Effect of Modifying Ovarian Feedback on the Reproductive Performance of Highlands Half-Bred Ewes

Paul N. Manua*

Abstract

An experiment was conducted at Tambul Research Station, Western Highlands Province, PNG, to determine the response of highlands half-bred ewes to the steroid hormone Androject, injected eight and four weeks before the onset of mating. The aim was to determine the potential use of this method for increasing lamb production in the national and provincial sheep farms producing lambs for distribution to farmers. Ewes that received Androject showed a fecundity of 1.42 per ewe compared to 1.18 per ewe for the control group. The number of lambs weaned per 100 ewes in the treated and the untreated groups were 119 and 97 respectively. It appears that under the prevailing feeding and management conditions at Tambul Research Station, the use of a steroid immunising vaccine such as Androject may result in a significant increase in the fecundity of ewes.

THE production of lambs by the national and the provincial sheep farms is inadequate to meet demand from farmers. Production of lambs can be increased from available breeding ewes by increasing the reproductive rate of these animals but a major factor limiting reproductive rate is low ovulation rate (Hanrahan 1980). Nutritional, photoperiodic, genetic or pharmacological means can be used to manipulate ovulation rates (Cummins et al. 1984).

Recent advances in veterinary science make it possible to increase the ovulation rate in sheep using a vaccine. The vaccine modifies ovarian feedback on the pituitary, neutralising the hormone that suppresses multiple ovulation in ewes. As a result, the number of multiple births increases.

This paper discusses an attempt to enhance the reproductive rate of the breeding ewes, and hence the output of lambs from the farm breeding centres, through modification of ovarian feedback using the vaccine Androject.

Materials and Methods

The study was conducted at the Tambul Research Station in the Western Highlands Province of PNG. Tambul is at an elevation of 2300 metres above sea level. The original flock of 192 highlands half-bred ewes with a lambing rate of 115% in the previous year was divided randomly into two groups. The first group was injected subcutaneously in the neck with 2 millilitres of a commercial preparation of the vaccine, eight and four weeks before the introduction of the rams. The second group did not receive any vaccine (controls). Both groups were fed and managed in the same ways. The breeding ewes were grazed rotationally and mineral supplements were provided at all times. Breeding rams were withdrawn after nine weeks of mating. During lambing, lambs

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were identified, ear-tagged, weighed and recorded along with the dam number. All lambs were docked at three weeks of age and weaned at three months of age. Weaning weights were recorded.

Results and Discussion

Reproductive performance

The effect of Androject on the reproductive performance of highlands half-bred ewes is presented in Table 1. Although the group that received Androject showed slightly higher fertility, the difference was not statistically significant ($P < 0.05$). The group that received Androject produced more lambs than the group that did not receive the hormone, with the lambing rate (number of lambs born per ewe available for mating) increased by 30% in the treated group. Fecundity was significantly ($P < 0.05$) higher in the treated group, with 142 lambs born per 100 treated ewes lambing, compared to 118 lambs born in the control group.

Influences of sex and lamb number on lamb survival at weaning

The influences of sex and birth type on lamb survival at weaning are presented in Tables 2 and 3 respectively. The lactating ewes were not able to find high quality feed for adequate lactation and this resulted in some ewes losing their lambs. The ratio of females to males at birth was 1:1.25 in the treated group and 1:1.11 in the control group. At weaning the sex ratio of the surviving lambs was 1:1.59 (female:male) in the treated group and 1:1.16 in the control group.

The mortality in the treated group was 9.5% in the treated group compared to 4.1% in the control group. All of the lambs that died in the treated group and three

Table 1. Effect of Androject on the reproductive performance of highlands half-bred ewes.

Group	Number of ewes at mating	Number of ewes lambing	Number of lambs born	Fertility (%)	Fecundity (%)	Lambing rate (%)
Control	96	82	97	85.4	118.3	101.0
Treated	96	89	126	92.7	141.6	131.3

Table 2. Influence of sex on lamb survival in treated and control groups.

Lambs	Control			Treated		
	Male	Female	Total	Male	Female	Total
No. born	51	46	97	70	56	126
No. weaned	50	43	93	70	44	114
% survival	98.0	93.5	95.9	100	78.6	90.5

Table 3. Influence of lamb number on lamb survival in the control and treated groups.

Lambs	Control			Treated		
	Single	Twin	Triplets	Single	Twin	Triplets
No. born	68	26	3	56	58	12
No. weaned	66	24	3	56	51	7
% survival	97.1	92.3	100	100	87.9	58.3

of the four that died in the control group were females. The survival rate in the treated group was influenced by the birth number, with losses considerably higher among the triplets, where ewes sometimes lost interest in mothering their newborn lambs.

Conclusion

The lamb numbers weaned per 100 ewes mated in the treated and the control groups were 119 and 97 respectively. This shows that use of the steroid immunising agent Androject can significantly increase lambing rates of highlands half-bred ewes, through an increase in fecundity. However, there is no indication that injection with Androject would result in any significant changes in fertility, female:male ratio, and number of lambs weaned. Ways to improve postnatal care of lambs from treated ewes should be investigated, to increase lamb survival rate.

Acknowledgments

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Inland Fish Farming

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Abstract

Aquaculture is thought to be a good way to provide a more regular supply of protein to the PNG highlands. The Highlands Aquaculture Development Centre was set up in 1996 to provide technical advice, training and a supply of fingerlings to provinces and people who are interested in fish farming. The success of the project is indicated by increased attendance at training courses and increased purchases of fingerlings by fish farmers.

PROTEIN intake in the highlands region is irregular. Most protein is taken as pork or lamb flaps or chicken at death ceremonies or Christmas functions. Aquaculture is being introduced to remedy this dietary inconsistency. Wild fish catches are likely to drop in the future, so aquaculture will be increasingly important for PNG as its population increases. Aquaculture is more likely than fishing to deliver ownership of the environment, a predictable supply of fish, quality control, and the potential for genetic improvement. It is also environmentally friendly. As well as producing much-needed protein, it can lead to greater employment, human resource development and economic diversification and increased export income. Conditions in PNG are apposite for aquaculture: the climate, water and soil conditions are favourable; there are suitable available species; there is sufficient labour, infrastructure and access to markets; and the country is politically stable.

Altogether, there are more than 5000 backyard fish farmers in the highlands. Our records and observations suggest that most fish farmers are based in Eastern Highlands Province (32%), Simbu Province (25%) and Morobe Province (20%). About 12% are based in Western, Southern Highlands and Enga provinces and about 6.5% in Madang Province. There are relatively few fish farmers in East Sepik or Sandaun (West Sepik) provinces (2%), the island provinces (1.5%) or Oro (Northern) Province (1%). Lowland provinces like Madang and Morobe provinces are progressing well with fish farming.

The Highlands Aquaculture Development Centre (HAQDEC) was set up in 1996 to contribute to food security in the region by providing technical advice and fingerlings to provinces and farmers who are interested in fish farming. Its main functions are to produce fingerlings, conduct training and carry out research. To help HAQDEC perform these tasks, the Japan International Cooperation Agency centre at Aiyura has provided technical input to make sure the region has sufficient institutional capacity, equipment, infrastructure and trained personnel. The centre now has the facilities, equipment and staff to implement the project objectives.

Fingerling Production

Figure 1 shows the number of fingerlings distributed from HAQDEC from 1992 to 1999. In 1992–94, production ranged from 13,288 to 64,147 fingerlings. After the aquaculture method was improved in April 1994, production increased steadily in most years; it increased from 180,007 in 1996 to 258,731 in 1999. The centre expects to produce over 300,000 fingerlings

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in the year 2000. HAQDEC now has the capacity to produce at least one million fingerlings a year. HAQDEC's work has benefited not only the highlands but also coastal regions of PNG.

Figure 2 shows the proportion of people buying specified numbers of fingerlings. Most purchasers are small-scale farmers, with 77% of customers purchasing fewer than 50 fingerlings at a time. The larger customers are mostly provincial divisions of livestock and institutions who subsequently sell the fish to smaller customers. This suggests that nearly all customers are very small-scale farmers having a pond of less that 50 square metres. A demand of 500,000 fish would arise from 10,000 potential farmers purchasing 50 fish each.

Training

HAQDEC conducts three kinds of aquaculture training courses: carp farming for extension officers, fingerling production for advanced farmers and small-scale trout farming. Ten training sessions were conducted between 1996 and 1999. The number of farmers attending the sessions increased from 28 in 1996 to 40 in 1999, indicating a significant increase in interest in fish farming. Altogether, 318 participants have attended training courses. HAQDEC is planning to expand the range of courses available. Future training programs may include courses in Yonki cage culture; Chinese carp and super tilapia; Java carp (*Puntius*); and trout farming.

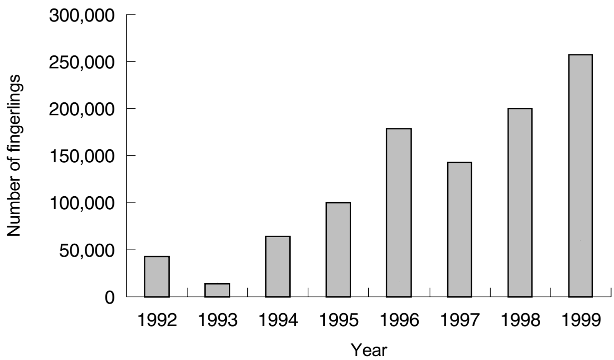

Figure 1. Fingerling distribution from the Highlands Aquaculture Development Centre, Aiyura, 1992–99.

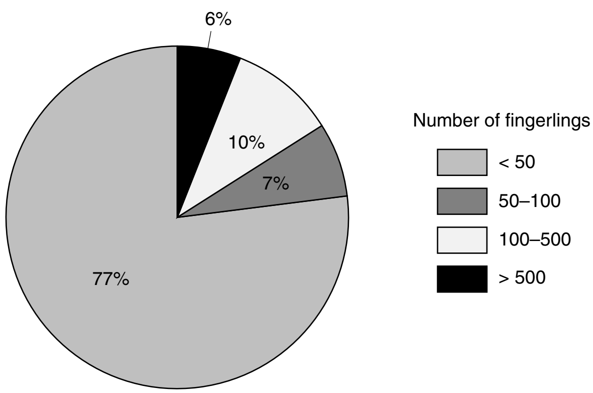

Figure 2. The proportion of people buying specified numbers of fingerlings from the Highlands Aquaculture Development Centre, Aiyura.

A Sweet Potato Research and Development Program for PNG

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Abstract

Sweet potato has been viewed only as a subsistence crop for many years in PNG. More recently, however, sweet potato has emerged as a significant cash crop. From 1989–99, there was an increase from 600 tonnes per year to over 2000 tonnes per year shipped from the highlands to Port Moresby. Given this development, this paper suggests that research efforts should be aimed at improving commercial production in the areas of agronomy, soil management, control of pests and diseases, processing, post-harvest transport, storage and utilisation. Benefits arising from improved production and marketing of this important staple include a decrease in import of starch-based products, associated savings on foreign currency and the creation of rural employment.

IN 1994, four consultative meetings were convened to increase the interaction between scientists in various organisations in order to formulate a comprehensive program for sweet potato research and development (R&D) in PNG. These meetings involved researchers from the Department of Agriculture and Livestock (DAL), South East Asian Potato Research and Development, the Pacific Regional Agricultural Program (PRAP) and the PNG University of Technology (Unitech). Separate meetings and correspondence were exchanged between DAL and the Australian Council for International Agricultural Research (ACIAR), and between DAL and the National Research Institute (NRI).

The sweet potato R&D program suggested here has evolved from these discussions. It builds on a long history of R&D on sweet potato in PNG (see Bourke 1985 for the most recently published review, and a special edition of *Harvest* devoted to sweet potato (Kilroy 1982)). In formulating the program, three major production systems have been identified: subsistence production in the highlands; market-oriented production systems in the highlands; and lowland production. R&D projects covering agronomy, soil fertility, pests and diseases, processing and utilisation are proposed, as well as two farmer surveys.

Under this program, the major partners would be the National Agricultural Research Institute (NARI), PRAP, the Fresh Produce Development Company (FPDC), Unitech, NRI, ACIAR, the private sector and farmers.

Background

The proposed sweet potato R&D program is set against a background of over 300 years of sweet potato culture in PNG. This has given rise to a food staple that is central to highlands agriculture and has a rich source of genetic diversity, with a high level of indigenous knowledge of the crop in PNG. A system of sweet potato production for subsistence is well established in the highlands. This represents a distinct system that continues to evolve. It is able to withstand climate variation and other environmental constraints and gives a

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continuity of supply and, hence, food security. However, the food security aspect of sweet potato production is improved where farmers are able to produce for both subsistence and cash-earning purposes.

Traditionally, sweet potato R&D has focused on aspects of improving the crop, understanding the farming systems and alleviating constraints to production systems. This remains an important area of R&D, but it is one that is unlikely to give quick returns on investment and to contribute meaningfully to the socioeconomic development of PNG in the medium term. To accelerate the trend towards market-oriented sweet potato production and to expand its utilisation and ultimately exploit the full potential of the crop, we have to look beyond the traditional approaches of sweet potato research.

In recent years, there has been a concerted effort by farmers to orient production and resource investment towards market gardening. In contrast to subsistence production, this system is characterised by some level of mechanisation, monoculture of a limited number of varieties (up to three), the use of chemical fertilisers and the use of not more than two harvesting regimes. This production has centred around growers in the main highlands who supply fresh sweet potato to lowland urban centres. The market-oriented production system is dynamic and is essentially a system in transition, as many rural villagers, mainly women, grow and sell significant quantities of sweet potato in local markets throughout PNG.

Table 1 shows that, from 1989–99, there has been an average increase from about 600 tonnes per year of sweet potato shipped from the highlands to Port Moresby, to over 2000 tonnes per year.

Production constraints in the market-oriented production system include low soil fertility, increased pest and disease problems due to monoculture and high post-harvest losses (of around 20%). Research focused on these problems is also likely to alleviate some production problems in the subsistence sector. Therefore, it is considered that research investment in the market-oriented sector would be cost-effective.

Since the devastation of taro by leaf blight in the lowlands, sweet potato is increasingly being adopted by farmers as a staple crop, and is now only second to either banana or taro (see Dimensions of PNG Village Agriculture by Bryant J. Allen et al., in these proceedings). Sweet potato may also be used as a starch substitute in the formulation of feed for pigs. If the adaptation and establishment of this crop in the lowlands is to be hastened, it needs to be promoted as a cash crop.

Rainfall extremes and the prevalence of pests such as sweet potato weevil, and diseases such as little leaf (a mycoplasma-like organism) are sometimes constraints to productivity in the PNG lowlands. However, the crop's relatively short growing period, higher yield per labour input and expanded utilisation in processed animal feeds outweigh the disadvantages.

Market Potential

There is a large potential for sweet potato to replace rice and wheat flour in the diets of urban dwellers. A study by Gibson (1995) showed that the low consumption of traditional staples in urban areas is due to their lack of price competitiveness; urban consumers do not view rice and wheat products as superior to sweet potato or banana (see also Migration and Dietary Change: Highlanders and the Demand for Staples in Urban PNG by John Gibson, in these proceedings).

The consumption of local produce should be promoted nationally. It will not only circulate money within the country but will also facilitate the employment of rural people in growing and marketing produce. In 1995, an average urban dweller consumed 75 kilograms (kg) of rice and 50 kg of sweet potato (Gibson 1995), whilst the average rural highlander consumed 47 kg of rice and 150 kg of sweet potato. The spending by an average urban household per fortnight was 9.05 PNG kina (PGK)[1] on rice and 3.09 PGK on sweet potato.

Greater production for the domestic market may also encourage people to remain in rural areas, thereby alleviating the pattern of rural–urban migration and its associated problems of urban poverty and lawlessness.

Constraints to Production

The following factors reduce productivity:

- soil fertility decline and nutrient deficiency under continuous production;
- insufficient knowledge of the suitability of varieties at different altitudes (genotype-by-environment);
- sweet potato pests—in particular weevil and leaf gall mite;
- sweet potato diseases—leaf scab, leaf and stem blight, stem and tuber rots and viruses;
- non-adoption by farmers of elite varieties;
- post-harvest losses of sweet potato shipped out of the highlands;

1. In 1995, 1 PGK = approx. US$0.75 (A$1.02).

Table 1. Amount of highlands sweet potato shipped to Port Moresby from 1989 to 1999.

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Quantity (tonnes)	593	820	871	1225	1859	2245	782	1555	1268	3567	1787
Three year moving average (tonnes)			761	972	1318	1776	1629	1527	1201	2130	2207
Retail value (1000 PGK)			819	1017	1562	1414	571	1073	1230	3103	1823
US$ value of 1 PGK			1.05	1.01	1.02	0.85	0.75	0.76	0.70	0.49	0.40
A$ value of 1 PGK			1.38	1.47	1.51	1.09	1.02	0.97	0.94	0.77	0.60

PGK = PNG kina
Source: FPDC (1989–99), Fresh Produce News—Data on Public Market Prices and Produce Movement

- limited processing and product utilisation;
- high labour costs; and
- production losses arising under moisture extremes (during and post-drought).

Objectives of the Research and Development Program

The following objectives have been identified for research and development.

- Improve efficiency of commercial sweet potato production through the application of organic matter and inorganic fertilisers.
- Develop practices for maintenance of soil fertility for different soil types.
- Establish yield performances (genotype-by-environment interaction) of the better-yielding varieties at different altitudes in the highlands.
- Develop a nonchemical control method against sweet potato weevil (*Cylas formicarius*).
- Determine crop losses by the leaf gall mite, its distribution, natural enemies and control measures.
- Investigate the prevalence and economic importance of leaf and stem blight, stem and tuber rots and viruses (mycoplasma-like organisms).
- Greater understanding of the factors involved in farmer adoption of sweet potato varieties.
- Survey current post-harvest handling of sweet potato, methods of transport and losses incurred.
- Select varieties suitable for commercial processing and aggressively market the products.
- Select varieties suitable as a substitute for imported cereal-based pig feed (subject to expression of interest by pig raisers).
- Explore the economics of varying levels of mechanisation (partial or full), such as bed makers and harvesters.
- Introduce suitable soil water conservation (irrigation) techniques and/or select varieties that are tolerant to drought conditions.

Program Activities (Trials, Surveys and Development Projects)

Agronomic

- Determine the effect of organic manures such as coffee pulp and chicken manures on yield (see The Effect of Chicken Manure on Growth and Yield of Intercropped Maize and Sweet Potato by Passinghan Igua, in these proceedings).
- Maximise yield in different soil types and altitudes with varying levels of nitrogen (N), phosphorus (P), potassium (K) and other deficient nutrients (see Selecting Sweet Potato Genotypes Tolerant of Specific Environmental Constraints by Jane O'Sullivan, Bill Humphrey and Passinghan Igua, in these proceedings).
- Examine the influence on yield after rotations with annual food legumes, maize or brassicas.
- Examine the influence of soil type and altitude on the yield of the more productive varieties (genotype-by-environment trials).
- Introduce suitable soil water conservation (irrigation) techniques.
- Select varieties tolerant to drought conditions (see The World Bank El Niño Drought and Frost Impact Management Project by Bill Humphrey et al., in these proceedings).
- Determine suitable cultural practice under extreme moisture conditions (frost and drought).

Pests

- Determine the influence of night irrigation, soil type, depth of planting and mulching on weevil (*Cylas formicarius*) population and related crop damage.
- Determine the economic significance of crop loss caused by gall mite and establish if natural enemies can control the mite.

Diseases

- Field-screen selected high-yielding varieties for resistance to leaf scab (*Elsinoe batatas*).
- Characterise *E. batatas* in PNG to determine if different physiological strains or races exist.
- Investigate factors which influence leaf and stem blight (*Alternaria* spp.) and develop cultural techniques to control these diseases.
- Investigate factors which influence stem and tuber rot (*Fusarium* spp.) and develop cultural techniques to control these diseases.
- Test performance of virus-free (indexed) varieties against local viruses.

Surveys

- Survey areas in close proximity to agricultural research station control areas (e.g. Asaro Valley), where specific attempts to promote recommended varieties have not been made.

- Conduct onfarm adoption trials at Goroka and Tambul research stations, and at the Highlands Agricultural Experiment Station, Aiyura.
- Survey varieties of sweet potato being shipped, current handling practices and fungal agents responsible for post-harvest rot.
- Identify varieties with longer post-harvest life that are less susceptible to bruising.
- Select suitable varieties for crisp and French fry testing, and promote marketing of these products. This should build on previous research of the Food Processing and Preservation Unit of Unitech.
- Identify suitable varieties as substitute/ supplementary feed to pigs.
- Compare the cost-effectiveness of various levels of mechanisation to human labour and recommend usage where appropriate.

Anticipated outcomes

- Increase sweet potato yields by 20–30% for commercial growers. Achieve food security (in terms of sweet potato) to subsistence farmers.
- Saving on foreign exchange through the substitution of imported starch such as rice and wheat flour (130 million PGK[2] per year is spent to import rice).
- Determine the significance of nutrient replenishment and recommended fertiliser rates for each soil type (by altitude).
- Improve soil fertility through appropriate crop rotations.
- Identify and promote high-yielding varieties for different soil types and altitude in the highlands.
- Develop procedures for the adoption of high-yielding varieties.
- Determine control measures to minimise damage by weevil and leaf gall mite.
- Identify varieties resistant to leaf scab (*E. batatas*).
- Develop cultural techniques to minimise crop loss caused by blight (*Alternaria* spp) and fungal rots (*Fusarium* spp).
- Establish record on yield performance of virus-indexed varieties.
- Reduce post-harvest loss through suitable techniques identified for curing, packaging and freight from highlands to the coast.
- Lower cost of commercially produced sweet potato by mechanisation.
- Produce sweet potato French fries and crisps that will sell.
- Recommended irrigation and cultural techniques for soil moisture retention during droughts.
- Establish yields under moisture stress and excess conditions and recommend cultivation practices to sustain yield.

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2. In July 2000, 1 PGK = approx. US$0.40 (A$0.60).

The Status of Sweet Potato Variety Evaluation in PNG and Recommendations for Further Research

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Abstract

Sweet potato is the major food crop in the highlands of PNG and is replacing other staple foods in large parts of the lowlands. PNG is considered the second-largest centre of sweet potato genetic diversity in the world. The number of varieties grown in PNG has been estimated at some 5000, of which about 1600 are maintained in ex situ collections.

From June 1990 to December 1998, the European Union funded a project under the Pacific Regional Agricultural Program on selection, trial and dissemination of sweet potato cultivars. The aim was to evaluate varieties of sweet potato in the lowlands and highlands of PNG. This paper discusses the status of research to evaluate sweet potato varieties up to the end of 1999. Screening methods and selection criteria are briefly discussed and recommendations made for further research.

ROOT crops are the staple foods in most of the South Pacific countries. Of the root crops, sweet potato (*Ipomoea batatas* (L.) Lam.) is the major staple crop in large parts of PNG and the Solomon Islands. It is also an important crop in Tonga and Vanuatu and its importance is increasing in other Pacific countries.

The ACP (Africa, Caribbean and Pacific) Pacific Group Council of Ministers, at their 1987 meeting, endorsed the concept of a European Union-funded Pacific Regional Agricultural Program (PRAP) and delegated the project selection to the regional advisory board (RAB). In a subsequent RAB meeting a project was chosen to concentrate on the 'Selection, trial and dissemination of sweet potato varieties' (PRAP project 4) in the Pacific region. The project started in June 1990 and ended in December 1998.

New Guinea is considered to be the second most important centre of sweet potato genetic diversity in the world. The number of cultivars grown in PNG has been estimated at some 5000 (Yen 1974). At present, there are about 1600 varieties maintained in ex situ collections: 1200 at the Highlands Agricultural Experiment Station (HAES) at Aiyura in Eastern Highlands Province, and 850 at the Lowlands Agricultural Experiment Station (LAES) at Keravat in East New Britain Province, with duplications between the two stations. Most of the varieties were described using the International Plant Genetic Resources Institute descriptors with some modifications (Guaf et al. 1992). The question as to whether PNG merely has many different looking varieties or also significant genetic diversity is often raised.

In a study carried out by the International Potato Centre (CIP) (Zhang et al. 1998) in Lima, Peru, using random amplified polymorphic DNA (RAPD), genetic variation and diversity in 18 cultivars from South America (the centre of origin of sweet potato) were compared with 18 PNG varieties (originating from both the PNG lowlands and highlands). Although the within-group (among individuals) variance accounted for 90.6% of the total molecular variance and the

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between-region ones for only 9.4%, the between-region difference was significant. The results suggest that the PNG varieties, since their introduction into PNG some 400 years ago, have become genetically distinguishable from their ancestors in South America.

Although the South American cultivars were significantly more diverse genetically than the PNG cultivars, the difference between the PNG cultivars was also significant. This was considered not so surprising, as the South American group was sampled from Peru, Ecuador and Colombia, the original centre of sweet potato production, while the PNG gene pool is a comparatively recent introduction. The results of the study would indicate that PNG not only has many varieties (which could be the result of only a few genes, determining, for example, leaf or tuber skin colour), but also has a relatively large genetic base.

Research on evaluating sweet potato varieties started in the 1970s when the first collections were made. More than 50 variety evaluation trials were carried out at 11 locations (Bourke 1985) before the start of the PRAP project, but because of a limited number of trained staff and shortage of funds these yielded results for only parts of the collections.

Screening Methods and Selection Criteria

The screening methods and selection criteria are detailed in a National Agricultural Research Institute report (Van Wijmeersch and Guaf 1999). A summary is given below.

After sweet potato varieties had been collected or introduced and then multiplied, they were planted in large screening trials. The large screening trials included controls for each five-by-five metre plot, so that the yield results could be adjusted and analysed, despite not being replicated.[1] All varieties were planted a minimum of three times in a large screening trial before promising varieties were identified and planted in replicated trials.

During the growing period, the varieties were assessed according to the incidence of scab disease (*Elsinoe batatas*) and plant growth vigour. At harvest, the yield of marketable and unmarketable tubers was recorded, and assessments made of rat damage, rots, tuber shape, cracking of tubers and market appeal. At Laloki Research Station, damage caused by sweet potato weevil (*Cylas formicarius*) was also assessed.

The complete results were stored in five computer files containing:

- all yield data obtained before PRAP and during the project;
- yield data of those varieties yielding higher than the trial average (this file includes the adjusted yields and other assessments);
- dry matter and protein content;
- all scab disease and growth vigour scores; and
- all textual assessments made during the harvests.

The first file showed how often a variety has been planted. The second file indicated in how many of those trials the variety yielded higher than the trial average and ranked each variety in the trial.

Although yield was the first criterion for selection, other criteria, such as resistance to scab, growth vigour, rot, cracking, rat damage, tuber shape, market appeal, dry matter content, and, most importantly, taste, strongly influenced the selection of the recommended cultivars. Selections were made after all characteristics had been assessed.

PNG Lowlands

Variety evaluation

A total of 1167 varieties have been evaluated at LAES. Of these, 118 were collected in the Islands Region (they consisted of varieties from the original LAES collection and cultivars collected during the PRAP project). There were 254 varieties from Laloki Research Station collection, 678 from the HAES collection, and 117 from overseas.[2] Fifteen large screening and 16 replicated trials were planted in addition to 30 multiplication blocks of promising and selected varieties.

From the results of those trials, the project recommended 79 first-class and 14 second-class selected varieties for lowland conditions. The first-class varieties have a constant high-to-good yield with good market appeal and/or a preferred taste.

1. With so many varieties being evaluated, each collection planting was over 1 hectare, making replication impractical.

2. During the variety evaluation, many duplicates were identified, especially in the lowland collections. The original LAES collection, for instance, contained 278 accessions, but after the description of them, 173 were identified as duplicates and were discarded.

The second-class varieties can be divided into two groups:

- high yielding varieties with some negative characteristics, such as a mostly irregular tuber shape or relatively high cracking; and
- varieties with good characteristics, for example, a deep orange flesh colour (indicating high ß-carotene) or high market appeal, but giving only a moderate yield.

The second-class varieties can be used for special purposes and/or in a breeding program.

The first-class selected varieties consisted of 53 from PNG, 18 from the Solomon Islands, three from the Philippines, two from Vanuatu, two from the International Institute for Tropical Agriculture (IITA) in Nigeria and one from Tonga. The second-class varieties consisted of six from PNG, three from Vanuatu, and one each from the Solomon Islands, the Philippines, Australia, Indonesia and IITA.

Most of the recommended varieties were from the Pacific region, especially from PNG and the Solomon Islands. This is because of the availability of many varieties resistant to, or tolerant of, scab disease in those countries, in contrast to Tonga, Samoa and Southeast Asia (Lenné et al. 1994). A descriptive list of the selected varieties, which is mainly for researchers (Demerua et al. 1998) and a descriptive list mainly for extension officers (Guaf et al. 1998a) are available from LAES and NARI headquarters.

For 17 varieties, further information is needed before selecting or discarding them. These are mainly introduced cultivars, but some were recently collected in PNG. These varieties should be further evaluated during the regular replanting and harvesting of the multiplication plots. Together with the 79 first-class and 14 second-class selected varieties, this gives a total of 110 unique cultivars in the active multiplication plots.

All selected varieties were analysed for dry matter and protein content, but not for ß-carotene and vitamin content. Several of them, however, have an orange tuber flesh colour and have a high dry matter (at least 30%). The importance of the chemical composition of tropical root crops is discussed by Bradbury and Holloway (1988). Some of the selected varieties were in the list of Laloki varieties analysed by Bradbury and Holloway. Their results for dry matter and protein content correspond closely with those obtained at the Kila Kila Chemistry Laboratory.

An initial selection of 35 varieties was made for evaluation of drought tolerance at Laloki under the World Bank Drought Relief Project. The selection was mainly based on growth vigour assessments and lost plants during the severe El Niño drought in 1997–98. At the request of the project leader, the number of varieties was reduced to 20. The reduction to 20 was based as far as possible on factors such as early yield and yields obtained during the drought. Unfortunately, during the drought, the harvests of the active collection and multiplication plots of the selected and promising varieties had to be postponed until sufficient rain fell to allow replanting. These postponements made the harvest data less reliable than they would otherwise have been.

All the selected varieties except five (which were collected towards the end of the project) were pathogen tested at the Institute for Horticultural Development in Australia. Some were virus indexed before the start of PRAP through the Australian Centre for International Agricultural Research (ACIAR) project 'Pathogen Tested Germplasm for the South Pacific', others through the Asian Sweetpotato and Potato Research and Development (ASPRAD) project, and yet others through PRAP.

Many of the selected varieties have already been distributed to schools, extension officers and farmers. More than 30 were planted in multiplication plots at Bubia and Laloki research stations, the Coconut and Cocoa Research Institute (CCRI) in Madang, and other places for distribution to farmers.

Germplasm maintenance

The varieties have been evaluated in at least three or four trials and 1057 varieties removed from the active collection since the PRAP project began. Of the 1057 varieties, 669 were from the HAES collection and 234 from the Laloki Research Station collection; 82 had been collected in the Islands Region and 72 introduced from overseas. They were discarded for various reasons, including low yield, scab disease susceptibility and/or low growth vigour, high tuber cracking, irregular tuber shape, low dry matter, bad taste, and/or low market appeal. They were planted on single mounds for maintenance only.

During the severe 1997–98 El Niño drought, however, 314 varieties were lost. It was fortunate that, of these, 229 were from the HAES collection and there were duplicates of them in the LAES collection, and 10 were introduced varieties. At present, 743 varieties are maintained on mounds from a total of 853 cultivars still present at LAES. Of these 743 varieties, 440 are from the HAES collection, 172 from the Laloki collection and 69 from the Islands Region; 62 have been introduced from overseas.

Recommendations for further research

Further collection, evaluation and/or breeding

At this stage, with many selected varieties now available, further collection and/or breeding is not recommended unless a particular characteristic not present in the selected varieties is needed. It is recommended that the 17 varieties for which more information is needed are further evaluated. If a breeding program is initiated, it is recommended that it should concentrate on selected varieties.

As 678 highland varieties, representing approximately 60% of the highland collection, have already been evaluated under lowland conditions with only limited success, it is not recommended that more highland varieties be tested under lowland conditions.

Distribution of the selected varieties

Many of the selected varieties have already been given to farmers and Division of Primary Industry (DPI) officers in East New Britain Province and to various other places in PNG for distribution. These places include Bubia Research Station, Laloki Research Station, the PNG University of Technology (Unitech) at Vudal, the CCRI at Madang, and the Fresh Produce Development Company at Karkar Island, Manus, Buka, Kavieng and Nissan Island. But there is still room for considerable improvement. Multiplication plots of the selected varieties should be established at all of the National Agricultural Research Institute (NARI) research stations, and at as many as possible provincial DPI stations. The major distribution in East New Britain Province occurred when there was an extension research liaison officer at LAES. To disseminate varieties and avoid confusion, multiplication plots of all the selected varieties are being maintained and monitored at LAES.

Processing

There has be no research into processing selected varieties of sweet potato in lowland conditions. However, from Unitech trials of highland varieties of sweet potato for processing (Srinivasan 1994), it is likely that many of the selected lowland varieties will also be suitable for processing. If there is a demand, selected varieties for lowland conditions should also be tested for their processing suitability.

Declining yield, and maintenance of varieties in tissue culture and screenhouse

During the project, a sharp yield decline was observed in several selected varieties. However, yields of those varieties recovered or even increased when pathogen-tested planting material received back from Australia was compared with the original material. When declines in yield are observed, procedures need to be modified. The yield of the selected varieties for distribution has to be monitored and, if a decline is observed, the variety has to be renewed from the screenhouse or tissue culture laboratory (Van Wijmeersch 1998). Therefore, all selected varieties have to be maintained in tissue culture and screenhouse, serving as duplicates in case of losses or mixing. Extensive losses occurred in the regional tissue culture laboratories of the Institute for Research and Extension in Tropical Agriculture in Western Samoa and the Secretariat for the Pacific Community, Fiji. Efforts are now being made to recover the lost varieties. Hence it is recommended that, for security reasons, PNG maintains its own set of the selected varieties in tissue culture.

A list (indicating their origin) is available of those varieties that are ready in the field for distribution, and there is another list of those that have to be renewed and/or reintroduced from tissue culture.

Pests and diseases

Sweet potato weevil (*Cylas formicarius*) is the main pest of sweet potato. At LAES, with its well-spread high rainfall, weevil damage is usually not a major problem. It was observed, however, that deep-rooting varieties are less susceptible to weevil damage than varieties whose tubers tend to stick out of the ground.

Weevil damage was assessed during collection harvests in the dry season at Laloki. The results, however, were not consistent. This corresponds with results obtained at the Asian Vegetable Research and Development Centre and IITA, where variety evaluation for weevil resistance was carried out for more than 10 years without consistent results. No further variety evaluation for weevil resistance is recommended. It is recommended that the current leaflets about ways to control weevil damage should be updated according to more recent research results from within and outside PNG. Further information on sweet potato weevil incidence in the humid PNG lowlands is provided in another paper in these proceedings (Sweet Potato Weevil (*Cyclas formicarius*) Incidence in the Humid Lowlands of PNG by K.S. Powell et al.).

Rats can cause considerable damage to some sweet potato varieties, especially when harvests are postponed. As found for weevil damage, deep-rooting varieties are less susceptible to rat damage than cultivars with tubers that tend to protrude from the ground. During harvests varietal differences in the amount of rat damage were assessed.

Hawkmoth (*Agrius convolvuli*), which attacks sweet potato leaves, is usually a minor problem. It can, however, cause severe defoliation especially during and after dry periods. When some rain fell in 1998, after the long El Niño drought, the sweet potato fields at LAES were completely defoliated in a matter of days.

The project evaluated the varieties only for the incidence of scab disease. As scab is dispersed by rain splashes, LAES is a favourable site to evaluate scab disease resistance. The disease can be so serious in some varieties that they hardly grow. All the selected varieties, however, have an acceptable level of resistance or have a vigorous growth making them tolerant to scab. As is the case for the susceptible Tongan varieties, chemical control would probably increase the yield of some of the more susceptible varieties, but farmers do not generally use chemicals in their sweet potato plots. No further research is recommended, unless a very susceptible variety has desirable characteristics not found in the resistant varieties.

Sweet potato little leaf, caused by a mycoplasma-like organism, can be a major problem in the drier areas of PNG, such as Central Province. Little leaf was not a problem at LAES during the project. Consequently, varieties could not be assessed for their susceptibility to little leaf. A review of sweet potato diseases in PNG is presented in these proceedings (Review of Sweet Potato Diseases in PNG by P. Kokoa).

Genotype-by-environment (G × E) trials

Although varieties were selected largely according to the results from LAES, several of the selected PNG lowland varieties were evaluated and found to perform well at Laloki and Bubia research stations and in other countries such as Tonga, Vanuatu and Sri Lanka. A variety that performs well under wet conditions (e.g. at LAES) is likely to perform even better in places with a distinct dry season. In addition, some of the selected varieties are from other Pacific countries or from Southeast Asia, and they yielded well under PNG conditions.

G × E trials are known to need more resources than on-station trials, and often give disappointing results because of early harvest by the cooperating farmers, theft or other reasons. With the limited staff and funds available, it is felt that it would be better to emphasise the distribution of the selected varieties and the further selection by farmers in the various agroclimatological zones of PNG. It is recommended, however, that selected varieties be compared with local varieties in areas with specific environmental constraints, for example, low pH and atoll island conditions.

Maintenance of germplasm

The loss of 314 varieties, despite the input of a scientific officer and an attempt to rescue dying varieties by planting them into poly bags (admittedly too late for some varieties), indicates that it is very difficult to maintain a large germplasm collection that is not active. There is only one mound per variety, and the germplasm maintenance block tends to get less attention as it is replanted only every two or three years (Guaf et al. 1996). There was a duplicate of the germplasm block, but the duplicate was abandoned because of the high labour input needed to maintain the two blocks.

The usefulness of keeping all the varieties when the evaluation of them has been completed is questionable. It would obviously be easier to maintain only a relatively small core of potentially useful varieties.

Of the 743 varieties maintained on mounds at LAES for maintenance only, 440 are from the highland collection and 62 were introduced from overseas. Once the confusion over the labelling in the highland collection has been sorted out, the highland varieties could be discarded or transferred to HAES. The introduced varieties, unless they have some specific desired characteristics, could also be discarded.

When some of the constantly zero-yielding Laloki varieties were duplicated at HAES, some of them began to produce sweet potato. The 172 Laloki varieties maintained on mounds should therefore be checked and, if consistent zero yields or low yields indicated they originated from the highlands, transferred to the highland collection.

For the 69 varieties collected from the Islands Region, a decision to discard or maintain them could be made according to the computerised information on, for example, cracking, dry matter content, tuber shape and market appeal.

The points mentioned above are only suggestions made in view of the high maintenance cost of the existing collection. Plant genetic resources is a national issue. There is concern, however, that varieties are usually lost at random, and some of these could be useful.

PNG Highlands

Variety evaluation

The screening process of the 1200 highland varieties has been slower than in the lowlands because of:

- a shortage of suitable well-drained land at the HAES at Aiyura (1600 metres above sea level);
- the more specific planting season (at LAES sweet potato can be planted at any time of the year);
- the slower growth rate (the growing period is nine months, compared with five months in the lowlands); and
- the absence of a tractor and, most importantly, the shortage of staff.

During several years, plantings and harvests have been undertaken by Mr Robert Lutulele, at that time acting officer in charge of Tambul Research Station (2400 metres above sea level). Tambul is a six- to seven-hour drive from HAES (Aiyura). Harvest results were then sent to Mr Guaf, PRAP Sweet Potato Officer, at LAES Keravat for processing. From time to time, Mr Guaf would travel to HAES to assist with plantings and harvests and discuss the results with Mr Lutulele (Guaf et al. 1995, 1998b).

Despite the difficulties, however, six large screening trials, including all varieties, were harvested at HAES. Though the average plot size was small (10 plants planted at close spacing compared with 30 in the lowlands planted at a wider spacing) and the harvesting time was most often overdue, some useful information can and has been obtained from those trials. The results of the trials have all been computerised and processed. All the information available about the highland collection was transferred to HAES in computer files and on hard copies early in 2000.

From the harvest results of the large screening trials, approximately 180 promising varieties (the list was updated after the subsequent harvests) were planted and harvested seven times in multiplication plots at HAES, and approximately 40 of them were planted and harvested five times in Tambul. In contrast with the large screening trials, the multiplication plots had an acceptable size of 30–40 plants per plot. Unfortunately, only one replicated trial, including 36 promising varieties, was planted and harvested at HAES.

Based on the combined results of the replicated trial and the first large screening trials and multiplication plots at HAES and Tambul, a selection of 54 preliminary selected varieties was made. Out of that list of 54 and with more recently obtained results, a selection of 30 varieties was made for evaluation under the drought relief project (these included 14 varieties independently recommended by Mr Lutulele for evaluation by the Livestock Development Corporation); 14 further varieties also selected, with some reservations, for evaluation. These selections excluded a few varieties that would have been chosen had they not been previously unrecoverably lost from the collection.

Twenty of the selected varieties are currently being evaluated for drought resistance at HAES (see the paper: The World Bank El Niño Drought and Frost Impact Management Project by Bill Humphrey et al., in these proceedings).

Some selected lowland varieties were also evaluated under highland conditions. Although most of the selected lowland varieties yielded well (in contrast with the majority of highland varieties tested under lowland conditions), most of them performed no better than the selected or promising highland varieties, especially on market appeal. An exception can be made for the Islands Region collected variety NGI 24, which is a first-class selected variety for lowland conditions and is also in the list of selected varieties for highland conditions.

For experimental purposes, some Laloki varieties with a constant zero yield under lowland conditions were duplicated in the highland collection. Within one season some of them were giving a reasonable yield, indicating their possible highlands origin. Others, however, continued to give a zero yield.

Most of the varieties that performed well at HAES were also performing well at Tambul, with some exceptions. A few of the varieties that yielded well at Tambul gave only average or low yields at HAES. As expected, yields were in general lower at Tambul than at HAES.

Germplasm maintenance

The sweet potato germplasm at HAES is maintained in two separate blocks. The first block, or the 'old germplasm collection', was planted on mounds in the late 1980s. The second block is the active collection, having been planted in June 1991.

In both blocks there was a lot of mixing of varieties. In the first this was because weaker varieties were overgrown by vigorous varieties planted on neighbouring mounds. When the vines were trimmed back during maintenance, the vines should have been lifted and pulled back before cutting them. However, this was not done and pieces of vines remained to grow on the neighbouring mound, thus mixing the varieties.

Mixing of varieties in the active collection occurred over the years because of the small plot size per variety and the generally late replantings. Recommendations have been made to try to solve this problem (Guaf 1996), but it will not be an easy task.

High-yielding varieties, if they do not correspond with their description, should be given a new number. The obtained information about them, in respect to farmers' use, is more important than their description.

During the very severe 1997–98 El Niño drought, all sweet potato varieties were planted in polythene bags to ensure their survival. Since then they have been planted out again in the field. Robert Lutulele (Sweet Potato Variety Developments in the PNG Highlands: Implications for Future Research and Extension Focus, in these proceedings) has discussed future developments in sweet potato production in the PNG highlands.

Recommendations for further research

Further collection, evaluation and/or breeding

Although evaluation of sweet potato varieties in the highlands is less advanced than in the lowlands, there is considerable information available. From the results of the multiplication plots of about 180 promising varieties, 30 were selected, with an additional 14 possible varieties. The 30 selected varieties should be planted in multiplication plots for distribution and the latter 14 for further observation. Those cultivars that were not selected because of low yield and/or other negative characteristics should be taken out of the active collection and planted on mounds for maintenance only.

The results of collection plantings at Kuk and HAES before the start of PRAP, and the first two large screening trials at HAES under PRAP, have been combined into three computer files: one with all the yield data, one with only those varieties yielding higher than average, and a third with scab and growth vigour scores.

It is recommended that the processed yield results of the four other large screening trials should also be put in two combined computer files (because of the size), with the scab disease and growth vigour in another file. It is recommended that from these six combined files an updated list of promising varieties be extracted. Although the results of one collection indicate that replanting might not be reliable on its own, if a variety yielded well in most of the trials it should be planted in a multiplication plot and in the active collection for further evaluation. Varieties that do not perform well in most trials can be taken out of the active collection and planted on mounds. When in doubt, the variety should be retained in the active collection. This should result in a more manageable active collection, with bigger plot sizes.

High-yielding varieties, if they do not correspond with their description, should be assigned a new number. Care should be taken not to lose the data already obtained.

Most of the selected lowland varieties tested under highland conditions were relatively high-yielding but did not outperform the selected highland varieties. Evaluation of more of them in the highlands is, therefore, not recommended, unless the aim is mid-altitude evaluation.

As the evaluation of the actual collection has not yet been finalised, further collection of varieties or breeding is not recommended, unless the variety is popular with farmers and/or the market.

Distribution of selected varieties

Only a few varieties were distributed to farmers, although those participating in the onfarm trials carried out under ASPRAD, and farmers around Aiyura and Tambul, received more. In previous years, the varieties planted in the multiplication plots were mainly considered as promising varieties. With the selection of 30 varieties, the distribution of varieties can be carried out with more confidence. Varieties should be planted in multiplication plots at provincial DPI stations in various agroclimatological zones for distribution, with farmers making their own further selection. The distribution of the selected varieties would certainly be improved if there was an extension research liaison officer at HAES and at Tambul Research Station.

Processing

Varietal trials of sweet potato for processing into deep fried crisps and composite flour bread (baking trials) at Unitech (Srinivasan 1994) indicated that four of the six tested varieties (five of these are in the list of selected varieties) were suitable for processing. If there is a demand for sweet potato processed products, it is recommended that more of the selected varieties should be evaluated for their processing qualities.

Yield decline

There is no clear/written evidence that there is a yield decline for particular varieties in the highlands, though farmers mention it. Varieties showing a yield decline might have been discarded by farmers over the years. Considering the positive results obtained at LAES with field material put into tissue culture without pathogen testing, it is recommended that some of the popular highland varieties are put into tissue culture. After a couple of tissue culture transplantings (preferably meristem culture), they should be hardened in a screenhouse and compared with the original planting material in the field (Van Wijmeersch 1998). The first planting results might not be reliable as the plants obtained from the screenhouse tend to be weaker than those grown outside.

This could begin as a small-scale project. As some varieties seem to be more susceptible to yield decline than others, the number of varieties should be 20 rather than 10. If yield increases are observed, a bigger project could be considered.

Pests and diseases

In a survey carried out around Goroka, sweet potato weevil (*C. formicarius*) was considered a major problem, especially during dry periods. It affected the three most popular varieties: Wanmun, Goife and Sugar. As the surveyed farmers were semicommercial farmers, they were concerned about the decreased market appeal of the tubers rather than a decrease in yield. It would be interesting to survey other areas to assess the extent of weevil damage.

Infection by gall mites has been observed but not studied in depth. Intensively cropped areas under sweet potato are particularly susceptible to gall mite damage (e.g. Fatima College, Western Highlands Province). To avoid infection, a proper rotation should be applied, healthy planting material used and, if the latter is not available, planting material dipped.

In the collection at HAES, varietal differences were observed. Some varieties appeared to be infected, while the surrounding plots were unaffected. The existence of varietal differences, however, needs to be confirmed.

The project evaluated the varieties only for the incidence of scab disease. Scab disease is a bigger problem in the highlands than in the lowlands. While few of the lowland selected varieties are moderately susceptible to scab, a higher percentage of the selected highland varieties are rated as moderately susceptible or susceptible to scab. This negative characteristic, however, is compensated for by vigorous growth (see Review of Sweet Potato Diseases in PNG by P. Kokoa, in these proceedings).

Genotype-by-environment (G × E) trials

No G × E trials were carried out by the PRAP project. However, most of the varieties that performed well at HAES also yielded well at Tambul. This indicates that the selected varieties should be distributed to provincial DPI stations and farmers in the various agroclimatological zones, with the farmers making their own selection from them.

Nine of the selected varieties, with the popular Wanmun (which is also a selected variety) as control, were evaluated at nine different sites in the Kainantu District during the wet season August 1995 to March 1996 (Lutulele et al. 1996). The results of the trial indicated that three (four if Wanmun is included) out of the nine varieties were well accepted by the farmers. Only three tested varieties were disliked. The choice of some relatively low-yielding varieties indicated that, as well as yield, market acceptability based on appeal and utilisation are also considered.

Maintenance of germplasm

It is recommended that the highland germplasm collection be reduced to a core collection with potentially useful varieties. This is currently difficult to achieve, however, because there are many varieties for which there are only limited reliable data available. This should improve when the active collection is reduced and varieties can be planted in large plots and harvested.

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Sweet Potato Variety Developments in the PNG Highlands: Implications for Future Research and Extension Focus

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Abstract

Sweet potato is a very important food crop affecting the food security and cash income needs and requirements of more than 90% of the population in the PNG highlands. Food security and cash income needs, in turn, have influenced the genetic diversity of sweet potato and the selection of particular varieties. This paper discusses changes in cropping patterns, demography and socioeconomic factors, as well as the impact of local topography, climate, and soil type. It suggests directions for future research and extension activities.

PNG is an important centre of genetic variability in the Asia–Pacific region, with more than 5000 varieties of sweet potato (*Ipomoea batatas* (L.) Lam.). Such diversity has resulted partly from local people's food needs changing in response to climate, cultural and other factors, and partly from sweet potato's intrinsic ability to adapt to changes in the demands of farmers and the environment. The high value placed on sweet potato has led to farmers paying close attention to variety developments, not only out of choice but possibly also out of necessity (Guaf et al. 1994). Dynamic changes have occurred in the macrophysical, microphysical, climatic, edaphic, biological, demographic and socioeconomic environments with varying degrees of impact (Ghodake 1994). Farmers need to understand these factors if they are to develop appropriate technologies for sweet potato production and use.

This paper examines some factors that may have led to the development of genetic diversity in sweet potato and suggests areas for future research and extension activities to improve its production and use, leading to greater food security and better cash incomes.

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Major Factors Affecting Variety Developments in the Highlands

The highlands region is the major centre of genetic diversity of sweet potato in PNG. Farmers place great value on food security and, to a lesser extent, cash income levels, because both affect their basic livelihood. Over the years, farmers are thought to have directed the evolution of varieties to improve food security and, recently, cash economy needs. Diverse cultural practices evolved in the highlands region in response to physical and other factors affecting the growth of different sweet potato varieties at different times. This paper briefly analyses some of these factors to give some insight into the dynamic nature of the development of sweet potato in the PNG highlands.

Physical factors

Physical factors such as altitude and topography affect yield, distribution and probably, to some extent, the generation of diversity.

Geography

Geographical isolation could have been important in generating new genotypes in the highlands. Rugged, mountainous terrain and tribal hostilities may have limited the movement of people and therefore of planting materials. People would have generated as many cultivars as possible to cope with the diverse demands of the environment. New genotypes of sweet potato may have developed by chance through spontaneous germination (Guaf et al. 1994), but may then have been cultivated in response to changing environmental conditions.

People have become more mobile as roads and transport have improved and hostility and fear have decreased. Two consequences have been a wider distribution of varieties and erosion of genetic diversity. If people can easily collect a new variety from elsewhere in the region, they may no longer feel compelled to maintain local genetic diversity. This makes it easier for research and extension programs to promote improved varieties, but threatens important genetic resources that have been in existence for more than 300–400 years. There is an urgent need to conserve this valuable genetic resource.

Altitude

Highlands agriculture is carried out at altitudes of 1200–2800 metres above sea level and sweet potato is the most important crop above 1500 metres above sea level (Bourke et al. 1994; Allen et al. 1995). The combined effects of temperature and altitude affect the growth and maturation periods of sweet potato. Based on observation, growth vigour and structure (size and length of leaf, stem and vine) appear to decrease and the maturity period to lengthen with increasing altitude. For example, the *wanmun* variety of sweet potato grows vigorously and matures within six months at the Highlands Agricultural Experiment Station (HAES) at Aiyura (1600 metres above sea level) but grows slowly and matures after nine months at Tambul Research Station (2240 metres above sea level). In addition, growth and time to maturity differ amongst genotypes, suggesting a strong interaction with the environment. The preference for traditional landraces over newly introduced varieties may be explained to some extent by this phenomenon.

Topography

Sweet potato production in the highlands is limited by topographical features such as valleys, sloping hills and mountainsides. Bourke et al. (1994, 1995), Hide et al. (1995) and Allen et al. (1995) have described cropping on sloping land. Bourke et al. (1994) recorded cultivation on slopes of more than 25° in Eastern Highlands Province. Sloping hills and mountainsides are characterised by shallow A-horizons of soil, with rapid soil erosion due to the loose soil structure (mudstone and sandstone), and possibly low soil organic matter buildup.

With increasing population pressure leading to a rapid increase in cultivation, the risk of severe soil erosion is a significant concern. Increasing cultivation could cause irreparable damage to the soil structure unless better land management techniques are introduced. This could force people to migrate to other areas, which would then also come under greater pressure, leading to total environmental degradation and famines, such as those experienced in Ethiopia. In developing sweet potato varieties for these areas, people could select for varieties with rapid establishment rates and a good canopy to protect the soil surface from the erosive force of raindrops and surface runoffs. Yields and particular attributes of concern to farmers must not be overlooked.

Some locations in the central highland valleys are characterised by peat soils, high organic matter content at first cultivation stage (Kimber 1982), seasonal floods and high watertables. People developing new varieties could focus on varieties that can yield well under high nitrogen (N) and soil moisture content.

Climatic factors

Climatic factors are very important for subsistence agriculture in the highlands. They include rainfall (especially the distinction between the wet season and the dry season) and temperature. McAlpine et al. (1983) gave rainfall and temperature measurements and described regional variations in climatic patterns. The weather patterns determined the cropping cycle, crop management practices (to some extent), and the choice of species and variety for planting. If food production strictly followed climatic patterns, there would be major fluctuations in the food supply, and in the species and varieties of crops used.

The recent pattern of sweet potato production and supply under normal weather conditions is almost nonseasonal (Bourke et al. 1995). The development and selection of new varieties, coupled with cultural adjustments to suit climatic conditions or variety requirements, has enabled sweet potato supplies to be fairly constant under normal weather patterns. However, extreme climatic conditions such as the 1997 frosts and drought associated with an El Niño weather pattern and recent wet seasons associated with a La Niña pattern are periodic and devastating in nature. People dread these events because they destroy the normal subsistence food production, by disrupting the normal production cycle and adversely affecting the growth and yield of sweet potato and other food crops.

Temperature depends to a large extent on altitude. For every 100 metre increase in altitude in PNG, there is a 0.5°C decrease in temperature (McAlpine et al. 1983). The mean maximum temperature of the highlands is 20–29°C and the mean minimum temperature is 11–13°C under normal climatic conditions. Occasionally, much lower temperatures are recorded. During the 1997 frost and drought period, the lowest temperature recorded at Tambul Research Station was –2.5°C.

Recent climatic conditions in the highlands have been unpredictable and have disrupted normal cropping patterns. Also, certain crops are now being grown in areas where they were formerly unknown; for example, cassava is being grown at high altitudes (more than 1800 metres above sea level). The performance of genotypes depends to a large extent on macro and microclimatic factors, so the development of new varieties must focus on extreme climatic conditions. The major concern is the frequency of such conditions.

Soil characteristics

Soil characteristics affect the growth and yield of food crops. To exploit the full potential of the soil, it is important to understand its limitations and potential. This knowledge can be used to devise appropriate cultural practices that maintain a balance between what the soil can give and what the plant needs.

In the highlands, sweet potato is mainly grown on inceptisols: highly weathered volcanic ash soils (VAS) that are part of the soil group Hydrandepts (Blecker 1983; Kanua 1995). It is also sometimes grown on the organic or peat soils classified as histosols, which result from draining swamps and which support dense populations in areas such as the Whagi Valley. Fertility is not a great problem on histosols but Kimber (1982) showed that imbalances in the soil nutrients (for example, high N content due to mineralisation of organic matter at an early stage of cultivation) could suppress tuber yield and negatively affect yield attributes. One fertiliser trial showed that histosols could give a sweet potato yield of more than 50 tonnes per hectare (t/ha) in the first crop, but that the yield and quality attributes dramatically dropped in the second planting (Kimber 1982). The application of inorganic fertiliser did not improve yield and maize rotation appeared to be the best agricultural option. Deep drainage to create beds for planting sweet potato is the common cultural practice in the highlands.

Kanua (1995) has described the physical and chemical properties of highland inceptisols and suggested how they can best be managed. Fertility is a major problem in this soil, because of deficiencies in the macronutrients phosphorus (P) and potassium (K) and in micronutrients such as boron (B), molybdenum (Mo) and magnesium (Mg), and because of high levels of the potentially toxic substances aluminium (Al) and manganese (Mn). This makes the management of VAS difficult. Traditionally, sweet potato growers use compost mounds to raise the temperature of the soil and provide nutrients directly to the crop (Kanua 1995). Many agronomists (e.g. Preston 1987; Floyd et al. 1987ab; MacFarlane and Quin 1989) have studied the use of inorganic fertiliser, compost, the interaction between inorganic fertiliser and compost, and liming to improve P availability on VAS.

Biological factors

Biological factors such as weeds, soil microorganisms, pests and diseases are likely to have a negative effect on the development of sweet potato varieties.

Diseases of sweet potato under favourable agroeconomic conditions are probably as old as the crop itself. In the highlands, important field diseases include sweet potato leaf scab caused by the fungus *Sphaceloma batatas* Sawada, black rot or stem blight caused by *Alternaria* spp. and a variety of viral diseases.

Leaf scab is the most widespread disease in the region. Infestation is probably more severe at lower altitudes. Disease caused by *Alternaria* is more common at high altitudes, where the climate is usually cold and moist. The intensive cropping of mounds for more than 40 years may be the reason why the disease is ubiquitous in the region. Under intensive disease pressure, farmers decide whether to continue with their usual varieties on the basis of susceptibility or tolerance to the disease. For example, Baim was previously the favoured sweet potato variety at Tambul Research Station, but it has been disappearing because of its susceptibility to stem blight, with other varieties resistant to the disease.

Leaf scab seems to be the most studied disease in the region, and the one that has had the greatest influence on variety evaluations. In 1992, The Asian Vegetable Research and Development Center (AVRDC) identified 33 highly resistant and 24 resistant varieties from

PNG. Lenne (1994) subjected these varieties to 43 *S. batatas* isolates of varying aggressiveness, and found all of them to be susceptible to moderately to highly aggressive isolates. The most aggressive isolates came from Tonga, a finding that has important quarantine implications for crops exposed to the less aggressive strains of *S. batatas* from PNG.

Viral diseases are common in the highlands; they include sweet potato feathery mottle virus (SPFMV) and sweet potato mild mottle virus (SPMMV). Research on new varieties should focus on resistance to these viruses.

Sweet potato weevil (*Cylas formicarius*) and gallmites (caused by mite sucking insects) are two major pests of sweet potato in the highlands. Sweet potato weevils are not a problem at higher altitudes (more than 1800 metres above sea level) but can be economically important in dry areas or during long periods of drought. For example, these pests were devastating during the 1997 frosts and drought associated with the El Niño weather pattern. Interviews with people in Simbu Province and Western Highlands Province during and after the drought (Kanua and Muntwiler 1998) indicated that frost affected a relatively small area at higher altitudes, but that weevils devastated storage tubers almost everywhere. None of the 1671 varieties maintained by AVRDC, including 441 PNG varieties, has demonstrated any degree of resistance to sweet potato weevil.

Gallmites cause gall formation on petioles, leaf midribs and stem tips. They are less conspicuous than sweet potato weevils and may have emerged only in the 1980s. They are found mainly in the Whagi Valley, especially in the Banz area. The HAES sweet potato collection showed symptoms of gallmite infection in 1996. So far there is no scientific evidence of its effect on yield in PNG.

Other sweet potato pests include aphids (*Aphis gossypii*) and whiteflies (*Bemisia tabasi*). They cause damage directly, by their feeding habits, and indirectly because they transmit viruses. Aphids transmit SPFMV and whiteflies transmit SPMMV (Skoglund and Smith 1994).

Land and demographic factors

Agricultural land availability, cropping intensity and the length of the fallow period depend largely on population pressures. Any assessment of land-use trends must therefore take into account population concentrations and growth rates, especially on agricultural land.

The total land area of PNG is approximately 45 million hectares (FAO 1996). In 1984, 376,000 hectares were estimated to be under agricultural production. By 1994 this figure had increased to 415,000 ha, or 1% of the total land area. The total population in PNG in 1985 was 3.4 million, increasing to an estimated 4.3 million in 1995. In 1985, 2.8 million people were engaged in agriculture; this figure increased to 3.3 million in 1995. Agricultural land and the agricultural population growth increased by 10.4 and 19.5%, respectively. The fact that the population is growing at almost twice the rate of the area of land used for agriculture is a trend that must be viewed with great concern by planners and policy makers.

On average, land use is more intensive in the highlands than in most other regions of the country (Allen et al. 1995; Bourke et al. 1994; Bourke et al. 1995; Hide et al. 1995). Most highlands provinces include districts where there are more than 90 people per kilometre square.

Socioeconomic factors

Socioeconomic factors are important in raising the status of sweet potato from subsistence to market crop and they influence the development of new varieties. Sweet potato serves a large population across PNG, regardless of location, class or status. Its resilience and adaptability make it the most important crop in PNG. It is also a source of cash income (Kronen and Kanua 1996). The Fresh Produce Development Company (FPDC) has established a program to address the development of sweet potato as an important source of food and cash security in the region.

In PNG, there has been a gradual shift from subsistence to commercially oriented production. This trend has been characterised by the cultivation of large areas (more than 0.5 hectares). In addition, sweet potato gardens are often required to have easy access to vehicles, labour and machinery, and farmers are paying increasing attention to postharvest quality attributes.

Recent and current socioeconomic changes in PNG are a major factor in this trend. They include increased demand in urban centres due to the increase in population, the devaluation of the kina and rising prices of imported food, such as rice. In rural areas, greater cash incomes have enabled people to enjoy more leisure activities and spend less time on food production. There is a trend to accord status to monetary wealth rather than material wealth: status is now determined more by the amount of cash someone has than by the number of pigs, wives or even land they own.

These trends in PNG have profound implications for research and extension, which should concentrate on exploiting the commercial or industrial potential of sweet potato rather than on subsistence production. Technologies developed for the commercial sector are likely to trickle down to the subsistence sector.

Cultural Practices

Like sweet potato varieties, traditional cultural practices have evolved in response to change. Farmers in the highlands region developed intrinsic cultural practices that are relevant for the particular varieties they cultivate. Farming systems in PNG have been the subject of major studies by agronomists and anthropologists (for example, Floyd et al. 1987ab; MacFarlane and Quin 1989; Preston 1987). However, there has been relatively little research on how crop varieties interact with major cultural practices. Traditional cultural practices are well developed, diverse and capable of adapting to change (Ghodake 1994). Recently there has been a small shift from traditional cultural practices to modern practices such as using machinery for land preparation. There is also an increasing tendency to intercrop, particularly with tree crops such as coffee (Ghodake et al. 1995). These trends demonstrate that farmers need to maintain a balance between food and cash needs. There will be further change when the influence of the cash economy outweighs subsistence food needs.

Varieties Developed by Research

Over the past 30 years, most sweet potato research in the highlands has focused on developing new varieties. This has involved collecting, introducing, establishing and evaluating sweet potato germplasm at Kuk Research Station and at HAES. Selections have been made and released (Akus 1982), and some have been evaluated for performance in farmers' fields. These include studies by Lutulel et al. (1996) and Naki (1987), who tested 30 varieties, including four developed from HAES (Akus 1982). However, not one of the recommended varieties has been adopted. The fact that farmers have not adopted apparently superior varieties indicates a serious flaw in the approach to developing new varieties for subsistence farmers, with important implications for future research into sweet potato varieties.

Conclusions

The factors that I have considered lead to the following conclusions.

- Dynamic changes over time have led to the development of different varieties of sweet potato.
- Genetic diversity in sweet potato has come about not only because of natural selection pressure, but also as a result of selection by people seeking to satisfy their needs for food and cash income.
- The trend in the shift from subsistence to commercially oriented production has important implications for future research and extension efforts.
- Sweet potato is an important food crop in the PNG highlands because of its potential value as an important source of food and cash income.
- Subsistence farmers do not readily adopt sweet potato varieties developed away from farming systems and local environments. Varieties must be developed in the major representative agroecological zones.
- Research and extension activities should focus on specific characteristics required for market or commercial purposes; desirable technologies developed from this are likely to trickle down to the subsistence sector and will provide a better return on investment, research and extension efforts.
- The value of sweet potato in terms of food and cash security is established amongst farmers in the region.
- Increased research funding for conservation of the genetic resource of sweet potato is urgently required.
- Any future variety developments must involve effective collaborative links between research institutions, extension agents and farmers, using a bottom-up rather than a top-down approach.

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Selecting Sweet Potato Genotypes Tolerant of Specific Environmental Constraints

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Abstract

The 'green revolution' promoted crop genotypes with high-yield potential, and high-input technology aimed at maximising their performance. However, there has been little benefit for those farmers with limited access to inputs, or where soil fertility problems are not easily corrected by fertilisers. Cultivars selected on research stations often fail to outperform traditional varieties, due to their vulnerability to environmental stresses. With appropriate screening, there is potential to combine stress tolerance with high yields and quality characteristics. This paper describes preliminary experiments aimed at identifying sweet potato (*Ipomoea batatas* (L.) Lam.) cultivars with tolerance to acid soils, low magnesium availability, and low phosphorus availability, respectively. There was considerable genetic variation in acid soil tolerance, and it was unrelated to yield potential on the research station. The potential for further screening of other stress-tolerance characters is discussed.

THE 'green revolution' was based on selecting and breeding crop genotypes with high yield potential, and then distributing them widely with a package of technology aimed at maximising their performance. This strategy greatly increased food production on fertile land where farmers had access to fertilisers and irrigation. However, for those farmers whose land poses particular fertility problems, and for whom fertilisers have limited availability or are ineffective in overcoming their fertility problems, the so-called high-performance plant varieties are not always successful.

In recent years, there has been increasing recognition and exploitation of the genetic diversity within and among crop species for tolerance to particular environmental stresses, including shading and low temperature, in addition to those relating to soil fertility.

Probably the most commonly studied trait is the tolerance to high soluble aluminium (Al) levels, which are largely responsible for the toxicity of acid soils. Sweet potato (*Ipomoea batatas* (L.) Lam.) is regarded as having intermediate tolerance of soil acidity (Abruna-Rodriguez et al. 1982). Munn and McCollum (1996) reported the use of root growth rate in solution culture as a rapid screening test for Al tolerance in sweet potato cultivars. Screening 379 sweet potato cultivars, Sangalang and Bouwkamp (1988) demonstrated that such tests correlated well with field performance in acid soil, but noted a negative correlation between Al tolerance and yield under nonstressed conditions. However, Ritchey (1991) identified high-yielding, Al-tolerant genotypes using similar methods. Ila'ava et al. (1996) compared 13 cultivars from PNG and the Pacific region, and observed that Al tolerance was correlated with tolerance to low calcium (Ca) concentrations in the root-zone. Abruna et al. (1979) also associated Al tolerance in sweet potato genotypes with ability to maintain adequate Ca uptake.

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Selection of salt-tolerant crops is emerging as an important strategy for managing salt-affected land. The International Potato Center (CIP) has had some success in selecting salt-tolerant sweet potato cultivars in Peru (Chávez et al. 1995) and Bangladesh (CIP 1995).

Tolerance of low phosphorus (P) availability has also attracted some research attention (Salinas and Sanchez 1976). P-fixing soils are widespread throughout the tropics, particularly in the Pacific region on soils of volcanic origin. P deficiency is the most common nutritional disorder limiting yield of sweet potato in the region (Halavatau et al. 1998). Fox et al. (1974) determined that sweet potato was more tolerant of low P than maize, Chinese cabbage or lettuce. Similarly, Djazuli and Tadano (1990) found sweet potato (cultivar Beniazuma) to be slightly more tolerant of low P than potato (cultivar Danshaku). However, the range of tolerance among sweet potato cultivars has not been studied. Tolerance of low P is often associated with high levels of endomicorrhizal infection of the roots. Khasa et al. (1992) ranked sweet potato among the crop species highly dependent on micorrhizas. Kandasamy et al. (1988) found considerable variation in the degree of micorrhizal infection among 60 sweet potato cultivars, suggesting potential for genetic difference in tolerance to low P.

Stress-tolerant crop genotypes alone cannot convert poor-quality land into highly productive farming systems. However, they form a valuable component of low-input strategies for improving crop production (Sanchez and Salinas 1981). There is evidence that stress-tolerant genotypes reach maximum performance at lower levels of amendment than sensitive genotypes (Salinas and Sanchez 1976). They may be particularly useful where the stress is difficult or expensive to fully alleviate, such as with soil acidity, P deficiency on P-fixing soils, and nutrient deficiencies due to mineral imbalance.

This paper describes preliminary experiments exploring the potential for selecting adapted sweet potato genotypes through field trials on soils with specific fertility problems.

Materials and Methods

Three sites were selected on the basis that they had suitable soil fertility problems, and that reasonable security and maintenance arrangements were possible. The sites were:

(a) an acidic tropudult on Lihir Island;

(b) a eutrandept with low magnesium availability at Hoskins, East New Britain Province; and

(c) a hydrandept with very low P availability, at Tambul, Western Highlands Province.

Bulk soil samples (0–0.15 metres (m) depth) were taken from each site and used for preliminary characterisation using small pot experiments. These included a nutrient-omission pot trial to determine which nutrients were inadequately supplied for optimal plant growth (Asher and Grundon 1991), and nutrient-rate pot trials for each deficient nutrient, to estimate the level of fertilisation needed in the field.

Twenty sweet potato cultivars were selected from the sweet potato improvement program (lowlands collection) at Keravat, for comparison in the Lihir and Hoskins trials. Multiplication plots were established adjacent to the field sites for production of planting material. However, at both Lihir and Hoskins, growth was poor and these needed to be supplemented with material from Keravat.

The trials were laid out in a split plot design, with four randomised complete blocks. Soil amendment treatment (lime or magnesium sulfate) was applied in strips the length of the field in the direction of tillage, and incorporated during the formation of ridges. Cultivars were planted on adjacent plots with and without amendment. Plots measured 4×6 metres (six ridges), of which the central four ridges were harvested. The Lihir trial received basal fertilisation of 100 kilograms per hectare (kg/ha) P as triple superphosphate (TSP), 100 kg/ha potassium (K) as potassium chloride (KCl) and 46 kg/ha nitrogen (N) as urea, with a lime application of 3 t/ha on amended plots. The Hoskins trial received basal fertilisation of 2 kg/ha copper (Cu) (broadcast in solution before forming ridges), 50 kg/ha N as urea, 100 kg/ha P as TSP and 50 kg/ha K as KCl, with 60 kg/ha magnesium (Mg) as magnesium sulfate on amended plots. All of the P, and half the N and K, were banded at planting, the remaining N and K were banded at approximately two months.

The Lihir trial was planted on 27 July 1998, and harvested on 27–28 January 1999. The Hoskins trial was planted on 24 September 1998 and harvested on 16–19 February 1999. For the Tambul site, preliminary pot trials were undertaken as described above, but the field trial has not yet been completed.

At harvest, tubers were separated into marketable and nonmarketable sizes and weighed. At Hoskins, leaves were sampled at approximately two months, and analysed for nutrient element concentrations at the University of Queensland, Australia, using inductively coupled plasma atomic emission spectrometry (ICPAES) following acid digestion.

Results and Discussion

Selected soil analysis results are given in Table 1. Notable are the low base status and high Al saturation in the Lihir soil, the relatively high base status but high Ca:Mg ratio in the Hoskins soil, and the high P retention in the Tambul soil. Tambul has a very high soil organic matter content, and a correspondingly lower Al saturation level than expected in mineral soils of such high acidity. The Hoskins soil also tested low in Cu, which supports the pot trial response to this nutrient.

Preliminary pot trials generally confirmed the results of the soil analyses. Table 2 shows a summary of the results from nutrient omission pot trials. Growth in the Lihir soil was poor at best, making it difficult to obtain clear responses. N and K were included as basal fertilisers in addition to P, as soil tests indicated they were low. In Hoskins soil, omission of Mg resulted in the lowest plant yield. Nutrient-rate pot trials confirmed these responses, with a large response to Mg up to the highest rate applied (equivalent to 60 kg/ha). Deficiencies of N, P, K and Cu were also detected, and were confirmed in nutrient-rate pot trials. Despite its low pH, the Tambul soil gave only slight responses to lime in preliminary trials with maize, and this was probably attributable to increased P availability, as tissue Al levels were low.

Yields from the Lihir trial are summarised in Table 3. Storage roots were stolen from a number of plots shortly before harvest, and the effect of theft on the observed yields cannot be estimated. It is likely that heavily yielding plots will have suffered greater theft, and plot position (accessibility) will have had an uneven effect. Thus, only tentative conclusions can be made from this trial.

Yields were generally low, and might have benefited from a longer equilibration period after the application of lime. Thieving is likely to have increased variability among replicates and thereby reduced statistical significance. Taking the trial overall, liming significantly increased marketable yield ($P < 0.05$). The effect on total yield was not as great, due to a significant reduction in the number of nonmarketable roots in response to liming.

There is no overall relationship between relative yields of cultivars and their response to lime. However, it is noteworthy that the five poorest-yielding cultivars in the absence of lime were also highly responsive to lime (Table 3). They can be said to be poorly adapted to acid soil conditions. In particular, L942 performed poorly without lime but was the second-highest yielder with lime. In addition, DOY2 showed a strong lime response, despite being a high yielder in the absence of lime. Cultivars which appeared to yield well regardless of lime application were K9 and KAV61. Interestingly, KAV61 came from Kavieng, an area with neutral to alkaline soils over lime, yet it appears to be relatively tolerant of acidity.

The soil in the Hoskins–Kimbe area, on the north coast of West New Britain Province, is notorious for Mg deficiency. The problem is well known to the oil palm industry, which dominates this region, but symptoms have also been recorded in sweet potato and cassava (R.M. Bourke, Research School of Pacific and Asian Studies, The Australian National University, pers. comm.). The problem appears to be due to a cation imbalance, rather than an absence of sufficient Mg in the soil. It was thought worthy of investigation for this reason: if there is enough Mg in the environment to sustain healthy growth, then there is potential for genetic variation in the plant's ability to capture it.

The Hoskins field trial unfortunately did not show evidence of Mg deficiency. This was despite the large Mg response observed in pot trials, and observations of foliar symptoms of Mg deficiency on some cultivars in the multiplication plots. The trial established well, and most plots attained good groundcover. However, storage root yields were generally poor, despite good growth of vines (Table 4). The season was unusually wet, particularly in the last two months, and this may have adversely affected yield. In terms of yield parameters, no cultivar responded significantly ($P < 0.05$) to Mg application. Overall, there was a significant increase in leaf Mg concentration (sampled at two months) in response to Mg application, but the magnitude was small. Leaf Mg concentration varied significantly among the cultivars, but was not correlated with yield. The critical concentration for Mg deficiency is not well defined as field evidence seems to vary. However, the range of Mg concentrations observed is considered to be marginal for Mg deficiency. Leaf Cu concentrations varied among cultivars, from levels considered deficient (< 5 mg/kg) to adequate. Leaf Cu concentration was positively correlated with yield. Although the relationship was weak, this suggests that Cu deficiency had not been completely corrected at least for some cultivars.

During the harvest at Hoskins, students and staff of Hoskins Secondary School conducted a taste evaluation. Roots were peeled and boiled, and students and staff sampled five cultivars each, scoring them for sweetness, texture, fibrousness and general appeal,

Table 1. Selected soil test results from the three sites chosen for field trials.

Site	Soil group	pH (H_2O)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (Olsen) (mg/kg)	Phosphorus retention (%)	Aluminium saturation (%)	CEC pH 7 (NH_4OAc) (me/100g)	Exchangeable cations (me/100g)			Copper (DTPA)
									Calcium	Magnesium	Potassium	(mg/kg)
Lihir	Tropudult	4.6	3.7	0.16	1.4	na	77	13.7	0.10	0.20	0.16	3.1
Hoskins	Eutrandept	6.5	2.6	na	31	na	na	11.7	10.20	1.02	0.48	0.5
Tambul	Hydrandept	4.7	16.2	1.05	10	76–96	44	31.0	1.10	0.55	0.52	9.5

na = not analysed; DTPA = diethylenetriaminepentaacetic acid; me = milliequivalents

Table 2. Summary of results from nutrient omission pot trials.

Site	Test species	Amendments giving positive yield response ($P < 0.05$)
Lihir	Maize	Lime
	Sweet potato	Phosphorus, lime
Hoskins	Maize	Magnesium, copper, nitrogen, phosphorus, potassium
Tambul	Maize	Phosphorus, potassium, lime
	Sweet potato	Nitrogen, phosphorus, potassium

Table 3. Yield results from the sweet potato cultivar comparison trial on acid soil, Lihir Island.

Cultivar[a]	Marketable yield (t/ha)		% change	Total yield (t/ha)	
	Unlimed	Limed		Unlimed	Limed
L 9	2.8	3.3	+16	4.4	8.7
DOY 2	2.8	9.4	+239	6.4	17.0
K 9	2.5	2.1	–18	5.2	4.7
KAV 61	2.5	2.2	–15	5.7	4.7
L 135	2.2	1.2	–45	6.3	2.6
KAV 79	2.2	0.8	–63	4.0	1.6
L 676	2.2	3.1	+41	6.0	8.6
L 43	2.2	3.4	+58	2.9	4.8
L 997	2.2	2.2	+1.6	6.7	3.9
L 949	2.0	1.6	–20	3.6	2.6
SIL 2	2.0	2.5	+25	4.5	5.3
MAS 1	1.9	1.4	–26	4.2	2.8
RAB 37	1.6	1.7	+6.4	4.0	4.0
B 11	1.6	1.6	0.0	3.4	3.9
K 142	1.5	1.2	–19	3.6	2.8
NUG 5	1.3	1.7	+39	3.9	3.2
L 46	1.2	2.2	+77	3.3	3.2
L 942	1.1	6.7	+488	3.5	9.5
L 879	0.4	1.4	+264	1.1	3.9
BUB 1	0.2	2.2	+933	2.7	3.8

[a]Cultivars are listed from highest to lowest marketable yield, in the unlimed treatment.

and ranking them in order of preference. This was the first such test that had been undertaken in the sweet potato improvement program, although cultivars are routinely scored for tuber shape and market appeal. In general, scores varied widely among testers for the same cultivar, but clear trends in preference emerged. Preference was well correlated with sweetness, and negatively correlated with fibrousness. Figure 1 compares the cultivars for yield and taste preference, illustrating how both parameters may be used in the selection of adapted cultivars that are likely to gain popular acceptance. Cultivars in the upper right-hand sector of the plot are most desirable. In this example, no cultivars are outstanding at Hoskins, but on the acid soil at Lihir DOY2 and K9 are promising.

To compare the relative performance of the cultivars at the two sites (Fig. 2), the marketable yield (unamended treatment) was plotted as percentage deviation from the trial average for each cultivar. The relative yields at Hoskins are correlated with those for the same cultivars at Keravat (P. van Wijmeersch, Pacific Regional Agricultural Program, pers. comm. 1998). However, relative yields at Lihir follow a very different pattern. This supports the conclusion that the cultivars are differentially adapted to the environment at each site—more specifically, that different levels of acid soil tolerance exist, and that these are not correlated with the yield in 'unstressed' conditions.

It is unfortunate that this project could not demonstrate similar genetic variation for tolerance to low Mg or low P. However, another character that may have relevance to environmental stress adaptation was found to vary enormously among the 20 cultivars studied. Leaf sodium (Na) concentration, measured during the Hoskins trial, showed a 20-fold difference between the lowest and highest testing cultivars (Fig. 3), and was unrelated to both yield and treatment in this trial. Such variability had been noted in sweet

Table 4. Summary of yield data and leaf magnesium (Mg) and copper (Cu) concentrations from Hoskins sweet potato variety evaluation.

Cultivar[a]	Total yield (t/ha)		Marketable yield(t/ha)		Leaf [Mg] (% dwt)		Leaf [Cu] mg/kg	
	Mg0	Mg60	Mg0	Mg60	Mg0	Mg60	Mg0	Mg60
B 11	21.34	13.47	19.94	11.34	0.268	0.272	10.6	9.1
BUB 1	9.38	8.40	7.79	7.00	0.279	0.324	4.8	5.8
K 9	5.44	7.23	3.36	4.27	0.272	0.239	5.2	7.6
K 142	6.04	4.65	5.00	3.71	0.220	0.262	7.9	8.0
KAV 79	6.21	2.54	4.63	1.48	0.297	0.345	2.9	3.8
L 676	5.22	3.17	3.75	2.05	0.301	0.331	4.2	5.6
L 997	4.38	3.25	3.81	3.06	0.291	0.306	3.1	2.6
L 43	4.25	3.35	3.00	2.40	0.316	0.270	4.6	2.8
L 949	4.13	2.98	3.17	2.02	0.226	0.229	6.1	4.7
KAV 61	3.16	2.59	2.30	1.66	0.211	0.226	8.1	8.1
L 942	3.25	2.36	2.63	1.80	0.232	0.245	2.4	2.8
L 135	2.81	2.33	2.11	1.83	0.226	0.233	7.1	7.7
DOY 2	2.17	1.92	1.45	1.27	0.247	0.259	6.6	5.8
SIL 2	2.30	1.59	1.75	1.09	0.296	0.331	8.8	7.2
RAB 37	2.06	1.72	1.53	1.23	0.302	0.308	6.1	3.5
L 46	1.19	1.69	0.81	1.33	0.283	0.279	3.7	8.2
MAS 1	1.19	0.75	0.50	0.36	0.236	0.273	10.1	8.9
L 9	0.25	0.95	0.13	0.66	0.288	0.312	3.0	2.8
L 879	0.66	0.42	0.48	0.19	0.215	0.218	4.4	5.6
NUG 5	0.53	0.39	0.03	0.06	0.292	0.335	4.2	3.2
LSD (0.05)	4.05		3.64		0.045		2.8	

dwt = dry weight; LSD = least significant difference; Mg0 = no Mg treatment; Mg60 = Mg treatment at 60 kg/ha
[a]Cultivars are listed in order of total yield across both treatments.

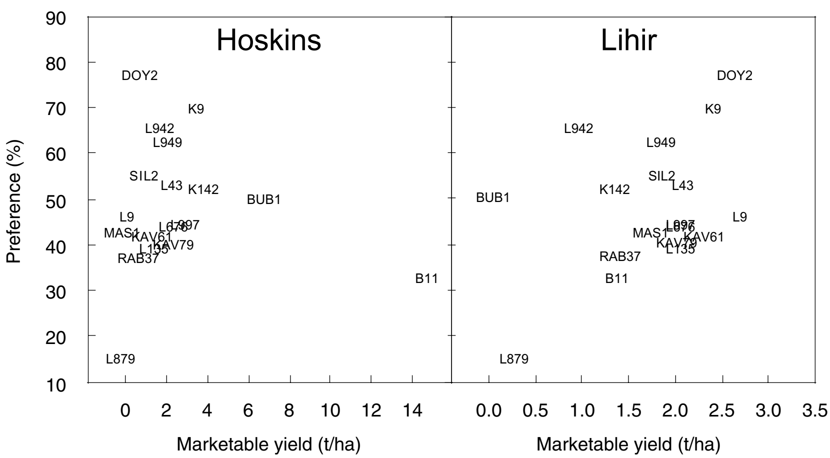

Figure 1. Comparison of sweet potato cultivars based on yield and taste-test preference at two trial sites and consumer preference.

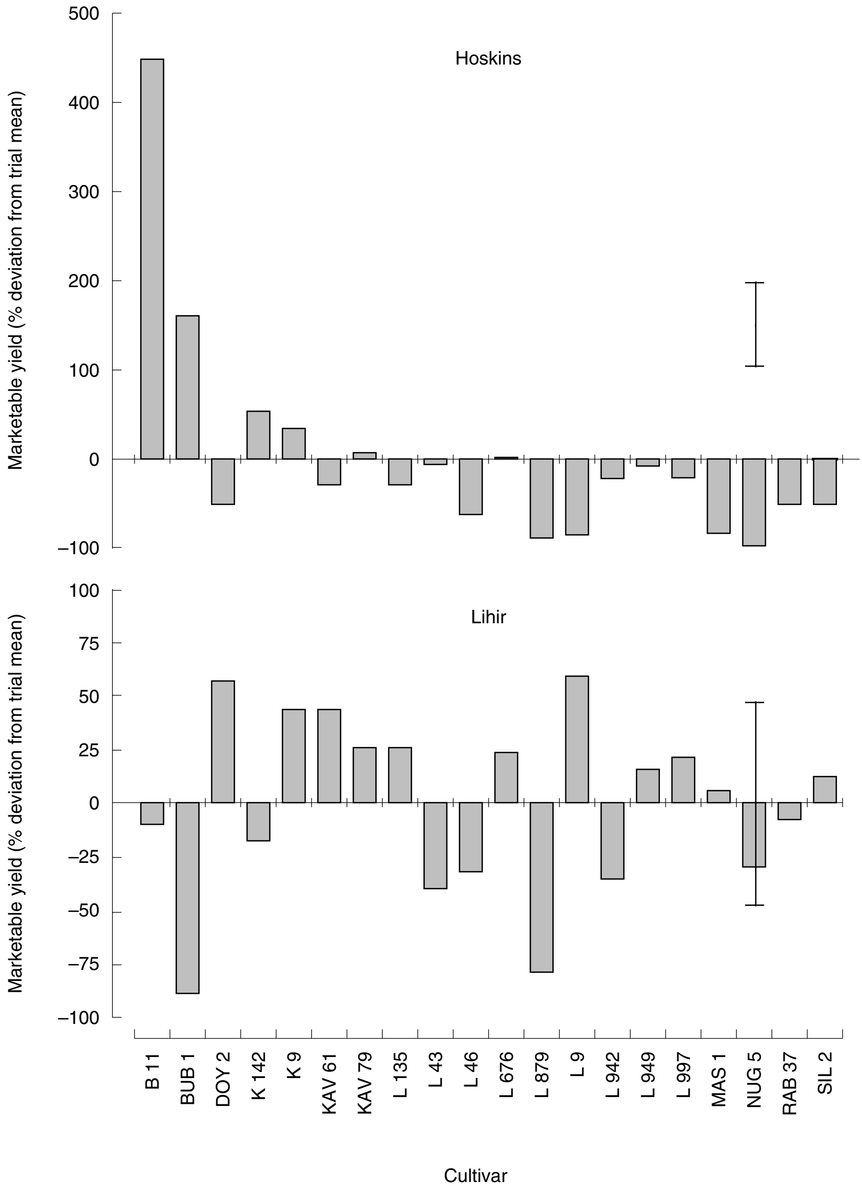

Figure 2. Comparison of relative yields of sweet potato cultivars at Hoskins and at Lihir. Error bars represent the least significant difference ($P = 0.05$).

potato in salinity tolerance trials, but Na exclusion was not found to confer tolerance to salinity (J. O'Sullivan and J. Yauwo, The University of Queensland, pers. comm. 1996). Ivahupa (1998) found that species with greater Na uptake had greater tolerance of low K availability, due to some substitution of Na for K. Sivan (1995) found that the Na excluder taro (*Colocasia esculenta*) had lower tolerance to water stress than the Na absorber xanthosoma (*Xanthosoma sagittifolium*), under low K nutrition. Thus, the observed Na variability may indicate the existence of genetic variation for tolerance to low K or to drought.

Conclusions

The Lihir experiment demonstrated that selected cultivars from PNG's more elite lowland sweet potato varieties showed differences in acid soil tolerance. It illustrated that cultivars ranked as high yielders on 'normal' sites should not be expected to rank similarly on acid soils. Deliberate selection of acid soil-tolerant cultivars is advisable. Yield under nonstressed conditions did not correlate with yield on acid soils: some high-yielding cultivars displayed considerable tolerance, while others performed poorly. These findings are contrary to the observation of Sangalang and Bouwkamp (1988) that acid soil-tolerant cultivars tend to have low yield potential in nonstressed conditions.

While this study was unable to demonstrate differential tolerance to low availability of Mg or P, we feel that the effects of these nutrient characteristics are worth further examination. Also of interest is the variability in Na uptake among sweet potato cultivars, which may be related to drought tolerance where K nutrition is suboptimal.

Acknowledgments

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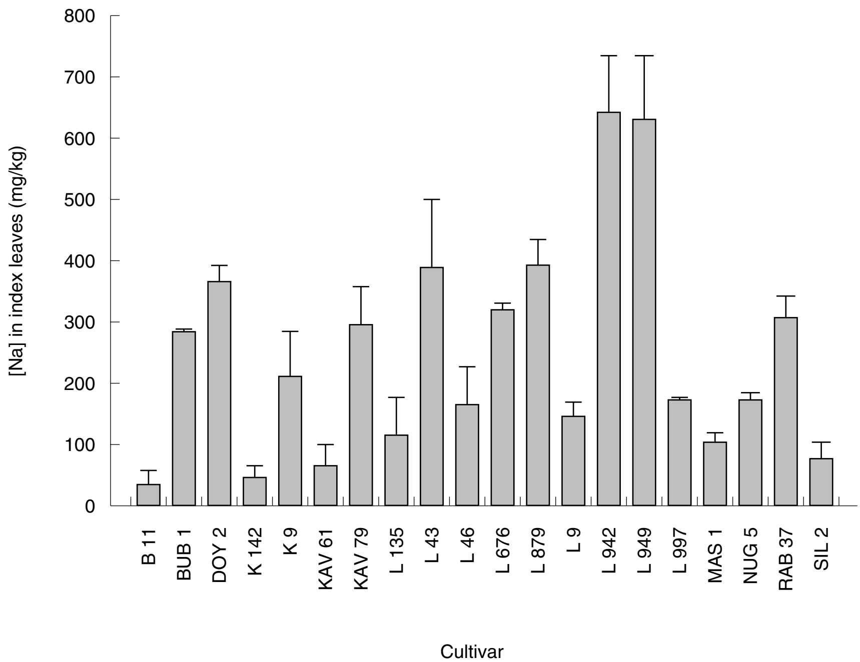

Figure 3. Sodium concentration in index leaf blades of sweet potato cultivars, sampled from the field trial at Hoskins. Error bars represent standard deviation.

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Integrated Nutrient Management Research on Sweet Potato at Hobu, Morobe Province

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Abstract

In order to investigate the effect of organic and inorganic nutrient sources on sweet potato tuber yield, we carried out a series of experiments at Hobu, Morobe Province, PNG. In the first experiment, plots were planted with *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica*. After one year, these plants were slashed and sweet potato was planted. Sweet potato yield was lowest in plots with previous gliricidia, but there were no differences in yield between previous piper and imperata. In the second season, there was no significant difference in sweet potato yields between the plots. The second experiment consisted of a factorial fertiliser trial with four levels of nitrogen (0, 50, 100 or 150 kilograms per hectare) and two levels of potassium (0 or 50 kilograms per hectare). Nitrogen fertilisers increased tuber yield in the first season, but depressed tuber yields in the second and third seasons. Nitrogen fertiliser significantly increased vine yields in all three seasons. Potassium fertiliser had no effect on marketable tuber yield, but increased nonmarketable tuber yields. The third experiment compared nitrogen provided by inorganic fertiliser or by poultry litter at four rates (0, 50, 100 or 150 kilograms per hectare). No difference was found between the inorganic fertiliser and poultry litter, and highest yields were found at 100 kilograms of nitrogen per hectare. In the second season, no significant response to nitrogen was observed. This research indicates that sweet potato yield can be significantly increased by either inorganic or organic nitrogen applications, although yield variation is considerable. Sweet potato yields after fallow were moderate but less variable than yields following inorganic nutrient inputs. Fallowing seems the safest way to obtain steady sweet potato yields; with extra inputs through inorganic fertiliser or poultry litter, tuber yields may be strongly increased or decreased.

UNTIL the 1980s, it was widely perceived that inorganic fertilisers were a viable means of increasing land productivity in the low fertility soils of the humid tropics. This line of thought was adopted by, among others, the Food and Agriculture Organization (FAO) Freedom from Hunger Campaign and its Fertiliser Program, which began in the 1960s. Organic fertilisers (e.g. compost or farmyard manure) were regarded as important, but it was obvious that they were not available in sufficient quantity to drastically increase food production. In the early 1980s, various reports showed that the use of inorganic fertilisers in the tropics had stagnated, and this was explained by poor marketing and inadequate profitability. From that time on, integrated nutrient management has been advocated. Essentially, this involves the combination of both inorganic and organic fertilisers to increase crop production (Janssen 1993).

In this paper, we present the results of integrated nutrient management research with sweet potato (*Ipomoea batatas* (L.) Lam.) in the humid lowlands of Morobe Province, PNG. Despite the fact that sweet

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potato is the main staple crop in many parts of PNG, the number of detailed, integrated nutrient management experiments with sweet potato is limited (Hartemink and Bourke 2000). Furthermore, most nutrient management experiments have been conducted on experimental stations and little work has been done in farmers' fields. This is particularly unfortunate since poor crop nutrition contributes to the low yield of root crops of many farmers in PNG and throughout the Pacific region (Halavatau et al. 1998).

The research that we report here took place onfarm at Hobu (6°34'S, 147°02'E), about 15 kilometres north of the PNG University of Technology (Unitech) at Lae, Morobe Province. The experimental site was amongst farmers' fields and 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) a fallow experiment with both natural and improved fallows; (ii) inorganic fertiliser experiments with nitrogen (N) and potassium (K); and, (iii) poultry litter fertiliser experiments. The main aim of these experiments was to assess the effect of different nutrient inputs on sweet potato yield.

Environmental Conditions at Hobu

Hobu is on the foothills of the Saruwaged mountain range in Morobe Province, which forms the major landmass of the Huon Peninsula. The experimental site was located on an uplifted alluvial terrace at an altitude of 405 metres above sea level, with slopes of less than 2%. The soils at this location were 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 layers below 0.2 metres of depth. Many of the gravels and stones are rotten, and effective rooting depth is over 0.7 metres. The soils are generally fertile with moderately high organic carbon (C) contents and high levels of exchangeable cations. The topsoils are clayey and have bulk densities of 0.6–0.8 kilograms per cubic decimetre (kg/dm^3). Table 1 presents some chemical and physical properties of the soils at Hobu. The soils are classified as mixed, iso-hyperthermic, Typic Eutropepts (United States Department of Agriculture Soil Taxonomy) or Eutric Cambisols (World Reference Base) (Hartemink et al. 2000b). Inceptisols (Eutropepts) are the most common soils in PNG, covering 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 tonnes per hectare (ha) per year, which is a very low erosion rate. However, since the experiments described in this paper were carried out on land with a slope of less than 2%, erosion was not a problem.

Rainfall records for the experimental site were available only since the start of the experiments in November 1996. In 1997, there was a total rainfall of 1897 millimetres (mm), probably well below the long-term average due to the El Niño southern oscillation climatic event that severely affected the Pacific 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. Unitech (Morobe Province) total rainfall in 1997 was only 2594 mm compared with the long-term annual mean of 3789 mm measured over 20 years. Temperature data are not available for the experimental site, but average daily temperatures at Unitech were 26.3°C. Since Unitech is at a lower altitude (65 metres above sea level) than the experimental site, temperatures at Hobu were probably slightly lower.

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, *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 done, which is in accordance with the land-clearing practices of local farmers.

Effect of Fallow on Sweet Potato Yield

Shifting cultivation systems, in which cropping periods alternate with short fallow periods, are still widely practised in the humid lowlands of Morobe Province. Very little is known about nutrient cycling in these shifting cultivation systems. In particular, the effect on sweet potato yield of nutrient addition by secondary fallow vegetation is largely unknown.

The secondary fallow vegetation in many parts of the lowlands is dominated by *Piper aduncum* (L.), a shrub indigenous to tropical America (Rogers and Hartemink 2000). It is not known how and when *P. aduncum* arrived in PNG, but it was firstly described in Morobe Province in 1935. Farmers claim that piper arrived in the Hobu area in the early 1970s. In the standard work

Table 1. Chemical and physical properties of Typic Eutropepts soil at the experimental site at Hobu, Morobe Province, PNG.[a]

Sampling depth (m)	pH_w	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC ($mmol_c$/kg)	Exchangeable cations ($mmol_c$/kg)			Base saturation (%)	Particle size fractions (g/kg)			Bulk density (tonnes/m^3 of soil)
						Ca	Mg	K		Clay	Silt	Sand	
0–0.12	6.2	54.6	5.0	9	400	248	78	16.9	86	480	160	360	0.82
0.12–0.23	6.3	25.4	2.3	2	155	220	84	1.9	100	620	110	270	0.85
0.23–0.39	6.6	13.7	1.3	1	338	200	105	1.4	91	600	140	260	0.97
0.39–0.99	7.4	2.1	0.3	4	357	189	99	1.4	82	340	110	550	1.30

CEC = cation exchange capacity (pH 7); $mmol_c$ = millimoles of charge; pH_w = pH in water

[a] Samples taken from a soil pit in February 1997, fallowed since 1992

on New Guinea vegetation by Paijmans (1976), *P. aduncum* is not mentioned as a separate species. Nowadays that is hard to imagine, because in many parts of the humid lowlands piper forms monospecific stands. In Morobe Province it occurs at altitudes of up to 600 metres above sea level, and it is also found in the highlands at altitudes of up to 1900 metres above sea level. It grows very fast, with virtually no undergrowth of weeds or shade-tolerant tree species. Despite this lack of undergrowth, we have never observed signs of severe erosion under piper in PNG.

Farmers in the Hobu area usually have short-term piper fallows (< 2 years) followed by one crop of taro gradually intercropped with sweet potato, sugarcane (*Saccharum* sp.) and banana (*Musa* sp.). The length of the fallow period has, however, recently been reduced due to the need for increased food and cash crop production to accommodate the growing population (Allen et al. 1995; Freyne and McAlpine 1987). In the Hobu area, secondary fallow vegetation is dominated by piper, and imperata grassland is also common.

Although the aggressive invasion of piper has been described, including its possible effect on PNG's rich biodiversity (Kidd 1997; 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 natural fallows such as imperata. With the shortening of the fallow period, there may be a need to introduce fallow species that improve the soil fertility more rapidly than natural fallows (Young 1997). *Gliricidia sepium* is planted as an improved fallow in some parts of the world, and is one of the most widely cultivated multipurpose tree (Simons and Stewart 1994). Gliricidia is common in the PNG lowlands, where it is used for shade in cocoa plantations.

Experimental design

Sixteen plots each of 6.0 square metres (m^2) were laid out, and four treatments were assigned to the plots in a randomised complete block design. The fallow plots were planted at the end of November 1996. Four plots were planted with piper seedlings (0.4 m) from a nearby roadside. Four plots were planted with gliricidia cuttings (0.4 m) from a local cocoa plantation. Piper and gliricidia fallows were planted at distances of 0.75 m × 0.75 m (17,778 plants per ha). These spacings are often observed in natural piper fallows. In four plots, natural regrowth was allowed to occur, which was immediately dominated by *Imperata cylindrica*. Some minor weeds in the imperata fallow were *Ageratum conyzoides, Sphaerostepanos unitus*, *Rottboellia exalta*, *Sida rhombifolia*, *Polygala paniculata*, *Euphorbia hirta* and *Emilia sonchifolia*. In the remaining four plots, the local cultivar of sweet potato, Hobu1, was planted (E. Guaf, Lowlands Agricultural Experiment Station, Keravat, pers. comm. 1997). This is a widely grown cultivar with red-skinned tubers and white flesh, which appears to be not very susceptible to sweet potato weevil, an important pest in PNG (Bourke 1985b). Planting material was obtained from local gardens and consisted of vine cuttings that were planted almost vertically in the soil using a stick. One cutting of about 0.4 m in length with 4–6 nodes was planted in each hole, a practice which generally gives the highest tuber yield (Levett 1993). Planting distance was 0.75 m × 0.75 m (17,778 plants/ha). The sweet potato plots were continuously cultivated with sweet potato for four seasons and no inorganic fertilisers were applied.

After one year, all fallow vegetation was cut to ground level. Piper plants were separated into stems, branches, leaves and litter. Gliricidia plants were separated into stems, leaves and litter. The imperata fallow produced virtually no litter, so total biomass was taken. In each plot, total fresh matter of the different plant parts was weighed, 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. The previous fallow plots were then planted with sweet potato like to the continuously cultivated plots. The previous fallow plots were not tilled for planting, and were cultivated with sweet potato for two seasons.

The sweet potato cropping seasons lasted for about 170 days, after which the plots were harvested. Vines were cut at ground level, weighed and removed from the plot. In their gardens, farmers remove vines, a practice that may be related to allelopathic effects that alter nutrient uptake (Walker et al. 1989). Tubers were manually dug, counted, separated into marketable tubers (> 100 grams (g)) and nonmarketable tubers (< 100 g) and removed from the plot. All plots were replanted directly after a harvest. Weeds were pulled out manually and were not removed from the plot. No pesticides were used in the experiments. Figure 1 shows the daily rainfall during the experimental period and during each of the four seasons.

Nutrient input and sweet potato yield

The nutrient input of the one-year fallow is shown in Table 2. Total N returned to the field via gliricidia leaves and litter was 192 kg N/ha compared to

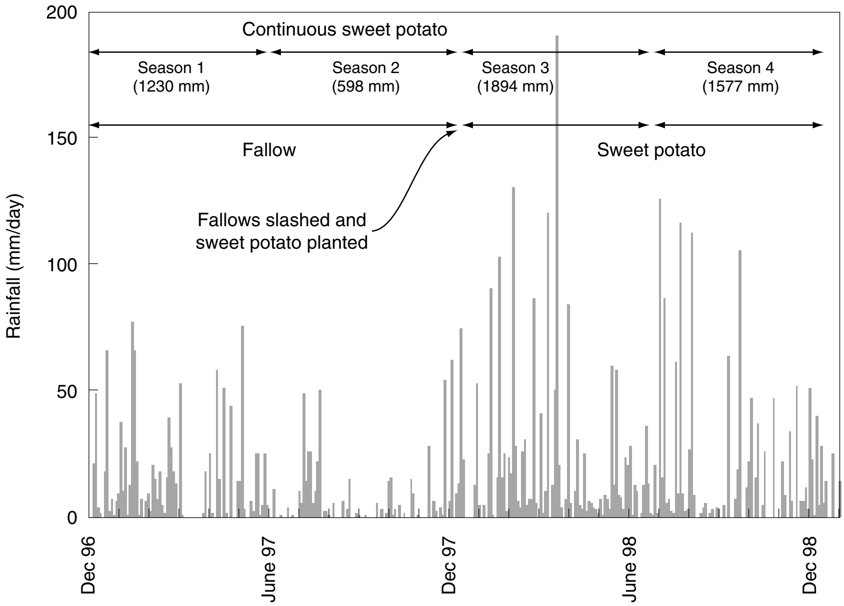

Figure 1. Daily rainfall during fallow trial (total rainfall during each season is given in parentheses).

97 kg N/ha for piper and 76 kg N/ha for imperata. The amount of phosphorus (P) returned by the fallow vegetation was similar for all three fallows at around 12–14 kg/ha. Piper returned 206 kg K/ha compared to 89 kg K/ha returned by gliricidia and imperata.

In the first season after the fallow, marketable sweet potato yield after piper and imperata was about 11 tonnes/ha, which was significantly higher than that under continuous sweet potato (7.8 tonnes/ha) or after gliricidia fallow (8.4 tonnes/ha) (Table 2). Variation in nonmarketable tuber yield after the fallows was large, and differences were not statistically significant. Total tuber yield (marketable plus nonmarketable tubers) was highest after piper (14.4 tonnes/ha) and significantly lower after gliricidia fallow (9.9 tonnes/ha). Vine yield was similar under continuous sweet potato cultivation and after piper and gliricidia fallow, but significantly lower after imperata fallow.

In the second season, there was no fallow effect on marketable sweet potato yield. Nonmarketable tuber yield was significantly lower in plots with previous imperata, but no differences were found between the other treatments. Total tuber yield in the second season was similar for all treatments. Cumulative tuber yield over the two seasons was about 29 tonnes/ha for piper and imperata but less than 25 tonnes/ha in the continuous sweet potato plots. Cumulative vine yield over the two seasons was 53–60 tonnes/ha for continuous sweet potato and plots with previous gliricidia or piper, but it was less than 40 tonnes/ha in plots with previous imperata.

Effect of Inorganic Fertiliser on Sweet Potato Yield

Literature is available on the use of inorganic fertilisers on sweet potato, although the amount of information is limited compared with other staple crops of the tropics such as rice and maize. Sweet potato consumes considerable amounts of K, and the responses to K fertilisers have been generally recorded (de Geus 1973). Sweet potato has a high N requirement, but can give reasonable yields in soils of poor fertility (Hill et al. 1990), which may be partly due to 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 wide range of N fertiliser 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).

Table 2. Sweet potato yield over two seasons following one year of piper, gliricidia or imperata fallows, or continuous cultivation.

Preceding treatment	Nutrient input[a] (kg/ha)			Yield in tonnes/ha (fresh weight)					
	N	P	K	Marketable tubers		Nonmarketable tubers		Vines	
				First season	Second season	First season	Second season	First season	Second season
Piper	97	14	209	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[b]	0	0	0	7.8	12.8	2.4	2.0	32.3	27.4
SED[c]				1.3	ns	ns	0.3	3.9	4.1

ns = not significant ($P > 0.05$)

[a]Nutrients returned with the aboveground biomass when the fallows were slashed and the first season of sweet potato was planted.

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

[c] Standard error of the difference in means (SED), with 9 degrees of freedom

In PNG, various inorganic fertiliser experiments have been conducted since the 1950s. Bourke (1977) summarised 17 field trials and 6 pot trials conducted on volcanic ash soils in Keravat, and concluded that N and K were most important. Nitrogen increased vine yield, but N responses to tuber yield were inconsistent. Potassium fertiliser 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 fertilisers. Overall, the literature seems to suggest that sweet potato in PNG responds inconsistently to inorganic fertilisers.

Experimental design

The inorganic fertiliser experiment at Hobu was laid out as a randomised block design with four levels of N (0, 50, 100 or 150 kg/ha) and two levels of K (0 or 50 kg/ha) in a factorial combination. Each treatment was replicated four times and plot size was 4.5 m × 4.5 m. The experiment lasted for three consecutive seasons between February 1997 and August 1998. Throughout this experiment the sweet potato cultivar Hobu1 was used. During the experiment, weeds were pulled out manually and were not removed from the plot. No pesticides were used.

The first crop was planted on 10 February 1997. Potassium was broadcast directly after planting. Nitrogen fertiliser was given in split applications. The 100 kg/ha treatment received 50 kg N/ha at planting and 50 kg N/ha 59 days after planting (DAP). The 150 kg/ha group received 50 kg N/ha at planting, 50 kg N/ha at 59 DAP and a further 50 kg N/ha at 80 DAP. The first crop was harvested on 30 July 1997 (170 DAP). At harvest, vines were cut at ground level, weighed, and removed from the plot. Tubers were manually dug, counted and separated into marketable tubers (> 100 g) and nonmarketable tubers (< 100 g), then removed from the plot. Total rainfall received during the first crop was 1028 mm. All plots were replanted directly after the harvest.

The second crop was planted on 1 August 1997. Potassium and the first application of N fertiliser were given on 8 August 1997. The second N application was given on 30 September 1997 (60 DAP) and the third on 21 October 1997 (81 DAP). Plots were harvested on 10 February 1998 (193 DAP) using harvesting procedures similar to the first season. Rainfall in the second season was 1034 millimetres (mm).

The third crop was planted on 12 February 1998. Potassium and the first N application were given on 20 February 1998. The second and third N applications were given on 10 April 1998 (57 DAP) and 6 May 1998 (83 DAP), respectively. Harvesting took place on 6 August 1998. Total rainfall received in the third season was 2214 mm. Figure 2 shows the daily rainfall during the experimental period and for each of the three seasons.

Sweet potato yield

Sweet potato tuber and vine yields from each of the three seasons are shown in Table 3. Marketable tuber yield in the first season ranged from 18.3 to 23.8 tonnes/ha but was not affected by K fertiliser. Marketable tuber yields were increased by N application ($P = 0.10$), with the highest yield being obtained with 100 kg N/ha. Nonmarketable tubers were significantly increased by about 1 tonne/ha due to the K fertiliser. Nitrogen fertiliser significantly ($P < 0.05$) increased total tuber yield (marketable + nonmarketable tubers) and also increased vine yield by about 10 tonnes/ha.

In the second season, N fertiliser significantly reduced marketable tuber yields. This reduction was almost linear, from about 25 tonnes/ha with no fertiliser to 17 tonnes/ha with 150 kg N/ha. Potassium fertiliser had no significant effect on the marketable tuber yield but increased nonmarketable tuber yield similarly to the first season. Both N and K fertilisers did not affect total tuber yield but increased vine yields similarly to the first season.

In the third season, yield levels dropped dramatically in all treatments. Marketable tuber yield in the control plots was only 7 tonnes/ha and N fertiliser reduced yield significantly by about 3 tonnes/ha. Nitrogen fertiliser also depressed nonmarketable yield. Vine yield in the control plots was 11 tonnes/ha lower than in the second season. Nitrogen fertiliser significantly increased vine yield to about 12 tonnes/ha at 100 kg N/ha.

The overall pattern emerging from these trials is an increase in yield in the first season with N fertilisers but a decrease in tuber yields in the second and third seasons (Table 4). Nitrogen fertiliser significantly increased vine yield in all three seasons. Potassium fertiliser had no effect on marketable tuber yield but increased nonmarketable tuber yield.

Effect of Poultry Litter or Inorganic Fertiliser on Sweet Potato Yield

In PNG, various field trials with sweet potato have shown that organic fertilisers give higher and more consistent yields than inorganic inputs (D'Souza and

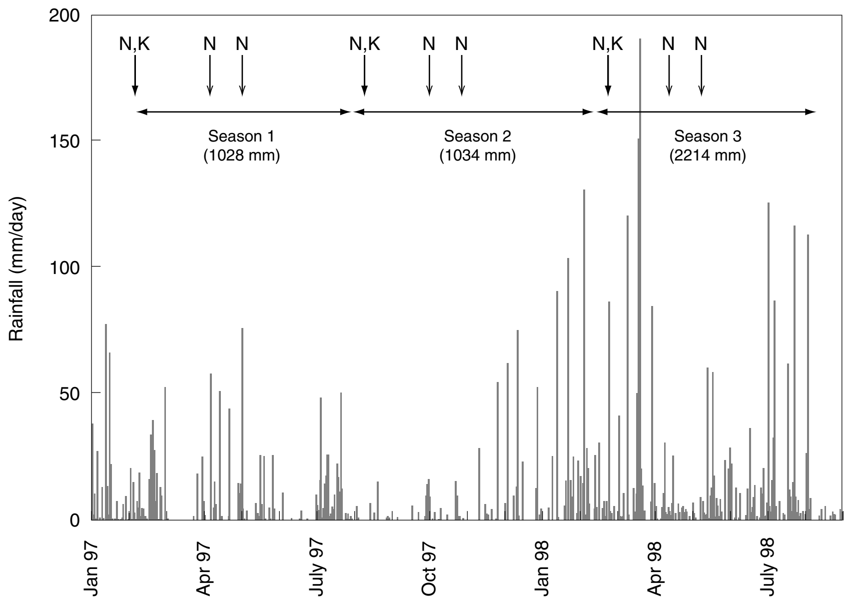

Figure 2. Daily rainfall during inorganic fertiliser trial (total rainfall during each season is given in parentheses). Vertical arrows indicate timing of nitrogen (N) and potassium (K) fertiliser applications.

Bourke 1986; Floyd et al. 1988; Preston 1990). Various factors could be involved, such as the addition of beneficial nutrients in organic matter that are not found in inorganic fertilisers, and the improvement of physical or biological properties of the soil.

In the highlands of PNG, 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 who raise chickens for large commercial companies such as Zenag and Tablebirds. The chickens are usually raised in sheds on sawdust, with feed provided by the companies. The poultry litter (manure and sawdust) is usually removed from the shed when the chickens are slaughtered, and it is dumped near the shed. It is hardly used in food gardens despite the fact that it contains many nutrients.

Igua (1985) conducted an experiment near Port Moresby with poultry litter as fertiliser for sweet potato, and found that highest yields were obtained with 10 tonnes of poultry litter/ha. Higher application rates depressed sweet potato yield. No other reports are available on the effect of poultry litter on sweet potato yield in PNG.

Experimental design

Our poultry litter experiment consisted of four levels of N (0, 50, 100 or 150 kg/ha) given as poultry litter or as inorganic fertiliser (NPK). The same

Table 3. The effect of nitrogen and potassium fertilisers on sweet potato yield over three seasons.

Inorganic fertiliser (kg/ha)[a]		Yield in tonnes/ha (fresh weight)								
N	K	Marketable tubers			Nonmarketable tubers			Vines		
		First season	Second season	Third season	First season	Second season	Third season	First season	Second season	Third season
0	0	18.3	24.6	7.0	3.2	1.0	1.3	39.9	37.3	26.4
50	0	22.7	20.4	5.2	3.2	1.2	0.9	49.1	46.6	30.4
100	0	23.8	21.5	5.8	3.3	1.1	1.5	52.9	51.0	39.9
150	0	23.2	17.3	2.9	4.0	1.1	0.5	53.0	47.5	36.9
0	50	17.7	21.7	5.6	3.3	1.7	1.8	51.5	49.4	30.9
50	50	21.2	17.9	2.6	4.5	1.7	0.9	49.1	45.5	32.9
100	50	23.5	20.4	6.0	5.4	1.4	1.9	57.5	61.7	36.6
150	50	19.6	17.8	2.7	4.5	1.9	0.7	55.7	53.1	35.5
SED[b]		4.3	3.6	1.5	0.9	0.5	0.4	5.3	6.2	3.1

[a] Applied during each season
[b] Standard error of the difference between two means (SED), with 21 degrees of freedom

Table 4. Summary of the effects of inorganic nitrogen and potassium fertilisers on sweet potato yield over three seasons.

	Nitrogen			Potassium		
	First season	Second season	Third season	First season	Second season	Third season
Marketable tuber yield	+	–	–	0	0	0
Nonmarketable tuber yield	0	0	–	+	+	0
Total tuber yield	+	0	–	0	0	0
Vine	+	+	+	0	+	0

0 = no effect; + = yield-increasing effect; – = yield-depressing effect

amount of K and P as was given to the poultry litter plots was applied to the inorganic fertiliser plots. The experiment was laid out as a randomised complete block design with four replicates per treatment. The experiment lasted for two seasons. The first crop was planted on 8 August 1997 and, directly after planting, the poultry litter or NPK fertiliser was applied. The NPK fertiliser (ammonium sulfate) application was split, and the second application was given on 18 November 1997 (108 DAP). All plots were harvested on 24 February 1998 (200 DAP). The second crop was planted on 4 March 1998 and poultry litter or NPK fertiliser was applied directly after planting. The second NPK application was given on 29 May 1998 (86 DAP). The crops were harvested on 10 September 1998 (190 DAP). Harvesting techniques were similar to those used in the fallow and inorganic fertiliser experiments. Figure 3 shows the daily rainfall during the experiment for the two seasons: 1203 mm and 2091 mm in the first and second seasons, respectively.

Nutrient concentrations of the poultry litter in the first season were 24.6 g N/kg, 15.7 g P/kg, 22.5 g K/kg, 30.2 g calcium (Ca)/kg, and 6.4 g magnesium (Mg)/kg. The poultry litter contained about 84% dry matter and 362 g Ca/kg. Application of 50 kg N/ha corresponded to 2.4 tonnes/ha of fresh poultry litter. In the second season, the poultry litter contained lower levels of nutrients: 13.0 g N/kg, 12.5 g P/kg, 10.3 g K/kg, 30.2 g Ca/kg, and 6.4 g Mg/kg. Dry matter content was 59% and application of 50 kg N/ha corresponded to 6.5 tonnes/ha of fresh poultry litter.

Sweet potato yield

In the first season, both poultry litter and inorganic N fertiliser significantly increased marketable sweet potato yield (Table 5). The yield pattern was similar for both N sources (a quadratic response) and highest yields were recorded when 100 kg N/ha was applied. There was no effect on nonmarketable tuber yield in the first season, although inorganic N fertiliser at 150 kg/ha significantly increased vine biomass.

In the second season, both poultry litter and inorganic N fertiliser significantly reduced marketable tuber yield. In the control plots, marketable tuber yield was similar to that of the first season but nonmarketable tuber yield was about 10-fold higher. No effect of poultry litter or inorganic fertiliser was recorded in the second season. Vine yield was, on average, lower in the second season in most treatments. Application of 150 kg N/ha as inorganic fertiliser significantly increased the vine biomass to 51 tonnes/ha.

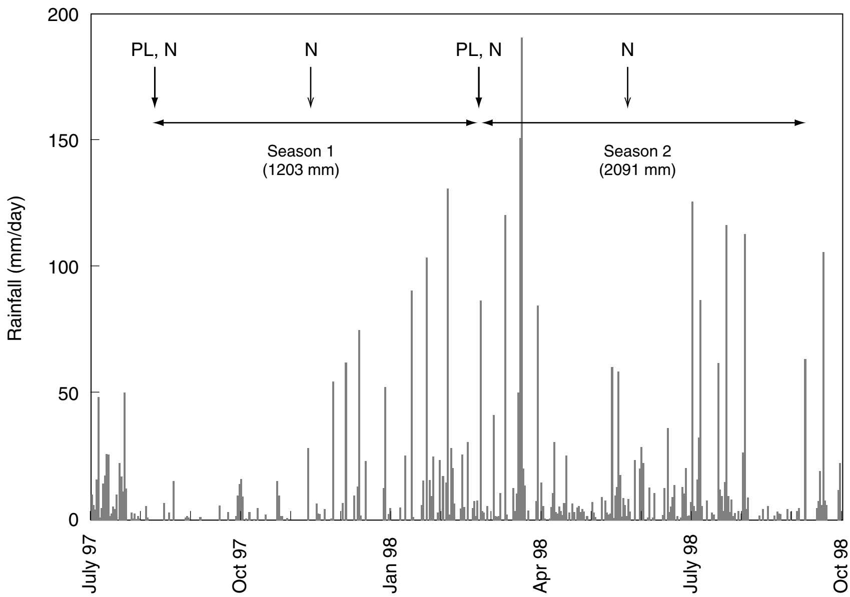

Figure 3. Daily rainfall during poultry litter and inorganic fertiliser trial (total rainfall during each season is given in parentheses). Vertical arrows indicate timing of poultry litter (PL) and inorganic nitrogen (N) fertiliser applications.

Table 5. The effect of inorganic fertiliser or poultry litter on sweet potato yield over two seasons.

N as poultry litter (kg/ha)	N as inorganic fertiliser (kg/ha)	Yield in tonnes/ha (fresh weight)					
		Marketable tubers		Nonmarketable tubers		Vines	
		First season	Second season	First season	Second season	First season	Second season
0	0	12.7	13.3	0.4	4.5	37.1	32.4
50	0	15.7	11.5	0.5	3.1	41.0	34.3
100	0	21.9	7.3	0.8	4.1	48.0	36.4
150	0	13.5	7.4	0.4	4.7	41.1	51.6
SED[a]		4.1	2.7	0.2	1.1	6.2	3.4
0	0	12.7	13.3	0.4	4.5	37.1	32.4
0	50	19.6	6.8	0.6	4.3	37.6	31.0
0	100	26.7	10.6	0.7	5.1	38.1	39.7
0	150	16.6	8.3	0.6	4.3	48.0	42.2
SED[a]		3.6	2.9	0.2	0.8	2.8	6.0

[a]Standard error of the difference in means (SED), with 9 degrees of freedom

Yield Variation and Yield Trends

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

Yields were generally higher in seasons with lower rainfall. Sweet potato is reportedly very sensitive to excess soil water during the first 20 DAP when tubers are formed (Hahn and Hozyo 1984). We therefore calculated a regression analysis between marketable yield and rainfall over the first 20 DAP (analysis not shown), but found no obvious relationship. We then calculated correlation coefficients for tuber yield, vine yield and total rainfall received in the season (Table 6), which showed that high rainfall at Hobu was significantly correlated with lower marketable and nonmarketable tuber yields. Vine yield was positively correlated with rainfall, suggesting that the reduction in tuber yield in wetter seasons favours the growth of the vine biomass. The number of cropping seasons at Hobu was significantly correlated with both marketable and nonmarketable tuber yield, but not with vine biomass.

At Unitech, the correlations between yield, rainfall and cropping seasons were weaker. The number of cropping seasons did not correlate with tuber yield, but marketable yield was negatively correlated with rainfall during the cropping season.

Changes in soil chemical properties as a result of continuous sweet potato cultivation may be a factor explaining the variation in yield. Table 7 shows soil chemical properties before the first planting and after four seasons (about 2 years) of continuous sweet potato cultivation. The topsoil pH had decreased by 0.4 units, accompanied by a decrease in base saturation. Bulk density was not altered in soils under continuous sweet potato cultivation. This is as expected, since harvesting sweet potato involves digging topsoil with a fork to about 0.2 m depth. No obvious pattern of decline was found in leaf nutrient concentrations, with the highest concentration of all major nutrients 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: in particular, considerable amounts of K are removed with the tubers and vines. At Hobu, about 16 kg N, 7 kg P and 51 kg K were found to be removed with each 10 tonnes/ha of fresh marketable sweet potato tubers (Hartemink et al. 2000b).

In the fallow and inorganic fertiliser experiments, Mr M. Maino and Dr K.S. Powell (University of Technology) made observations on nematodes and sweet potato weevil, respectively. Nematode counts in soil extracts from the fallow experiment showed that the juvenile population of *Meloidogyne* sp. increased with the number of cropping seasons (Hartemink et al. 2000b). The increase in number of nematodes was significant between the first and second seasons but numbers did not differ significantly between the third and fourth seasons. Although the species of *Meloidogyne* could not be identified with certainty, common root-knot species under sweet potato in PNG 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 proportion of the marketable tubers and vines were damaged. Damaged tubers over both seasons were predominantly categorised in category 1 (only superficial damage to the periderm) (Sutherland 1986). The high level of vine damage was not reflected by tuber damage.

Discussion

Piper fallows resulted in higher sweet potato yields than gliricidia fallows, so there is no obvious advantage of using an improved N-fixing fallow species such as gliricidia. The low yield response after gliricidia fallow is puzzling; it is possible that yields may have been affected by allelopathic compounds in gliricidia. Reports from India have shown that applications of 4–12 tonnes of gliricidia leaf mulch/ha effectively controlled weeds, and that mulching improved total yield of sorghum (Ramakoorthy and Paliwal 1993). The control of weeds was attributed to certain phenolic compounds in the gliricidia mulch. Alan and Barrantes (1998) showed that extracts from gliricidia leaves drastically reduced the germination of certain weed species, including *Ipomoea* sp., in Costa Rica. It is hard to estimate whether the variation in sweet potato yield in our

Table 6. Correlation between rainfall, number of cropping seasons, sweet potato tuber yield and vine yield.

Site	Variable	Marketable yield	Nonmarketable yield	Vine yield
Hobu	Rainfall during the growing season[a]	-0.601^{**}	-0.814^{***}	$+0.866^{***}$
	Number of cropping seasons[b]	-0.556^{*}	-0.622^{**}	+0.274
PNG University of Technology	Rainfall during the growing season[a]	-0.558^{**}	+0.085	−0.167
	Number of cropping seasons[b]	−0.202	+0.018	-0.628^{**}

[a]Covariate = number of cropping seasons (i.e. 4 at Hobu and 5 at the PNG University of Technology)
[b]Covariate = rainfall received in the season
*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$
Source: Hartemink et al. (2000b)

Table 7. Changes in soil chemical properties under continuous sweet potato cultivation (at a sampling depth of 0–0.15 m).[a]

Sampling time	pH_w	C (g/kg)	N (g/kg)	P (mg/kg)	Cation exchange capacity pH 7 ($mmol_c$/kg)	Exchangeable cations ($mmol_c$/kg)			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	$P < 0.001$

$mmol_c$ = millimoles of charge; ns = not significant; pH_w = pH in water
[a]Data from fallow experiment; values are the arithmetic mean of four plots
Source: Hartemink et al. (2000b)

experiment was due to allelopathic effects, although the polyphenolic content of the gliricidia leaves was indeed much higher than that of piper or imperata (Hartemink and O'Sullivan, in press).

The gliricidia fallow produced three times more wood than the piper fallows, which is advantageous in the lowland areas where firewood is scarce. The greater biomass of gliricidia may be because gliricidia is better at scavenging the limited nutrients than piper is. It is likely that piper suffered from too little water due to the El Niño drought (Fig. 1): piper grows faster in wetter periods (Hartemink, in press). Piper significantly reduced soil moisture, which is of advantage in wet seasons: Hartemink et al. (2000b) have shown that sweet potato yields were significantly reduced in wetter seasons regardless of the cropping history of the soil (see also Table 7).

Sweet potato tuber yields after imperata fallow were comparable to those after the woody fallows of piper or gliricidia. However, imperata biomass returned less N to the soil, and vine biomass was lower due to the slow decomposition of the biomass and N immobilisation (Hartemink and O'Sullivan, in press). The reduced vine yield after imperata fallow did not result in higher tuber yield, although vine and tuber yields are often inversely related (Enyi 1977). Similarly, a significant yield reduction of sweet potato was observed following the application of more than 10 tonnes/ha of imperata mulch (Kamara and Lahai 1997). The yield reduction was attributed to the low C:N ratio of the mulch, resulting in poor mineralisation and immobilisation of N. Furthermore, it has been suggested that imperata biomass has phytotoxic properties (Kamara and Lahai 1997).

Table 8. The 10 highest and 10 lowest marketable sweet potato yields observed in all nutrient management trials at Hobu.

	Yield (tonnes/ha)	Experiment	Treatment[a]	Season	Rainfall during season (mm)
Highest yield	26.7	Poultry litter	100 kg N/ha (as inorganic fertiliser)	First	1203
	24.7	Inorganic fertiliser	Unfertilised	Second	1034
	23.8	Inorganic fertiliser	100 kg N/ha; no K	First	1028
	23.5	Inorganic fertiliser	100 kg N/ha; 50 kg K/ha	First	1028
	23.3	Inorganic fertiliser	150 kg N/ha; no K	First	1028
	22.7	Inorganic fertiliser	50 kg N/ha; no K	First	1028
	21.9	Poultry litter	100 kg N/ha (as poultry litter)	First	1203
	21.7	Inorganic fertiliser	No N; 50 kg K/ha	Second	1034
	21.5	Inorganic fertiliser	100 kg N/ha; no K	Second	1034
	21.3	Inorganic fertiliser	50 kg N/ha; 50 kg K/ha	First	1028
Lowest yield	2.6	Inorganic fertiliser	150 kg N/ha; no K	Third	2214
	2.7	Inorganic fertiliser	150 kg N/ha; 50 kg K/ha	Third	2214
	2.9	Inorganic fertiliser	50 kg N/ha; 50 kg K/ha	Third	2214
	5.2	Inorganic fertiliser	50 kg N/ha; no K	Third	2214
	5.6	Inorganic fertiliser	100 kg N/ha; 50 kg K/ha	Third	2214
	5.8	Inorganic fertiliser	100 kg N/ha; no K	Third	2214
	6.0	Inorganic fertiliser	No N; 50 kg K/ha	Third	2214
	6.8	Poultry litter	50 kg N/ha (as poultry litter)	Second	2091
	6.9	Inorganic fertiliser	Unfertilised	Third	2214
	7.3	Poultry litter	100 kg N/ha (as inorganic fertiliser)	Second	2091

N = nitrogen; K = potassium

[a]Note that in the poultry litter experiment, the source of N was either inorganic fertiliser or poultry litter; in the inorganic fertiliser experiment, the source of N was only inorganic fertiliser.

In our experiments, short-term fallows of piper and imperata gave slightly higher sweet potato yields than fallows of gliricidia did. From a nutrient perspective, gliricidia fallows are probably more effective, but additional research into nutrient budgets is required before a final assessment can be made of the sustainability of short-term fallows.

The inorganic fertiliser and poultry litter experiments have shown that sweet potato responded to N fertiliser, which confirms other research in PNG (Bourke 1985a; Bourke 1985b; O'Sullivan et al. 1997). The highest yields were obtained with application of 100 kg N/ha, although the response was mostly found in the first season after the fallow, and subsequent seasons gave inconsistent results. However, the response to nutrient inputs was greatly affected by other factors such as rainfall, number of cropping seasons, pests and diseases (Hartemink et al. 2000a; Hartemink et al. 2000b).

Now the question arises as to what is the best treatment to sustain and improve sweet potato yield in the Hobu area. Table 8 shows the 10 highest and lowest yields from all of the experiments. These are average yields for each treatment—variation between plots was large. Some plots had very high marketable tuber yields (up to 39 tonnes/ha), while others had marketable tuber yields of below 20 tonnes/ha. Table 8 clearly shows that most of the highest yields were found in the first and second seasons after the fallow, and when seasonal rainfall was 1000–1200 mm. The lowest yields were recorded in the third season after the fallow, when the seasonal rainfall exceeded 2000 mm. Most importantly, Table 8 shows that none of the fallow treatments were associated with either the highest or the lowest yield rankings. Thus, using fallows appears to be the safest way to obtain steady sweet potato yields. Extra inputs through inorganic fertiliser or poultry litter may either strongly increase or decrease yields.

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The Effect of Chicken Manure on Growth and Yield of Intercropped Maize and Sweet Potato

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Abstract

A maize–sweet potato intercropping experiment using chicken manure was conducted at the University of Papua New Guinea. A randomised block design was used, with four levels of chicken manure applied to maize and sweet potato in pure stands or in association. There were a total of 12 treatments, replicated four times.

Plant height, yield and selected yield components of maize gave positive responses to chicken manure application. Intercropping significantly decreased yield and yield components as compared to pure stands of maize. Yield (grain) reduction between monocropped and intercropped maize were 60.36, 12.29, 8.59 and 17.76% for 0, 5, 10 and 20 tonnes per hectare (t/ha), respectively. Marked reductions in nutrient content were also observed under intercropping as compared to pure stands.

Yield and selected yield components of sweet potato in association with maize were significantly lower than their respective pure stands. Concentration of nutrient content showed similar trends. Yield (tuber) reduction between monocropped and intercropped sweet potato were 81.01, 81.23, 80.92 and 76.13% for 0, 5, 10, and 20 t/ha manure application, respectively. The effect of shading by maize plants, low initial soil nitrogen and competition contributed to yield reduction of sweet potato under intercropping.

The highest land equivalent ratio (LER) of 1.10 was recorded at 10 t/ha level of chicken manure application, while 0 t/ha (control) had the lowest LER value, 0.59. The other levels of 5 and 20 t/ha both recorded LERs of 1.06.

INTERCROPPING is defined as the growing of two or more crops on the same piece of land at the same time. Plants are not necessarily sown or harvested at the same time, but much of their growth occurs simultaneously. The term 'intercropping' is also used to imply that crops are grown in separate rows, as opposed to the irregular broadcasting or mixing of plants within rows, which should be termed 'mixed cropping' (Andrews and Kassam 1975; Freyman and Venkateswarlu 1977). In this paper, 'intercropping' is used in the more general sense unless specific spatial arrangements are mentioned.

The importance of intercropping has long been recognised, as highlighted by Aiyer (1949) in a comprehensive review of intercropping in India. For many centuries, farmers have been practising this type of agriculture. Swindale (1979) reported that as many as 84 different crops have been used in mixed cropping gardens. A relatively simple mixture of only two or three is common nowadays.

Intercropping is the most popular crop production system in subsistence tropical agriculture (Willey 1979). Its merits have been well documented (Andrews 1972; Finlay 1974). Intercropping provides a balanced diet, it reduces labour peaks, and crop failure risks are minimised. Numerous studies

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(Agboola and Fayemi 1971; Enyi 1973; Gardiner and Cracker 1979; Makena and Doto 1980; Tay et al. 1979) have reported lower yields of one or both crops in the intercrop than in their respective pure stands; but the combined yield of the intercrop is higher than the yield of any of the crops in pure stands. It has also been suggested that intercropping is more effective at reducing the adverse effects of pests (diseases, insects and weeds) than monocropping, and that it can provide a higher return and protect against soil erosion (Okigbo 1979). However, Crookston and Hill (1979) found that the land-use efficiency in Minnesota, in the United States, was not improved by intercropping.

Moreno (1982) found that simultaneous planting of maize and sweet potato resulted in the strongest competition for available magnesium (Mg) between the two crops. It was also reported (Moreno 1982) that a reduction in the number of roots accounted for the yield reduction in intercropped sweet potato. Intercropping trials using a maize–sweet potato combination have been found to increase yield and economic return (Kesavan 1982).

In PNG, intercropping is still an integral part of people's livelihood. The mixture of crops and pattern of crop mixing varies with altitude, rainfall, soil type, and ethnic and cultural group. With increasing population pressure on the land, especially in areas such as Gumine (Simbu Province), Maprik (East Sepik Province) and the Gazelle Peninsula (East New Britain Province), the traditional system needs to be modified to support the growing number of people (Bourke 1978).

Subsistence farming systems in PNG have been documented in the working papers of the Mapping Agricultural Systems of PNG project (Bourke et al. 1998). Most research on food crops has been carried out for monocultures. For example, Bourke (1985) reported that the timing of tuber and vine growth of sweet potato is a function of both cultivar and seasonal conditions, and that no fixed general pattern can be defined. He also reported that nitrogen (N) had a greater influence on the growth and yield of sweet potato than did phosphorus (P), although both nutrients increased tuber yield and mean tuber weight. N increased total plant dry weight and leaf area index, while P increased the number of tubers per plant (Bourke 1985).

Researchers have also focused on mixtures of perennials and food crops. Gallasch (1980) suggested growing pineapples, cassava, *Xanthosoma* taro and ginger under coconuts in PNG. The Tolai people of the Gazelle Peninsula intercrop bananas and *Xanthosoma* taro as shade trees for young cocoa trees (Bourke 1978).

For many subsistence food crops, it is still uneconomical to use inorganic fertilisers such as mixtures of N, P and potassium (K). It is better to use organic fertilisers such as cattle manure, pig manure, chicken manure, cocoa pods and coffee husks, which are now often wasted in PNG. There is little or no use of organic manures by subsistence farmers. Research has been carried out on the use of pig manure (Kimber 1982), coffee pulp (Siki 1980), and chicken manure (Thiagalingam and Bourke 1982; Mesa 1983). Mesa (1983) reported a significant increase in maize plant height when chicken manure was applied. It is estimated that 4700, 3000 and 4500 tonnes of N, P and K, respectively, are available from organic wastes from animals, agricultural sources and industries in PNG (Thiagalingam and Bourke 1982).

Several methods can be used to evaluate the yield advantage of intercropping over monocropping; one of the most commonly used is the land equivalent ratio (LER) (Willey 1979). In its simplest form, the LER can be defined as the relative land area of sole crop required to produce yields achieved by intercropping under the same type of management. LER can be written:

$$LER = LA + LB = \frac{YA}{SA} + \frac{YB}{SB}$$

where LA equals the yield of intercrop A (YA) divided by the yield of monocrop A (SA) and LB equals the yield of intercrop B (YB) divided by the yield of monocrop B (SB).

The concept of LER has criticised by Hiebsch (1981), who argued that it is not an accurate method of comparing relative production potentials for intercropping and monocropping systems. He suggested an alternative, area–time equivalent ratio (ATER), calculated by redefining yield to be quantity per unit area per unit time. Okigbo (1979) suggested that LER, competition coefficients, relative yields, calorific equivalents and gross returns could be used as indices to select efficient crop mixtures. Although there is much scope for investigating the concept further, the philosophy of LER can be useful in interpreting data from intercropping experiments (Rao and Willey 1980).

Intercropping combinations have often included cereal–legume mixtures but there has been little previous work on cereal–tuber crop mixtures in PNG. The current study aimed to:

- investigate the effect of different levels of chicken manure on plant height and yield of monocropped and intercropped maize and sweet potato;

- investigate the effect of chicken manure on N, P and K levels in maize leaves at the time of silking;
- investigate the effect of chicken manure on N, P and K concentrations in sweet potato leaves at eight weeks after planting; and
- evaluate LER and the competitive relationship of maize and sweet potato in association.

Materials and Methods

Location and climate

The experimental site was a farm at the University of Papua New Guinea, Port Moresby (147°9'E, 9°24'S, altitude 34 metres above sea level). This is located in one of PNG's driest regions. Total annual rainfall ranges from 1000 to 1300 millimetres per year, more than three-quarters falling from December to May. The area has a mean annual maximum and minimum screen temperature of 31.2°C and 22.7°C, respectively. The vegetation is predominantly *Eucalyptus* and *Themeda australis* savannah.

Table 1. Some physical and chemical properties of the experimental soil, University of Papua New Guinea, Port Moresby, 1983.

Property	Value
Sand (%)	61.93
Silt (%)	14.75
Clay (%)	23.32
Textural class	Sandy clay loam
pH (H_2O)	6.20
pH (0.01M $CaCl_2$)	5.98
Carbon (%)	2.26
Organic matter (%)	3.89
Total nitrogen (%)	0.16
Carbon:nitrogen ratio	14.13
Phosphorus (Olsen) (ppm)	46.11
Exchangeable potassium (me%)	0.36
CEC (me %)	28.46
Bulk density g/cm^3	1.36

CEC = cation exchange capacity; me = milliequivalent; ppm = parts per million

Previous land use and soil sampling

From July to October 1983, the study site had been used for a maize–peanut intercropping trial. Soil samples were taken prior to planting and analysed for various soil properties using the methods outlined by Black et al. (1965). The results are shown in Table 1.

Tillage and general preparations

A tractor was used to plough the soil; other preparations were carried out manually. Ridges were formed to a height of 20–25 centimetres (cm); they were 1 metre (m) apart for monocrop plots and 0.5 m apart for intercrops. The bulk density of the soil was 1.36 g/cm^3 (Table 1), within the optimum range of 1.3 to 1.5 g/cm^3 reported by Sajjapongse and Roan (1982).

Experimental design and layout

A randomised block design was used, with four levels of chicken manure applied to maize and sweet potato grown in pure stands and in mixed cropping. There were 12 treatments, (Table 2) replicated four times. The plot sizes were 7.0 m × 4.0 m, with 1 m between plots.

Table 2. Experimental protocols for crop combinations and rates of applied chicken manure.

Treatment	Crop combination	Rate of applied chicken manure (tonnes/hectare)
1	Maize	0
2	Maize	5
3	Maize	10
4	Maize	20
5	Maize and sweet potato	0
6	Maize and sweet potato	5
7	Maize and sweet potato	10
8	Maize and sweet potato	20
9	Sweet potato	0
10	Sweet potato	5
11	Sweet potato	10
12	Sweet potato	20

Varietal characteristics of *metro* (maize) and *wanmun* (sweet potato)

The *metro* variety of maize was used in the study; this is an introduced variety from Bogor, Indonesia. It is open-pollinated, with good yielding ability, though it is susceptible to downy mildew. The sweet potato used was the *wanmun* variety, an early maturing variety from Laloki Research Station.

Chicken manure analysis and application

The manure of 70 week-old layer birds was obtained from an Ilimo farm and analysed for N, P and K content, using the methods for determining soil nutrient content. The chicken manure contained 2.31% N, 2.27% P and 1.44% K. Chicken manure was applied four days before planting, evenly spread and incorporated into the soil.

Planting

Maize in association and in pure stands was planted in five rows, 1 m apart with an intra-row spacing of 20 cm, giving a density of 250,000 plants per hectare. Sweet potato in pure stands was planted in five rows, 1 m apart, with an intra-row spacing of 30 cm, giving 150,000 plants per hectare. In the intercropped plots, there were five rows of maize and four rows of sweet potato, with the companion crops 50 cm apart.

The companion crops maize and sweet potato were both planted on 13 July 1984. Two maize seeds were sown per hole; plants were thinned to one plant per hole after germination. One sweet potato cutting was planted per hole; cuttings were approximately 30 cm in length, with at least two nodes beneath the soil.

Crop husbandry

Gramoxone was used to control weeds growing on the sides; weeds within the rows were hand-weeded. Insect pests were controlled by spraying Orthene; rat poison was placed on sweet potato ridges to control rats. Throughout the crop's growth, soil moisture was maintained at field capacity by means of a sprinkler irrigation system.

Sunlight measurements

Sunlight measurements were recorded using a portable sunlight meter from the UPNG Physics Department. The measurements were taken at 1 pm once each week from 30 to 90 days after planting. For the intercropped plots, readings were taken above the canopy and below the canopy, about 20–30 cm above the sweet potato plantings. For maize and sweet potato monocrop plots, readings were taken as 100% sunshine over the canopy.

Plant sampling and analysis

Maize leaves were sampled at the time of silking, sweet potato leaves at eight weeks after planting. For maize, 10 random plants were selected and samples obtained from the leaves below and opposite the ear. For sweet potato, the sixth leaf from the tip was sampled for analysis. A total of 20 leaves were randomly sampled in both the monocropped and intercropped sweet potato plots. Both maize and sweet potato, in monocrops and in intercrops, were sampled in an 18 m^2 harvest area.

N was analysed using the Kjeldahl method. For P and K, plant samples were ashed at 500°C and the ash dissolved in 5 millilitres of 2N HCl. P was analysed using the Vandate molybdate yellow method; K was determined using an Eel flame photometer.

Plant height measurements

The height of maize plants was measured after the plant reached maximum growth. Measurements were recorded from 10 randomly selected plants in each monocropped and intercropped plot.

Harvest

Maize was harvested on 8 October 1984, sweet potato 2–3 days later. The three central rows of all plots were harvested, whether the plants were in pure stands or in association. The harvest area was 18 m^2. The harvested fresh cobs were put into separate gunney bags and sun-dried for three weeks to approximately 14% moisture content.

Yield and yield component measurements

Total cob weights and 1000-grain seed weights were recorded after sun drying to 14% moisture. For sweet potato, the marketable tuber number and fresh weight were recorded. For both crops, total plant matter (fresh) was recorded, and total dry matter production (DMP) calculated from an oven-dried subsample.

Data processing

Analysis of variance was used to analyse the data collected.

Results and Discussion

Maize

Growth: plant height

Under both cropping systems, there was a highly significant increase in maize plant height when chicken manure was applied (Table 3). In the pure stands, plant height was significantly greater ($P < 0.05$) when manure was applied at 20 tonnes per hectare (t/ha) than it was when manure was applied at 5 t/ha. The height difference after manure applications of 20 t/ha and 0 t/ha (control) was highly significant ($P < 0.01$). The height differences at other rates of fertiliser application were not statistically significant.

In addition to differences in plant height as a result of different levels of manure application, there were also highly significant differences in plant height between the monocropped and intercropped maize. The height of the intercropped maize was significantly lower ($P < 0.01$) than maize grown as a monoculture, perhaps due to intercrop competition and the low initial soil N (Table 1). Thus, the results suggest that the response was due to N provided by the chicken manure.

Growth: dry matter production

At any given level of chicken manure application, DMP of maize grown in association with sweet potato was lower than that of maize grown in pure stands (Figure 1). The highest DMP was observed at 20 t/ha under monocropping and 10 t/ha under intercropping.

DMP for maize varied with different levels of manure and also different cropping systems. When maize was the sole crop, the DMP in the intercropped maize was significantly lower ($P < 0.05$) than monocropped maize. For maize grown in association with sweet potato, DMP when manure was applied at 10 t/ha was significantly greater ($P < 0.05$) than that for manure levels of 0 (control) or 5 t/ha. There was no statistically significant difference in DMP from maize grown as part of an intercrop after manure applications of 10 t/ha and 20 t/ha. Edje (1980) reported that intercropping of peanuts with maize similarly had no appreciable effect on the DMP of maize. The analysis of variance (ANOVA) of the current results indicated a significant ($P < 0.05$) difference in DMP between monocropped and intercropped plots. DMP was significantly ($P < 0.05$) lower under intercropping than in pure stands.

Yield: 1000-grain seed weight

Chicken manure applications also had a highly significant effect on 1000-grain seed weight of maize under pure and intercropped stands (Table 4). For maize grown in pure stands, the differences in yield between chicken manure applications of 0 t/ha (control) and 5 t/ha, and between 10 t/ha and 20 t/ha, were not significant. Under intercropping, manure rates of 10 t/ha and 20 t/ha produced highly significant increases in seed weight over 0 t/ha (control) and the 5 t/ha level. The differences in weight between applications of 0 t/ha and 5 t/ha, and between 10 t/ha and 20 t/ha, were not significant.

Yield: total grain

Table 5 shows the total grain yields of maize grown as a monocrop compared with those of maize grown as an intercrop, at different levels of chicken manure application. Grain yield under monocropping was significantly ($P < 0.05$) higher than under intercropping.

Table 3. Maize height under monocropping and intercropping.

Chicken manure (tonnes/hectare)	Plant height (metres)	
	Monocrop	Intercrop
0	2.16	1.18
5	2.36	2.05
10	2.48	2.39
20	2.69	2.46
LSD (0.05)	0.298	0.298
LSD (0.01)	0.405	0.405

LSD = least significant difference

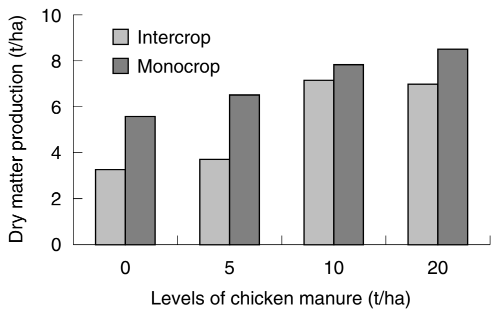

Figure 1. Effect of chicken manure on dry matter production of monocropped and intercropped maize.

However, the difference between the levels of chicken manure applications was highly significant ($P = 0.01$) in both systems, particularly when the controls were compared to plants receiving manure at 20 t/ha. Mesa (1983) found similar trends when experimenting with chicken manure on maize–peanut combinations. However, Risimeri (1983) found that, whether maize was grown in pure stands or in association with peanuts, there was no statistically significant difference in maize yields at different levels of urea fertiliser (N).

In the present study, there were statistically significant differences in monocrop maize yields between manure applications of 0 t/ha (control) and 10 t/ha; between 5 t/ha and 20 t/ha; and between 20 t/ha and 0 t/ha (control). When grown in association with sweet potato, there were highly significant differences in maize yield between plants grown at manure applications of 0 t/ha (control) and 5 t/ha, 10 t/ha or 20 t/ha.

Table 5 illustrates the difference in maize grain yield under the two cropping systems. The grain yield under intercropping is significantly less than that under monocropping at all levels of manure application, although the application of manure significantly increases the yield within both systems. Previous studies have reported similar findings (Agboola and Fayemi 1971; Enyi 1973; Makena and Doto 1980). The highest yield reduction (60.36%) was obtained at a level of application of 0 t/ha, the lowest at 10 t/ha (8.59%). Manure applications of 5 t/ha and 20 t/ha resulted in yield reductions of 12.29 and 17.76%, respectively. Nadar (1982) reported a 57% reduction in maize yield when grown with beans. Tay et al. (1979) reported that maize grain yield reduced from 7.59 t/ha in monocrop to 3.97 t/ha under intercropping with phaseolus beans. Manure at 5 t/ha seems adequate for acceptable grain yield production, although increased levels will increase grain yield. The increased yield of maize was due to the applied chicken manure and the initial low status of soil N of the experimental soil (Table 1).

Nutrient content of monocropped and intercropped maize at silking

Table 6 shows N, P, K, Mg and calcium (Ca) concentrations in maize leaves.

There was a highly significant difference in N content in maize leaves at silking time at different rates of manure application and in monocropping compared to intercropping. Leaf N content increased with increasing levels of chicken manure under both systems, correlating with grain yield data presented in Table 5. For maize grown in pure stands, there were highly significant differences in leaf N concentrations between higher levels of chicken manure application and the control treatment, and also between 5 t/ha and 20 t/ha.

Initial soil analysis (Table 1) prior to planting indicated a low (0.16%) N content; it is assumed that N content increased with increasing levels of manure. N concentrations in maize of 1.9%, 2.4–3.7% and 3.7% are considered low, intermediate and high, respectively (SSSA 1967). Monocropped maize receiving 0 t/ha (control) and 5 t/ha of chicken manure had low N content, while the higher levels of manure application resulted in intermediate N content. In intercropping plots, despite highly significant increases when chicken manure was applied, N content was low at all levels of application. Perhaps this resulted from competition between the companion crops. These findings suggest that intercropping of maize and sweet potato

Table 4. The 1000-grain seed weight of maize under monocropping and intercropping systems.

Chicken manure (tonnes/hectare)	1000-grain seed weight (grams)	
	Monocrop	Intercrop
0	194.49	160.19
5	201.82	176.38
10	218.92	207.29
20	220.09	219.30
LSD (0.05)	21.448	21.448
LSD (0.01)	29.192	29.192

LSD = least significant difference

Table 5. Grain yield of maize under monocropping and intercropping systems.

Chicken manure (tonnes/hectare)	Grain yield (tonnes/hectare)	
	Monocrop	Intercrop
0	2.24	1.01
5	2.60	2.28
10	3.55	3.24
20	4.10	3.38
LSD (0.05)	1.228	1.228
LSD (0.01)	1.671	1.671

LSD = least significant difference

Table 6. Nutrient concentration in maize leaves (below and opposite ear leaf) at silking time under monocropping and intercropping systems, with different levels of chicken manure.

System	Nutrient	Chicken manure (tonnes/hectare)				LSD (0.05)	LSD (0.01)
		0	5	10	20		
Monocrop	Nitrogen	1.51	1.56	1.95	2.45	0.391	0.533
	Phosphorus	0.25	0.27	0.34	0.41	0.007	0.100
	Potassium	2.88	3.40	3.60	3.56	ns	ns
	Magnesium	0.32	0.37	0.32	0.29	ns	ns
	Calcium	0.53	0.58	0.72	0.62	ns	ns
Intercrop	Nitrogen	1.04	1.39	1.78	1.78	0.391	0.533
	Phosphorus	0.29	0.38	0.40	0.41	0.007	0.100
	Potassium	2.46	2.69	2.85	2.84	ns	ns
	Magnesium	0.25	0.28	0.29	0.25	ns	ns
	Calcium	0.41	0.53	0.54	0.38	ns	ns

LSD = least significant difference; ns = not significant

would require higher levels of chicken manure applications for better yields.

P concentration in maize leaves also increased with increasing levels of chicken manure application, under monocropping and intercropping systems. For monocropped maize there were significant differences in concentration after manure applications of 0 t/ha (control) compared with 5 t/ha. Manure applications at 10 t/ha resulted in significant differences in P content between 0 t/ha (control), 5 t/ha and 20 t/ha levels. The difference in P concentration at manure application rates of 20 t/ha compared with 0 t/ha (control) and 5 t/ha were highly significant.

For maize grown with sweet potato, the application of chicken manure at 5 t/ha, 10 t/ha and 20 t/ha resulted in highly significant differences in leaf P content as compared with the control treatment of 0 t/ha. There was a significant difference in leaf P content at manure application rates between 5 t/ha and 0 t/ha (control). Leaf P content was also significantly different between higher levels of manure application (10 and 20 t/ha) compared with 5 t/ha, and manure application at the higher levels also produced a significant difference in leaf P content compared with lower levels.

P concentrations of 0.20% and 0.20–0.40% are considered to be low and intermediate, respectively (SSSA 1967). Both intercropped and monocropped maize had intermediate P content in the leaves, irrespective of the level of chicken manure application.

There was a highly significant difference in leaf P content between maize grown as a monocrop and maize grown as an intercrop. When maize was grown in association with sweet potato, leaf P concentration was significantly higher (0.01% level) than in monocropped maize at all levels of chicken manure application except 20 t/ha, at which P leaf concentration was the same for both systems. Analysis of the soil prior to planting (Table 1) indicated that soil P was adequate for plant growth; plant analysis confirmed this finding. This suggests that soil P is not limiting growth. Van Keulen (1983) reported an interaction between N and P where available N improved the uptake of P even if P is limiting. The soil and plant analyses suggest that P is at an adequate level, indicating a luxurious uptake of P by maize as a direct result of chicken manure application.

Under both monocropping and intercropping, the differences in the K content of maize at different levels of manure application were not significant. However, intercropped maize had a significantly lower K content than monocropped maize. Leaf contents of 1.7%, 1.7–12.5% and 2.5% are considered to be low, intermediate and high, respectively (SSSA 1967). The results of the present study indicate that K content is not a limiting factor. Initial soil analysis also indicated adequate K content.

There was no significant difference in Mg and Ca content in maize grown under monocropping and maize grown in association with sweet potato. An Mg content of 0.17% is considered to be intermediate (SSSA 1967).

Sweet potato

Growth: dry matter production

Table 7 shows the effect of chicken manure on DMP of sweet potato yields. The effect of chicken manure application on DMP was much greater (highly significant) in monocropped sweet potato than for sweet potato that was intercropped and at higher levels of manure application.

For monocropped sweet potato, there was a significant difference in DMP between the control (0 t/ha) and the other manure treatments (5, 10 and 20 t/ha). DMP was higher at the 10 t/ha than the 5 t/ha level. For intercropped sweet potato, the corresponding differences in DMP were not statistically significant; DMP was significantly lower than for the monocropped sweet potato at a corresponding level of manure application. The decreased DMP is a direct result of shading by maize (Figure 2) and competition for nutrients. Reducing light intensity by about 50% is sufficient to reduce DMP and probably also lignification of stele cells and cambial activity (Arze 1975, cited by Moreno 1982). Under optimum soil conditions, if the photosynthetic canopy of one component crop is set higher than that of the other, the taller plant intercepts a greater share of light (Trenbath 1977). Maize develops its canopy before sweet potato, intercepting most available light and reducing the light available for sweet potato.

Table 7. Dry matter production (tonnes/hectare) of sweet potato under monocropping and intercropping systems.

Chicken manure (tonnes/hectare)	Monocrop	Intercrop
0	2.25	1.06
5	3.44	1.19
10	4.75	1.45
20	4.25	1.49
LSD (0.05)	0.944	ns
LSD (0.05)	1.284	ns

LSD = least significant difference; ns = not significant

Yield: tuber characteristics under monocropping and intercropping systems

Table 8 shows the number of sweet potato tubers per plot, tuber yield and individual tuber weight at different levels of chicken manure for both monocropping and intercropping. For monocropped and intercropped sweet potato, the increases in the number of marketable tubers and tuber yield after manure application were not statistically significant; however, there were some significant differences in individual tuber weight with increased manure application.

Under intercropping, the number of sweet potato tubers, tuber yield and individual tuber weight were lower than in monocrops with corresponding levels of manure application. Intercropping of sweet potato significantly ($P < 0.01$) decreased the number of tubers per plot, as well as yield and individual tuber weight. Figure 3 shows the marked reduction in yield in sweet potato grown with maize.

For sweet potato, the highest yield reduction in tuber yield between monocropping and intercropping was observed at 5 t/ha of manure application (81%); the lowest yield reduction was obtained at 20 t/ha level (76%). The control (0 t/ha) and 10 t/ha levels both had yield reductions of 81%. Earlier studies (Kaoshiung 1961) reported that simultaneous planting of sweet potato and soybean resulted in losses of 13% of sweet potato tuber weight. It was also reported that 60% yield reduction in total tuber weight is expected if sweet potato is grown simultaneously with maize (Kaoshiung 1961).

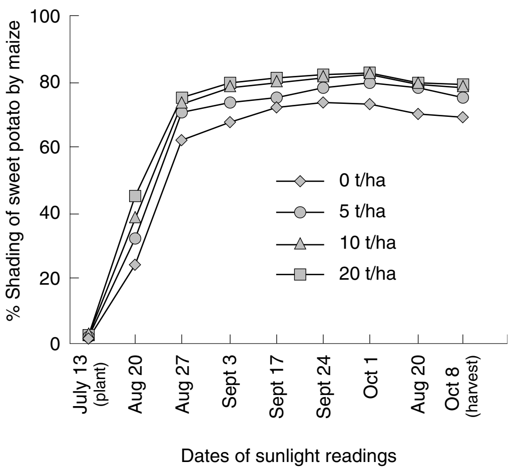

Figure 2. Shading of sweet potato by maize under intercrop conditions.

When chicken manure was applied, there were significant increases in individual tuber weight under monocropping. Individual tuber weight increases from the 10 t/ha level compared to the control (0 t/ha) and 5 t/ha level were highly significant ($P < 0.01$). At the 20 t/ha level there were significant ($P < 0.05$) increases in individual tuber weight over the control and 5 t/ha level. For intercropped sweet potato, the effect of chicken manure on individual tuber weight was not significant. A manure application rate of 10 t/ha yielded the best individual tuber weight for both cropping systems (248 grams under monocropping and 115 grams under intercropping).

Radiation, nutrients, temperature and soil moisture are known to determine sweet potato yield (Hahn 1977). As with DMP, when sweet potato is grown with maize, its yield presumably decreases as a result of shading by the maize (Figure 2) and competition for nutrients, especially N.

Nutrient content in sweet potato leaves

The analysis of sweet potato leaves for N, P, and K concentrations showed that the major nutrients of sweet potato grown in association with maize were lower than for those grown in pure stands at corresponding manure application rates. The cation concentration of Mg and Ca followed similar trends; except at the 5 t/ha level, where Ca content under intercropping was higher than for the respective pure stand. Of the major three nutrients, N was observed to differ significantly ($P < 0.05$) with chicken manure application levels, and highly significantly ($P < 0.01$) between the two cropping systems. In both monocropped and intercropped systems, the effect of the application of chicken manure on P concentration in sweet potato leaves was not statistically significant. However, the difference in P concentration of sweet potato leaves was highly significant ($P < 0.01$) between the two cropping systems. Application of chicken manure had no appreciable effect on the K content, and there were no significant differences in K content between sweet potato grown as a monocrop and that grown with maize.

For sweet potato under monocropping, only the control (0 t/ha) and 20 t/ha treatments produced a statistically significant ($P < 0.05$) difference in foliar N concentration (Table 9). Under intercropping, there was a statistically significant difference in foliar N concentration at all higher levels of manure application (5, 10 and 20 t/ha) compared with the control. The foliar N content of monocropped sweet potato was highly significantly ($P < 0.01$) greater than that for sweet potato grown with maize.

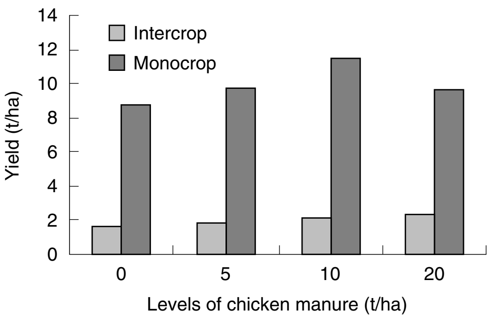

Figure 3. Effect of chicken manure on tuber yield of monocropped and intercropped sweet potato.

Table 8. Tuber characteristics of sweet potato under monocropping and intercropping systems, with different levels of chicken manure application.

Chicken manure (t/ha)	Monocrop			Intercrop		
	No. of tubers	Tuber yield (t/ha)	Individual tuber weight (grams)	No. of tubers	Tuber yield (t/ha)	Individual tuber weight (grams)
0	789	8.69	194	26	1.65	113
5	91	9.75	197	31	1.83	106
10	87	11.48	248	38	2.19	115
20	74	9.68	236	38	2.31	109
LSD (0.05)	ns	ns	34	ns	ns	ns
LSD (0.01)	ns	ns	47	ns	ns	ns

LSD = least significant difference; ns = not significant; t/ha = tonnes per hectare

Intercropping of sweet potato significantly ($P < 0.01$) decreased P content in leaves compared to monocropped sweet potato at a corresponding level of manure application. N gave a more positive response than P or K (Table 9). Initial soil analysis (Table 1) indicated a soil N value of 0.16%, which is below the critical value of 0.3%. Response to a nutrient will only occur if that nutrient is limiting. The effect of chicken manure on monocropped and intercropped sweet potato had no significant effect on the foliar concentration of Mg and Ca.

Land equivalent ratio

The LER can be used to standardise intercropped yields against the sole crop (Willey 1979). Calculated LERs are presented in Table 10. The LER values range from 0.59 to 1.10. When chicken manure was applied at 0 t/ha, the calculated LER was less than 1, indicating a yield disadvantage. Manure levels of 5 and 20 t/ha both recorded slight yield advantage, with an LER value of 1.06. The highest LER value (1.10) was obtained at 10 t/ha level of chicken manure application. LER is defined as the relative land area required by monocrops to produce yields achieved in intercropping (Mead and Willey 1980). An LER of 1.10 means 10% more land under sole crop would be required to produced the same yield achieved in intercropping under the same management. For monocropped and intercropped maize and peanuts, Mesa (1983) recorded LERs of 1.60, 1.93, 1.51, and 1.36 respectively for 0, 5, 10 and 20 t/ha of chicken manure.

Table 9. Nutrient concentrations in leaves of sweet potato under monocropping and intercropping systems at different levels of chicken manure application.

System	Nutrient	Chicken manure (tonnes/hectare)				LSD (0.05)	LSD (0.01)
		0	5	10	20		
Monocrop	Nitrogen	3.04	3.46	3.53	3.73	0.572	0.778
	Phosphorus	0.42	0.48	0.43	0.41	ns	ns
	Potassium	5.21	5.49	6.53	7.48	ns	ns
	Magnesium	0.67	0.45	0.41	0.59	ns	ns
	Calcium	1.48	0.94	1.24	1.30	ns	ns
Intercrop	Nitrogen	2.17	2.77	2.90	2.92	0.572	0.778
	Phosphorus	0.32	0.38	0.40	0.38	ns	ns
	Potassium	5.16	5.27	6.17	6.17	ns	ns
	Magnesium	0.35	0.42	0.38	0.37	ns	ns
	Calcium	0.98	1.08	1.04	0.98	ns	ns

LSD = least significant difference; ns = not significant

Table 10. Land equivalent ratios for monocrop and intercrop maize and sweet potato at different application rates of chicken manure.

Chicken manure (tonnes/hectare)	Maize grain yield (tonnes/hectare)		Sweet potato tuber yield (tonnes/hectare)		LER
	Monocrop	Intercrop	Monocrop	Intercrop	
0	2.55	1.01	8.69	1.66	0.59
5	2.60	2.28	9.75	1.83	1.06
10	3.55	3.24	11.48	2.19	1.10
20	4.10	3.38	9.68	2.31	1.06

LER = land equivalent ratio

Conclusion

For monocropped maize, the application of chicken manure had a highly significant effect in increasing plant height, yield and yield components. It also resulted in a highly significant increase in N and P content in maize leaves at the time of silking. Manure applications did not significantly affect K, Mg or Ca. For monocropped sweet potato, the application of chicken manure had no appreciable effect on the numbers of marketable tubers per plot, the yield, or the levels of P, K, Mg or Ca in leaves. DMP and the N content in sweet potato leaves were significantly increased ($P < 0.01$) with manure applications.

For intercropped maize, the application of chicken manure had a significant effect in increasing yield, yield components and nutrient content (N, P, K), but no appreciable effect on Mg or Ca content. Because N was found to be the main limiting factor in the soil, a relatively high dosage of chicken manure is required for improved yields. For sweet potato, the yield and yield components of intercropped stands were significantly lower than those of their respective pure stands. N, P, K, Mg and Ca showed similar trends.

Yield reduction was more severe in sweet potato than maize. Yield reductions between monocropped and intercropped sweet potato were 81, 81, 81 and 76%, respectively, for manure applications of 0, 5, 10 and 20 t/ha. The corresponding figures for maize plants were 60.4, 12.3, 8.6 and 17.8%. The more severe yield reduction in intercropped sweet potato is attributable to the effects of shading by maize, to competition and to low initial soil N.

The best LER level was obtained at a manure application rate of 10 t/ha (LER value of 1.10); the control (0 t/ha) had the lowest LER value (0.59). The other levels (5 t/ha and 20 t/ha), both recorded an LER value of 1.06.

With increasing land pressure, shortening fallow periods and declining yields (Levett 1992; Cook et al. 1989), there is a need to develop cropping systems that will increase yield sustainability under continuous cropping. The use of inorganic fertilisers on subsistence food crops remains uneconomical so the potential to exploit organic fertilisers such as chicken manure is enormous, especially in areas with marginal soils.

Further studies should aim to increase the yields of maize and sweet potato by means of higher manure applications (20, 30, 40 and 50 t/ha). They should also investigate a competition-free period in intercropping, where planting of maize would be delayed by two, three or four weeks to reduce the shading effect on crops like sweet potato. Multilocation trials should be carried out to determine the optimum levels, spatial arrangements, planting dates and other management practices for different sites.

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Sweet Potato Research in Acid Soils

V.P. Ila'ava*

Abstract

Acid soil infertility is a major problem throughout the tropics. Many of these soils have been classified as Oxisols and Ultisols, which, combined, occupy approximately 40–60% of the total land area of the tropics. In the tropics, sweet potato is grown extensively on highly leached acid soils and is well adapted to soils of low to moderate fertility. Poor yields are most likely to be due to aluminium (Al) toxicity or, to a lesser extent, calcium (Ca) deficiency. Manganese toxicity or deficiencies in magnesium, phosphorus or molybdenum are potential limiting factors, but these elements play a less important role than do Al or Ca. This paper reviews the literature on sweet potato research in acid soils and highlights areas for future research, particularly into an apparent link between tolerance to low Ca and soluble Al. The recommendations encourage a policy of ensuring sustainable utilisation of species and ecosystems.

SWEET potato (*Ipomoea batatas* (L.) Lam.) is an important tropical root crop produced and consumed around the world. Asia and Africa are the largest producers, accounting for 53% and 36%, respectively, of the world's tropical root crop production. The Oceania region, which includes Australia, New Zealand and the South Pacific countries, is only of minor importance, accounting for less than 1% of the world's total production in 1993 (FAO 1994). PNG, which has a larger land area than the other South Pacific countries, produces about 70% of the region's root crops, with more than 50% of this being sweet potato (FAO 1994).

Acid soil infertility is a major problem throughout the tropics. Many acid soils have been classified under the United States Department of Agriculture (USDA) soil classification system as Oxisols or Ultisols. Together they occupy approximately 40–60% of the total land area in the tropics (Sanchez and Logan 1992; Wambeke 1992; von Uexküll and Mutert 1995). In the tropics, sweet potato is grown extensively on highly leached acid soils and is believed to be well adapted to soils of low to moderate fertility (Hahn 1977).

In the South Pacific (as is the case elsewhere in the tropics), tropical root crops are grown in soils that differ widely in their chemical and physical properties, and environmental and climatic conditions are equally diverse. Furthermore, the agronomic practices used in the production of these crops differ considerably. The average yield of sweet potato in the Oceania region ranges from 2 to 25 tonnes per hectare (FAO 1994). However, sweet potato yields from fertiliser trials in the region suggest a potential yield of approximately 100 tonnes per hectare for this crop, which is much higher than that presently achieved by farmers (Blamey 1996).

In addition to low pH, one or more of the following growth-limiting factors are commonly associated with acid soils: aluminium (Al) or manganese (Mn) toxicities, and deficiencies of calcium (Ca), magnesium (Mg), phosphorus (P) or molybdenum (Mo) (Foy 1992). While sweet potato is grown extensively on acid soils in the tropics (Hahn 1977), little is known about the effects of individual acid soil infertility factors on

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the growth of the crop. This paper reviews sweet potato research on acid soils and suggests possible future research.

Soil pH and Aluminium Toxicity

Hartman and Gaylord (1939) reviewed the early studies investigating the growth of sweet potato on acid soils in the United States and noted that there were conflicting results. For example, in one experiment there was little change in sweet potato yield when soil pH was increased from 4.9 to 7.3, whereas other studies reported increasing yield with increasing soil pH. Still other experiments indicated that sweet potato yield at soil pH < 5.0 was higher than that at soil pH > 6.0.

Subsequent studies on tropical acid soils have also produced conflicting results with regard to the effects of soil pH on the growth of sweet potato. Perez-Escolar (1977) found no statistically significant effects of liming on the yield of sweet potato in three highly weathered soils from Puerto Rico. Liming increased the soil pH from 4.0 to 5.3 and decreased Al saturation from 45% to 0%. Since Al saturation in all of the treatments was less than 50%, Al toxicity was probably not an important growth-limiting factor. In contrast, Abruna et al. (1979) reported that liming increased sweet potato yield in four tropical acid soils. The beneficial effects of lime were observed in soils with Al saturation of more than 60%. In one soil that had 35% Al saturation, liming caused a relatively small (10%) increase in yield. Using two strongly acid soils from Queensland in Australia, Ila'ava (1998) observed close relationships between sweet potato growth and both exchangeable Al and soil pH. In this experiment, maximum or near maximum growth occurred at a soil pH of around 5.0 and soil exchangeable Al of kess than 3.0 centimoles of positive charge (cmol (+)) per kilogram.

Sweet potato was reported to be more tolerant of soil acidity than tobacco (*Nicotiana tabacum* L.), maize or soybean (Abruna et al. 1979). In this study, the high tolerance of sweet potato to soil acidity was attributed to the maintenance of adequate tissue Ca concentration for normal growth. Abruna-Rodrigues et al. (1982) found that sweet potato was second only to cassava in its tolerance to soil acidity, and was more tolerant than are taro or yam. In this study, cassava achieved approximately 87% of maximum yield at a soil pH of 4.5, whilst the corresponding values for sweet potato, taro and yam were 72%, 57% and 23%, respectively. The relatively high tolerance of cassava and sweet potato to soil acidity implies that both species are tolerant of factors that limit the growth of less tolerant species.

Limited information is available on acid soils in the South Pacific, but analytical data for some soils from the region suggest that acid soils are widespread (Bleeker 1983; Bell 1988; Naidu et al. 1991). Since tropical root crops are grown extensively in the region, it is highly likely that acid soil infertility factors may play an important role in limiting the yields of these crops. Despite this, the effects of acid soil factors on the growth of sweet potato and the other tropical root crops have received little attention in the region.

Munn and McCollum (1976) were the first to study differential tolerance to Al among sweet potato cultivars using solution culture. They found that sweet potato cultivars differed in tolerance to Al toxicity. Differential tolerance to Al toxicity among sweet potato cultivars was confirmed in subsequent studies (Sangalang and Bouwkamp 1988; Ritchey 1991). Solution culture experiments using complete nutrient solutions similar in chemical composition to tropical acid soils showed that low pH (pH 4.0) per se did not have an effect on growth of 15 sweet potato cultivars (Ila'ava et al. 2000a). In another study, again using complete nutrient solutions at low pH (approximately 4.2), Ila'ava et al. (2000b) observed differential tolerance to Al among 15 sweet potato cultivars from PNG and Tonga. They concluded that Al, rather than low Ca supply, is more important in limiting sweet potato growth in acid soils. They also found that the growth of sweet potato was severely depressed by Al ion activity of 12 micormolar (μM), an activity commonly found in soil solutions of many tropical acid soils (Bruce et al. 1989; Menzies et al. 1994).

Calcium Deficiency

Calcium deficiency is a major factor associated with poor plant growth in acid soils (Foy 1992). Most research on Ca nutrition has involved legumes, cereals and pastures. Except for cassava (Spear et al. 1978; Islam et al. 1987), little is known about the effect of Ca on the growth of the other tropical root crops, including sweet potato.

The flowing solution culture (FSC) technique has enabled the study of plant growth and nutrient uptake under conditions similar to those experienced by plant roots growing in the soil (Asher and Edwards 1978; Asher and Edwards 1983). Using FSC, the concentrations of elements at which optimum plant growth occurs for many plant species are lower than those reported from many nonflowing culture studies. For example, Loneragan et al. (1968) demonstrated that, while there were differences among species, all 30 grass, cereal, legume and herb species grew well and without symptoms of Ca deficiency at a solution Ca concentration of 100 μM. A subsequent study by Islam et al. (1987), using 13 species, produced similar results. Furthermore, Islam et al. (1987) noted that solution Ca concentration required for 90% of maximum yield was lower for monocotyledons (3–20 μM) than for dicotyledons (7–720 μM), concluding that as a group the former were less susceptible to Ca deficiency than were the latter. However, of the 13 species investigated, cassava was as tolerant of low solution Ca (≤ 10 μM) as was rice, which was the most tolerant monocotyledon. These relatively low Ca concentrations contrast with the much higher concentrations (1000– > 5000 μM) commonly employed in non-flowing nutrient solutions (Asher and Edwards 1983).

There are conflicting reports in the literature regarding growth of sweet potato in tropical acid soils. Many of these soils are low in Ca, and satisfactory yields in some cases have led to the conclusion that sweet potato is tolerant of low Ca (Abruna et al. 1979). However, there are many sweet potato cultivars, and it is likely that cultivars would differ in their response to low Ca. Indeed, differential tolerance to low Ca supply among cultivars has been reported for many crops. With sweet potato, results of recent studies indicate that tolerance to low Ca and soluble Al may be linked (Ila'ava et al. 2000b).

Symptoms of Ca deficiency usually appear first in the young, meristematic parts of plants. In sweet potato plants grown in the glasshouse using sand culture, Spence and Ahmad (1967) attributed small chlorotic patches scattered over the leaf surface to Ca deficiency. With time, the chlorotic spots became necrotic. These workers also observed death of growing points, restricted root formation and marked necrosis of roots in plants that were grown in the absence of added Ca. O'Sullivan et al. (1997) also observed symptoms indicative of Fe deficiency, which they attributed to poor uptake of iron (Fe) by the Ca-deficient plants. These workers reported that a Ca concentration of 0.9–1.2% in the 7^{th}–9^{th} leaf blades of sweet potato plants was considered to be adequate.

Magnesium Deficiency

Because Mg is a poor competitor with Al and Ca for exchange sites on solid surfaces of acid soils, a larger proportion of the dissolved Mg remains in solution (Sumner et al. 1990). Hence, it is to be expected that the concentration of Mg in the soil solution of acid soils would tend to be somewhat higher than that of Ca (Gillman and Bell 1978; Bruce et al. 1989; Menzies et al. 1994). Bruce et al. (1989) analysed surface horizons of 91 acid soils from Queensland and reported mean exchangeable Ca and Mg levels of 2.4 and 1.5 cmol (+)/kg, respectively. In contrast, the mean concentrations of Ca and Mg in the soil solutions were 308 μM and 345 μM, respectively.

Deficiency symptoms usually appear first in the older leaves, because Mg is mobile in the plant (Mengel and Kirkby 1987). Initial symptoms in cassava (Spear et al. 1978), maize, sorghum (Clark 1984), sweet potato (Bolle-Jones and Ismunadji 1963; Spence and Ahmad 1967; O'Sullivan et al. 1997) and wheat (Edmeades et al. 1991) are characterised by interveinal chlorosis of the older leaves. As deficiency becomes more severe, dark necrotic lesions may appear in the interveinal regions and the leaves often turn reddish purple.

Phosphorus Deficiency

Plant roots absorb P from the soil solution primarily as dihydrogen orthophosphate and hydrogen orthophosphate ions (Lindsay 1979). When pH increases above 5.5 or drops below this value, the concentration of the $H_2PO_4^-$ ion decreases, largely as a result of reactions with solid surfaces (Lindsay 1979; Sumner et al. 1990). In highly weathered tropical acid soils, phosphate ions in solution readily react with the sesquioxide minerals, resulting in very low concentrations of P in the soil solution (Parfitt and Thomas 1975; Sanchez 1976). The concentration of P in soil solutions ranges from < 2 μM to about 100 μM (Asher 1978; Gillman and Bell 1978; Mengel and Kirkby 1987). FSC studies indicate large differences between species in ranges of P concentration corresponding to deficiency, adequacy and toxicity (Asher 1978). However, it appears that many species will grow well at 1–5 μM P in solution.

Symptoms of P deficiency vary among plant species. With sweet potato, the purple pigmentation was observed on the petiole and main veins of the older leaves (Spence and Ahmad 1967). In other studies, chlorosis was followed by necrotic zones scattered at random over the older leaves (Bolle-Jones and Ismunadji 1963; O'Sullivan et al. 1997). O'Sullivan et al. (1997) studied four sweet potato cultivars from the South Pacific (Wanmun, Lole, Hawaii and Markham) and noted that P deficiency symptoms differed among the cultivars. In some cultivars, the chlorotic stage was not evident, and necrotic lesions appeared on green tissue. Others developed a dark purple pigmentation on the upper surface of older leaves before the development of necrotic lesions, while other cultivars developed purple pigmentation on the upper surface of the youngest leaves.

Molybdenum Deficiency

Molybdenum solubility decreases with decreasing soil pH (Sumner et al. 1990). In strongly weathered tropical acid soils, reactions of Mo with Fe oxide minerals are believed to be largely responsible for the low concentrations of Mo in solution (Clark 1984; Mengel and Kirkby 1987). Furthermore, Mo deficiency in acid soils may be exacerbated under conditions of high sulfate (SO_4^{2-}) in solution, which further reduces Mo uptake by plant roots (Mengel and Kirkby 1987). The inhibitory effect of SO_4^{2-} on MoO_4^{2-} absorption has been attributed to competition between two anions of similar size (Clark 1984).

Deficiency symptoms in many species often resemble N deficiency symptoms: older leaves become pale or chlorotic first, and as Mo deficiency increases in severity, symptoms will show on the other leaves as well (Jones et al. 1991). One stage of Mo deficiency can be the spotting on the leaf margins associated with nitrate toxicity. However, Mo deficiency symptoms are generally more severe in seedlings, while N deficiency symptoms increase in severity with plant age. There appears to be no information available on the Mo nutrition of sweet potato.

Manganese Toxicity

Manganese toxicity has been considered to be, after Al toxicity, the second most important growth-limiting factor in acid soils (Foy 1992). While redox potential is more important than pH in determining the level of soluble Mn in soils, at any given redox state Mn solubility increases with decrease in pH < 5.8 (Sumner et al. 1990). Thus, where soil Mn reserves are high, Mn toxicity is likely to be a growth-limiting factor in acid soils.

In sweet potato, O'Sullivan et al. (1997) reported that Mn toxicity symptoms first appeared on the older leaves. Initially, angular patches of pale tissue in the interveinal zones were observed, and this was followed by the appearance of roughly circular necrotic spots, often accompanied by the blackening of minor veins on the lower side of the leaf. Eventually the affected leaves turned yellow and were shed. As in wheat and maize, Mn toxicity also inhibited the uptake of Fe and, to a lesser extent, Ca and Mg (O'Sullivan et al. 1997).

Edwards and Asher (1982) reported maximum dry matter yields of 13 crop and pasture species in solutions containing 1.3–42 µM Mn. Marked reductions in growth occurred in all species at ≥ 130 µM Mn in solution. Sweet potato was considered to be tolerant of high solution Mn concentration. A subsequent study revealed that sweet potato growth was reduced by 10% when Mn concentration exceeded 1600 milligrams (mg) per kg in soil (O'Sullivan et al. 1997). These workers used low ionic strength nutrient solutions and also closely monitored the concentrations of elements in solution. Their findings are generally consistent with those of Edwards and Asher (1982), who suggested that, compared to other species, sweet potato is relatively tolerant of high solution Mn concentrations. Hence, it was concluded that Mn toxicity was unlikely to be as important as Al toxicity or Ca deficiency for sweet potato production on tropical acid soils.

Conclusions and Recommendations

Sweet potato appears to be moderately to highly tolerant of acid soils. Poor yields of sweet potato in acid soils will most likely be due to Al toxicity. Since sweet potato production is widespread in acid soils, more research is required to better understand the effects of the important acid soil infertility factors on the growth and yield of this crop. Research in this area should focus on the following points.

- Determining an agreed definition for acid soils.
- Accurately mapping the distribution of acid soils in PNG on the basis of the agreed definition.
- Screening cultivars for tolerance to acidity. Initial screening could be done in greenhouse studies to allow a large number of cultivars to be evaluated relatively rapidly. The next step would be to conduct field trials to evaluate promising cultivars identified from the initial greenhouse studies.
- Exploring further the close relationships between sweet potato growth and both exchangeable Al and soil pH to determine whether they will hold across a wide range of acid soil groups. With sweet potato, Al toxicity appears to be the most important of the acid soil infertility factors. Since soil pH is relatively easy and inexpensive to measure, having soil pH as an index for Al toxicity would indeed be a useful crop management tool.
- Investigating the hypothesis that tolerance to low Ca and soluble Al may be linked in sweet potato—an interesting suggestion which warrants further

research. Results from such studies would contribute much in terms of highlighting the importance of selecting sweet potato cultivars for specific conditions such as soil acidity.

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Review of Sweet Potato Diseases in PNG

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Abstract

In this paper, we review the diseases of sweet potato in PNG. Although many sweet potato diseases caused by fungi, bacteria, viruses, mycoplasma-like organisms (MLOs) and parasitic nematodes have been described, there has been very little research on these important diseases in PNG. Some work has previously been reported on sweet potato scab and, to a lesser extent, little leaf MLO and nematode infections. Whilst the distribution of most of the important diseases appears to be widespread and increasing, the impact of these diseases on cultivation of sweet potato is sporadic and location-specific. The importance of sweet potato disease depends upon production systems and the use of the crop. The cultural techniques of cultivating sweet potato are diverse and have a great influence on disease development and spread. These techniques have changed, or are changing, in some parts of PNG. Disease surveys and epidemiology are priority areas for future research to develop suitable preventive strategies in a variety of different production systems. Intensive cultivation of sweet potato, land shortage, increasing population pressure, and improved transportation are some factors that will contribute to future increases in disease spread and severity.

IN PNG, sweet potato is attacked by a wide range of diseases caused by fungi, viruses, a mycoplasma-like organism (MLO) and parasitic nematodes. Most of the pathogens recorded are fungi or nematodes. Only one or two diseases caused by bacteria, viruses or MLOs have been found in PNG.

Diseases of sweet potato are a major constraint to production in other parts of the world, particularly in temperate climates (Clark and Moyer 1988). Whilst only a few of the most serious sweet potato diseases are found in PNG, the diseases cause serious crop damage in certain parts of the country. One of the main reasons that the consequences of sweet potato disease are not more significant in PNG is that a large number of sweet potato varieties are grown together with other crops in traditional food gardens. However, this practice appears to be changing in some parts of the country, which may lead to more serious crop losses due to sweet potato diseases.

This paper presents a brief overview of sweet potato diseases in PNG. The main objectives of this review are:

- to identify the types of diseases that have been recorded in the past;
- to see how much work has been done on diseases in terms of research;
- to identify important diseases in the country; and
- to assist the prioritisation of future research on sweet potato diseases.

Diseases Caused by Fungi

A list of fungi recorded on sweet potato in PNG is given in Table 1.

Sweet potato scab

The fungus *Elsinoe batatas* causes sweet potato scab. The disease is widely distributed throughout PNG wherever sweet potato is grown. The disease

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Table 1. Fungi recorded on sweet potato in PNG.

Species name	Disease	Species name	Disease
Alternaria alternata	SPB	*Monilia stophila*	TR
Alternaria bataticola	LS	*Moniliochaetes infuscans*	scurf
Alternaria solani	SPR	*Mucor* sp.	TSR
Arthrobotrys sp.	SR	*Nigrospora* sp.	SR
Ascochyta convolvuli	LS	*Nigrospora sphaerica*	LS
Aspergillus sp.	TSR	*Penicillium* sp.	TSR
Aspergillus flavus	TR	*Penicillium citrinum*	TR
Aspergillus ostianus	TR	*Penicillium crustosum*	TR
Aspergillus repens	TR	*Penicillium funiculosum*	TR
Aspergillus terreus	TR	*Penicillium glabrum*	TR
Aspergillus versicolor	TR	*Penicillium islandicum*	TR
Athelia rolfsii	CR	*Penicillium simplicissimum*	TR
Botryodiplodia theobromae	JBR	*Periconia* sp.	SR
Botryosporium longibrachiatum	SR	*Pestalotiopsis royenae*	LS
Ceratocystis fimbriata	BR	*Pestalotiopsis versicola*	LS
Ceratocystis paradoxa	TR	*Phoma* sp.	SR
Cercospora bataticola	LR	*Phoma exigua*	SLPR
Choanephora sp.	TR	*Phoma leveilleri*	LS
Cladosporium sp.	TSR	*Phoma sorghina*	LS
Colletotrichum sp.	TSR	*Phomopsis batatas*	TR
Corynespora cassiicola	LS	*Phomopsis ipomoea*	LS
Cylindrocarpon destructans	LS/TR	*Phomopsis ipomoea-batatas*	SR/DB
Dendrophoma sp.	SR	*Phyllosticta* sp.	LS
Didymella sp.	LS	*Pseudocercospora timorensis*	LS
Elsinoe batatas	SPS	*Pythium* sp.	SR
Epicoccum sp.	SR	*Ramularia* sp.	LS
Fusarium sp.	TSR	*Rhizoctonia solani*	SR
Fusarium lateritium	SR	*Rhizopus* spp.	TSR
Fusarium oxysporium	TSRR	*Rhizopus oryzae*	TR
Fusarium pallidoroseum	SR	*Rhizopus stolonifer/nigricans*	TsoftR
Fusarium solani	TR	*Trichoderma* sp.	TSR
Fusarium subglutinans	SR	*Trichoderma hamatum*	TSR
Geotrichum candidum	TR	*Trichoderma harzianum*	TR
Glomerella cingulata	LS/SR	*Trichoderma koningii*	TSR
Leptosphaerulina sp.	LS	*Trichoderma neolongitrachiatum*	TR
Leptosphaerulina trifolii	leaves	*Verticillium* sp.	SR
Macrophomina phaseolina	TR/CR		

KEY: BR = black rot; CR = charcoal rot; DB = dieback; JBR = Java black rot; LS = leaf spot; SLPR = stem, leaf and petiole rot; SPB = stem and petiole blight; SPR = stem and petiole rot; SPS = sweet potato scab; SR = stem rot; TsoftR = tuber soft rot; TSR = tuber and stem rot; TSRR = tuber stem and root rot; TR = tuber rot

Sources: Shaw (1984); Waller (1984); Muthappa (1987); Kokoa (1991); Lenne (1991) attacks only the stem and leaves. Infection causes small lesions or spots to develop on the stem, petioles and veins on the underside of the leaf. Infected stems and leaves become distorted and reduced. Cool, wet weather conditions are most favourable to the development and spread of the pathogen.

Sweet potato scab is the most serious of all foliar diseases of sweet potato. Yield reductions due to scab have been reported in the highlands. Goodbody (1983) and Floyd (1988) have reported yield losses of 57% and 19%, respectively. P. Kokoa (unpublished data) has recorded yield differences in three varieties of sweet potato with different degree of susceptibility: the most susceptible variety had a 27% loss in tuber weight.

Disease appears not to be a major problem because of the great number of resistant varieties available in traditional food gardens. This has been confirmed by scab evaluations of sweet potato varieties in field collections at the Lowlands Agricultural Experiment Station (LAES) at Keravat and the Kuk, Aiyura and Laloki research stations (P. Kokoa et al., unpublished data). Scab assessment carried out at Kuk Research Station showed 590 accessions as highly resistant, 116 as moderately susceptible and 280 as highly susceptible to the disease. Studies carried out in the highlands showed that fungicides may be used to effectively control the disease (Floyd 1988; P. Kokoa, unpublished data).

Alternaria stem and leaf blight

Stem and petiole blight caused by *Alternaria alternata* was first recorded in PNG in gardens in Nebylier Valley, Western Highlands Province, in early 1987 (Kokoa 1991). About eight months later, the disease was recorded at Kuk and Tambul, followed by the Highlands Agricultural College and then Kol in Upper Jimi Valley in 1988. The first records of the disease from Simbu and Southern Highlands provinces were made in early 1989 at Boromil (Gumine District) and Birop (Upper Mendi District), respectively. The first confirmed report of the disease in Eastern Highlands Province was at the Highlands Agricultural Experiment Station (HAES) at Aiyura in 1991. It is likely that the disease was introduced to Aiyura by infected plants as early as 1988.

Inoculation tests were carried out at Kuk Research Station in 1988, and fungi commonly isolated from stem and petiole lesions were tested. The fungi included *Alternaria* sp., *Phomopsis* sp., *Fusarium* sp. and a species of *Colletotrichum*. The disease produces small, black, oval or circular lesions about 1 millimetre in diameter on stems and petioles. The lesions are initially superficial and may become depressed as they increase in size. Individual lesions may develop to up to 50 millimetres long. The lesions girdle stems and petioles as they enlarge and gradually cause the death of shoots (dieback) or collapse of individual leaves. Dieback symptoms usually become more severe in drier weather conditions when the lesions completely girdle stems. Cracks are observed along the stems engulfed by the lesions, especially during drier weather conditions.

In 1989, sweet potato varieties in the Kuk Research Station sweet potato germplasm collection were screened to find out the number of varieties with the disease symptoms (P. Kokoa, unpublished data). Otherwise, there has been no other work carried out on the disease since 1989.

Fusarium stem rot

Symptoms of stem rot causing wilt and death of vines were first reported from a polycross seed nursery at Kuk Research Station in 1986. Infection of stems caused leaf chlorosis and wilt and eventually whole vines became necrotic. Vascular discolouration was noticed on affected stems. Under favorable weather conditions the pathogen produced fruiting bodies (sporodochia) on necrotic tissues. In 1988, similar disease symptoms were observed in a plant pathology working collection at Kuk Research Station and on a local variety (Gorokagi) at Boromil in Gumine District of Simbu Province.

An unknown species of *Fusarium* was isolated from affected stems and petioles. Initially, *Fusarium oxysporum* f. sp. *batatas*, the causal agent for vascular wilt in sweet potato, was suspected. Waller (1984) isolated *Fusarium oxysporum* from discoloured vascular tissues of vines, but could not prove whether it was the vascular wilt pathogen. Cultures were sent to the Fusarium Research Laboratory at the University of Sydney and identified as *Fusarium lateritium* (Kokoa 1991), which was the first record of this species on sweet potato. Pure cultures of the pathogen have been used in pathogenicity tests in the laboratory and screenhouse at Kuk Research Station, showing that *F. lateritium* was the pathogenic species responsible for the stem rot at Kuk and Boromil.

Storage rots

Sweet potato is attacked by several fungal pathogens after tubers are harvested and stored. A survey carried out in 1985 by Gosford Horticultural Postharvest Laboratory in New South Wales found surface rot

(*Fusarium* spp.), black rot (*Ceratocycsis fimbriata*) and Rhizopus rot (*Rhizopus nigricans*, *Rhizopus oryzae*) to be the predominant postharvest diseases or storage rots in PNG (Morris, unpublished data). *Fusarium oxysporum*, *Fusarium solani*, *C. fimbriata* and species of *Rhizopus* have frequently been isolated or observed from necrotic tissues of tubers (Kokoa 1991). The fungi are very aggressive colonisers of tuber wounds, and are widespread in the highlands where sweet potato is intensively cultivated. Infection takes place primarily through wounds inflicted during harvest.

Postharvest diseases may not be a problem when tubers are consumed shortly after harvest, but become a major constraint when tubers are stored for a longer period of time or when tubers are in transit to distant markets, such as Port Moresby. The incidence of storage diseases can be reduced by minimising injury to tubers during harvest. For long distance shipment of tubers, curing and cool storage would be ideal, but small farmers in PNG do not have access to such facilities.

Diseases Caused by Mycoplasma-Like Organisms

Sweet potato little leaf

Plants affected by little leaf disease have small leaves, short internodes and a proliferation of axillary shoots resulting in an overly upright growth and some general leaf chlorosis (Shaw 1984; Muthappa 1987).

Sweet potato little leaf is caused by MLOs (Pearson et al. 1984). The first record of the disease in PNG was at LAES (Keravat) in East New Britain Province (Van Velsen 1967). Up to the early 1980s, the disease was reported at Keravat and Lae and in Central Province (Pearson 1981). The disease appears to be confined to parts of Central Province and other coastal areas with a marked dry season. There have been a few new unconfirmed reports of the disease in East New Britain and Milne Bay provinces and even in the highlands in recent years.

The reaction of sweet potato to little leaf disease varies with variety. The disease is reportedly more serious in Central Province, particularly during the dry season (Pearson et al. 1984; Philemon, unpublished data). Affected plants have a reduced tuber size, and tubers may not form at all if vines are severely affected at an early growth stage.

Cultural control methods can be effectively used to reduce severe crop losses or restrict its spread. Work carried out at Laloki Research Station in 1985–86 (Philemon, unpublished data) has shown that there are varieties with some degree of resistance to little leaf disease in PNG.

Diseases Caused by Viruses

Very little research has been done to identify virus disease problems and their impact on sweet potato production in PNG. The only information available at present are names of viruses that have been identified from samples sent overseas (Table 2) (Shaw 1984:79–80; Waller 1984; Clark and Moyer 1988; Lenne 1991) and from field trials carried out at Laloki Research Station and LAES (Keravat). The field trials mainly compared tuber yields of dirty (field) and clean (pathogen-tested) planting materials. In most cases, there was no significant difference in yield between pathogen-tested and field materials.

Table 2. Viruses recorded on sweet potato in PNG.

Species name	Disease
Nepovirus	Sweet potato ring spot virus (SPRSV)
Potyvirus	No symptoms
Potyvirus	Leaf curl
Badnavirus	Sweet potato leaf curl virus (SPLCV)
Caulimovirus	Sweet potato caulimo-like virus (SPCLV)

Sources: Shaw (1984:79–80); Waller (1984); Muthappa (1987); Clark and Moyer (1988); Lenne (1991)

Diseases Caused by Bacteria

Only three genera of bacteria have been recorded on sweet potato in PNG (Table 3). *Bacillus* sp. and *Pseudomonas cichori* were isolated from stem and petiole lesions caused by the fungus *Alternaria alternata* (Kokoa 1991). *Erwinia chrysanthemi*, the causal agent for bacterial soft rot, has been associated with tuber rot in the highlands (Muthappa 1987). Bacterial soft rot is reported to be one of the important bacterial diseases of sweet potato.

No research has been done on bacterial soft rots of sweet potato in PNG. Its importance as a postharvest pathogen can only be demonstrated through proper disease surveys.

Diseases Caused by Nematodes

A total of 22 different genera of plant parasitic nematodes have been found to be associated with sweet potato in PNG (Table 4) (Bridge and Page 1982; Kokoa 1991). There are 19 known and 12 possible species yet to be described. According to Bridge and Page (1982), five of the species cause considerable damage, particularly in the highlands of PNG. These are: the root-knot nematodes *Meloidogyne incognita*, *M. javanica*, *M. hapla*; the spiral nematode *Helicotylenchus mucronatus*; and an undescribed species of *Radopholus*. The general symptoms of damage caused by the nematodes are leaf chlorosis and root and tuber malformation, and possibly yield loss (Bridge and Page 1982).

Survey results from the 1980s indicated that although these nematodes are widespread but serious root damage was reported in only some areas of the highlands (e.g. in Upper Mendi, Tari Basin, Gumine districts) where the fallow period is short due to the high population pressure on land use. Work done in Southern Highlands Province gave a mean yield loss of 28%, using carbofuran to control nematodes, but the result was inconclusive (D'Souza 1986). More research is required to quantify yield loss due to sweet potato nematodes.

Table 3. Bacteria recorded on sweet potato in PNG.

Species name	Disease
Bacillus sp.	Stem and petiole rot
Erwinia sp.	Tuber rot (BNM)
Erwinia chrysanthemi	Tuber rot
Pseudomonas cichorii	Stem and petiole rot

Sources: Muthappa (1987); Kokoa (1991)

Table 4. Nematodes recorded on sweet potato in PNG.

Species name	Location (if known)	Species name	Location (if known)
Aphelenchoides sp.	Roots, soil	*Nothotylenchus* sp.	
Aphelenchoides bicaudatus	Roots	*Paratrichodorus minor*	
Aphelenchus spp.		*Pratylenchus* sp.	Soil
Aphelenchus avenae	Roots, soil	*Pratylenchus coffeae*	
Coslenchus sp.		*Radopholus similis*	
Criconematid sp.		*Radopholus* n.sp. (a)	
Criconemella sp.	Roots	*Radopholus* n.sp. (b)	
Criconemella onoensis		*Radopholus* n.sp. (c)	
Crossonema civellae	Soil	*Rotylenchulus reniformis*	Roots, soil
Discocriconemella sp.	Roots, soil	*Scutellonema insulare*	
Gracilacus aonli		*Seriespinula* n.sp.	
Helicotylenchus sp.	Roots, soil	*Syro vexillatrix*	Soil
Helicotylenchus dihystera	Roots, soil	*Trichodorus cylindricus*	
Helicotylenchus microcephalus	Soil	*Tylenchus* sp.	Soil
Helicotylenchus mucronatus	Roots, soil	*Xiphinema brasiliense*	
Heterodera spp.		*Xiphinema ensiculiferum*	
Meloidogyne sp.	Root-knot	*Xiphinema orthotenum*	
Meloidogyne hapla	Root-knot	*Xiphinema* sp.	
Meloidogyne incognita	Root-knot	*Xiphinema* n. sp.	
Meloidogyne javanica	Root-knot		

n.sp = new species
Sources: Bridge and Page (1982); Kokoa (1991)

At present, nematode problems are only evident in certain areas of the highlands. However, increasing land shortage and shortened bush fallow are likely to lead to widespread nematode disease problems in the future. Farmers can use certain traditional methods to reduce the level of infestation in their gardens, including crop rotation with nonhosts and resistant varieties. Bridge and Page (1982) have reported that some varieties are poor hosts for the highlands species of *M. incognita*. Shiga and Takemata (1981) have reported 69 varieties from PNG as resistant to root-knot nematodes. P. Kokoa (unpublished data) recorded 14 varieties of sweet potato with different reactions to infection by root-knot nematodes. These results may help to explain the different types of resistance in sweet potato reported by D'Souza (1986). The high number of resistant varieties from PNG may be attributable to high selective pressure, especially in the highlands.

Conclusion

A wide range of diseases that affect sweet potato in PNG have been recorded or identified since the 1940s. Many of these diseases are widespread in PNG, except for a few that appear to be confined to certain areas of the country. Past work has concentrated on the identification of diseases and their distribution through field surveys. There has been very little research carried out to quantify the impact of important disease problems, or to develop disease-control methods for farmers to use. The situation at present is still the same, with a limited number of plant pathologists actively engaged in crop pathology research.

The impact of major disease problems on sweet potato production in PNG is at present minimal, except in certain areas of the country where serious damage has been reported. However, this may change in the future, particularly in areas of the country that are at present densely populated and experiencing problems related to declining soil fertility and acute land shortage.

There is no current research on sweet potato diseases. Future work in this area should concentrate on surveys to update the current status of some of the disease problems that have been highlighted in this paper. This should be followed by research to assess economic crop losses and disease epidemiological studies to assist in developing disease management strategies.

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Sweet Potato Weevil (*Cylas formicarius*) Incidence in the Humid Lowlands of PNG

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Abstract

Sweet potato is the main staple crop in PNG and this paper presents a study from the humid lowlands of the Morobe Province. Three experiments were carried out at two locations (Hobu and Unitech) to evaluate the effect of inorganic fertiliser inputs and fallow vegetation on the incidence of sweet potato weevil, *Cylas formicarius* (Coleoptera: Brentidae), and damage to sweet potato *(Ipomoea batatas*) under natural levels of infestation. Nitrogen and potassium application at rates from 0 to 150 kilograms per hectare and 0 to 50 kilograms per hectare, respectively, and fallow vegetation treatments of *Imperata cylindrica*, *Piper aduncum* or *Gliricidia sepium,* had no significant effect on sweet potato weevil incidence and tuber damage over two consecutive seasons. At Hobu, the mean tuber damage category in the continuous sweet potato treatment was slightly higher than fallow treatments in two consecutive seasons, though not significantly so. In the second season, there was a 20-fold increase in the numbers of weevil stages found in damaged tubers of the continuous sweet potato treatment.

Differences in above-ground weevil incidence were recorded between sites with up to 28.5 weevils per square metre at Unitech and a maximum of 0.5 weevils per square metre at Hobu. Levels of tuber and vine damage also differed between sites. At the Hobu site, despite low above-ground weevil incidence, vine and tuber damage was high over consecutive seasons with more than 51% of vines and 34% of tubers damaged. At Unitech, vine damage was consistently above 83%, yet tuber damage did not exceed 16%. Tuber damage, although sometimes high in terms of the percentage of tubers damaged, was superficial at both sites. This had little effect on marketability or yield as low levels of weevil life stages were recorded in the tubers. Site-related differences, in particular rainfall, soil properties and cultivar characteristics may have contributed to the relatively low levels of tuber damage compared with the high levels of weevil incidence on the vines and foliage.

SINCE its introduction to PNG around 400 years ago, sweet potato (*Ipomoea batatas* (L.) Lam.) has been cultivated in low and high altitude ecogeographical environments, and over a wide range of soil types and farming systems (Bourke 1985). Sweet potato is particularly important as a staple in subsistence agriculture where its tubers (storage roots) and, to a lesser extent, vines and leaves are used for human and animal consumption (Kimber 1972).

Sweet potato weevil (*Cylas formicarius* (Fabricius) (Coleoptera: Brentidae)) is the major pest constraint of sweet potato production and is ranked as the fifth most important invertebrate pest in PNG (Waterhouse 1997). It causes economic damage in areas with a marked dry season or in unseasonally dry years (Bourke 1985). The weevil spends its entire life cycle on the host plant, and both larval and adult stages

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damage the tubers and vines. Damage to tubers can reach up to 90% (Sutherland 1986a) and relatively minor damage can both reduce yield and render infested tubers unmarketable due to the presence of feeding marks and oviposition holes. Weevil-infested tubers emit offensive odours due to the presence of terpenes produced by the insects (Sato et al. 1981) and to a rise in the level of phenolic compounds in the tubers (Padmaja and Rajamma 1982), rendering them unpalatable for human or animal consumption. Tuber shrinkage also occurs due to loss of water through feeding or oviposition cavities made by the weevils. The main damage is due to larvae developing inside the edible tubers, but yield losses also occur due to adults and larvae feeding on the vines (Sutherland 1986a). Despite the considerable importance of sweet potato to the subsistence economy of PNG, there are few published studies that examine the interactions of sweet potato weevil with sweet potato, its primary host. In PNG, sweet potato yields are declining or static and there is a potential for yield improvement through both improved nutrient management and an understanding of the fundamental factors that influence the incidence of sweet potato weevil.

A number of management practices influence the incidence of sweet potato weevil and damage to sweet potato. In this study we consider three key factors: fallow vegetation, inorganic nutrient inputs and cultivar selection. Fallow vegetation can influence soil fertility levels but can also potentially reduce pest incidence by disrupting the pest's life cycle either through a break in crop rotation or by the release of allelopathic chemicals (allelopathy is the ability of one plant to use chemicals to repel other plants in order to gain nutrients and light).

Nitrogen (N) and potassium (K) can influence host plant–insect interactions and pest damage levels by changing the chemical characteristics of a crop. This has the potential to influence the feeding or ovipository (egg laying) behaviour of insect pests. Nitrogen increases the protein and starch content of sweet potato (Bartoloni 1982; Li 1982) and influences the levels of triterpenoids in other plants (Gershenzon 1991). Protein and starch are important nutritional requirements of insects, whilst triterpenoids are known to influence the ovipository behaviour of sweet potato weevils (Nottingham et al. 1988).

The objectives of our study were to quantify the incidence of sweet potato weevils and subsequent damage to the sweet potato crop under natural infestation pressure, and to evaluate the effects of inorganic fertiliser inputs and fallow regimes on these parameters. Incidence of sweet potato weevils is also related to cultivar and soil characteristics and rainfall patterns and the relationship between these factors is described. Data included in this paper form part of a series of long-term experiments examining integrated nutrient management strategies (Hartemink et al. 2000).

Materials and Methods

Experimental sites

Experiments were conducted at two locations in the humid lowlands of Morobe Province, PNG. Three experiments were conducted between November 1997 and November 1998 onfarm at Hobu (6°34', 147°02'E, 405 metres above sea level) and on an experimental farm at the PNG University of Technology (Unitech), Lae (6°41', 146°98'E, 65 metres above sea level).

Soils at Hobu were classified as sandy-clay Typic Eutropepts whereas soils at Unitech were sandy Typic Tropofluvents (Soil Survey Staff 1998). At Hobu, secondary vegetation consisting mainly of seven-year old *Piper aduncum* L. was slashed manually in October 1996 prior to site establishment. At Unitech, the experimental site had been under grassland for six years and was chisel-ploughed in June 1996 prior to planting sweet potato. Three successive seasons of sweet potato cultivation had been carried out at the Unitech site prior to the establishment of the trial described in this study.

Rainfall records at Hobu for the experimental periods are shown in Figure 1. At Hobu in 1997, the total annual rainfall of 1897 millimetres (mm) was below the long-term average due to the El Niño phenomenon that affected the Pacific region during that year. In the following year, annual rainfall almost doubled, reaching 3667 mm. At Unitech, the mean annual rainfall is 3789 mm but has varied from 2594 to 4918 mm over the past 25 years. Annual rainfall in 1997 was 2606 mm.

Experimental design and analysis

All experiments were laid out as randomised complete block designs. Plot sizes at Hobu were six square metres (6.0 m × 6.0 m) for trial I and 4.5 m × 4.5 m for trial II. Cultivar Hobu1, obtained from local gardens, was planted on a 0.75 m × 0.75 m grid. At Unitech, plot sizes were 3.2 m × 4.0 m with planting distances of 0.4 m × 0.8 m and the cultivars Markham (trial III, two seasons) and Hobu1 (trial III, one season) were planted. Vine cuttings of 0.3 m length were used as planting material in all trials. Plots were replanted directly after each harvest. Weed control was manual for all trials and no pesticides were applied. Weevil infestation was natural for all trials.

Trial I

In trial I the effect of fallow vegetation on sweet potato weevil incidence and sweet potato damage was investigated. The trial consisted of four treatments replicated four times. The fallow treatments were *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* and the control treatment was continuous sweet potato. The control had previously been under continuous sweet potato for two seasons whilst the fallow plots had been under fallow for one season previously. The fallow vegetation was slashed prior to planting sweet potato. The trial was carried out over two consecutive cropping seasons of 168 and 174 days, respectively, at the Hobu site. Total rainfall was 1894 mm for the first season and 1576 mm for the second season (Fig. 1).

Trial II

The effects of inorganic fertilisers on sweet potato weevil incidence and damage to sweet potato were examined in trial II. It consisted of eight treatments replicated four times and was carried out over one growing season at Hobu. The trial was laid out as a factorial combination of four levels of N (0, 50, 100 and 150 kilograms per hectare) and two levels of K (0 and 50 kilograms per hectare). Fertilisers were applied in split dressings at 8, 55 and 81 days after planting. The growing season lasted 179 days. Total rainfall for the growing season was 2214 mm (Fig. 1).

Trial III

During the first season of trial III, three levels of inorganic N (0, 50 and 100 kilograms per hectare) were applied and the sweet potato cultivar Markham was used. In the subsequent season, the trial was repeated using the same treatments but with the addition of sweet potato cultivar Hobu1 in order to compare cultivar susceptibility to sweet potato weevil. Each treatment and control was replicated four times in both seasons. Fertilisers were applied in split dressings at 29 and 51 days after planting. The length of the growing season was 171 and 163 days for the first and second seasons, respectively. Total rainfall for the first and second seasons was 1838 mm and 2293 mm respectively (Fig. 1).

Weevil incidence and damage

At both sites, for trials II and III (second season) within-foliage populations of adult sweet potato weevil were monitored bi-weekly throughout the season, up to and including the final harvest. For trials I and III (first season) weevil counts were only made at final harvest. All above-ground weevil counts were determined using one metre square metal quadrats randomly positioned and repeated three times in each plot.

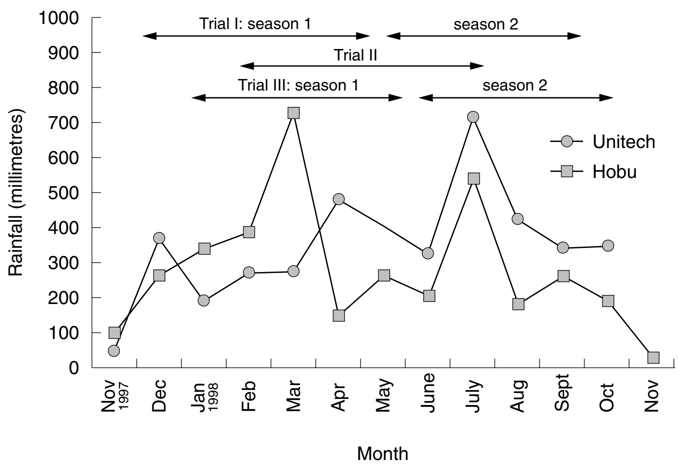

Figure 1. Monthly rainfall patterns at experimental sites during growing seasons.

At harvest, all vines were slashed to within 0.15 m of the tuber crown and removed from the plot. Three plants were dug manually, removed from each plot and the remaining vine sections cut and placed in paper bags. The number of vines (damaged and undamaged) and vine weights were recorded. Vines were dissected to assess damage as indicated by the presence of feeding marks and weevil life-stages. Tubers were counted, weighed and separated into marketable (> 100 grams) and non-marketable (< 100 grams) tubers. Marketable tubers were subdivided by external appearance of the outer periderm as either damaged (presence of feeding and/or ovipositon marks) or undamaged (no marks). Damaged marketable tubers were sliced at the zone of maximum surface damage and categorised using the visual damage rating scale of Sutherland (1986b). Damaged tubers were sliced into 3 mm sections to count weevil life stages.

Data analysis

Data from all trials were analysed using the statistical software package Statistix for Windows and subjected to analysis of variance. The test of least significant difference (LSD) was used to compare treatment means. After preliminary analysis of final harvest data from all trials, no significant differences between treatments were observed and treatment data were therefore pooled to allow comparison between treatments and controls in each trial.

Results

Trial I

Above and below-ground parameters measured for the fallow trial at Hobu over two consecutive cropping seasons are shown in Table 1. Above-ground adult weevil populations at final harvest were low for all treatments and there were no differences ($P > 0.05$) between treatments over both growing seasons. Vine damage was high over both seasons, with more than 50% of vines damaged, but few life stages were observed in the vines. There were no differences ($P > 0.05$) between treatments for all above-ground parameters examined within each season. However, the number of weevil life stages per vine was consistently higher for the continuous sweet potato treatment for both seasons but 2.5-fold higher in the first season.

Over three-quarters of all marketable tubers were damaged in the first season and over one-third of tubers in the second season for all treatments. Damaged tubers were predominantly category 1–2 (i.e. only superficial damage by weevils) over both cropping seasons and treatment differences were not significant ($P > 0.05$).

When examining the between-season trends for weevil damage, there was at least 50% less tuber damage in the second season compared with the first season. However, in the second season there was a 20-fold increase in the number of weevil stages found in damaged tubers of the continuous sweet potato treatment (Table 1), which was reflected in the higher mean damage category value.

Trial II

Table 2 shows the above- and below-ground parameters measured in the inorganic fertiliser trial over one growing season at Hobu. The above-ground adult weevil population was highest in the control and, although it was lower where fertiliser had been applied, the differences were not significant ($P > 0.05$). Vine damage was high for all treatments, with more than three-quarters of vines damaged. However, few life-stages were observed in the vines. There were no significant differences ($P > 0.05$) between treatments for any of the above-ground parameters examined. Damaged tubers for all treatments were predominantly category 1 (i.e. only superficial damage by weevils) with the exception of the control (category 2), but the number of damaged tubers was high (78–100%). This was in marked contrast to the number of weevil stages found in the tubers, which was low for all treatments. There were no significant differences ($P > 0.05$) between treatments for any of the below-ground parameters examined.

Trial III

Table 3 shows the above and below-ground parameters measured in the inorganic N fertiliser trial over two consecutive cropping seasons at the Unitech site using the Markham cultivar. There were no significant differences ($P > 0.05$) between treatments, in any parameter, within each season.

There was a marked reduction in the number of above-ground weevils on the foliage at final harvest in the second season compared to the first season, but this was not reflected in other above-ground parameters. The number of weevils on the foliage prior to harvest increased with increasing N application in both seasons although the increase was not statistically significant ($P > 0.05$). Weevil counts at the Unitech site were relatively higher than those recorded at the Hobu site (Tables 1 and 2).

Table 1. Comparison of above and below-ground sweet potato weevil incidence and damage (± SD) under continuous cropping and fallow treatments (trial I, Hobu site).

Season	Treatment	Weevils on foliage (no. per m^2)	Damaged vines (%)	Weevil life stages per damaged vine	Marketable tuber damage (%)	Weevil life stages per damaged tuber	Mean damage category
First	Continuous sweet potato	0	52 ± 20	1.5 ± 2.4	78 ± 11	0.3 ± 0.5	1.7 ± 0.4
	Sweet potato after one year fallow[a]	0	62 ± 14	0.6 ± 0.9	88 ± 20	0.7 ± 1.2	1.5 ± 0.5
Second	Continuous sweet potato	0.5	55 ± 18	0.5 ± 0.6	35 ± 18	5.3 ± 10.5	2.6 ± 0.7
	Sweet potato after one year fallow[a]	0.1	51 ± 30	0.3 ± 0.7	34 ± 21	0	1.6 ± 0.8

[a]Fallow vegetation is pooled data from fallow treatments with *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* for both seasons.

Table 2. Assessment of above and below-ground sweet potato weevil incidence and damage (± SD) at four combinations of inorganic fertiliser input rates (trial II, Hobu site).

Treatment	Weevils on foliage (no. per m^2)	Damaged vines (%)	Weevil life stages per damaged vine	Marketable tuber damage (%)	Weevil life stages per damaged tuber	Mean damage category
No fertiliser	0.9 ± 1.4	87 ± 16	0.25 ± 0.50	78 ± 11	0.25 ± 0.50	2.1 ± 0.9
N 100 kg /ha	0.5 ± 0.7	83 ± 18	0.16 ± 0.55	88 ± 20	0.16 ± 0.55	1.3 ± 0.9
K 50 kg/ha	0.2 ± 0.3	97 ± 5	0	100 ± 0	0	1.3 ± 0.6
N+K[a]	0.2 ± 0.3	80 ± 18	0.33 ± 0.89	100 ± 0	0	1.3 ± 0.5

[a]N+K = N at 100 and K at 50 kilograms per hectare (kg/ha)

Table 3. Assessment of above and below-ground sweet potato weevil incidence and damage (± SD) to sweet potato cultivar Markham at three different rates of inorganic nitrogen (N) application over two consecutive seasons (trial III, Unitech site).

Treatment	Weevils on foliage (no. per m^2)	Damaged vines (%)	Weevil life stages per damaged vine	Marketable tuber damage (%)	Weevil life stages per damaged tuber	Mean damage category
First season						
No fertiliser	12.8 ± 3.5	100	3.5 ± 3.9	0	0	0
N 50 kg/ha	20.5 ± 12.5	100	3.0 ± 1.8	0	0	0
N 100 kg/ha	28.5 ± 14.8	100	4.8 ± 2.2	16	0.3	1
Second season						
No fertiliser	2.3 ± 2.2	97 ± 7	5.3 ± 5.9	0	0	0
N 50 kg/ha	3.0 ± 3.4	100	3.0 ± 2.6	6	0	0.3
N 100 kg/ha	3.8 ± 2.5	93 ± 14	3.0 ± 2.3	6	0	0

The percentage of damaged vines was high (93–100%) for all treatments over both seasons. Despite considerable vine damage in both seasons, tuber damage was relatively low as reflected by the low number of weevil life stages in the tubers (Table 3). Whilst weevil counts on the foliage were relatively high, only the N treatments showed some degree of marketable tuber damage (category 1).

Table 4 shows the parameters measured in trial III, which compared the effect of N applications on two sweet potato cultivars, Hobu1 and Markham, over one cropping season at the Unitech site. There were no significant differences ($P > 0.05$) between treatments or cultivars. Vine damage was relatively high (83–100%) for all treatments, and this was reflected in the higher number of weevil life stages recorded in dissected vines. The percentage of marketable tubers with weevil damage was relatively low for all treatments and the mean tuber damage category level was low (< 1), with the exception of the Hobu1 cultivar control treatment which had a mean damage category of 2 and higher weevil numbers present in the tubers.

Weevil incidence, rainfall and cultivar

When comparing above-ground weevil counts at final harvest (Tables 1–4) there was no correlation with total seasonal rainfall levels at either experimental site. For trials II and III (second season), no significant differences in weevil counts were observed between treatments in both trials throughout the season. However, the above-ground incidence of weevils fluctuated throughout the season. At Hobu during the period of trial II, above-ground weevil incidence was relatively low for the first nine weeks of the season. The incidence of weevils steadily increased from week 14 up to and including final harvest at week 23 (Fig. 2).

At Unitech, from week 10 to week 18 of trial III, weevil incidence on the foliage was relatively high on both varieties. Approaching final harvest, corresponding with a period of high rainfall, weevil levels generally declined on both varieties (Fig. 3). This was in marked contrast to weevil levels at the Hobu site which were relatively high at final harvest despite high rainfall (Fig. 2). Differences in above-ground weevil populations on the two cultivars were not significant but the Markham cultivar showed generally lower above-ground weevil levels over the season than the Hobu1 cultivar (Fig. 3).

Discussion

Fallow treatment and weevils

Fallow vegetation had no effect on weevil incidence or tuber damage. Continuous crops of sweet potato, however, resulted in a cumulative build-up in weevil populations in the tubers. This was reflected in the higher mean damage categories in the second season. The presence of old vine material, near or within the plots after harvesting in the first season, may have acted as a source of weevil infestation in the following season. This highlights the need for crop rotation, fallow or effective sanitation to break the weevil's life cycle (Talekar 1983) as the insect can only survive on sweet potato or related plants of the family Convolvulaceae (Sutherland 1986c).

Table 4. Comparison of sweet potato weevil incidence and damage (± SD) to two sweet potato cultivars, Markham and Hobu1, at three different rates of inorganic N application (trial III, Unitech site).

Treatment	Weevils on foliage (no. per m^2)	Damaged Vines (%)	Weevil life stages per damaged vine	Marketable tuber damage (%)	Weevil life stages per damaged tuber	Mean damage category
Markham						
No fertiliser	2.3 ± 2.2	97 ± 7	5.3 ± 5.9	0	0	0
N 50 kg/ha	3.0 ± 3.4	100	3.0 ± 2.6	6	0	0.3 ± 0.5
N 100 kg/ha	3.8 ± 2.5	93 ± 14	3.0 ± 2.3	6	0	0
Hobu1						
No fertiliser	2.3 ± 1.7	100	2.3 ± 1.0	11	2.8 ± 4.9	2.0 ± 2.3
N 50 kg/ha	3.0 ± 2.9	94 ± 12	2.5 ± 1.3	4	0	0.3 ± 0.5
N 100 kg/ha	3.3 ± 1.9	83 ± 25	0.8 ± 1.0	5	0.3 ± 0.5	0.5 ± 1.0

Inorganic fertiliser and weevil damage

Levels of some nutrients and ovipository stimulants in the sweet potato, and their effect on sweet potato weevils, could have been influenced by the use of inorganic fertilisers in this study. Further studies should consider qualitative and quantitative measurements of these chemical factors. Increased N application increases the protein and starch content of sweet potato tubers (Bartolini 1982), which could act as feeding stimulants for the sweet potato weevil. Li (1982) has shown that the protein content of sweet potato roots and foliage varies according to the level of N applied. Applications of between 50 and 150 kilograms of N per hectare can increase protein content significantly. Although we did not assess starch and protein levels, the application of inorganic N at similar levels in our study resulted in increased N

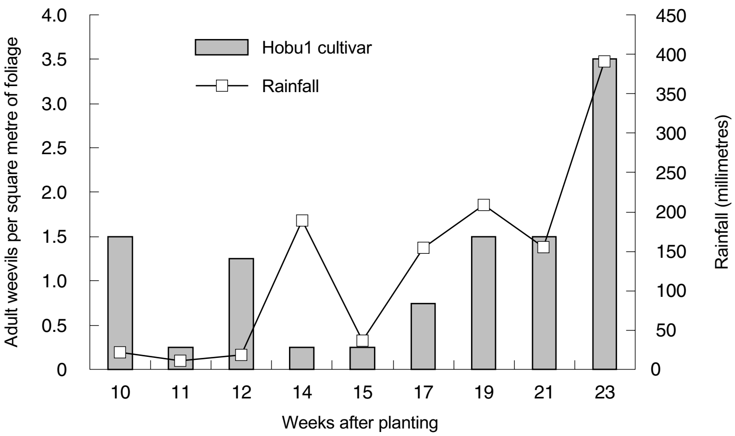

Figure 2. Relationship between adult sweet potato weevil incidence and rainfall distribution throughout the growing season on the Hobu1 sweet potato cultivar, under unfertilised conditions at Hobu (trial II).

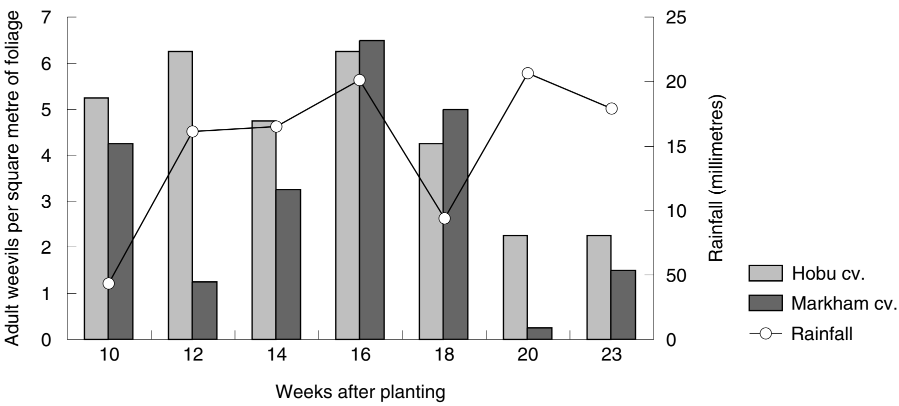

Figure 3. Relationship between adult sweet potato weevil incidence and rainfall patterns on Hobu1 and Markham sweet potato cultivars, under unfertilised conditions throughout the growing season at Unitech (trial III).

levels in the leaves (data not presented). Nottingham et al. (1988) have shown that the leaf surface chemistry appears to have no major influence on resistance to sweet potato weevil, but leaves are required for a nutritionally balanced diet (Hahn and Leuschner 1982). The leaves and vines of both varieties used in this work sustained high weevil incidence and damage, indicating that there was no apparent resistance factor in the foliage and that the foliage may have acted as a nutrient source for the insects.

Sweet potato cultivars susceptible to attack by sweet potato weevil have triterpenoids located in the outer periderm of the tubers (Nottingham et al. 1987; Son et al. 1990), which increase the ovipository behaviour of adult females. Triterpenoid levels can be reduced or remain unchanged following N inputs and can increase in drought conditions (Gershenzon 1991). Although triterpenoid levels were not measured in our study, N inputs showed no significant effect on tuber damage and hence ovipositional behaviour.

Soil factors and weevil damage

Soil differences between the two sites could have influenced weevil accessibility to tubers. Cracking around tubers as they enlarge and when soils dry out under low rainfall conditions can influence tuber accessibility. Weevils generally fail to penetrate wet soils but can penetrate dry soils readily and to depth (Teli and Salunkhe 1994). Tuber damage at Unitech was very low despite high weevil numbers in the canopy, which suggests that the sandy soil type at this site may have hampered access to the tubers.

Low levels of weevil population on the foliage at final harvest are indicative of either a generally low level of infestation per se or migration of weevil populations from the foliage to the tubers earlier in the season. The relatively high levels of tuber damage and low levels of weevils on the foliage at Hobu suggest the latter scenario and that the sandy-clay soil at Hobu may have facilitated accessibility to tubers.

Rainfall and weevil incidence

Rainfall has been shown to influence sweet potato weevil incidence and damage levels in PNG (Sutherland 1986b). In PNG, high levels of weevil incidence generally correspond with lower rainfall levels (Smee 1965; Sutherland 1986b) but in other countries the reverse has been shown (Pardales and Cerna 1987; Jansson et al. 1990). This suggests that the interactions between rainfall distribution and host plant growth and development and soil-related factors may be important in determining correlations between weevil incidence and rainfall. Rainfall may have influenced the severity of tuber damage and weevil accessibility at both experimental sites in our study. The reasons for this were hitherto not fully understood.

During weeks 10 to 15 at Hobu both rainfall levels (< 50 mm) and above-ground weevil levels were relatively low. During this dry period, weevils may have gained access to the tubers and this would account for the higher tuber damage levels at Hobu compared to Unitech. This increase could also be related to the fact that sweet potato tubers actively enlarge during the 6–16 week period (Bouwkamp 1983) and may have provided a greater food source for the weevils thereby leading to an increased population. The swelling of tubers could have also enhanced soil cracking in the tuber zone in the more clayey soils at Hobu. After week 15, rainfall increased and the above-ground weevil incidence also increased, suggesting that the weevils could no longer access the tubers because of high rainfall and a possible reduction in soil cracking.

At Unitech, rainfall levels were relatively high (> 100 mm) during weeks 10 to 15 and this corresponded with relatively high weevil levels on the foliage. During this period, rainfall may have reduced tuber accessibility. By week 20, above-ground weevil levels were lower, suggesting that weevils may have moved into the soil later in the season than at the Hobu site, and this could account for the lower tuber damage at Unitech. Sequential tuber harvesting would help to resolve these questions in future studies.

Cultivar and weevil damage

Preliminary observations suggest that cultivar characteristics may have influenced the incidence of weevils and degree of damage to sweet potato tubers. The Hobu1 cultivar showed consistently higher damage levels at both trial locations whereas the Markham cultivar over two seasons at Unitech showed relatively low tuber damage levels. However, the levels of damage observed on both cultivars were generally below those affecting marketable quality, suggesting that chemical characteristics of the tuber periderm could be influencing feeding or ovipository behaviour. To verify whether the Markham and Hobu1 cultivars have different levels of resistance, further observations need to be carried out under controlled conditions.

Conclusion

Fallow vegetation and inorganic fertiliser inputs, in the form of N and/or K, had little influence on weevil incidence or weevil damage to sweet potato. In our experiments, site factors, particularly rainfall and soil type, and cultivar characteristics are more likely to have influenced weevil incidence levels, their accessibility to sweet potato tubers and subsequent damage to marketable tubers. This study highlights the fact that further studies are required to understand the complex host plant–pest–environment interactions to be able to effectively manage sweet potato weevil in PNG.

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Breeding Taro for Food Security in PNG

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Abstract

The past few decades have seen major changes in the farming systems of PNG. New insect pests and diseases have become established and demand for land has increased, as has population. This has caused loss of diversity and the consequent deleterious replacement of traditional taro by other crops. To attain crop self-sufficiency and improve human nutrition, a taro breeding program has been established by the National Agricultural Research Institute supported by activities of Taro Genetic Resources: Conservation and Utilisation Project (TaroGen), funded by the Australian Agency for International Development. This will ensure sustainability of taro production and growers' confidence in the crop. Seven genetically improved new lines of taro have been identified, which will be distributed to farmers. To give direction to the national breeding program, taro improvement coordinating committees are being established, comprising farmers, nongovernment organisations and representatives from government departments of agriculture and other departments (e.g. health, education and finance).

THE vast majority of the PNG population helps to produce traditional staple fruit and vegetable crops. One such important traditional staple is taro (*Colocasia esculenta*). After sweet potato, taro is an important root crop staple in the country, and it also acts as a source of cash income for small subsistence farmers. However, its cultivation and production have declined in recent years. This can be attributed to various factors, including:

- the establishment of new pests and diseases that affect taro and changes in the technology for producing, processing and marketing taro;
- the continuous depletion of taro genetic resources;
- local production not keeping pace with the rate of population growth and consequently with the annual number of entrants to the labour force; and
- the change from a diet largely reliant on taro or other root crop staples to one based on imported cereals, snacks and convenience food.

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The TaroGen Project: Addressing Food Security Needs

The regular decline and neglect of cultivation and production of taro and other root crops may lead to a national food security problem in PNG and throughout the Pacific generally. Awareness of the seriousness of this led to the development of Taro Genetic Resources: Conservation and Utilisation Project (TaroGen). TaroGen is a three-year project funded by the Australian government through the Australian Agency for International Development (AusAID). It is implemented by the Secretariat of the Pacific Community (SPC) in collaboration with the National Agricultural Research Institute (NARI) and the PNG University of Technology (Unitech), the University of the South Pacific (USP), and the International Plant Genetics Resources Institute (IPGRI). The ultimate goal of the project is to guarantee long-term access to diverse varieties of taro by Pacific island populations to ensure food security and opportunities for income generation. This goal will be achieved by collecting and conserving taro genetic resources and by genetic improvement of taro varieties.

Collecting and Conserving Taro Genetic Resources

Genetic resources are fundamental to food security and are the key to improving cultivated plant varieties. In PNG, TaroGen will focus on collecting taro germplasm and describing the collected accessions by agreed morphological and molecular methods. Taro varieties that have been collected from different provinces of PNG are being maintained as a national germplasm bank by NARI at the Bubia Research Station, near Lae, Morobe Province. The gene bank will be useful in genetically improving taro by breeding high-yielding, quality, competitive varieties that can be cultivated successfully and economically, without any significant losses from parasites (taro leaf blight, taro beetle and viruses).

From the prime collection, a core collection will be selected and maintained in tissue culture at the Regional Germplasm Centre of SPC. This will be pooled with core collections from other countries and a regional core collection representative of the diversity of the region will be maintained. In addition, several methods will be tested to provide a better understanding of ways to conserve germplasm, and to understand its reliability and cost. Field gene banks have proved to be unsatisfactory in the past, and methods using tissue culture, cryopreservation, seed storage, and onfarm maintenance will be investigated.

Genetic Improvement

Genetic improvement of crops is also an essential part of any program to improve food security. The aim of genetic improvement is to provide growers with improved varieties to overcome factors that limit production. Genetic improvement can be achieved through classical plant breeding and/or modern biotechnologies. TaroGen is assisting the PNG taro-breeding program to develop taro with tolerance to leaf blight, improved yield and better eating quality. Breeding strategies are based on durable or horizontal resistance. This is achieved by a cyclic recurrent breeding approach (accumulation of superior genes, cycle by cycle). Each breeding cycle includes three steps—developing a new population, evaluating individuals in a population, and selecting the best individuals for intercrossing. The duration of each cycle in PNG varies from 12 to 18 months and the population size varies from cycle to cycle. However, with the efforts of TaroGen, a strategy has been developed that can compress the breeding cycle to one year. The average number of individual taro plants forming the breeding population in the field during each cycle is higher than 10,000.

Breeding is currently in its fourth cycle of recurrent selection. Seven selected elite lines from the second-cycle plant population are being evaluated in trials in different agroecological zones of PNG. The trials are planted on farms so that farmers can contribute to selecting and evaluating lines. The selected lines are to be distributed and released to farmers once the tests are completed. Forty-eight new lines with better yield, resistance to taro leaf blight and better quality have also been identified from the third-cycle plant population. Further testing is under way.

To give direction to the national breeding program, taro improvement coordinating committees (TICCs) will be formed comprising farmers, nongovernment organisations, representatives from departments of agriculture, health, education and finance and regional programs assisting NARI. The formation of TICCs is important in maintaining enthusiasm for, and sustainability of, new plant lines. Including groups with interest in subsistence agriculture will sustain the momentum and give taro growers more options for improving taro production and managing various parasites. Open days will be held so the community can participate in and feel part of the taro-breeding program. Frequent visits by farmers to the breeding centre will familiarise them with various aspects of the work and encourage them to participate. A breeders club, which should make the taro improvement program more efficient and sustainable, is also being considered. Such a club has been formed in Western Samoa by the efforts of TaroGen, and is proving to be a great success. Club members (not necessarily those specialising in agriculture) might assist in crossing plant lines, raising seedlings, screening, assessing the selections and maintaining contact with farmers who would carry out the final selections.

Discussion

Collecting and conserving plant lines and using them to improve crops in various ways can help PNG to attain food security of national commodities like taro. The taro improvement program would expand taro cultivation, and consequently enhance sales in the domestic market. It is conceivable that health budgets would be improved by increasing taro consumption. Increased consumption of taro leaves might lead to the decline of some nutritional problems seen in the population. However, any changes that do occur will be difficult to ascribe solely to increased supplies of taro unless properly monitored.

The target beneficiaries of the program (i.e. the stakeholders, subsistence and semicommercial growers) will readily accept the provision of taro with greater resistance to taro leaf blight.

Effect of Taro Beetles on Taro Production in PNG

Roy Masamdu* and Nelson Simbiken†

Abstract

Surveys and onfarm trials in several areas of PNG suggest that taro beetles of the genera *Papuana* and *Eucopidocaulus* (Coleoptera: Scarabaeidae) are increasingly causing damage to taro (*Colocasia esculenta*), leading to food insecurity. Food security is a concern in areas where taro is an important daily staple and where high taro beetle damage occurs. Taro beetle populations are increasing as a result of new farming practices that are detrimental to the environment. Areas with intense cultivation, logging and high population pressure are under threat.

In PNG, taro (*Colocasia esculenta* Schott) is an important subsistence crop and a daily staple in many areas where rainfall is well distributed throughout the year. It is generally grown after a long forest fallow. Seasonal planting is common, reaching its peak during the wet season (Bourke 1982; Rangai 1982). Taro is a perennial crop with edible underground corms.

The Taro Crop

Colocasia esculenta belongs to the family Araceae and is cultivated along with several other edible species of the genera *Colocasia*, *Xanthosoma, Alocasia, Cyrtosperma* and *Amorphophallus*. The edible species are *Xanthosoma sagittifolium* (L.) Schott, *Cyrtosperma chamissonis* (Schott) Merr., *Alocasia macrorrhiza* (L.) Schott and *Amorphophallus campanulatus* (Roxb.) Blume. *Colocasia* is the most widely cultivated aroid in PNG.

Taro has both nutritional and cultural significance in PNG. It is an important carbohydrate source in many parts of the country and its energy value is comparable with sweet potato, cassava and banana (Wills et al. 1983; Bourke 1977). Taro corms are the edible part of the plant. In many areas, the young, tender leaves are eaten and some cultivars are grown only for their leaves. Taro is used in many traditional exchange and feasting ceremonies such as compensation and bride price, and special varieties of *Colocasia esculenta* are grown for use on such occasions.

The Insect

The main constraint to yield and quality of taro production in PNG are taro beetles from the genera *Papuana* and *Eucopidocaulus* (Coleoptera: Scarabaeidae). Eleven species of taro beetles feed on taro corms in the South Pacific (Perry 1977).

Taro beetle adults are shiny black, 15–35 millimetres (mm) in size, with elytra having parallel rows of punctations. Males usually have tubercles on the clypeus and the pronotum-bearing pronotal cavity, and a knob. The labrum bears one or two tubercles depending on the sex and species. Newly emerged adults are brownish, eventually turning black as the exoskeleton hardens. There is often variation in the size of tubercles, pronotal knob and areola apposita within adults of a population. The beetles are nocturnally active from dusk to around midnight.

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The typical taro beetle life cycle averages five months and consists of an egg stage, three larval instars, a prepupal and a pupal stage before the emergence of adults (Autar and Singh 1986; Perry 1977).

The oval-shaped eggs are laid singly in the soil under decaying vegetative matter and become round as they accumulate moisture and grow in size. The larval stages feed by ingesting soil, usually rich in organic matter. They do not feed on taro corms.

Adult beetle migration into taro gardens occurs soon after planting. Male beetles tend to remain longer in taro gardens than females; the latter search for oviposition sites and are strong flyers. The length of the life cycle ranges from 17–28 weeks in vitro (Autar and Singh 1986; Perry 1977). The life cycle in vivo is likely to be variable but of shorter duration. The length of development of each life stage depends on temperature, soil moisture and abundance of organic matter. Taro beetles breed throughout the year and suitable conditions can result in three generations per year.

Taro beetles have diverse breeding habitats and are often found within or adjacent to food gardens where light to heavy soils are found. However, larvae are also found away from cultivated food gardens, in areas such as river banks with high stands of wild saccharum and other grasses which are important breeding sites for some *Papuana* spp. (Perry 1977).

Larvae of *Papuana* spp. have been recorded under stands of living *phragmites* reeds, wild saccharum (*Saccharum spontaneum*), *Saccharum robustum*, sugarcane (*Saccharum officinarum*), *Imperata cylindrica*, *Paspalum paniculatum*, *Sorghum verticilliflorum*, *Pennisetum purpureum*, *Miscanthus* spp., *Tripsacum laxum*, *Brachiaria mutica* and *Commelina diffusa* (Sar and Niangu 1993; Bayliss-Smith 1985).

Larvae are common in dead organic matter such as chicken manure, kitchen refuse, logs, sawdust, compost, banana pseudo-stems, sugarcane thrash, coconut husk, polybags with seedlings in nurseries and sweet potato and yam mounds (Thistleton et al. 1995). It is most likely that the beetles select these sources of organic matter as larval feed stock.

In suitable breeding sites, continuous oviposition occurs and all of the beetle life stages are present. Species overlapping in geographical distribution often share the same breeding habitats. Examples of overlapping distribution include *Papuana woodlarkiana* and *P. uninodis* on Guadalcanal, Solomon Islands; *Papuana woodlarkiana* and *P. huebneri* at Ringi, Solomon Islands and Keravat, PNG and *Papuana woodlarkiana* and *E. tridentipes* at Megiar, Madang Province and Bubia, Morobe Province, PNG (Masamdu 1997).

The primary host plants of adult beetles are aroids of the genera *Colocasia*, *Alocasia, Xanthosoma, Cyrtosperma, Amorphophallus*, the banana species *Musa* spp., and the fern species *Angiopteris* spp. and *Marattia* spp. (Thistleton et al. 1995; Greve and Ismay 1983).

Secondary host plants include sweet potato, Irish potato, yams, sugarcane, pineapple, peanuts, cocoa, coffee, betel nut, coconut, oil palm, tea, *Crinium* spp., wandering jew (*Commelina diffusa*) and *Pandanus odoratissimus*. This wide range of primary and secondary host plants enables the adult beetles to survive in the wild when *Colocasia esculenta* and other cultivated aroids are absent.

Pest Status

Adult taro beetles damage underground taro corms by chewing and burrowing into the corms creating tunnels the same diameter as the beetles' width, enabling them to crawl through the tunnel as they bore out the corm. In severely damaged plants, the tunnels run together to form large cavities, allowing secondary rots to develop (Thistleton 1984). Secondary pathogenic organisms may cause corm rot, resulting in poor quality plants for consumption and marketing. Similarly, taro beetle damage has been recorded on *Xanthosoma sagittifolium*, *Alocasia macrorrhiza*, *Cyrtosperma chamissonis*, *Amorphophallus campanulatus* and on tubers of other root crops including sweet potato, yam and Irish potato and at the base of banana stems (Thistleton et al. 1995).

In areas with high beetle populations, early migration of beetles into taro gardens and subsequent feeding at the base of the plant can lead to wilting and plant death, especially in young taro, while plant vigour and growth is retarded in older plants. The beetles rarely feed on corms exposed above the soil.

The effect of taro beetles on yield and quality of taro is highlighted by the dwindling production in many areas (Gaupu et al. 1992; King et al. 1985; Masamdu 2000). Taro as a crop can be economically viable in many areas if taro beetle damage can be reduced. Arura et al. (1987) estimated that the physical yield loss at Bubia Research Centre, Morobe Province was only 6.2% but the economic loss was greater due to the poorer quality of the taro corms available for consumption and for marketing.

Financial loss caused by taro beetles is highly variable, in the range 0–55%, with an average of 15% loss.

Field-based surveys and trials suggest that physical corm damage of 15% and above renders taro corms unmarketable in most areas of PNG (Gaupu et al. 1992).

The price of traditional staple food crops including taro has risen in recent years due to their perishable nature, lack of storage facilities, constraints from pest and diseases, and reduction in soil fertility due to continuous cropping. The price of taro in the urban markets in PNG is high and varies from 0.65–2.35 PNG kina (PGK)[1] per kilogram (Anon. 1997).

Damage by taro beetles to other commercial crops is relatively low. The beetles occasionally ringbark young tea, cocoa, coffee, betel nut, oil palm and coconut seedlings (Thistleton 1984; Macfarlane 1987; Sar et al.1990).

Materials and Methods

Damage by taro beetles in various areas of PNG was assessed during surveys of pathogens and other natural enemies of taro beetles conducted from 1996–2000.

Field surveys

During field surveys conducted for insect-pathogen studies, rapid assessments were done in gardens. A number of plants were harvested and the severity of corm damage (SOD) on the taro was recorded. Alternative beetle host plants, suitable breeding sites and the general farming patterns in each location were noted.

Areas surveyed included:

- Western Highlands Province—Baiyer River, Banz, Kindeng block, Evangelical Bible Church (EBC) Minj, Kuk, Kagamuga, Dobel, Mt Hagen;
- Simbu—Province Barawagi;
- Madang—Province Amele, south coast, Ambanop, north coast, Malolo plantation, Megiar;
- Morobe—Province Busanim, Wagan, Situm, Wantoat, Wau, Wandumi, Laubutu, Muya, Boana;
- East Sepik—Province Yawosoru, Kubalia, Maprik, Yangoru, Angoram;
- East New Britain—Province Keravat, Vuvu, Kokopo; and
- West New Britain—Province Kandrian inland (five villages).

Trials and observation plots

Field plots were established in some accessible sites to assess *Papuana* damage. On each site, a 10-square metre plot consisting of 100 plants was established. The plots were harvested at maturity (six months) except in Aiyura, where the plants took eight months to mature.

At harvest each corm was weighed and measured to assess the SOD and percentage corm removed (PCR). The PCR was used to calculate the estimated weight of damaged (EWD) and undamaged (EWU) corm. Data from other formal trials from untreated plots are also presented here. Damage assessment plots were established at Situm in Morobe Province, Ramu Sugar Estate in Madang Province and Aiyura in Eastern Highlands Province.

Results and Discussion

The importance of taro beetle damage varies from one area to another (Table 1). Farmers in locations with a SOD rating of 1 perceive taro beetles as relatively unimportant. Farming practices in these areas discourage the build-up of taro beetle populations. For example, in the Amele area of Madang Province, taro is a seasonal crop planted together with yams. Similarly, in Maprik, taro is not an important staple, although taro beetle is present in gardens. In Wantoat, taro is planted in primary forest areas, where beetle populations are low.

The people of Kandrian Inland of West New Britain Province are heavily dependent on taro as a daily staple and it is usually planted in continuous cultivation. In 1999, an upsurge in the beetle population led to heavy beetle damage and villagers resorted to wild plants to meet their food requirements (Masamdu 2000). In Situm, where the trial was carried out, farmers had given up planting taro for food. Taro plots were maintained only to obtain material for planting in other sites. However, farmers in adjacent blocks were able to grow adequate taro.

Farmers in most areas surveyed in PNG have mentioned increases in taro beetle damage. The growing taro beetle damage is related to the increasing intensity of gardening, shorter fallow periods and increasing availability of breeding sites. In many areas, intensive gardening is related to land shortages caused by high population densities.

Short garden fallows provide suitable breeding habitats for taro beetles, such as fallen logs, dead tree stumps, dead banana stumps and stems. Late maturing

[1] In May 2000, 1 PNG kina (PGK) = US$0.40 (A$0.70).

Table 1. Severity of damage and estimated yield loss of taro (*Colocasia esculenta*) caused by taro beetles in selected sites surveyed in PNG.

Location	Province	Mean SOD[a]	Yield loss estimates (%)
Kandrian	West New Britain	3	50
Bukawa	Morobe	2	20
Bubia	Morobe	1	8
Wau	Morobe	2	15
Lae	Morobe	2	15
Wantoat	Morobe	1	8
Boana	Morobe	2	15
Amele	Madang	1	10
North coast	Madang	2	15
South coast	Madang	2	20
Wewak	East Sepik	2	25
Maprik	East Sepik	1	10
Yangoru	East Sepik	2	20
Angoram	East Sepik	1	5
Keravat	East New Britain	2	30
Kokopo	East New Britain	1	5
Baiyer River	Western Highlands	2	20
Banz	East New Britain	2	25
Mt Hagen	East New Britain	2	20
Minj	East New Britain	2	20
Kuk	East New Britain	2	25
Barawaghi	Simbu	2	25

[a]Severity of damage (SOD) scale:
0 = no damage
1 = damage but saleable
2 = damaged, unsaleable but edible
3 = damaged, inedible but fit for animal consumption
4 = very heavily damaged, corm almost completely eaten, not fit for animal consumption

food plants such as banana and sugarcane are left after harvest in the old gardens, acting as food sources for surviving beetle populations. Wild aroids are important food plants that establish rapidly in gardens under fallow and again support beetle survival and population.

Logging and deforestation for road and other infrastructure development projects have increased beetle populations by providing breeding sites such as dead tree stumps and logs. A number of wild host plants establish rapidly in such environments (e.g. *Alocasia, Cyrtosperma*, *Amorphophallus* and the wild fern species *Angiopteris*). An outbreak of taro beetle was recorded in March 2000 at Kandrian, West New Britain Province (Masamdu 2000). Infestations of taro beetles in Lababia and Wangang (Bukawa) in Morobe Province resulted in farmers changing from taro to sweet potato for their cropping systems and staple diet.

Table 2 shows the amount of taro lost (in weight and as a percentage of the total crop) due to taro beetles in three study areas. The economic loss is much greater since low-quality corms with taro beetle feeding holes

Table 2. Yield loss of tari (*Colocasia esculenta*) caused by taro beetles in three study sites in PNG (tonnes/hectare).

Location (Province)	EWU (t/ha)[a]	EWH (t/ha)[b]	EWD (t/ha)[c]	% loss[d]
Aiyura (Eastern Highlands)	2193 ± 19.7	2134 ± 19.1	595 ± 149	27.1
Situm (Morobe)	4211 ± 30.5	2230 ± 17.9	1981 ± 18.4	47.0
Ramu (Madang)	7616 ± 27.1	4847 ± 26.1	2669 ± 12.4	35.0

[a]EWU = Estimated weight of undamaged taro corms
[b]EWH = Estimated weight of harvested taro corms
[c]EWD = Estimated weight of damaged taro corms
[d]Average percentage loss

will fetch a low price or be unsaleable in many markets. The market price depends on accessibility to urban markets.

Conclusions

Damage by taro beetles is likely to increase. There are no natural enemies known to regulate taro beetle populations. The beetle's ability to breed in a wide range of habitats and feed on a large variety of host plants and its subterranean lifestyle make it a difficult target to control. Farming practices adopted due to high population pressure lead to intensive cultivation, logging and deforestation. This has resulted in rapid infestation of taro beetles and in some areas termination of semicommercial farming. Taro beetles will continue to threaten taro production and thus food security in some areas of PNG.

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