INTENSIFICATION OF SUBSISTENCE AGRICULTURE ON THE NEMBI PLATEAU, PAPUA NEW GUINEA 2. ORGANIC FERTILIZER TRIALS

E. D'Souza*† and R. Michael Bourke*††

ABSTRACT

*Four sources of organic fertilizer were compared as part of a research programme to find means of intensifying subsistence agriculture on the Nembi Plateau. The organic fertilizers tested were: compost formed within sweet potato (*Ipomoea batatas *(L.) Lam.) mounds using the technique that is traditional in the Papua New Guinea highlands but not widely used in the study area; the aquatic nitrogen fixing fern* Azolla pinnata *R. Br.; pig manure; and coffee pulp. The following were conducted: (a) three sweet potato rate-of-compost application trials, (b) a sweet potato organic fertilizer trial that compared* Azolla pinnata*, pig manure and coffee pulp, (c) a trial evaluating the effect of* Azolla pinnata *and soil cultivation on taro (*Colocasia esculenta *(L.) Schott) in a drained doline.*

Large responses were obtained to compost in each trial. An optimum economic application rate of 33 t/ha of fresh organic matter was indicated. A lower application rate of 20 t/ha is recommended for the Plateau. Azolla pinnata *did not increase taro yields and resulted in a non-significant increase in sweet potato yield. Pig manure gave a significant yield response when applied to sweet potato and had a positive residual effect on sweet potato yield in a demonstration plot. Coffee pulp gave the largest increase in sweet potato yields. Examination of the major nutrients supplied in the sweet potato trial suggests that the response was due mostly to potash contained in the various organic fertilizers. Limitations on the usage of various organic fertilizers are discussed.*

The use of compost and coffee pulp as fertilizers should be promoted in sweet potato gardens on the Plateau. Pig manure will have an important role in improved farming systems, but further research is needed on this and also on the usefulness of Azolla pinnata.

INTRODUCTION

This paper reports on trials to evaluate organic fertilizers which are available on the Nembi Plateau: compost, pig manure, coffee pulp and *Azolla pinnata*. Compost is used by villages to fertilize sweet potato in other parts of the Southern Highlands and Enga Provinces, but the practice is uncommon on the Nembi Plateau. Pig manure is abundantly available around houses and along walking tracks in the village and garden area, but it is not used by villagers to fertilize sweet potato in Papua New Guinea. Earlier work has shown that pig manure increases sweet potato yields (Kimber 1982). A limited amount of coffee is grown as a cash crop on the Plateau and the pulp of the

* Highlands Agricultural Experiment Station, D.P.I., Aiyura, P.O. Box 384, Kainantu, E.H.P., Papua New Guinea.

† Present address: 92 St. Stephens, Hounslow, TW3 2BN, England.

†† Present address: Department of Human Geography, Australian National University, Canberra, Australia.

cherry is available from village processing. Coffee pulp has been shown to increase sweet potato yields (B.F. Siki, unpublished data). *Azolla pinnata* is a small floating aquatic fern. It has a nitrogen-fixing, blue-green alga (*Anabaena azollae* Strasburger) living within the cavities of its leaves. *Azolla* is extensively used as an organic fertilizer in paddy rice cultivation in China and Vietnam (FAO 1977). It grows on ponds on the Nembi Plateau, entirely covering the water surface in some locations.

The experiments are described under the following three groups:

Series A. Sweet potato compost trials.
Series B. Sweet potato organic fertilizer trials (*Azolla*, pig manure and coffee pulp).
Series C. Taro organic fertilizer trial (*Azolla*).

SERIES A. SWEET POTATO COMPOST TRIALS

Composting of sweet potato is practised in much of the Southern Highlands and Enga Provinces (D'Souza and Bourke 1982). In the Wapenamanda area of Enga Province large sweet potato mounds are broken open after the final harvest of the sweet potato crop and sweet potato vines, weeds, leaves of sugarcane (*Saccharum officinarum* L.) and *Setaria palmifolia* (Koenig) Stapf are placed in a hollow in the mound. After about 10 weeks, the mound is reformed and planted with sweet potato (Waddell 1972). Waddell recorded that 20.2 kg of fresh organic matter were applied per mound. At Waddell's quoted mound density of 840 mounds per hectare, this gives an application rate of 17.0 t/ha of fresh material. At a high altitude location in the Kandep area, P. Wohlt (pers. comm.) recorded that the application rate of green matter for compost was 25 kg per mound and people make 1160 mounds per hectare, giving an application rate of 29.0 t/ha. On the Nembi Plateau levels of organic matter applied to form compost are low. Our measurements of nine composted gardens indicate a mean application rate of 4.8 t/ha (fresh weight).

Materials and methods

Three trials were conducted in sweet potato gardens on Humic Brown Clay soils (*Table 1*). The sites had been cropped continuously with sweet potato for 8, 20 and 12 years respectively, prior to the trials. Typical Nembi rectangular mounds were used. Thus, any treatment response would be due solely to composting, not to different shaped or sized mounds. Soil from the centre of the rectangular mound was dug out leaving a hollow for grass emplacement. Fresh grass of *Ischaemum polystachyum* Presl was cut and placed in the hollow. A different cultivar was planted in each trial. The three cultivars used represent between them some 62% of cuttings planted in sweet potato gardens on the Plateau (*Table 1*).

The trials were harvested once only and the total tuber weight recorded. The weight of sweet potato top growth was recorded in Trial 3 only. Samples of *Ischaemum* for chemical analysis were collected from an old sweet potato garden, a doline floor and the edge of a current sweet potato garden.

Results

The samples of *I. polystachyum* gave a mean fresh weight yield of 76.4 t/ha with a moisture content of 63.4%. The chemical composition (dry weight basis) was 1.03% N, 0.13% P, 0.99% K, 0.12% S, 0.31% Ca, 0.22% Mg, 108 ppm Fe, 127 ppm Mn, 40 ppm Zn, 33 ppm B and 5 ppm Cu. The quantity of N, P and K supplied in the various treatments and the sweet potato tuber yields are given in *Table 2*.

Table 1.—**Sweet potato compost Trials 1, 2, 3: materials and methods used**

Materials and methods	Trial 1	Trial 2	Trial 3
Trial design	Completely randomized	R.B.D.[1]	R.B.D.
No. of replicates	5	7	7
Plot size (m^2)	5	4	4
Cultivar used	Sokol	Gonime	Peripam
Proportion of this cv. in village gardens (%)	38	7	17
Planting density (cuttings/ha)	50,000	125,000	22,500
Treatments (t/ha fresh grass)	0,12,24,36	0,10,20,30	0,10,20,30,40
Period between placing grass and closing mounds/planting (weeks)	0	6	7
Crop duration (weeks)	23	25	26
Rainfall during crop (mm)	1010	1460	1380

Note: (1) Randomized block design

Table 2.—**Application rate of compost (fresh/dry weights); N, P, K content of applied compost; tuber yields; and top growth yield (Trial 3) in sweet potato compost Trials 1, 2, 3**

Applic. rate (fresh wt.) (t/ha)	Applic. rate (dry wt.) (t/ha)	Nutrients applied			Total tuber yield			Top growth yield Tr.3 (t/ha)
		N (kg/ha)	P (kg/ha)	K (kg/ha)	Tr.1 (t/ha)	Tr.2 (t/ha)	Tr.3 (t/ha)	
0	0	0	0	0	8.9	7.6	4.6	9.7
10	3.7	38	5	36		10.3	10.9	12.2
12	4.4	45	6	44	11.9			
20	7.3	75	10	73		12.7	16.0	16.3
24	8.8	90	11	87	13.7			
30	11.0	113	14	109		11.9	16.2	19.5
36	13.2	136	17	131	14.1			
40	14.6	151	19	145			18.4	20.5
Level of significance					**	n.s.	***	***
L.S.D. (0.05)					2.75	4.32	2.15	3.15
C.V. (%)					30	27	15	18

Compost gave large increases in tuber yield in all three trials (*Figure 1*). The response curve in all trials was quadratic, that is, sweet potato yield was increased by compost application initially, but with further application the rate of yield increase declined. Compost increased top growth significantly in Trial 3 (*Table 2*). A linear relationship was found between the rate of compost application and the top growth, as follows:

$$Y = 9.86 + 0.289x \qquad r = 0.985^{***}$$

where Y = top growth yield (t/ha) and x = application rate of compost (t/ha).

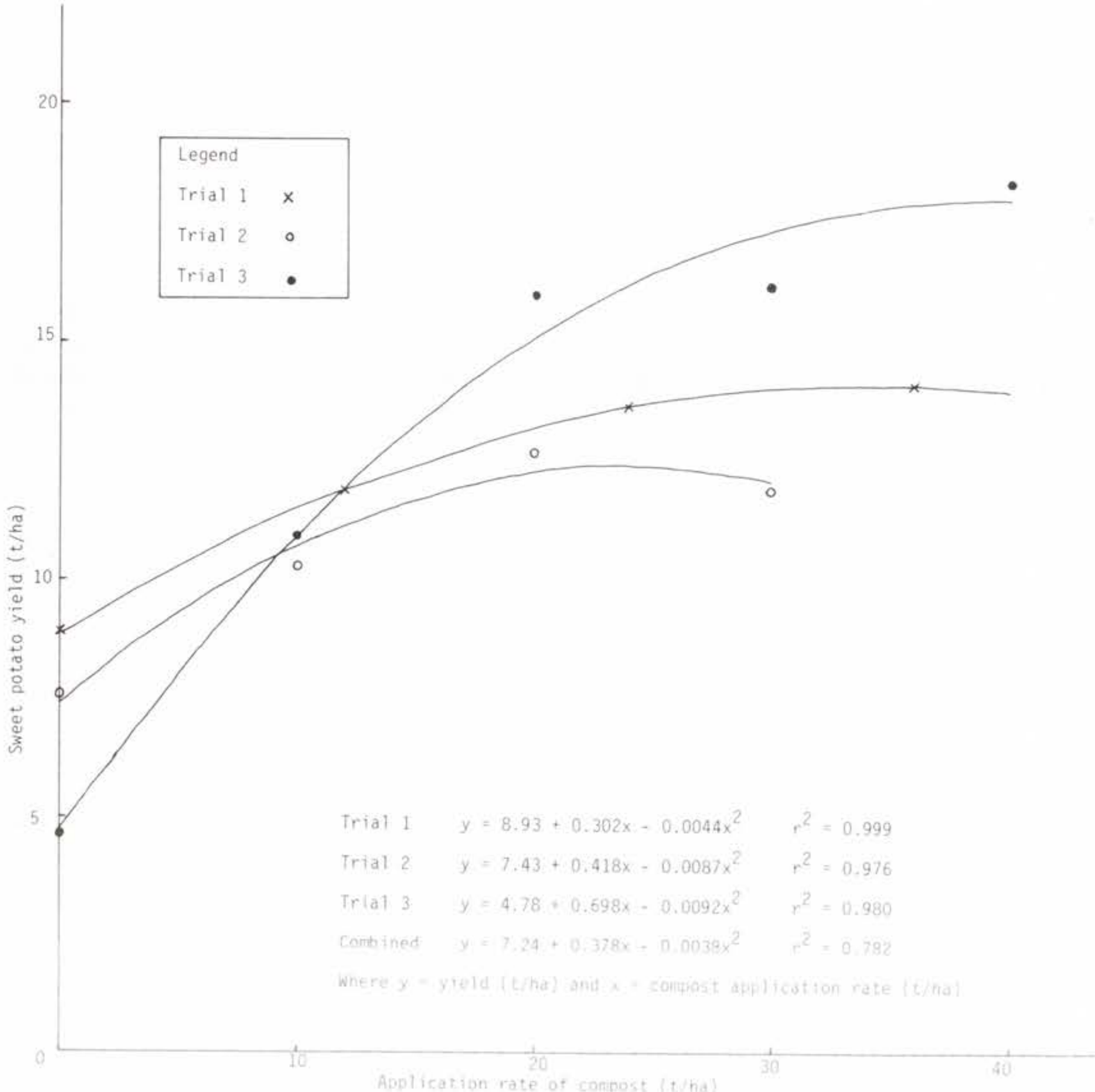

Figure 1.–**Sweet potato composting trials 1,2,3. Tuber yield (t/ha) vs application rate of fresh compost (t/ha)**

SERIES B. SWEET POTATO *AZOLLA*, PIG MANURE AND COFFEE PULP FERTILIZERS TRIAL

Materials and methods

This trial compared three sources of organic fertilizer for sweet potato. They were *Azolla pinnata*, pig manure and Arabica coffee pulp. Trial design was a randomized block with five replicates and four treatments. Plot size was 5 m^2. The treatments were control, *Azolla pinnata* at 30 t/ha, pig manure at 20 t/ha and coffee pulp at 30 t/ha. Average N, P and K composition of the organic fertilizers are given in *Table 3* and the application rate of these nutrients is presented in *Table 4*.

All of the organic fertilizers were applied as fresh material and were collected locally. Traditional rectangular mounds 50 cm high were constructed that ensured deep placement of the organic material. The local cultivar Sumbil was used. Terminal cuttings 30 cm in length were planted at a density of 22,500 cuttings per hectare.

A partial tuber harvest was made 24 weeks after planting and a final harvest at 42 weeks to simulate the local method of progressive harvesting. Recordings were made of marketable tuber yield (tubers heavier than 100 g) and total tuber yield at both harvests. Top growth yield was recorded at the second harvest. Rainfall during the crop life was 1920 mm.

Results

Marketable and total tuber yields and top growth showed a significant response to pig manure and coffee pulp (*Table 4*). Tuber and top growth yield in the *Azolla* treatment was not significantly greater than the control.

Regressions derived between the total tuber yield and top growth yield and the quantity of the major nutrients supplied in the organic fertilizer show a significant relationship between the rate of K applied and the tuber and top growth yields. The relationship was linear in the case of tuber yield (*Figure 2*) and quadratic for top growth (*Figure 3*). The quantity of nitrogen and phosphate applied in the organic fertilizers was not correlated with tuber yield. This suggests that the major effect from the organic fertilizers was from the potash contained in them.

Table 3. Average moisture and major nutrient contents of three organic fertilizers (dry weight basis)

Organic fertilizer	Moisture percentage	N (%)	P (%)	K (%)	Data source (1)
Azolla pinnata	90	2.32	0.16	1.0	(2)
Pig manure	79	2.70	1.52	1.89	(3)
Arabica coffee pulp	87	1.88	0.14	3.57	(4)

Notes: (1) The composition of organic fertilizers is dependent on the diet of the animals producing the manure or the nutritional status of plant material used. The material for analysis came from different locations and was analysed in different laboratories. For these reasons, the average compositions quoted are approximations only.
(2) Analysis done by University of Technology from sample collected at Aiyura.
(3) Average of three values given by FAO (1977) and Loehr (1974).
(4) Average of three values given by Barrie (1967), Hart (1960) and B.F. Siki, (unpublished data).

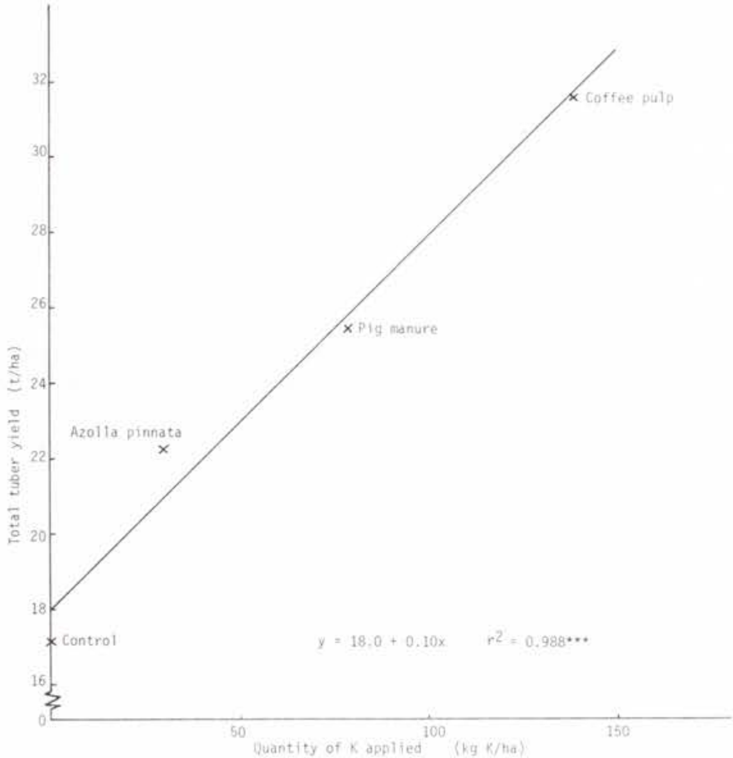

Figure 2.–**Sweet potato organic fertilizer trial. Total tuber yield (t/ha) vs quantity of potash applied in various fertilizers**

SERIES C. TARO *AZOLLA* FERTILIZER TRIAL

The objective of this trial was to assess the effectiveness of *Azolla pinnata* as an organic fertilizer on taro (*Colocasia esculenta* (L.) Schott.). The trial was located in a specific land type, a flooded limestone depression (doline). Thus any recommendation from the trial would be specifically for this land type which is common on the Plateau.

Materials and methods

An existing doline pond containing a dense cover of *Azolla pinnata* was carefully drained enabling the *Azolla* to settle on the pond floor. This natural seeding rate was measured at 30 t/ha of *Azolla* as fresh material. The soil in the doline was a heavy clay. A randomized block design was used with four replicates. Plot size was 5 m^2. Treatments were:

1. control (removal of *Azolla* from the surface); no soil cultivation
2. removal of *Azolla*; soil cultivated by spade to a depth of 25 cm
3. *Azolla* left on the surface; no soil cultivation
4. soil cultivated to 25 cm and *Azolla* incorporated into the soil.

After the pond was drained, the *Azolla* was left on the soil surface for two weeks and the treatments were applied. The experiment was then planted with setts of a local taro cultivar, Daylakae, at a density of 24,000 setts/ha. This is said to be a wetland cultivar. The crop was harvested at

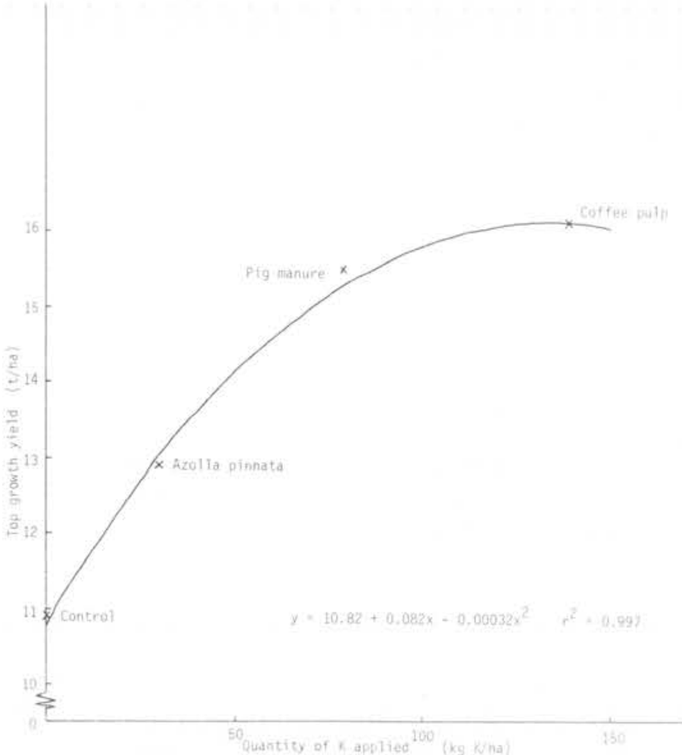

Figure 3.–**Sweet potato organic fertilizer trial. Top growth yield (t/ha) vs quantity of potash applied in various fertilizers**

nine months after planting. Corms were cleaned to edible portions before the yield was recorded.

Results

At this altitude, taro normally matures at 11 to 12 months. The early harvest was necessitated because of a number of disease and pest problems which did considerable damage to the crop, including a fungal attack suspected to be due to *Phyllosticta colocasiophila* Weedon, and infection by dasheen mosaic virus (D.P.I. Plant Pathology section, pers. comm.). Minor damage by taro beetle (*Papuana* spp) was observed at harvest.

The mean corm yield in the trial was 7.5 t/ha. There were no significant differences between treatments (*Table 5*). Nor were there visible differences in petiole and leaf dimensions between treatments during the crop's growth.

DISCUSSION

Compost

Compost made from freshly cut grass increased sweet potato yields in all three trials (*Table 2*). Its usefulness as an organic fertilizer is clearly indicated by these trials.

In order to calculate the optimum economic application rate of compost, it is necessary to know the 'cost' of gathering and transporting the organic material for the compost. At Aiyura, in an observation of labour inputs, 4.5 man-days were needed to cut and transport one tonne of fresh grass about

Table 4.– **Sweet potato organic fertilizer trial: application rate; N, P, K content of three organic fertilizers, marketable tuber yields, total tuber yields and top growth yields**

Organic fertilizer	Applic. rate (t/ha)	Nutrients applied N (kg/ha)	P (kg/ha)	K (kg/ha)	Yield Marketable tubers (t/ha)	Total tubers (t/ha)	Top growth (t/ha)
Control	–	0	0	0	16.4	17.1	10.9
Azolla pinnata	30	70	5	30	21.2	22.2	12.9
Pig manure	20	113	64	79	24.4	25.4	15.5
Coffee pulp	30	73	5	139	30.8	31.5	16.1
Level of significance					**	**	***
L.S.D. (0.05)					6.76	6.82	2.31
C.V. (%)					21	21	12

Table 5.– **Effect of *Azolla pinnata* (at 30 t/ha) and soil cultivation on taro yield**

Treatment	Yield edible corm (t/ha)
1. Control (*Azolla* removed)	8.3
2. *Azolla* removed; soil cultivated	6.9
3. *Azolla* left on soil surface; no cultivation	7.8
4. Soil cultivated and *Azolla* incorporated	7.0
Level of significance	n.s
L.S.D. (0.05)	2.55
C.V. (%)	21

100 metres. Wohlt (1978, pp. 131, 430 and pers. comm.) found in the Kandep area that about 33 woman-hours are required to gather and transport a tonne of organic matter for composting sweet potato mounds. This is about 4.2 woman-days/tonne. If a shadow value for people's labour is placed at K2 per day, compost 'costs' K9 per tonne. Our market survey data in 1979 to 1981 indicate that sweet potato is valued at about K70 per tonne (7 toea/kg) on the Plateau. These figures and the combined quadratic equation for the three trials (*Figure 1*) indicate that the optimum economic application rate of fresh organic matter is 33 t/ha.

There are two reasons why this economic optimum should not be recommended. Firstly, this calculation is strongly influenced by the very marked response in Trial 3. The lower response in the other two trials, which agree closely with each other, would indicate a lower optimum. Secondly, the use of an optimum economic application rate is only applicable if all of a grower's crop is to be treated with compost. In the Nembi Plateau situation, it is more likely that only part of the crop would receive compost in early stages of adoption. In this situation, it is better to apply compost at a lower rate as the tuber response is greater per tonne of compost applied at a lower rate. Accordingly we recommend an application rate of 20 t/ha, comparable with the application rate being used in the nearby Enga Province.

Azolla

Azolla gave a non-significant increase in tuber and top growth yield of sweet potato (*Table 4*). It has no effect on taro yield (*Table 5*), though the yield potential may have been reduced by disease problems. Judging from the excellent initial growth of the taro crop, the site was inherently very fertile. It is possible that *Azolla* may have increased taro yields in all plots in this trial as the *Azolla* had been growing in the doline for many months before the trial.

Azolla grows only on a limited number of natural ponds, which restricts its potential as an organic fertilizer. Because of difficulties in transporting *Azolla* to gardens, any possible usage is likely to be restricted to locations near these ponds. These include taro and mixed vegetable gardens in or near dolines. *Azolla* is moderately rich in nitrogen on a dry weight basis (*Table 3*). It is thus more likely to be useful for crops that have a high requirement for N, such as taro or leafy green vegetables.

In the two trials in which it has been tested so far, *Azolla* has not been shown to have much potential as an organic fertilizer. However, it should be tested further, especially on crops that are grown in or near flooded dolines.

Pig manure

Pig manure increased sweet potato tuber and top growth yield (*Table 4*) confirming results obtained by Kimber (1982) in the Eastern Highlands. We calculate that there is sufficient pig manure available on the Plateau to fertilize 115 m^2 of sweet potato garden for every person. This is derived from the following data and assumptions: there is a pig to person ratio of 0.77:1 for the Puit clan (Bourke 1984); each pig produces 1000 kg of manure per year (A. Campbell and G. Malynicz, pers. comm.); 30 per cent of available pig manure can be recovered; pig manure is applied to sweet potato at a rate of 20 t per ha per year. The mean area of sweet potato cultivated per person is ca 400 m^2 per year (D'Souza and Bourke 1984). Hence a large proportion of the cultivated sweet potato could be fertilized by the available pig manure.

The disadvantage of pig manure as a fertilizer for sweet potato is that it is high in nitrogen and phosphate but only moderately rich in potassium (*Table 3*). Sweet potato has a high requirement for K, a lesser requirement for N and a low requirement for P (Tsuno, no date), and Plateau soils are deficient in potash for sweet potato, but nitrogen and phosphate levels are adequate (D'Souza and Bourke 1986).

The available pig manure may be better utilized by applying it to a crop with a high requirement for nitrogen and phosphate, such as corn. The corn could be grown in rotation with sweet potato to maintain the sweet potato yields. A demonstration plot of corn followed by sweet potato gave support to this concept. Pig manure was applied to corn at a rate of 22 t/ha. A control plot yielded 3.0 t/ha of corn whilst the fertilized plot yielded 5.2 t/ha. In the subsequent sweet potato crop, the plot that had previously received pig manure yielded 11.0 t/ha of tubers compared with the control plot yield of 4.5 t/ha. See *Plate I*.

Highlanders are said to have an aversion to pig manure which could preclude its use as a fertilizer for food crops. We observed however that village people stole tubers from our demonstration plots which they knew had

Plate I.– **Corn fertilized with pig manure (left of figure) and unfertilized (right) on the Nembi Plateau. Pig manure increased the yield of corn and a subsequent sweet potato crop**

been fertilized with pig manure.

Further research is needed to examine the technical and social possibilities of using pig manure to fertilize sweet potato, either directly, or indirectly by fertilizing another crop grown in rotation with the sweet potato.

Coffee pulp

Coffee pulp applied to sweet potato at 30 t/ha gave the greatest increase in yield of all the organic fertilizers tested (*Table 4*), a result which confirms large responses by sweet potato to coffee pulp at Aiyura (Siki, in preparation). The nutrient composition of coffee pulp makes it an ideal fertilizer for sweet potato as it is rich in potash, moderately rich in nitrogen and low in phosphate (*Table 3*).

The potential of coffee pulp as a fertilizer on the Plateau is limited by the small quantities available. We calculate that only 11 kg of coffee pulp is available per person per year. This is calculated from the following data and assumptions: there is 0.0034 ha of coffee per person amongst Puit clan members (Bourke 1984); coffee yields 1140 kg/ha of parchment (Anderson 1977); the parchment to cherry ratio is 1:5.5 and the pulp to cherry ratio is 1:2. At a fertilization rate of 30 t/ha, this amount of pulp would fertilize only 4 m^2 of sweet potato per person per year. This is only about 1% of the area of sweet potato needed to support each person for a year.

All available coffee pulp on the Plateau should be used to fertilize sweet potato gardens. If there are no sweet potato gardens located near the site of pulping, the pulp should be used on other crops, such as vegetables or bananas.

Effect of various organic fertilizers

Organic fertilizers with differing nutrient content were compared in the sweet potato organic fertilizer trial (Series B) to investigate which nutrients were most effective in increasing sweet potato yield. Responses cannot be definitely attributed to individual nutrients as each organic fertilizer contains a number of nutrients. Other benefits from the organic fertilizer, such as improved soil aeration, may also be influential.

Nevertheless, the very high correlations between the levels of potash applied in the various organic fertilizers and tuber and top growth yields suggest that the responses were due mainly to potash applied in the organic matter (*Figures 2* and *3*). *Figure 2* suggests that potash rates higher than the 140 kg K/ha applied in the coffee pulp treatment would give additional yield increases. This is consistent with results from the sweet potato inorganic fertilizer trial (D'Souza and Bourke 1986).

CONCLUSIONS

Compost, pig manure and coffee pulp have been shown to increase sweet potato yields. The technique of composting sweet potato gardens should be promoted on the Plateau. Fresh organic matter should be applied at a rate of 20 t/ha. All available coffee pulp should be used to fertilize sweet potato gardens or other crops.

Pig manure is likely to have an important role in improving crop yields, as it is available in large quantities in the villages. Further research is needed to identify its place in improved farming systems. A likely role may be as a fertilizer for non-root crops, particularly in mixed vegetable gardens, which are grown in rotation with sweet potato.

Azolla pinnata has not been shown to be a useful organic fertilizer, but further experimentation is needed before it can be dismissed because it may have a role where there are flooded dolines.

REFERENCES

ALLEN, B.J. (1984). Agricultural and nutritional studies on the Nembi Plateau, Southern Highlands. *Department of Geography Occasional Paper No. 4*. University of Papua New Guinea and Southern Highlands Rural Development Project.

ANDERSON, D. (1977). An economic survey of smallholder coffee producers – 1976. Department of Primary Industry, Port Moresby.

BARRIE, J.W. (1967). Fertilizer value of coffee pulp. *South Pacific Planter*, 1(9): 3–4, 8.

BOURKE, R.M. (1984). Systems of agriculture. In Allen (1984) pp. 55–67.

D'SOUZA, E. and BOURKE, R.M. (1982). Compost increases sweet potato yields in the highlands. *Harvest*, 8(4): 171–175.

D'SOUZA, E. and BOURKE, R.M. (1984). The subsistence agriculture research project. In Allen (1984) pp. 101–111.

D'SOUZA, E. and BOURKE, R.M. (1986). Intensification of subsistence agriculture on the Nembi Plateau, Papua New Guinea. 1. General introduction and inorganic fertilizer trials. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries*, 34: 19–28.

FAO (1977). China: Recycling of organic wastes in agriculture. *FAO Soils Bulletin*, 40:4, 27, 29–40.

HART, G. (1960). Coffee nutrition – Part II. Plantation survey. *Papua New Guinea Agricultural Journal*, 18: 69–75.

KIMBER, A.J. (1982). The effect of pig manure on sweet potato yields. *Harvest*, 8(2): 81–82.

LOEHR, R.C. (1974). *Agricultural Waste Management Problems. Processes and Approaches.* Academic Press, New York and London, pp. 528–554.

TSUNO, Y. (no date). *Sweet Potato. Nutrient Physiology and Cultivation.* International Potash Institute, Berne.

WADDELL, E. (1972). *The Mound Builders. Agricultural Practices, Environment, and Society in the Central Highlands of New Guinea.* University of Washington Press, Seattle.

WOHLT, P.B. (1978). Ecology, agriculture and social organization: the dynamics of group composition in the highlands of Papua New Guinea. Unpublished Ph.D. dissertation, University of Minnesota.