Research Reports, 9. 71–74.

Weeraratna, C.S. and Asghar, M. 1992. Effects of grass and dadap mulches on some soil (an Inceptisol) properties and yield of taro (*Colocasia esculenta*) in Western Samoa. Tropical Agriculture (Trinidad), 69. 83–87.

Yamoah, C.F., Agboola, A.A. and Wilson, G.F. 1986. Nutrient contribution and maize performance in alley cropping systems. Agroforestry Systems, 4. 247–254.

Young, A. 1976. Tropical Soils and Soil Survey. Cambridge University Press, London. 468 p.

— 1989. Agroforestry for Soil Conservation. Wallingford, Oxon, CAB International. 276 p.