INTENSIFICATION OF SUBSISTENCE AGRICULTURE ON THE NEMBI PLATEAU, PAPUA NEW GUINEA
1. GENERAL INTRODUCTION AND INORGANIC FERTILIZER TRIALS

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ABSTRACT

*A crop intensification programme was conducted in an area of high population density, extended periods of land use, low crop yields, and consequent high child malnutrition rates. Sweet potato (*Ipomoea batatas *(L.)Lam.) is grown in continuously cropped fields without fertilizers or crop rotation and supplementary crops are planted seasonally. In this first of three papers, the Nembi Plateau environment is described and results are given from inorganic fertilizer trials undertaken to investigate nutrient imbalances and deficiencies.*

The first fertilizer trial included nitrogen (N), phosphate (P), potassium (K), minor elements, and boron (B). Sweet potato tubers and top growth showed a large response to K. P increased tuber yield, and minor elements increased top growth yield. B significantly depressed tuber yield whilst increasing top growth yield. A marked K deficiency was confirmed by sweet potato leaf analysis and soil analysis.

A further small trial examined the effect of boron fertilizer on Casuarina oligodon *Johnson. A very marked response to B was found. Another trial examined the effect of minor elements and B on peanuts (*Arachis hypogaea L.*), cowpea (*Vigna unguiculata *(L.) Walpers var.* unguiculata*) and winged bean (*Psophocarpus tetragonolobus *(L.) A.P. de Candolle). There were no significant responses.*

GENERAL INTRODUCTION

The 1978 national nutrition survey of Papua New Guinea showed that the child malnutrition rate on the Nembi Plateau of the Southern Highlands Province was particularly high. To determine the cause, an intensive agricultural and land use survey was conducted in September 1978. It found that the very high population densities on the Plateau had led to extended periods of subsistence food garden usage without adequate fallow periods. This has resulted in very low yields of sweet potato (*Ipomoea batatas* (L.) Lam.) which is the major subsistence crop, and chronic food supply problems. The sweet potato supply is variable and for certain periods the supply is especially inadequate. These food shortages contribute importantly to the particularly high malnutrition rates (Allen 1984b; Allen *et al.* 1979). Subsequent measurements in food gardens indicated subsistence sweet potato yields of 6.3 t/ha (Bourke and D'Souza 1982) and 7.1 t/ha (Crittenden 1982, p. 402). These represent some of the lowest sweet potato subsistence yields ever recorded in

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Papua New Guinea (Bourke 1984) and gave support to the hypothesis that child malnutrition was related to stress in the agricultural system.

Following the initial multidisciplinary survey, an agricultural research programme was initiated on the Plateau, which examined intensification of subsistence agriculture and seasonality of food supply. One of the authors lived on the Plateau between July 1979 and July 1981 and continued the research programme there until June 1982. In this series of papers we report on aspects of the intensification programme.

The environment

The Nembi Plateau (about 143°30′E, 6°15′S) is located between the Wage and Nembi Rivers in the Southern Highlands, some 20 km southwest of Mendi. The Plateau is dominated by limestone ridges and pinnacles with associated dolines and underground karst drainage. Rainfall recordings at Hol (1800 m) over the two year period commencing July 1979 indicated a mean annual rainfall of 2700 mm and a weak suggestion that the period May to November tended to be drier. The rainfall pattern is likely to be similar to that of Nipa which has a mean annual rainfall of 3200 mm and lower rainfall in June and July (McAlpine *et al.* 1975). The average maximum daily temperature is 25.7°C and the average minimum temperature is 14.1°C, with low variability throughout the year.

The Plateau ranges in altitude from 1650 m to 2300 m with agriculture practised between 1650 m and 2000 m. The trials reported here were conducted between 1650 m and 1800 m. Some clans have land near the Wage River at lower altitudes. There is no road access to the Wage River; medical facilities and stores are lacking; and there is reportedly a high incidence of malaria. For these reasons few people cultivate land or reside at the lower altitude location. The major agricultural soil is a Humic Brown Clay derived from volcanic ash (Wood 1984). Gross human population densities are high and are considerably higher on arable land. For example, population densities on arable land for three clans were recorded as 140 to 184 persons per km^2 by Allen (1984c).

Agriculture

Agriculture on the Plateau is dominated by sweet potato gardens which are made on the valley and doline slopes. Sweet potato is planted in long raised beds with drains running up and down the slope on the steeper land and in rectangular mounds on the flatter land. The land is cultivated continuously with breaks of up to a few months only between crops. During this short fallow phase, the ground is covered with the vines of the previous crop. Garden ages typically range from 15 to over 30 years. Some of the sweet potato vines, weeds and fallow vegetation are incorporated into the beds/mounds at replanting, but application rates are lower than in other highland areas.

The other important garden type is the mixed vegetable and coffee gardens situated on the deep, dark clay soils of the doline floors, on alluvial soils, and on the more fertile sites on the slopes. Soil tillage in these gardens is minimal. Fallow periods range from 1 to 10 years. The fallow vegetation is cut, piled and burned. The soil surface is lightly worked with a digging stick before planting. Crops in the mixed gardens include highland 'pitpit' (*Setaria palmifolia* (Koenig) Stapf), sugar cane (*Saccharum officinarum* L.), bananas (*Musa* cvs), pumpkins (*Cucurbita moschata* Duchesne ex Poiret), *Rungia klossii* S. Moore, winged beans (*Psophocarpus tetragonolobus* (L.) A.P. de Candolle), corn (*Zea mays* L.), taro (*Colocasia esculenta* (L.) Schott), Chinese taro

(*Xanthosoma sagittifolium* (L.) Schott), cabbage (*Brassica oleracea* L.), common beans (*Phaseolus vulgaris* L.), sweet potato, *Oenanthe javanica* A.P. de Candolle, *Ficus copiosa* Steudel, *Amaranthus tricolor* L., pak choi (*Brassica chinensis* L.), and lima beans (*Phaseolus lunatus* L.). The crops are mix cropped at the cultivar and species level.

Mixed crop gardens are planted seasonally in September to December. Traditionally only one planting of crops is made and the gardens are abandoned to grass fallow or are planted with *Casuarina oligodon* Johnson fallow as the food is harvested. In many instances, coffee is now being interplanted with the food crops and the garden are being converted to coffee gardens. See *Plates I* and *II*.

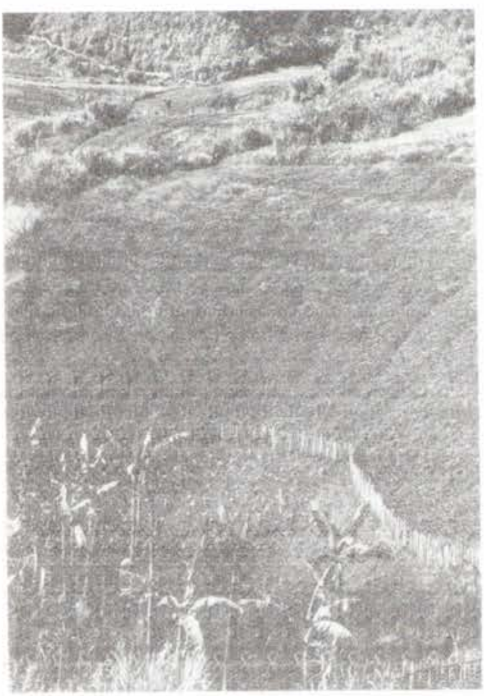

Plate I. **Sweet potato gardens (on slope) and a mixed vegetable garden (foreground) on the Nembi Plateau. Sweet potato gardens are planted for up to 30–40 years whilst mixed gardens are planted to one crop only before fallow**

Plate II. **A villager displays typical sweet potato tubers from a garden. Sweet potato yields are some of the lowest ever recorded in Papua New Guinea**

Intensification programme

The intensification research programme was conducted to identify agricultural technologies which would increase food supply. It was directed at the subsistence food sector as there are only limited possibilities to obtain cash to purchase food. The ultimate aim of the research programme is to provide technologies that can improve people's nutritional status.

All experimental work was conducted entirely in villagers' gardens, mostly under the land owners' management. Work was concentrated in sweet potato gardens as the malnutrition problem is viewed as a result of inadequate calorie intake linked to low sweet potato yields (Allen *et al.* 1979). All trials were low input ones. Unless stated otherwise, no fertilizer was added or pest control conducted. Because of problems in obtaining blocks of adequate area in the one location, guard rows were not used in the trials.

The intensification programme borrows heavily from component technologies that are being used elsewhere in the Papua New Guinea highlands under similar agroclimatic conditions. These include sweet potato composting, use of casuarina fallows, and legume/sweet potato rotations. These technology components were not formulated to fit into existing seasonal labour patterns or to alleviate seasonal food shortages as little data on these were available when the project was initiated. Some suggestions are made for a more holistic approach for agricultural intensification research by D'Souza and Bourke (1984). In this series of papers we report results of the intensification research as follows:

1. Inorganic fertilizer trials with sweet potato, *Casuarina oligodon* and three grain legumes. These trials were done to identify soil nutrients limiting crop growth.
2. Organic fertilizer trials. Three compost trials with sweet potato; an *Azolla*, pig manure and coffee pulp trial with sweet potato; and an *Azolla* trial with taro were conducted.
3. Evaluation of introduced sweet potato cultivars, other introduced food crops and crop rotation trials. The following trials were done: three sweet potato cultivar trials; a comparison of five grain legumes; evaluation of potato, cassava and pigeon pea as new food crops; and three rotation trials evaluating a peanut/sweet potato rotation.

INORGANIC FERTILIZER TRIALS

SWEET POTATO FERTILIZER TRIAL

This trial was conducted to define what nutrient imbalances and deficiencies occur in the continuously cropped sweet potato gardens. Inorganic fertilizers have no role in the agricultural systems of the Plateau because people cannot afford them.

Materials and methods

The aim of the trial was to define the limiting nutrients for sweet potato cultivation on Plateau soils. The method used (Mukerjee 1963) involves locating each replicate on a uniform soil type and slope in different farmers' fields. All of the replicate sites had been cropped continuously with sweet potato from 7 to 30 years and represented a spectrum of typical sweet potato gardens.

A factorial design with 7 replicates and the following treatments was used: 3 levels of nitrogen, 2 of phosphate, 2 of potash, 2 of minor elements and 2 of boron ($3N \times 2P \times 2K \times 2M \times 2B$). Treatment details are given in *Table 1*. The boron levels in the B treatment and the minor element treatment were adjusted to give identical per plot values (1.5 kg B/ha), which effectively gave three boron treatments of 0 (M_0B_0 plots), 1.5 (M_0B_1 and M_1B_0 plots) and 3.0 (M_1B_1 plots) kg B/ha. The boron treatment was added after a boron deficiency was proven on *Casuarina oligodon* on the Plateau. Symptoms of boron deficiency on sweet potato (Nusbaum 1946) have also been observed on the worst soils on the Plateau.

Treatments were randomized within each replicate. Plot size was 5 m^2. The area covered by a single replicate at each site was 240 m^2. No guard rows were used. Seven replicates were planted with a local cultivar (Sumbil), at a density of 24,000 cuttings/ha. Terminal cuttings 30 cm long were used.

Residues of the previous sweet potato crops were removed, the soil cultivated by hand, fertilizer applied, the traditional rectangular mounds

Table 1.–**Treatments used in sweet potato inorganic fertilizer trial**

Nutrient	Treatment	Fertilizer	Nutrient % of fertilizer	Rates of element applied
Nitrogen	N_0,N_1,N_2	Urea	46	0,75,150 kg N/ha
Phosphorus	P_0,P_1	Triple superphosphate	25	0,75 kg P/ha
Potassium	K_0,K_1	Muriate of potash	56	0,75 kg K/ha
Minors	M_0,M_1	Minors mixture	(1)	0.454 kg compound/ha
Boron	B_0,B_1	Borax	10	0,1.5 kg B/ha

Note: 1 Minor element mix contained 3.8% Mg, 4.8% Fe, 2.8% Zn, 1.2% Mn, 2.5% Cu, 0.33% B, 0.05% Mo, 0.01% Co plus sulphur. This gives application rates of 17.3 kg Mg/ha, 21.8 kg Fe/ha, 12.7 kg Zn/ha, 5.4 kg Mn/ha, 11.4 kg Cu/ha, 1.5 kg B/ha, 0.2 kg Mo/ha and 0.05 kg Co/ha.

formed and the runners planted. Regular hand weeding was done by the farmers until a good ground cover was established. The only pest or disease problem was minor infestation of sweet potato scab caused by the fungus *Elsinoe batatas* Jenkins and Viegas. Rainfall during the growing period (28 weeks) was 1690 mm.

At harvest marketable tuber weight (tubers over 100 g in weight), number of marketable tubers, total tuber weight and top growth weight (stem, petioles, leaves) were recorded per plot. A month prior to harvest, leaf samples were taken from 12 selected treatments, as follows: $N_{(0,1,2)}P_0K_0M_0B_0$, $N_{(0,1,2)}P_0K_1M_1B_0$, $N_{(0,1,2)}P_1K_0M_0B_1$ and $N_{(0,1,2)}P_1K_1M_1B_1$. The sampling scheme was a quarter fractional replicate with aliases of boron/phosphate and minor nutrients/potash. Ten leaf blades were collected from the first fully expanded leaf for each treatment above for all replicates. Samples were oven-dried at 40°C and a composite sample formed for each treatment from the seven replicates. Kjeldhal's digestion was used for nitrogen and nitric perchloric acid for all other elements (P, K, S, Ca, Mg, Na, Fe, Mn, Zn, Cu, B).

Results

Nitrogen had no significant effect on tuber or top growth yield (*Table 2*). Phosphate gave a small but significant increase in marketable and total tuber yield. Potash resulted in large and highly significant increases in tuber number, marketable and total tuber yield and top growth yield and an increase in mean tuber weight (260 to 300 grams). The minor elements significantly increased top growth yield. Boron depressed total tuber yield and increased top growth yield.

Applied potassium resulted in a large and significant increase in the leaf potassium content (*Table 3*). There was an apparent significant reduction in leaf Mg level in the minor fertilizer treatment. Boron fertilizer gave a large and significant increase in the boron level in the leaves.

Discussion

Nitrogen. The failure of nitrogen to increase vine yield was unexpected. These results are inconsistent with those reported elsewhere (Tsuno, no date; Bourke 1977). It is possible that the cultivar used (Sumbil) does not respond to nitrogen fertilizer, as certain cultivars in the highlands have been found to be unresponsive to N (W. Akus, pers. comm.). Alternatively, soil N levels may be adequate for top growth production.

Results of the leaf analysis (*Table 3*) show no significant increase in leaf

Table 2.–**Effect of inorganic fertilizer on sweet potato tuber and vine yield**

Treatment	Number of marketable tubers ('000/ha)	Marketable tuber yield (t/ha)	Total tuber yield (t/ha)	Top growth yield (t/ha)
N_0	31.3	8.1	9.1	20.8
N_1	32.4	7.9	8.9	21.0
N_2	30.2	7.6	8.7	22.8
P_0	30.3	7.4	8.5	20.8
P_1	32.3	8.3	9.4	22.3
K_0	26.1	5.8	6.8	16.9
K_1	36.5	9.9	11.0	26.2
M_0	32.2	8.1	9.2	20.4
M_1	30.4	7.6	8.6	23.5
B_0	33.6	8.3	9.4	20.3
B_1	31.4	7.9	9.0	21.7
B_2	28.8	7.3	8.3	24.0
Significant effects	K***	P* K***	P* K*** B*	K *** M** B **
L.S.D. (0.05) N	4.68	0.90	0.94	2.49
L.S.D. (0.05) P,K,M	3.82	0.74	0.77	2.04
L.S.D. (0.05) B	5.40	1.04	1.09	2.88
C.V. (%)	57	44	40	43

Table 3.–**Level of nutrients in sweet potato leaf blades versus rate of applied fertilizer**

Treatment	N (%)	P (%)	K (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)
N_0	4.7								
N_1	4.7								
N_2	4.8								
P_0		0.31							
P_1		0.31							
K_0			1.38						
K_1			1.81						
M_0				0.87	405	22.5	85	19.5	
M_1				0.75	450	23.5	89	19.0	
B_0									36
B_1									61
B_2									78
Level of significance	n.s.	n.s.	***	*	n.s.	n.s.	n.s.	n.s.	***
L.S.D. 0.05	0.4	0.02	0.17	0.11	97	1.6	16	1.6	7
C.V. (%)	5.5	5.4	8.1	10.0	17.6	5.7	13.9	6.5	5.8

nitrogen levels with application of N which is consistent with the lack of a response by tubers and top growth. N levels recorded in the leaves were above 4 per cent which is well above the critical limit for nutrient deficiencies (*Table 4*; Hahn 1977; Tsuno, no date). Soil analyses from sweet potato gardens on the Plateau (Wood 1984) indicate that soil N levels are adequate, although some problems of unavailability of N are possible because of a high C:N ratio (*Table 5*).

Phosphorus. The small response in tuber yields to phosphate (*Table 2*) is consistent with other work in Papua New Guinea where small yield responses to P have been recorded (Bourke 1977; Kimber 1982). The high level (over 0.3 per cent on a dry matter basis) of P in leaf tissue and the failure of applied P to increase leaf P levels also suggests that soil phosphate levels are adequate for sweet potato growth (*Tables 3* and *4*).

Potash. Potash application, even at the moderately low rate of 75 kg K/ha, increased tuber yield and top growth by almost 60 per cent. This suggests that the sweet potato soils of the Plateau are deficient in potash. The large increase in top growth is unexpected as top growth responses to K are usually small (Bourke 1977; Tsuno, no date).

Further evidence for a potash deficiency comes from the increases of K levels in leaves with increasing levels of applied K (*Table 3*). The leaf values of 1.4 to 1.8 per cent are high compared with critical leaf concentrations for potash of 0.5 to 0.75 per cent (*Tables 3* and *4*) but below the level of about 2.7 per cent for leaf blade at maturity given by Tsuno (no date). Soil analysis

Table 4.–**Critical concentrations of nutrients in sweet potato leaves for nutrient deficiency symptoms to occur (% dry weight basis)**

Material	N	P	K	Mg	Ca	S	Source
Stems and leaves	2.5	0.12	0.75	0.16	0.2	0.08	Spence and Ahmad (1967)
Leaf blade	1.5	0.10	0.5	0.05	0.2	0.08	Bolle-Jones and Ismunadji (1963)

Table 5.–**Chemical composition of black topsoil from sweet potato gardens, Nembi Plateau (adapted from Wood 1984)**

Parameter	Mean value	Comments on levels
pH	5.5	Somewhat acidic
Avail. P (ppm)	5.0	Low
Exch. Ca (m.e.%)	6.7	Medium
Exch. Mg (m.e.%)	2.6	Medium
Exch. Na (m.e.%)	0.3	Low
Exch. K (m.e.%)	0.2	Low
Total exch. bases (m.e.%)	9.9	Medium
C.E.C. (m.e.%)	56.3	Very high
Base saturation (%)	18	Low
Organic carbon (%)	8.2	High
Total N (%)	0.61	High
C:N ratio	13.5	Slightly high. May restrict N uptake
Mg:K ratio	13	High. Likely to restrict K uptake
Ca+Mg:K ratio	47	Very high. Likely to restrict K uptake

(Wood 1984) also indicates low soil K levels in sweet potato gardens and the possibility of magnesium and calcium antagonism (*Table 5*).

Minor elements. Top growth yield was increased significantly by applied minor elements (Mg, Fe, Zn, Mn, Cu, B, Mo, Co, S) (*Table 2*). However, there was no indication from foliar analysis that increased uptake occurred for any applied micronutrient except boron. The increase in top growth yield to the applied micronutrients is likely to be a response to the boron in the mix.

Boron. Boron fertilizer gave a significant increase in top growth yield and a significant decrease in total tuber yield (*Table 2*). Leaf analysis indicated that a large and statistically significant uptake of B occurred (*Table 3*). Eaton (1944, cited by Chapman 1973) gives boron levels in sweet potato tops of 16 ppm for deficiency, 118 ppm as medium and 310 to 1410 ppm as toxic. However, average levels of boron in sweet potato leaves in the Pangia, Tari and Upper Mendi areas of the Southern Highlands are in the range 25 to 34 ppm (n = 44) (M. Anders, pers. comm.). Thus the level in the control treatment in this trial of 36 ppm may be within the normal range and a toxic uptake of boron may have led to the reduced tuber yield.

CASUARINA BORON TRIAL

Casuarina oligodon trees on the Plateau display marked symptoms of boron deficiency including severe stunting and shortening of internodes and tip dieback giving the trees a characteristic, round, bushy appearance. Borax was applied to five affected casuarina trees with severe symptoms growing adjacent to the Plateau access road. Symptoms are generally more severe adjacent to roadsides because the plants are growing in subsoil transported during road construction. The borax was applied at a rate of 30 g per tree (3 grams B/tree). Adjacent trees were left as controls.

Treated trees grew more than twice as tall (an average of 115 per cent in height) compared with the control trees over a growth period of 20 months. This result occurred on the poorest soils containing the least organic matter. A more modest response by casuarina would be expected on slopes used for sweet potato gardens and possibly no response to B on doline and valley floors where casuarina are most common.

LEGUMES FERTILIZER TRIAL

A third trial was conducted to investigate the application of a minor element mixture and boron on the yields of peanuts (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* (L.) Walp. *unguiculata*) and winged beans (*Psophocarpus tetragonolobus* (L.) DC.). These species were considered as possible rotation crops in sweet potato gardens. A randomized block design was used with 10 replicates, although some plots were lost and the final replicate number harvested varied from 8 to 10. Plot size was 6 m^2. Plots were planted in existing sweet potato gardens. Cultivars used were Virginia Bunch Upright, Gutpela Cowpea and UPS 122 for peanuts, cowpea and winged beans respectively. The minor element mix was applied at 165 kg/ha and borax (11% B) at 3.3 kg B/ha. The minor element mix contained 2% MgO, 2% Fe, 2% Zn, 1.5% Mn, 0.5% Cu, 0.5% B plus molybdenum and cobalt.

None of the applied fertilizer had a significant effect on crop yield (*Table 6*). Yields of cowpea and winged bean were low and variability high. Highly variable soil fertility and uneven germination of the winged bean was responsible for the variable crop yields.

Table 6.—**Effect of minor elements and boron on yield of peanuts, cowpea and winged bean (kg/ha)**

Crop	Control	Minor elements	Boron	Significant effects	L.S.D. (0.05)	C.V.
Peanuts	1010	1240	1120	n.s.	200	17
Cowpea	400	490	520	n.s.	150	34
Winged beans	90	140	100	n.s.	80	65
Winged bean tubers	2420	1670	1760	n.s.	1400	66

CONCLUSIONS

Results of a single fertilizer trial supported by leaf and soil analysis data indicated a severe potassium deficiency in sweet potato soils of the Nembi Plateau. A small response to phosphate fertilizer by sweet potato tubers indicates a minor P deficiency also exists. The wide dispersal of the replicates and the large increase in tuber yield following potash application give confidence in the results obtained. The very low sweet potato yields recorded on the Plateau in subsistence gardens are likely to be caused by a potassium deficiency. Fertility maintenance techniques of composting with material rich in potash, such as coffee pulp, and crop rotations are necessary to correct the potash deficiency so as to increase sweet potato yields.

A boron deficiency was also identified in *Casuarina oligodon*, although boron fertilizer reduced sweet potato tuber yields in the field experiment. This deficiency has implications for crops that are particularly susceptible to B deficiency, in particular *Casuarina* and *Pinus*.

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