Integrated nutrient management research with sweet potato in Papua New Guinea

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Abstract: *This paper summarizes a series of field experiments that investigated the effects of organic and inorganic nutrients on sweet potato tuber yield in the humid lowlands of Papua New Guinea. In the first experiment, plots were planted with Piper aduncum, Gliricidia sepium and Imperata cylindrica, which were slashed after one year, whereafter sweet potato was planted. Sweet potato yield was lowest after Gliricidia fallow, but no yield differences were found after piper and imperata fallow. In the second season, there was no significant difference in sweet potato yields. The second experiment consisted of a factorial fertilizer trial with four levels of N (0, 50, 100, 150 kg ha*$^{-1}$*) and two levels of K (0, 50 kg ha*$^{-1}$*). Nitrogen fertilizers increased yield in the first season, but depressed tuber yields in the second and third seasons. Potassium fertilizer had no effect on marketable tuber yield. The third experiment consisted of a comparison between N from inorganic fertilizer and poultry litter at four rates (0, 50, 100, 150 kg ha*$^{-1}$*). No difference was found between the inorganic fertilizer and poultry litter, and the highest yields were found at 100 kg N ha*$^{-1}$*. In the second season no significant response was observed. Although yield variation was considerable, this series of experiments has shown that sweet potato yield can be significantly increased by inorganic or organic N applications. Sweet potato yields after fallows were less variable than after inorganic nutrient inputs. Inputs of inorganic fertilizer or poultry litter may strongly increase or decrease tuber yields.*

Keywords: *sweet potato; fertilizers; poultry litter; inproved fallow; natural fallow*

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Up to the 1980s it was widely perceived that inorganic fertilizers would be a viable option to increase land productivity in the low-fertility soils of the humid tropics. Organic fertilizers (eg compost, farmyard manure) were regarded as important, but it was realized that organic fertilizers would not be available in sufficient amounts to increase food production drastically. In the early 1980s, various reports showed that use of inorganic fertilizers in the tropics had stagnated, and this was explained by poor marketing and inadequate profitability from inorganic fertilizer use (Hartemink, 2002). From then on, integrated nutrient management was advocated: this essentially means the combination of both inorganic and organic fertilizers to increase crop production (Janssen, 1993).

This paper reviews integrated nutrient management research with sweet potato (*Ipomoea batatas* L.) in the humid lowlands of Papua New Guinea. Sweet potato is the main staple crop in many parts of Papua New Guinea, but the number of detailed integrated nutrient management experiments with sweet potato is limited (Hartemink and Bourke, 2000). Most nutrient management experiments have been conducted on experimental stations and little work has been done in farmers' fields. This is particularly unfortunate as poor crop nutrition contributes to the low yield of root crops of many farmers in Papua New Guinea and throughout the Pacific region (Halavatau *et al*, 1998).

The research reported in this paper took place on-farm at Hobu (6°34′S, 147°02′E), which is about 15 km north of the Papua New Guinea University of Technology in Lae. The experimental site was in farmers' fields, but all field operations (planting, weeding, harvesting, etc) were managed by the researchers. The experiments were conducted between November 1996 and December 1998. Three sets of experiments were conducted: (i) fallow experiment with both natural and improved fallows; (ii) inorganic fertilizer experiments with N and K; and (iii) poultry litter experiments. The main aim of the experiments was to assess the effects of different nutrient inputs on sweet potato yield.

Environmental conditions at the experiment site

Hobu is in the foothills of the Saruwaged mountain range, which forms the major land mass of the Huon peninsula. The experiment site is located on an uplifted alluvial terrace at an altitude of 405 m above sea level (asl) with slopes of less than 2%. Soils are derived from a mixture of alluvial and colluvial deposits dominated by sedimentary rocks and coarse to medium grained, basic, igneous rocks. The soils are layered with water-worn gravelly and stony horizons below 0.2 m depth; effective rooting depth is over 0.7 m. Air-dried and sieved (<2 mm) soil from the top 0.12 m had the following properties: pH = 6.2, organic C = 55 g kg^{-1}, available P (Olsen) = 9 mg kg^{-1}, CEC = 400 mmol$_c$ kg^{-1}, exchangeable Ca = 248 mmol$_c$ kg^{-1}, exchangeable Mg = 78 mmol$_c$ kg^{-1}, exchangeable K = 16.9 mmol$_c$ kg^{-1}, clay = 480 g kg^{-1} and sand = 360 g kg^{-1}, bulk density = 0.82 Mg m^{-3}. Further details can be found in Hartemink *et al* (2000b). The soils are classified as mixed, isohyperthermic, Typic Eutropepts (USDA Soil Taxonomy) or Eutric Cambisols (World Reference Base). Inceptisols (Eutropepts) are the commonest soils in Papua New Guinea and are estimated to cover approximately 40% of the country (Bleeker, 1983). In the Hobu area, Sayok and Hartemink (1998) showed that erosion under sweet potato on a 58% slope was less than 4 mg ha^{-1} y^{-1}, which is a very low erosion rate. The site for the experiments described in this paper had a slope of less than 2% and erosion was therefore not a problem. Figure 1 shows an aerial view of the experiments.

In 1997, there was a total rainfall of 1,897 mm, which is below the long-term average, due to the El Niño/Southern Oscillation climatic event, which hit the Pacific severely in 1997–98. In the first six months of 1998, more rain fell than in the whole of 1997. March 1998 was a particularly wet month with 725 mm of rain. At the University of Technology total rainfall in 1997 was only 2,594 mm, compared with the long-term (20-year) annual mean of 3,789 mm. Temperature data are not available for the site, but average daily temperatures at the University of Technology are 26.3°C. Since the University is at a lower altitude (65 m asl) temperatures at the experiment site are probably slightly lower on average.

An area of about 0.5 ha of secondary vegetation was slashed manually at the beginning of November 1996. The vegetation consisted mainly of *Piper aduncum* L., and to a lesser extent of *Homolanthus* sp., *Macaranga* sp., *Trichospermum* sp. and *Trema orientalis* (Rogers and Hartemink, 2000). The site had been intensively used for growing food crops, but had been fallow since 1992. All vegetation debris was removed and no burning was practised, following the land-clearing practices of local farmers.

Figure 1. Aerial view of integrated nutrient management experiments in the humid lowlands.

(1) Experiments with natural and improved fallows

Shifting cultivation systems, with cropping periods alternating with short fallow periods, are still widely used in the humid lowlands of Papua New Guinea. Very little is known about nutrient cycling in these shifting cultivation systems. The particular effects of the addition of nutrients by the secondary fallow vegetation and subsequently on sweet potato yield are largely unknown.

The secondary fallow vegetation in many parts of the lowlands is dominated by *Piper aduncum* (L.), which is a shrub indigenous to tropical America (Hartemink, 2001). It is not known how and when *Piper aduncum* arrived in Papua New Guinea, but it was first described in Morobe province in 1935. In the standard work on New Guinea vegetation by Paijmans (1976), *Piper aduncum* (hereafter referred to as piper) is not mentioned as a separate species. This is hard to imagine nowadays, as in many parts of the humid lowlands piper forms monospecific stands. In Morobe province it occurs at altitudes up to 600 m asl, but is also found in the highlands up to altitudes of 1,900 m asl. It grows very rapidly, but there is virtually no undergrowth of weeds or shade-tolerant tree species. Despite this lack of undergrowth, severe erosion under piper has not been observed in Papua New Guinea.

Farmers in the Hobu area usually have short-term piper fallows (<2 years) followed by one crop of taro, gradually intercropped with sweet potato, sugar cane (*Saccharum* sp.) and bananas (*Musa* sp.). The length of the fallow period has, however, been reduced due to the need for increased food and cash crop production to keep up with the growing population (Allen *et al*, 1995; Freyne and McAlpine, 1987). Farmers claim that piper arrived in the

Hobu area in the early 1970s. In this area, the secondary fallow vegetation is dominated by piper, but *Imperata cylindrica* grassland is also common.

Although the aggressive invasion of piper has been described, including its possible effect on Papua New Guinea's rich biodiversity (Rogers and Hartemink, 2000), there is no information available on the effect of piper fallows on soil and crop productivity. For example, it is not known whether piper fallows are more productive than other natural fallows such as *Imperata cylindrica* grasslands (hereafter referred to as imperata). With the reduction in the length of the fallow period there may be a need to introduce fallow species that improve soil fertility more rapidly than natural fallows (Young, 1997). *Gliricidia sepium* (hereafter referred to as gliricidia) is in some parts of the world planted as an 'improved fallow' and is one of the most widely cultivated multipurpose trees (Simons and Stewart, 1994). In the Papua New Guinea lowlands it is used as a shade tree in cocoa plantations.

Experiment set-up

Sixteen plots, each 6.0 by 6.0 m, were laid out and four treatments were assigned to the plots in a randomized complete block design. At the end of November 1996, the fallow plots were planted. Four plots were planted with seedlings (0.4 m) of piper obtained from a nearby roadside, and four with gliricidia cuttings (0.4 m) obtained from a nearby cocoa plantation. Piper and gliricidia fallows were planted at distances of 0.75 by 0.75 m (17,778 plants ha^{-1}). These spacings are often observed in natural piper fallows (Hartemink and O'Sullivan, 2001). In four plots the vegetation consisted of natural regrowth, which was immediately dominated by *Imperata cylindrica* (see Figure 2). Some minor weeds in the imperata fallow were *Ageratum conyzoides, Sphaerostepanos unitus, Rottboellia exalta, Sida rhombifolia, Polygala paniculata, Euphorbia hirta* and *Emilia sonchifolia*.

Sweet potato – local cultivar, Hobu1 (Guaf, 1997) – was planted in the remaining four plots. Hobu1 is a widely grown cultivar with red skin tubers and white flesh. It appears not to be very susceptible to sweet potato weevils, an important pest of sweet potato in Papua New Guinea (Bourke, 1985b; Powell *et al*, 2001). Planting material was obtained from local gardens and consisted of vine cuttings, which were planted almost vertically in the soil using a stick. One cutting of about 0.4 m length with four to six nodes was planted per hole, which generally gives the highest tuber yield (Levett, 1993). Planting distance was 0.75 by 0.75 m (17,778 plants ha^{-1}). The plots were continuously cultivated for four seasons.

After one year (20–24 November 1997), all fallow vegetation was cut at ground level. Piper plants were separated into stems, branches, leaves and litter; gliricidia plants into stems, leaves and litter; and for the imperata fallow, total biomass was taken as there was virtually no litter. In each plot, the total fresh matter was weighed for each of the different plant parts and samples were taken for dry matter determination and nutrient analysis. Piper and gliricidia stems were removed from the plots; all other plant parts were applied as surface mulch after weighing. On 26 November 1997, the previously fallow plots were planted with sweet potato, as for the continuously cultivated plots. The previously fallow plots were not tilled when planted, and they were cropped with sweet potato for two seasons.

Figure 2. Experiment with fallows: *Piper aduncum, Gliricidia sepium* and *Imperata cylindrica.*
Note: These were grown for one year, slashed, and sweet potato planted.

The sweet potato cropping seasons lasted about 170 days, whereafter the plots were harvested. Vines were cut at ground level, weighed, and removed from the plot. Vines are also removed in farmers' gardens (perhaps to avoid allelopathic effects), which alters nutrient uptake (Walker et *al*, 1989). Tubers were manually dug, counted and separated into marketable tubers (>100 g) and non-marketable tubers (<100 g); these were also removed from the plot. All plots were replanted directly after harvest. Weeds were pulled out manually but not removed from the plot. No pesticides were used in the experiments. Figure 3 shows the daily rainfall during the period of the experiment and during each of the four seasons.

Nutrient input and sweet potato yield after the fallows

The nutrient return from the one-year-old fallows is presented in the left-hand columns of Table 1. Nitrogen returned to the field with gliricidia leaves and litter was 192 kg ha^{-1}, compared with 97 kg N ha^{-1} for piper and 76 kg N ha^{-1} for imperata. The amount of P returned with the fallow vegetation was similar for all three fallows, at around 12 to 14 kg ha^{-1}. Piper returned 206 kg K ha^{-1} compared with 89 kg K ha^{-1} from gliricidia and imperata.

In the first season after the fallow, marketable sweet potato yield after piper and imperata was about 11 mg ha^{-1}, and significantly higher than under continuous sweet potato or after gliricidia fallow (Table 1). Marketable yield under continuous sweet potato cultivation was 7.8 Mg ha^{-1}. Variation in non-marketable tuber yield after the fallows was large and differences were not statistically significant. Total tuber yield (marketable plus non-marketable tubers) was highest after piper (14.4 Mg ha^{-1}) and significantly lower after gliricidia fallow (9.9 Mg ha^{-1}). Vine yield was similar under continuous sweet potato cultivation and after piper and gliricidia fallow, but significantly lower after the imperata fallow, which produced about 10 Mg ha^{-1} fewer sweet potato vines.

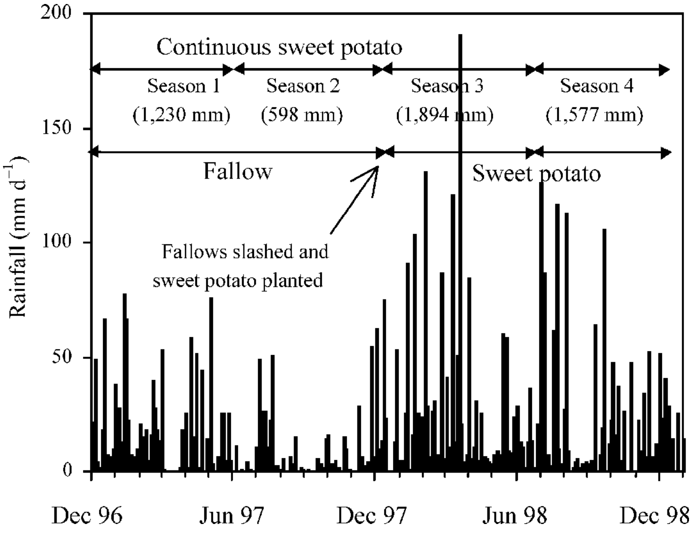

Figure 3. Daily rainfall (mm) at site during fallow experiment. Total rainfall during each of the four seasons is given in parentheses.

In the second season there was no fallow effect on marketable sweet potato yield. Non-marketable tuber yield was, however, significantly lower in the previous imperata plots, but no differences were found in the other treatments. Vine yield from imperata plots was statistically comparable with previous fallow treatments. Total tuber yield in the second season was similar for all treatments. Cumulative tuber yield over the two seasons was about 29 Mg ha^{-1} for piper and imperata, but less than 25 Mg ha^{-1} in the continuous sweet potato plots. Cumulative vine yield over the two seasons was between 53 and 60 Mg ha^{-1} for continuous sweet potato and previous gliricidia and piper plots, but was less than 40 Mg ha^{-1} in the former imperata plots.

(2) Inorganic fertilizer experiments

There is fair a body of literature on the use of inorganic fertilizers on sweet potato, although the information is limited compared with that for other staple crops in the tropics, such as rice and maize. Sweet potato consumes considerable amounts of K, and responses to K fertilizers are generally recorded (de Geus, 1973). Sweet potato has high N requirements, but can produce reasonable yields in soils of poor fertility (Hill *et al*, 1990). This may be partly caused by its capacity to fix atmospheric N through association with symbiotic, non-nodulating bacteria. Estimates have shown that as much as 40% of the N uptake of sweet potato may be derived from di-nitrogen (Yoneyama *et al*, 1998), although cultivar differences are large. A very wide range of N fertilizer requirements has been reported for sweet potato (Hill, 1984), but much depends on the cultivar, soil type and climatic conditions (O'Sullivan *et al*, 1997).

In Papua New Guinea, various inorganic fertilizer experiments have been conducted since the 1950s. Bourke (1977) summarized 17 field trials and 6 pot trials conducted on volcanic ash soils in Kerevat, and found that N and K were generally needed. Nitrogen increased vine yield, but N responses to tuber yield were inconsistent. Potassium fertilizer had no effect on vine yield, but K increased tuber yield and the number of tubers. Somewhat similar findings have been reported by Hartemink *et al* (2000a) working on alluvial soils near Lae. Floyd *et al* (1988) also working on volcanic ash soils, showed that P and K applied as organic manure gave better responses than inorganic fertilizers. Overall the literature seems to suggest that sweet potato in Papua New Guinea responds inconsistently to inorganic fertilizers.

Experiment set-up

The inorganic fertilizer experiment at Hobu was laid out as a randomized block design with four levels of N (0, 50, 100, 150 kg ha^{-1}) and two levels of K (0, 50 kg ha^{-1}) in a factorial combination. Each treatment was replicated four times and plot size was 4.5 by 4.5 m. The experiment lasted for three consecutive seasons. Throughout this experiment the sweet potato cv Hobu1 was again used. During the experiment weeds were pulled out manually and not removed from the plot. No pesticides were used.

Potassium fertilizer was broadcasted directly after planting. Nitrogen fertilizer was given in split application: 50 kg ha^{-1} was given at planting; 50 kg ha^{-1} was given 59 days after planting (DAP) to the 100 kg ha^{-1} treatment. The 150 kg N ha^{-1} treatment received another 50 kg ha^{-1} at 80 DAP. At harvest, vines were cut at ground

Table 1. Sweet potato yield for two seasons after one-year piper, gliricidia and imperata fallows, and under continuous cultivation.

				Yield in Mg ha^{-1} (fresh weight)					
	Nutrient input [1](kg ha^{-1})			*Marketable tubers*		*Non-marketable tubers*		*Vines*	
Fallow species	*N*	*P*	*K*	First season	Second season	First season	Second season	First season	Second season
Piper	97	14	206	11.2	13.4	3.1	2.1	30.4	22.9
Gliricidia	192	12	89	8.4	14.3	1.6	1.8	31.6	26.1
Imperata	76	12	89	11.3	15.2	1.5	1.1	20.7	18.9
Continuous sweet potato [2]	0	0	0	7.8	12.8	2.4	2.0	32.3	27.4
SED [3]				1.3	ns	ns	0.3	3.9	4.1

[1] Nutrients returned with the above-ground biomass when the fallows were slashed and the first season of sweet potato was planted.

[2] Yields from the third and fourth season under continuous cultivation.

[3] Standard error of the difference in means (9 df); ns = not significant ($P>0.05$).

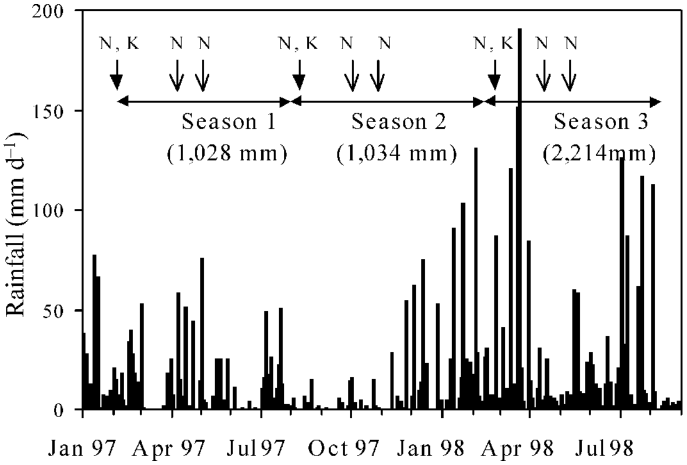

Figure 4. Daily rainfall (mm) during inorganic fertilizer experiment.
Note: Vertical arrows indicate timing of N and K fertilizer application. Total rainfall during each of the three seasons is in parentheses.

level, weighed, and removed from the plot. Tubers were manually dug, counted and separated into marketable tubers (>100 g) and non-marketable tubers (<100 g), which were also removed from the plot. Total rainfall received during the first crop was 1,028 mm. All plots were replanted directly after the harvest. Rainfall in the second season was 1,034 mm and total rainfall received in the third season was 2,214 mm. Figure 4 shows the daily rainfall during the experimental period, and for each of the three seasons.

Sweet potato yield

Sweet potato tuber yields for the three seasons are presented in Figure 5. Marketable tuber yield in the first season ranged from 18.3 to 23.8 Mg ha^{-1}, but was not affected by K fertilizer. Nitrogen fertilizer increased marketable tuber yields ($P = 0.10$) and the highest yield was obtained with 100 kg N ha^{-1}. Non-marketable tubers were significantly increased by about 1 Mg ha^{-1} due to the K fertilizer.

In the second season, N fertilizer significantly reduced marketable tuber yields. The reduction was almost linear, from about 25 Mg ha^{-1} when no fertilizer was applied to 17 Mg ha^{-1} at 150 kg N ha^{-1}. Potassium fertilizer had no significant effect on the marketable tuber yield, but increased non-marketable tuber yield.

In the third season, yield levels dropped dramatically with all treatments. Marketable tuber yield in the control plots was only 7 Mg ha^{-1} and N fertilizer significantly reduced yield by about 3 Mg ha^{-1}.

(3) Poultry litter experiments

In Papua New Guinea, various field trials with sweet potato have shown that organic fertilizers produce higher and more consistent yields than inorganic inputs, (eg D'Souza and Bourke, 1986; Floyd *et al*, 1988; Preston, 1990). Various factors could be involved such as, for example, the addition of beneficial nutrients within the organic manure that are not found in inorganic fertilizers, or the improvement of the soil physical or biological properties.

In the highlands of Papua New Guinea, compost and coffee pulp are available as organic nutrient sources for sweet potato. In the lowlands of Morobe province, poultry litter is widely available because of the many smallholders raising chickens for large commercial companies. The poultry litter (manure plus sawdust) is usually removed from the shed when the chickens are slaughtered, and dumped near the shed. It is rarely used in food gardens despite its containing many nutrients.

Igua (1985) conducted an experiment near Port Moresby with poultry litter and sweet potato, and found that the highest yields were obtained when 10 mg poultry litter ha^{-1} was applied. Higher application rates depressed sweet potato yield. No other reports are available on the effect of poultry litter on sweet potato yield in Papua New Guinea.

Experiment set-up

The poultry litter experiment consisted of four levels of N (0, 50, 100, 150 kg ha^{-1}) given as poultry litter or as inorganic fertilizer (NPK). The equivalent amount of K and P applied to the poultry litter plots was used on the inorganic fertilizer plots. The experiment was laid out as a randomized complete block design with four replicates per treatment (Figure 8). The experiment lasted for two seasons. Directly after planting, the poultry litter and inorganic fertilizer (NPK) was applied. The application of inorganic N fertilizer (sulphate of ammonia) was split. Harvesting techniques were similar to those used in the fallow and inorganic fertilizer experiments. Figure 6 shows the daily rainfall during the experiment and for the two seasons. During the first season total rainfall was 1,203 mm and 2,091 mm of rain fell in the second season.

Nutrient concentration of the poultry litter in the first season was 24.6 g N kg^{-1}, 15.7 g P kg^{-1}, 22.5 g K kg^{-1}, 30.2 g Ca kg^{-1}, and 6.4 g Mg kg^{-1}. The poultry litter contained about 84% dry matter and 362 g C kg^{-1}. Application of 50 kg N ha^{-1} corresponded to 2.4 Mg ha^{-1} fresh poultry litter. In the second season the poultry litter contained fewer nutrients: 13.0 g N kg^{-1}, 12.5 g P kg^{-1}, 10.3 g K kg^{-1}, 30.2 g Ca kg^{-1}, and 6.4 g Mg kg^{-1}. Dry matter content was 59% and application of 50 kg N ha^{-1} corresponded to 6.5 Mg ha^{-1} fresh poultry litter.

Sweet potato yield

In the first season, marketable sweet potato yield was significantly increased by poultry litter and inorganic N fertilizer (Figure 7). The yield pattern was about the same for both N sources (quadratic response) and highest yields were recorded when 100 kg N ha^{-1} was applied.

In the second season, marketable tuber yield was significantly reduced by both poultry litter and inorganic N fertilizer. Marketable tuber yields in the control plots were similar to the yields in the first season, but non-marketable tuber yield was about 10 times higher. No effect of poultry litter or inorganic fertilizer was recorded in the second season.

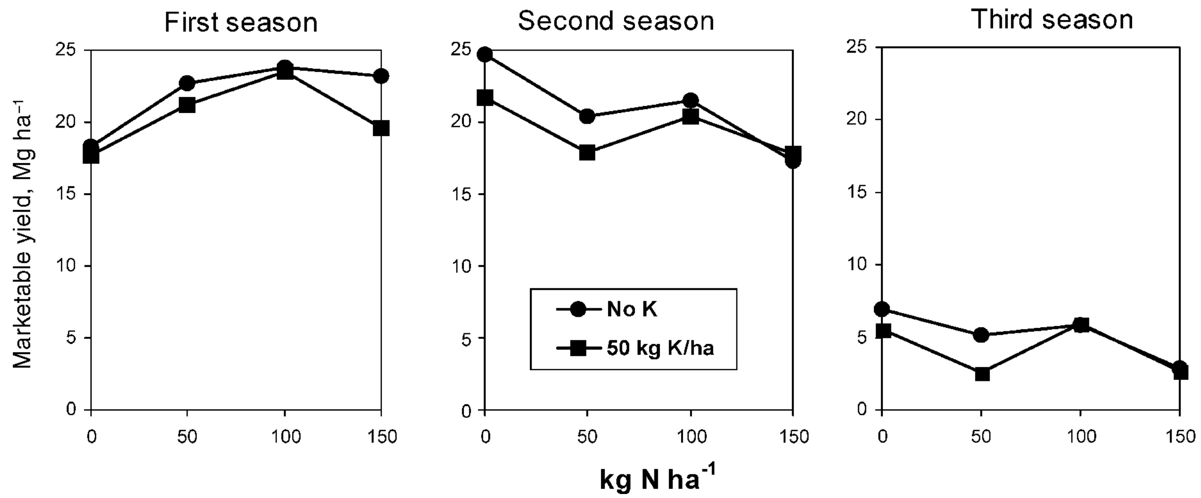

Figure 5. Marketable sweet potato tuber yields for three consecutive seasons at different rates of inorganic N and K application.

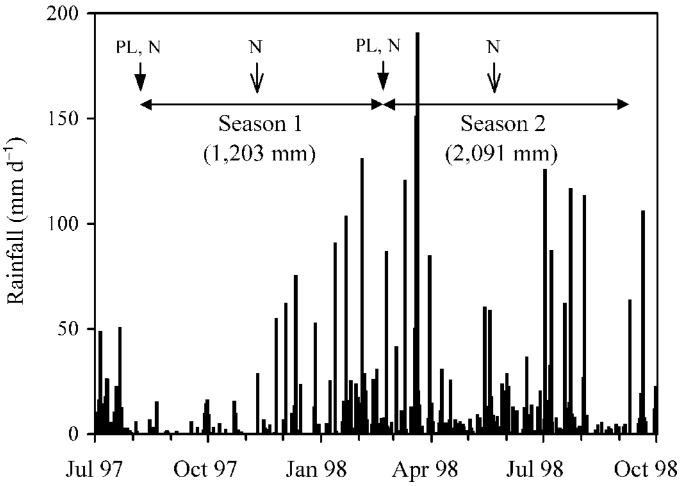

Figure 6. Daily rainfall (mm) during poultry litter experiment. *Note:* Vertical arrows indicate timing of poultry litter and fertilizer application. Total rainfall during the two seasons is in parentheses. PL = poultry litter; N = nitrogen fertilizer.

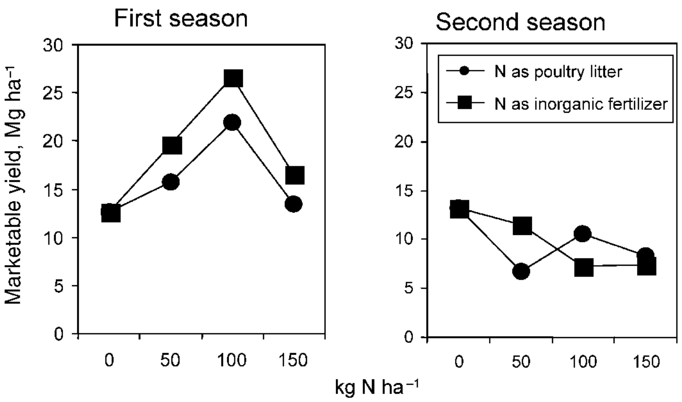

Figure 7. Marketable sweet potato yields for two consecutive seasons at different N rates given as poultry litter.

Yield variation and yield trends

Considerable yield variation was observed in all experiments; this is generally the case in field experiments with sweet potato (Hartemink *et al,* 2000b; Martin *et al,* 1988). Several factors contributed to this variation: rainfall, soil changes and the build-up of pests and diseases.

During the experiments the impression was formed that yields were generally higher in seasons with lower rainfall. Sweet potato is reported to be very sensitive to excess soil water during the first 20 days after planting when tubers are formed (Hahn and Hozyo, 1984) and a

Table 2. Correlation between rainfall, number of cropping seasons, sweet potato tuber yield and vine yield.

Site[1]		Marketable yield	Non-marketable yield	Vine yield
Hobu	Rainfall during the growing season[2]	– 0.601 **	– 0.814 ***	0.866 ***
	Number of cropping seasons [3]	– 0.556 *	– 0.622 **	0.274
Unitech	Rainfall during the growing season[2]	– 0.558 **	0.085	– 0.167
	Number of cropping seasons[3]	– 0.202	0.018	– 0.628 **

***, **, * indicates significant correlation at $p<0.001$, $p<0.01$ and $p<0.05$ respectively.

[1] Results from experiments at Hobu and the experimental farm of the University of Technology in Lae.

[2] Covariate = number of cropping seasons (ie four at Hobu and five at Unitech).

[3] Covariate = rainfall received in the season.

Source: Hartemink *et al,* 2000.

Figure 8. Sweet potato experiments with poultry litter and inorganic fertilizers in the humid lowlands.

regression analysis between marketable yield and rainfall received during the first 20 days of growth was conducted (analysis not shown). No obvious relationship was found, and instead correlation coefficients were calculated for the tuber yield, vine yield and total rainfall received in the season (Table 2). It was found that rainfall at Hobu was significantly correlated with the marketable and non-marketable tuber yield, as follows: the higher the rainfall, the lower the tuber yield (see Figure 9). Vine yield was positively correlated with rainfall, which suggests that the reduction in tuber yield in wetter seasons favours the growth of vine biomass. The number of cropping seasons at Hobu was significantly correlated with both marketable and non-marketable tuber yield, but not with the vine biomass: tuber yield declined under continuous cultivation, but vine yield was not affected. At the University of Technology (Unitech) correlations between yield, rainfall and cropping seasons were weaker. The number of cropping seasons was not correlated with tuber yield. Marketable yield was also negatively correlated with rainfall received during the cropping season.

Another major factor that may explain the variation and trends observed relates to changes in soil chemical properties as a result of continuous sweet potato cultivation. Table 3 shows soil chemical properties before the first planting and after four seasons (± 2 years) of continuous sweet potato cultivation. The topsoil pH had decreased by 0.4 units; this was accompanied by a decrease in base saturation. Bulk density was not altered in soils under continuous sweet potato cultivation. This was to be expected as harvesting sweet potato involves topsoil digging with a fork to a depth of about 0.2 m. No obvious pattern of decline was found in the leaf nutrient concentrations, but the highest concentration of all major nutrients was found in the first cropping season at Hobu (Hartemink *et al*, 2000b). A decrease in leaf nutrient concentration was expected because large amounts of nutrient are removed with the sweet potato harvest. Considerable amounts of K are removed with the tubers and vines. In Hobu it was found that sweet potato removed about 16 kg N, 7 kg P and 51 kg K ha^{-1} per 10 Mg ha^{-1} of fresh marketable tubers (Hartemink *et al*, 2000b).

Figure 9. Large sweet potato tuber after cropping period during 1997–98 El Niño.

In the fallow and inorganic fertilizer experiment, observations were made on nematodes and sweet potato weevils. Nematode counts in soil extracts from the fallow experiment showed that the juvenile population of *Meloidogyne* sp. increased with the increasing number of cropping seasons (Table 4). The increase in numbers of nematodes was significant between the first and second seasons, but the number of nematodes in soils did not differ significantly over three or four seasons. Although the species of *Meloidogyne* could not be identified with certainty, common root-knot species under sweet potato in Papua New Guinea are *Meloidogyne incognita* and *Meloidogyne javanica* (Bridge and Page, 1984).

In the fallow experiment, the above-ground population of weevils at harvest was very low for both seasons, but a considerable portion of the marketable tubers and vines was damaged (Table 5). Damaged tubers over both seasons were predominantly described as category 1, ie only superficial damage to the periderm (Sutherland, 1986). The high level of vine damage was not reflected in tuber damage.

Discussion

Sweet potato yields were higher after piper fallows than after gliricidia fallows, so there is no yield advantage in employing an improved N-fixing fallow species such as gliricidia. The low yield response after the gliricidia fallow is puzzling and yields could have been affected by the high input of N, which may decrease yield (Hill *et al*, 1990; Marti and Mills, 2002). Yields may also be affected by the allelopathic compounds found in gliricidia leaves. Reports from India have shown that applications of 4 to 12 Mg leaf mulch ha^{-1} effectively control weeds – thought to be attributable to phenolic compounds in the gliricidia mulch (Ramakoorthy and Paliwal, 1993). Alan and Barrantes (1998) showed that extracts from gliricidia leaves drastically reduced the germination of weed

Table 3. Changes in soil chemical properties under continuous sweet potato cultivation (sampling depth 0–0.15 m).

Sampling time	**pH H_2O (1:5 w/v)**	**Organic C (g kg^{-1})**	**Total N (g kg^{-1})**	**Olsen P (mg kg^{-1})**	**CEC pH7 (mmol$_c$ kg^{-1})**	**Exchangeable cations (mmol$_c$ kg^{-1})**			**Base saturation (%)**
						Ca	*Mg*	*K*	
Before planting	6.2	69.9	6.0	10	405	268	61	12.2	84
After four seasons	5.8	71.3	5.9	6	466	227	59	8.4	63
Difference	$p<0.01$	ns	ns	ns	$p<0.01$	ns	ns	ns	$p<0.001$

Note: Data from fallow experiment; values are the arithmetic mean of four plots.
Source: partly from Hartemink *et al*, 2000.

Table 4. Nematode counts (number per 200 mL ±1 SD) in soils under sweet potato.

Hobu			**Unitech**		
Cropping season	*Sampled plots*	*Nematodes*[1]	*Cropping season*	*Sampled plots*	*Nematodes*[2]
1	12	65 ±52	4	4	1795 ±329
3	4	211 ±73	5	4	1208 ±250
4	4	157 ±52			

[1] Root-knot nematodes (*Meloidogyne* sp.).
[2] Reniform nematodes (*Rotylenchulus reniformis*).
Source: Hartemink *et al*, 2000b.

species including *Ipomoea* sp. in Costa Rica. It is hard to estimate whether allelopathic effects influenced the sweet potato yield in our experiment, although the polyphenolic content of gliricidia leaves was indeed much higher than that of piper or imperata (Hartemink and O'Sullivan, 2001).

The gliricidia fallow produced three times more wood, which is of advantage in the lowland areas where firewood is scarce. The greater biomass of gliricidia could be due to the fact that gliricidia is better at scavenging the limited nutrients than piper. It is likely that piper suffered from too little water due to the El Niño drought (see Figure 3) as piper grows faster in wetter periods (Hartemink, 2001). Piper significantly reduced soil moisture, which is of advantage in wet seasons, as Hartemink *et al* (2000b) have shown for sweet potato yields, which were significantly reduced in wetter seasons regardless of the cropping history of the soil (see also Table 5).

Sweet potato tuber yields after imperata fallow were comparable with those after the woody fallows, ie piper and gliricidia. However, imperata biomass returned less N to the soil, and vine biomass was lower due to the slow decomposition of the biomass and the N immobilization (Hartemink and O'Sullivan, 2001). The reduced vine yield after the imperata fallow did not result in higher tuber yield, even though vine and tuber yields are often inversely related (Enyi, 1977). A significant yield reduction in sweet potato when more than 10 Mg ha^{-1} was applied was found by Kamara and Lahai (1997). The yield reduction was attributed to the low C/N ratio of the mulch resulting in poor mineralization and immobilization of N. It has been suggested that imperata biomass has phytotoxic properties (Kamara and Lahai, 1997).

The experiment has shown that short-term fallows with piper and imperata give slightly higher sweet potato yields than with gliricidia. From a nutrient perspective, however, gliricidia fallows are probably more effective, but additional research in nutrient budgets is required before a final assessment can be made on the sustainability of short-term fallows.

The inorganic fertilizer and poultry litter experiments have shown that sweet potato responded to N fertilizer, which confirms other research in Papua New Guinea (Bourke, 1985a and 1985b; O'Sullivan *et al*, 1997). The highest yields are obtained with applications of 100 kg N ha^{-1}. However, the response was mainly recorded in the first season after the fallow, and subsequent seasons gave inconsistent results. The response to nutrient inputs is, however, greatly affected by other factors such as rainfall, number of cropping seasons and pests and diseases.

The question arises as to the best treatment to sustain and improve sweet potato yield in the Hobu area. Table 6

Table 5. Weevil counts and vine and tuber damage in unfertilized sweet potato plots of different ages.

Site	**Cropping season**	**Weevil counts (No m^{-2})**	**Tubers**		**Vines**	
			Damage (%)	*Life stages per tuber (No)*	*Damage (%)*	*Life stages per vine (No)*
Hobu	3	0.0	78	0.25	52	1.5
	4	0.5	35	5.25	55	0.5
Unitech	4	12.8	0	0	100	3.5
	5	1.1	0	0	100	5.3

Note: Values are the average for four sampled plots.
Source: Hartemink *et al*, 2000b.

Table 6. Ranking of 10 highest and lowest marketable sweet potato yields observed in all nutrient management experiments at Hobu.

Rank	Yield (Mg ha^{-1})	Experiment	Treatment	Season	Rainfall during season (mm)
10 highest yields	26.7	Poultry litter	100 kg N ha^{-1} as inorganic fertilizer	First	1,203
	24.7	Inorganic fertilizer	Unfertilized	Second	1,034
	23.8	Inorganic fertilizer	100 kg N ha^{-1}; no K	First	1,028
	23.5	Inorganic fertilizer	100 kg N ha^{-1}; 50 kg K ha^{-1}	First	1,028
	23.3	Inorganic fertilizer	150 kg N ha^{-1}; no K	First	1,028
	22.7	Inorganic fertilizer	50 kg N ha^{-1}; no K	First	1,028
	21.9	Poultry litter	100 kg N ha^{-1} as poultry litter	First	1,203
	21.7	Inorganic fertilizer	No N; 50 kg K ha^{-1}	Second	1,034
	21.5	Inorganic fertilizer	100 kg N ha^{-1}; no K	Second	1,034
	21.3	Inorganic fertilizer	50 kg N ha^{-1}; 50 kg K ha^{-1}	First	1,028
10 lowest yields	2.6	Inorganic fertilizer	150 kg N ha^{-1}; no K	Third	2,214
	2.7	Inorganic fertilizer	150 kg N ha^{-1}; 50 kg K ha^{-1}	Third	2,214
	2.9	Inorganic fertilizer	50 kg N ha^{-1}; 50 kg K ha^{-1}	Third	2,214
	5.2	Inorganic fertilizer	50 kg N ha^{-1}; no K	Third	2,214
	5.6	Inorganic fertilizer	100 kg N ha^{-1}; 50 kg K ha^{-1}	Third	2,214
	5.8	Inorganic fertilizer	100 kg N ha^{-1}; no K	Third	2,214
	6.0	Inorganic fertilizer	No N; 50 kg K ha^{-1}	Third	2,214
	6.8	Poultry litter	50 kg N ha^{-1} as poultry litter	Second	2,091
	6.9	Inorganic fertilizer	Unfertilized	Third	2,214
	7.3	Poultry litter	100 kg N ha^{-1} as inorganic fertilizer	Second	2,091

presents the 10 highest and lowest yields from all the experiments. These are average yields for a treatment, since variation between plots was large. Some plots had very high marketable tuber yields (up to 39 Mg ha^{-1}) whereas others yielded below 20 Mg marketable tubers ha^{-1}. The table clearly shows that most of the highest yields were found in the first and second season after the fallow and when seasonal rainfall was about 1,000 to 1,200 mm. The lowest yields were recorded in the third season after the fallow when the seasonal rainfall exceeded 2,000 mm. Most importantly, the table shows that none of the fallow treatments occur in either the highest or lowest yield ranking. Apparently using fallows is the safest way to obtain steady sweet potato yields, whereas with extra inputs of inorganic fertilizer or poultry litter, yields may be strongly increased or decreased.

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