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CONTENTS

FEEDING RABBITS ON LOCALLY AVAILABLE FEEDS IN PAPUA NEW GUINEA

Martin Lobao[1] and Alan Quartermain[2]

ABSTRACT

Domesticated rabbits (Oryctolagus cuniculus) were introduced into Papua New Guinea (PNG) in 1993 to improve family nutrition, income generation, self-employment opportunities for subsistence farmers and supply a by-product in the form of manure for improving soil fertility. The introduction was successful and rabbits are now kept by households in most mainland provinces. Since most rabbit farmers are located in rural areas where; access to goods and services is difficult and purchase of commercial feed is not an option due to its high cost, farmers have to resort to feeding their animals on readily available local feedstuffs. Studies conducted by the PNG University of Technology and later by the National Agricultural Research Institute (NARI) assessed available feedstuffs and low cost feeding options for farmers. Based on these studies, NARI released the recommendation that either sweet potato tubers or coconut, fed together with a suitable palatable fresh green leaf material, can be used to give satisfactory growth of weaner rabbits when fed free choice and to appetite. These diets can be entirely made up from locally available resources.

Key words: *Weaner rabbits, low cost feed options, locally available feedstuffs, sweet potato, coconut, pelleted feed, palatable green leaf.*

INTRODUCTION

The farming of domesticated rabbits *Oryctolagus cuniculus* has been a success since the introduction of the animal into Papua New Guinea (PNG) in 1993. The objectives were improvement in family nutrition, self-employment opportunities and hence income generation for subsistence farmers, and supply of a by-product in the form of manure for improving soil fertility. This initiative was suggested by the reported success of village rabbit keeping in the highlands of West Papua. The assumption was that community development can only take place if people have access to good nutrition, and that the rabbit, because of its size and feeding habits, seemed well suited to supply the high quality proteins necessary for balanced human diets. The strictly controlled importation was of 15 specific-pathogen-free rabbits, 10 Canberra Half Lop and five New Zealand White breed. Controlled distribution to 30 selected and trained breeders began in early 1994 and restrictions were eventually lifted to allow anyone to acquire and breed rabbits.

Rabbits do not get too much mention in textbooks on animal nutrition or general animal husbandry. They have the ability to utilize different types of garden crops, legumes and forages grown in or around gardens, on roadsides and in garden areas left to fallow. They have the capacity to utilize fibrous material of plant origin but cannot produce well on plant leaf material alone. They have a unique way of dealing with the problem associated with the digestion of fibre in foods. The caecum of the large intestine is capable of sustaining a significant microbial population and food components not yet digested and absorbed are subjected to fermentation. However, although microbial digestion in the caecum is similar to that in the rumen of animals such as cattle, sheep and goats, it is less effective because digesta are not held for sufficient time and many of the products of digestion, particularly amino acids and vitamins, are not absorbed. The rate of passage through the system is only 30 hours as against 120 hours for a ruminant. The rabbit has partially overcome this problem by coprophagy; the consumption of faeces. It produces two types of faeces, the normal hard pellets which are not eaten and the soft faeces or caecotrophes which contain well fermented material and are consumed for further digestion. However, coprophagy is not too helpful in improving fibre digestion because the soft faeces have much less fibre than the hard faeces. While young forages may have a digestibility of over 70 percent, mature forage digestibility may be only 45-50 percent. In spite of this, fibre is essential in the diet to aid the passage of food through the system and prevent di-

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gestive disorders. Feeds that are too succulent, however, may give rise to diarrhoea. A good diagram of the digestive tract is given in Fielding (1991) who also gives the comparative composition of the two types of faeces.

Nevertheless, studies and farmer practice in many tropical countries have shown that rabbits will perform well when fed tropical forages as a major component of the diet. In PNG the earlier work on rabbit feeding was done at the PNG University of Technology and has been summarized by Grant et al. (1996, 2005). The work involved feeding of weaner rabbits on a range of feeds, solely or in combination. These included sweet potato tubers and vines, cowpea or pigeon pea forage, lucerne meal, leucaena leaf meal, copra meal and poultry feed (broiler finisher pellets). The results, as summarized in Table 1, show that growth of rabbits is poor when they are fed on green leaf material alone, but when concentrated energy feeds such as sweet potato tubers, broiler chicken pellets or copra expeller meal are added to the diet then satisfactory growth performance of 16 or more grams per day can be achieved.

It is clear from this work and international experiences that rabbits can be fed on many different types of tropical forages such as legume tree forages (leucaena and erythrina), leaves of legume shrubs and beans, tuber crop leaves and vegetables provided they are supplemented with energy feeds. Although a number of forages can be fed to rabbits, some are not recommended to be fed in large quantities because of anti-nutritional factors (e.g. leucaena) and some are not palatable (e.g. gliricidia). In PNG, crops that have high energy content such as cassava, banana, sweet potato, sugarcane and coconut can be major sources of energy for rabbits where they are available in abundance and are accessible at low cost.

Further work involved the use of the milling by-products such as; wheat millrun, copra meal and soyabean meal, plus added amino acids, lysine and methionine (Bangita 2000). The upshot of all this effort was the development of a commercial pellet containing millrun, copra meal, limestone, salt and a pig feed pre-mix for additional vitamins and minerals as a complete feed for rabbits and this was produced commercially by Lae Feed Mills. However, due to escalating costs, demand for the pellet declined and production ceased. While there are alternatives to rabbit pellets in the form of commercial pellets made for feeding broiler chickens, pigs or horses, cost remains a prohibiting factor and, since most farmers interested in keeping rabbits are located in rural areas, access to goods and services is difficult and purchase of commercial feeds is not an option. Hence farmers have to resort to feeding their animals on readily available local feedstuff.

Table 1. Average growth rates of rabbits fed different diets (Grant *et al* 1996)

Treatment	Growth g/day
Sweet potato vines fresh + Broiler finisher pellets (40 g/h/d)	22
Broiler finisher mash (100 %) + Cowpea forage	20
Broiler finisher mash (75 %) + Copra expeller meal (25 %) *ad libitum*	20
Broiler finisher mash (*ad libitum*)	18
Broiler finisher mash (50 %) + Copra expeller meal (50 %) *ad libitum*	18
Copra expeller meal (100 %) + Cowpea forage (*ad libitum*)	18
Broiler finisher mash (25 %) + Copra expeller meal (75 %) *ad libitum*	16
Copra expeller meal (100 %)	16
Sweet potato vines fresh + Sweet potato tubers (120 g fresh/h/d)	12
Sweet potato vines fresh (*ad libitum*)	8
Sweet potato vines fresh + Pigeon pea leaves (100 g fresh/h/d)	6
Cowpea forage fresh (*ad libitum*)	5
Sweet potato vines oven dried (*ad libitum*)	4
Lucerne meal (*ad libitum*)	2
Lucerne meal (75 %) + Leucaena leaf meal (25 %)	-7
Lucerne meal (50 %) + Leucaena leaf meal (50 %)	-14
Lucerne meal (25 %) + Leucaena leaf meal (75 %)	-18

Rational for On-going Research

Considering the increasing cost and the limited availability of commercial feeds for use by most subsistence farmers, the Livestock Research Programme of the PNG National Agricultural Research Institute (NARI) instituted a series of trials in 2002, following on from the University of Technology work, with emphasis on assessing available feedstuffs and developing low cost feeding options for farmers. Since many rabbit farmers in most areas of PNG feed sweet potato and its leaves to rabbits in large quantities, this crop needed to be further assessed. In lowland areas, fresh coconut can be available in quantity and it may be more beneficial to feed it to animals than to make copra. Hence one major purpose of the NARI work was to confirm, through replicated trials, the utility of these two feed sources for growing rabbits. Velvet bean leaves were used for the green leaf component of the diets but other work and experience in PNG have indicated that other leaf materials such as cowpea, sweet potato and kangkong (*Ipomoea aquatica*), and kikuyu grass and white clover in the high altitude highlands are equally as useful.

NARI Experimental Results

Results from three relevant experiments as originally reported in the NARI 2003-2004 Biennial Report (National Agricultural Research Institute 2005) are given here. Control diets were either commercial rabbit pellets or horse pellets which were shown by other work to be equivalent in feeding value. The intake figures are for the feed as fed and for the non-leaf component of the diet only. All feeds were given to appetite with rabbits free to select their preferred diet from the feedstuffs presented.

In the first experiment, male and female weaner rabbits were grown for eight weeks on one or other diet of rabbit pellets (RP), fresh sweet potato (SP) plus velvet bean leaf (VB) or sun-dried cassava tuber (CT) plus velvet bean. The results are summarized in Table 2.

In the second experiment, female weaner rabbits were fed for seven weeks on one or other diet of horse pellets (HP), sweet potato plus velvet bean leaves or the sweet potato / velvet bean diet supplemented with either 10 or 20 grams per day of horse pellet. The rationale was that the addition of small, measured quantities of pellet could boost production from local material diets. The results are summarized in Table 3.

Table 2. Summary of means for sex of rabbit and diet experiment 1.

Effect	Level	Wt 0 (g)	Wt 8 (g)	Gain (g)	ADG (g)	Feed Intake (g)	FCR
Sex	Female	1274 *a*	2096 *a*	820 *a*	14.7 *a*	4001 *a*	6.8 *a*
	Male	1229 *a*	1823 *b*	596 *b*	10.7 *b*	3871 *b*	9.2 *a*
Std Error		34.2	68	76.6	1.37	320.3	1.98
Diet							
1	RP	1282 *a*	2244 *a*	960 *a*	17.2 *a*	3962 *a*	7.6 *a*
2	SP + VB	1245 *a*	1992 *a*	747 *a*	13.3 *a*	3309 *b*	4.6 *a*
3	CT + VB	1229 *a*	1643 *b*	414 *b*	7.4 *b*	4537 *c*	11.7 *a*
Std Error		102.6	204.1	229.7	4.1	311.8	6.0

Means with the same subscript are not significantly different (P > 0.05)

Table 3. Summary of means for diet experiment 2.

Effects	Level	Wt 0 (g)	Wt 7	Gain	ADG	Feed Intake	FCR
Diet 1	HP	1647 *a*	2434 *b*	788 *a*	18.75 *a*	9109 *a*	11.9 *a*
Diet 2	SP+VB+10g HP	1371 *a*	1950 *ab*	579 *b*	13.79 *b*	4163 *b*	7.2 *b*
Diet 3	SP+VB+20g HP	1569 *a*	2060 *ab*	491 *b*	11.69 *b*	4255 *b*	9.0 *ab*
Diet 4	SP+VB	1390 *a*	1799 *a*	409 *b*	9.73 *b*	6605 *c*	16.6 *c*
Std Error		263.6	254.6	100	2.4	668	2

Means with the same subscript are not significantly different (P > 0.05).
Wt=Weight, ADG= Average Daily Gain

In the third experiment, male and female weaner rabbits were grown for eight weeks on one or other diet of horse pellet, sweet potato plus velvet bean leaves or fresh coconut (C) plus velvet bean leaves. The results are summarized in Table 4.

Table 4. Summary of means for diet experiment 3.

Effects	Levels	Wt 0 (g)	Wt 8(g)	Gain(g)	ADG(g)	Feed	FCR
Sex	M	1212 a	2058 a	746 a	12.1 a	11232 a	14.6 a
	F	1054 a	1943 b	890 a	12.7 a	10535 a	12.7 a
Std Error		102.2	66.2	225.6	1.8	813.1	1.4
Diet 1	HP	1216 a	2345 a	1128 a	16.1 a	10372 a	10.4 a
Diet 2	SP + VB	1056 a	1778 b	722 b	10.3 b	12685 a	17.6 b
Diet 3	C + VB	1126 a	1879 b	754 c	10.8 b	9594 b	12.9 ab
Std Error		125.2	249.9	276.3	2.2	995.9	1.7

Means with the same subscript are not significantly different (P > 0.05)
Wt = Weight, ADG = Average Daily Gain

The analysis of weekly live weights showed significant diet effects from week three to week 10 in favour of animals fed the MULHP diet. The effects of sex of animal and diet by sex interaction were not significant. For the diets, the mean live weights (Figure 1) were similar in weeks one and two, but from week three onwards rabbits fed the MULHP diet had significantly higher live weights

A summary of all the relevant experimental results is given in Table 5.

Table 5. Average growth rates of grower rabbits fed on different diets

Treatment diets	Growth rates g/day
Horse Pellet (100%)	18
Rabbit Pellet (100%)	17
Sweet potato + Velvet bean leaves fresh + 10g Horse Pellet	14
Sweet potato + Velvet bean leaves fresh + 20g Horse Pellet	12
Sweet potato vines fresh + Sweet potato tubers (120 g fresh/h/d) **	12
Sweet potato + Velvet bean leaves fresh	11
Coconut + Velvet bean leaves fresh	11
Cassava tuber + Velvet bean leaves fresh	7

**Comparison of growth rates from previous study by Grant at el. 1996.

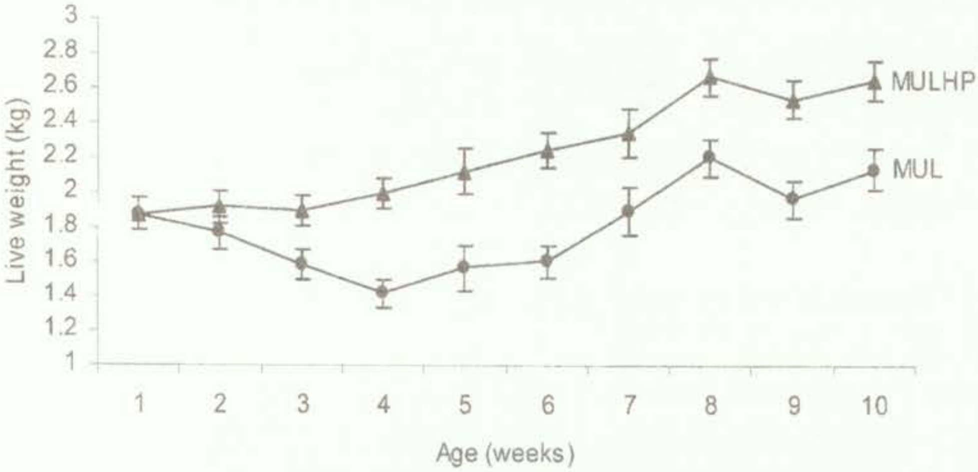
Use of Mulberry (*Morus alba*) and Kangkong (*Ipomoea aquatica*) Leaves

A fourth NARI trial (Kohun and Thomas 2006) tested the use of mulberry leaves in rabbit feeding. Eight male and eight female weaner rabbits (1.88 kg mean live weight) were allocated in same sex pairs to diets of mulberry leaves only (MUL) or mulberry leaves plus horse pellets (MULHP). Each animal on the MUL diet received 1 kg of mulberry leaves fed twice daily, while each animal on the MULHP diet received 1 kg of mulberry leaves fed twice daily plus 50g of horse pellets fed once a day. The animals were given a week to adjust to the diets before the trial commenced.

(P<0.05) than those fed the MUL diet, the latter group having lost weight from weeks two to six due to a decline in intake which is a recognized phenomena for rabbits on all-forage diets. Live weight gains during the trial were 260 and 770g for the MUL and MULHP diets, or 3.7 and 11.0g per day.10 in favour of animals fed the MULHP diet, the latter group having lost weight from weeks two to six due to a decline in intake which is a recognized phenomena for rabbits on all-forage diets.

A further trial (Moliola and Ayalew 2007) tested mulberry leaf diets with either coconut or horse pellets in a completely randomized design with 12 weaner rabbits. Rabbits achieved average

Figure 1. Growth of rabbits fed mulberry leaves with or without supplement



daily gains over a six week period of 15.3g on the coconut diet and 13.3g on the horse pellet diet, compared to 16.4g on a diet of horse pellets alone. The authors concluded that a mix of coconut and mulberry leaf can replace horse pellets without adverse effects on rabbit growth.

Finally, Ignatius (2003) compared the growth over four weeks of six weaner rabbits fed a sole diet of commercial rabbit pellets with a comparable six rabbits fed pellets plus 1 kg each per day of fresh kangkong leaves. Growth rates were high in this trial at 31.6 and 31.1g respectively due to the short feeding period during the stage of maximum growth. Total intake of pellets over the period was reduced from 105g per rabbit-day to 95g by the use of the leaves, a saving of close to 10 percent.

CONCLUSIONS

While the growth rates on pellet diets were lower in the NARI studies compared to the University studies, the University used broiler chicken feeds with high energy content and consequently greater cost. Rabbit growth on sweet potato plus leaf is similar in the two sets of data. Rabbit feeding studies are notoriously difficult due to high variation in intakes between rabbits and therefore high variation in growth rates. Rabbits are also very sensitive to environmental conditions. However, the conclusions are that diets of sweet potato or coconut fed together with a palatable green leaf material, including mulberry and kangkong, give satisfactory growth in weaner rabbits up to live weights of around two kilograms but reaching this weight will take an additional three weeks. These results and other field experience enabled NARI to make a technology release endorsing these conclusions. More work needs to be done to determine the value of cassava tuber. The results did not demonstrate any advantages in supplementing these diets with additional measured quantities of pellets.

ACKNOWLEDGEMENTS

Dr Ian Grant and David Askin initiated and facilitated the original rabbit importation. Martin Lobao carried out the first three NARI experiments reported here. Dr Alan Quartermain initiated the NARI work and wrote the 2003-2004 Biennial Report entry upon which much of this paper is based. Dr Pikah Kohun and Mr. Andrew Thomas provided support and technical assistance. Bob Mayer of the Queensland Department of Primary Industries and Fisheries provided biometrical support.

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FEEDING MUSCOVY DUCKS ON LOCALLY AVAILABLE AGRO-INDUSTRIAL BY-PRODUCTS AND FEED RESOURCES

Saun Ignatius

ABSTRACT

The development of low cost farm-made feeds for Muscovy ducks, based on increased use of agro-industrial by-products will be crucial in encouraging Muscovy duck production in Papua New Guinea (PNG). Agro-industrial by-products such as; copra meal, rice bran, wheat millrun and palm kernel expeller meal are available locally in large quantities. As part of the National Agricultural Research Institute's efforts to develop effective feeding systems for Muscovy ducks, two Muscovy duck feeding trials using agro-industrial by-products were conducted in 2004 at the National Agricultural Research Institute's Labu Livestock Station. The first trial assessed the growth of male Muscovy ducks on commercial broiler feed (Lae Feed Mills) and a test diet of agro-industrial by-products (rice bran, wheat millrun and palm kernel expeller meal) over seven days during their period of rapid growth. The second trial assessed the growth of male Muscovy duck on commercial broiler feed (Lae Feed Mills) and two test diets (local maize diet and copra diet). In the first study, it was found there was no difference ($p>0.05$) in weight gain between the commercial feed (698 ± 33(SE) grams) and the test diet (677 ± 78(SE) grams). In the second study, the ducks on commercial broiler pellets had higher ($p<0.05$) weight gain and feed intake than the two test diets during the same period; however, there was no difference ($p>0.05$) in feed intake between the copra diet and commercial feed. Even though the commercial feed has better feed conversion ratio (FCR) than copra and maize diets, the two test diets were cheaper ($p<0.05$) to produce a kilogram of weight gain. These results showed that these locally available feed resources and agro-industrial by-products can be effectively used to make cheaper farm-made poultry diets. The use of these locally available feed resources will encourage Muscovy duck farming and promote economic development and food security.

Keywords: *Muscovy ducks, agro-industrial by-products, local feed resources, duck feeding*

INTRODUCTION

The popular duck breed in Papua New Guinea (PNG) is the Muscovy duck, which has been successfully adopted into PNG farming systems since the 1970s (Abdelsamie, 1979; Bilong, 1981; Ignatius and Quartermain, 2002). Usually Muscovy ducks are kept under an extensive system of free-ranging and supplementary feeding with fruits, cooked tubers and kitchen leftovers. However the trend is now changing as more farmers are now keeping Muscovy ducks in confinement with commercial poultry feeds for the local live duck market (Ignatius and Quartermain, 2002). These commercial poultry feeds which are formulated from imported grains (maize, sorghum, soybean, etc.) are quite expensive and are of high nutrient density. Ignatius and Quartermain (2002) have highlighted the need to develop suitable feeding systems based on increased use of agro-industrial by-products. Many people are interested in farming Muscovy ducks, but since they consume more feed than chickens for the same weight gain, it is uneconomical to feed this high nutrient density feeds to Muscovy ducks (Ignatius and Quartermain, 2002). The making of farm-made feeds is not a common practice by livestock farmers in PNG and some attempts are now being made by National Agricultural Research Institute (NARI), Department of Agriculture and Livestock (DAL) and the National Fisheries Authority (NFA) to develop the capacity of poultry and fish farmers to formulate and prepare on-farm feeds using locally available feed materials (Booth, *et al.* 2007). In order to improve duck feeding systems, optimized use of these resources in farm-made diets should be encouraged and promoted.

Agro-industrial by-products such as copra meal, wheat millrun, palm kernel expeller meal, brewer's grain, rice bran and pyrethrum marc are available in large quantities and can be utilized by poultry farmers to make poultry feeds. Even low quality fishmeal is now readily available from fish canneries and tuna loining plants that were es-

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tablished recently. Currently, some of these agro-industrial by-products, especially wheat millrun, fishmeal and copra meal, are used in limited quantities in pig and poultry feeds. However, with the increasing cost of commercial poultry feeds and the opportunities to use low intensity feeds, optimal amounts of these agro-industrial by-products can be utilized cheaply in commercial pelleted feeds or farm-made feeds. Some of the agro-industrial by-products and feed resources available locally in Morobe Province are copra meal, wheat millrun, fishmeal, Markham maize, poultry offal meal, meat and bone meal. Palm kernel meal was sourced from West New Britain Province while a significant quantity is also available from Oro Province. Copra meal in Morobe Province is accessed from Madang and East New Britain Provinces.

The study by Ignatius and Quartermain (2002) was one of the initial efforts by NARI to develop effective feeding systems for Muscovy ducks. This study found that, even though Muscovy ducks on high nutrient density grain-based diets have better growth than those on low nutrient density feed (agro-industrial by-product diet), low nutrient density feeds can be as good as the high density feeds in terms of the cost of a kilogram of weight gain. The two diets that they compared were commercially manufactured feeds for broiler chickens and rabbits. Their study did not confirm the hypothesis that the commercial low density feed was cheaper and was as good as the high density feed However, it may be cheaper to produce an on-farm feed using the agro-industrial by-products (copra meal and wheat millrun) that were used in the commercial low-density feed tested by Ignatius and Quartermain (2002). The subsequent trials that followed were based on evaluating the grain-based commercial feeds with agro-industrial by-product based farm-made feeds.

The use of farm-made feeds in livestock production is a common practise in most Asian countries and the use of farm-made feeds is known to optimise production and maximise profits for poultry and fish farmers in South-East Asia (Dong, 2005). It is anticipated that the development of farm-made feeds using local feed resources would be cheaper and therefore minimise cost of production and encourage Muscovy duck production in rural and peri-urban areas of PNG. The diets prepared in the following studies were made as simple as possible for farmers to adopt; if it is possible for them to source the ingredients.

MATERIALS AND METHODS

The study was undertaken at the NARI Labu Livestock Research Station of the Sir Alkan Tololo Research Centre, which is located near Lae in the wet-lowland areas of PNG. This Station is situated at latitude 06° 40´ South and longitude 146° 54´East. It receives an average annual rainfall of about 2900 mm (Ignatius and Quartermain, 2002).

Only male Muscovy ducks were used in these two studies to test the treatment diets because of obvious sexual dimorphism in growth between male and female Muscovy ducks. All the diets were fed *ad libitum*, with the commercial feed (Lae Feed Mill) in pelleted form and the on-farm diets in mash form. The first trial had a completely randomised design (CRD) with two treatments: the commercial broiler finisher feed from Lae Feed Mills and a farm-made diet of 40% rice bran, 20% wheat millrun, 14% palm kernel expeller meal, 20% soybean plus salt (0.3%), limestone (1.1%), broiler premix (0.4%), methionine (1%), DCP (2%), vegetable oil (1%) and choline chloride (0.2%). Since the commercial broiler feed is about 20% crude protein (CP) and 12 MJ/kg of metabolizable energy, the on-farm diet was calculated to give an estimated 20% CP and 12 MJ/kg. Ducklings of about 5 weeks (35 - 40 days) of age weighing 1,333± 244 (SD) grams were used for this study over a seven days feeding period (between days 35 and 50). Eighteen birds were housed in six separate pens with three birds in each pen (1 m x 1 m) and each bird was tagged to measure individual weights. The study took only seven days during the period of rapid growth (Leclercq and Carville, 1986) and weight measurements were taken only on the first day (Day 0) and the last day (Day 7). There was an adaptation period of two days on the test diets prior to the trial. Feed intake was not recorded since the feeds were offered in mash form and the feed container height was low, so it was practically difficult to measure left over feed due to feed wastage and contamination with faeces.

The second trial also had a CRD with three treatments and five replicates. The three treatments were the commercial broiler feed (Lae Feed Mills), a copra meal diet and a maize diet. Using Evans (1997), the copra diet crude protein (CP) and energy (DE) were estimated at 25% CP and 12 MJ/kg DE while the maize diet was estimated at 16% CP and 13 MJ/kg DE. The crude fibre (CF) levels were also estimated to be 9% for the copra diet and 4% for the maize diet. The experiment was conducted over 10 weeks and the ducks were fed *ad libitum* commercial broiler starter (22% CP) for 3 weeks before they were randomly allocated into respective treatment groups and fed commercial broiler finisher (20% CP), copra meal diet (25% CP) and the maize diet (16% CP). The farm-made diets were made as simple as possible with local maize diet having 80% maize, broiler premix (0.5%), fishmeal (15%) and fish oil (4.5%). The copra diet had 80% copra meal, broiler premix (0.5%), fishmeal (15%) and fish oil (4.5%). Copra oil can be a viable substitute for fish oil due to the fact that fish oil may not be readily available but it was considered because it was very cheap (Kina 5 per 200 L drum).

Thirty male ducks were used in the study and they were allocated, two each into a small pen of 1 m x 1 m. There were three treatments and each treatment was replicated five times, giving a total of 10 ducks per treatment. Duck weights were measured weekly while feed intake was measured daily since larger containers reduced feed wastage and contamination by faeces. Feed intake estimates were made possible by drying the waste feeds and separating the faeces as much as possible. Weight gain was measured per duck and averaged, while feed intake was measured on a pen basis (Table 2) (two ducklings per pen). The Feed Conversion Ratio (FCR) and the unit cost of feed (cost/kg) were also calculated. The unit cost of feed was calculated based on a retail price of Kina 1.25 per kilogram for commercial broiler feed and an estimated ingredient cost of Kina 0.96 and Kina 0.84 respectively per kilogram for copra and maize diets. Weight gain and feed intake for each treatment diet were analysed on a pen basis (2 ducks per pen). The cost of each ingredient used in the diets was also taken into account with the commercial broiler finisher feed to calculate the cost of a kilogram of weight gain (Cost/kg gain).

RESULTS

In the first trial, it was found that there was no significant difference ($p > 0.05$) in the weight gain between ducks fed the commercial feed and the farm-made feed (Table 1). The growth rates were also similar; 97g/day and 100g/day for commercial feed and test diet respectively, during the feeding period when the Muscovy ducks are expected to have rapid growth.

Table 1: Mean weight (grams) and weight gain of the ducklings on the commercial and farm-made diets (Trial 1).

Feed	Initial weights (g)	Final weights (g)	Weight gain (g)
Test diet (± SE)	1289.6 ± 83.4	1987.4 ± 95.1	697.9 ± 33.2
Commercial feed (± SE)	1376.6 ± 81.7	2053.9 ± 124.0	677.3 ± 78.0
Significance (p <0.05)	NS	NS	NS

The two parameters measured in the second trial were daily feed intake and weekly weights. Weekly weights were used to show the difference in the effect of treatment diets over the trial period. Accordingly, male ducks on the commercial broiler diet were heavier than those on the maize and copra diets, while those on the copra diet were heavier than those on the maize diet (Figure 1 and Table 2). The weight gain of ducks on the commercial broiler feed was significantly better ($p<0.05$) than those on the copra and maize diets, while the copra diet had better gains than the maize diet (Table 2). Ducks on commercial feed had significantly greater feed intake ($p<0.05$) than those on the maize diet but there was no difference ($p> 0.05$) in feed intake between the copra diet and the commercial feed.

The FCR was significantly ($p<0.05$) better for the commercial broiler feed than for the maize diet and copra diet but the copra diet ($p<0.05$) was significantly better than the maize diet (Table 3). In terms of the cost of producing a kilogram of weight gain, the maize diet and the copra diet were cheaper ($p<0.05$) than the commercial feed (Table 3).

DISCUSSION AND CONCLUSION

The results of these studies show that agro-industrial by-products and local maize can be effectively used to grow Muscovy ducks economically. Since there was no difference in weight gain between the test diet and commercial feed in the first trial, we can conclude that this particular test diet is as good as the commercial broiler diet. The daily gain in the two diets (97g/day vs 100g/day) appears higher than what was reported by Leclercq and Carville (1986) (80g/day), however this relates to the age difference of the ducks used in the trial.

In the second trial, the commercial broiler feed had better weight gain compared to the two test diets (local maize and copra diet) but in terms of feed intake, both the commercial feed and the copra diet are higher than the maize diet.. The FCR for the commercial feed is better than the two test diets; however, the agro-industrial by-product based diets are cheaper than the commercial broiler feed. Generally, the feed intake of the ducks corresponds to the energy level of the feed and ducks will eat more of a lower intensity feed to meet their energy requirements as shown by Ignatius and Quartermain (2002). The ducks on the copra diet and the maize diet have lower feed intake than those on broiler feed because they might have slightly higher energy levels (~12 MJ/kg and 13 MJ/kg). The results of the FCR may be related to the protein level. The copra diet is

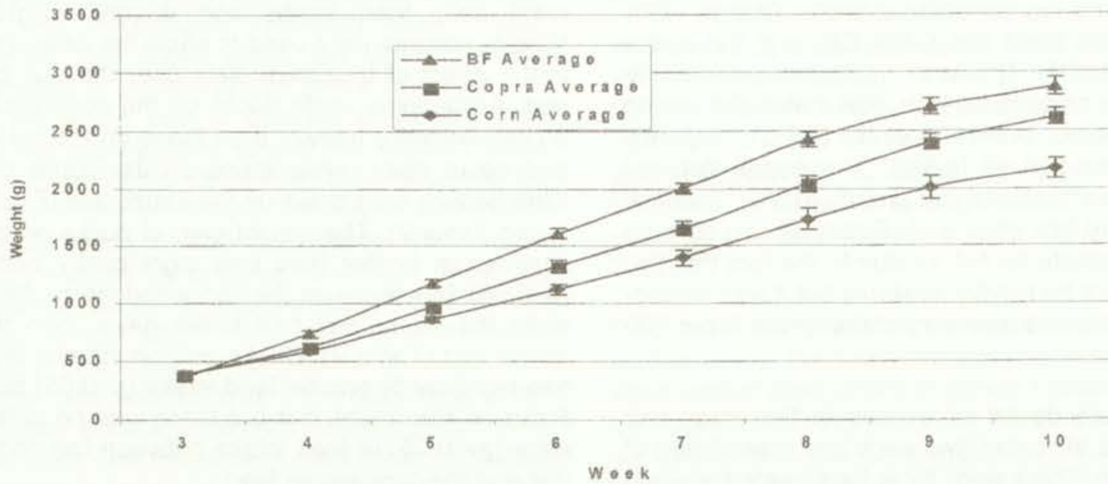

Figure 1: Weekly weights of male ducklings on broiler finisher (BF), copra meal and Markham maize diet (Trial 2).

Table 2: Weight gain (g) and feed intake (g) of Muscovy ducklings (Trial 2)

Diets	Weight gain (±SE)	Feed intake (±SE)
Commercial feed	2,504.3 ± 82.8[a]	15,843.2 ± 804.3[a]
Copra diet	2,228.2 ± 68.7[b]	15,167.8 ± 426.5[a]
Maize diet	1,787.2 ± 78.0[c]	13,341.6 ± 500.0[b]
Lsd (p = 0.05)	108.5	848.1

Means with the same superscript are not statistically different at 5% level of significance

Table 3: FCR and feed cost (Kina) per kg of weight gain of the of Muscovy ducklings on the diets (Trial 2).

Diets	FCR (±SE)	Cost/kg gain
Commercial feed	3.16 ± 0.09[a]	3.95 ± 0.11[a]
Copra diet	3.41 ± 0.08[b]	3.27 ± 0.08[b]
Maize diet	3.76 ± 0.20[c]	3.16 ± 0.17[b]
Lsd (p = 0.05)	0.2	0.18

Means with the same superscripts are not statistically different at 5% level of significance

comparable to the commercial feed because their protein levels are 25% CP and 20% CP. A poor FCR is achieved by the maize diet due to lower protein level (16%). Even though the copra diet had much higher protein level (25% CP) compared to the broiler feed (20% CP) given the same energy levels (12 MJ/kg) for both diets, the protein and energy ratio may be unbalanced.

The use of effective feeding systems is crucial for the development of the smallholder livestock industry. However in PNG, livestock farmers either rely on commercial feeds or foraging (free-ranging system) to provide food for their livestock. The practice of making farm-made feeds that are nutritionally sound or comparable to commercial feeds is uncommon in PNG. This practice is uncommon in PNG because of the very limited information about feeding values of these local feed resources, lack of information about feed formulation and preparation, and availability of feed making equipments such as hand grinders, hammer mills, feed mixers and feed pelleters to produce farm-made feeds. Recent attempts by the Australian Centre for International Agricultural Research (ACIAR) to support poultry feed research and development capacity in NARI and fish feed research and development in (National Fisheries Authority) NFA, (Department of Agriculture and Livestock) DAL and its stakeholders (Booth, *et al.* 2007) is quite significant for the development of the smallholder livestock industry. The much needed information about feeding values of locally available feed resources, feed formulation and preparation (poultry and fish) is now available in NARI, NFA and DAL while the private sector (Project Support Service Limited) is now engaged in providing feed making equipments for making, on-farm feeds. The studies by Dong (2005) in Vietnam shows that agro-industrial by-products or other local feeds resources can be effectively used in duck feeds to maximised production. These agro-industrial by-products can be good protein substitutes, such as the use of soy waste, brewery waste and ensiled prawn waste in farm-made duck feeds in Vietnam (Dong, 2005) or energy substitutes in lower intensity feeds. Agro-industrial by-products can be used to develop low intensity (high fibre, and lower nutrient density) feeds, which are cheaper and comparable to high nutrient density feeds (Ignatius and Quartermain, 2002). Feed cost can also be dramatically reduced by the addition of agro-industrial by-products like copra meal to commercial feeds at 40% level (Pandi, 2005).

The diet in the first trial consisted of commonly used commercial feed ingredients and agro-industrial by-products (rice bran, wheat mill run and palm kernel meal) while the second trial consisted of ingredients that can be put together on-farm by smallholder Muscovy duck farmers. Now that the information and technology for production of farm-made feeds are available in the country, research and extension efforts should now focus on evaluating locally available feed resources for feeding Muscovy ducks, especially with the use of farm-made feeds. Further studies are also needed to define the energy and protein requirements of Muscovy ducks under lowlands, highlands or even high altitude areas in order to develop proper duck rations for duck farmers in PNG. With these experiences in the use of agro-industrial by-products as protein substitutes, energy substitutes and the development of lower intensity feeds, Muscovy duck farmers should be encouraged to develop farm-made feeds using locally available feeds resources and by-products of agro-processing industries. The use of these agro-industrial by-products and locally available feeds resources will encourage Muscovy duck production and promote economic development and food security for rural and peri-urban communities in PNG.

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MILE-A-MINUTE (*MIKANIA MICRANTHA*): ITS DISTRIBUTION, GROWTH AND PHYSICAL AND SOCIO-ECONOMIC IMPACTS IN PAPUA NEW GUINEA

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ABSTRACT

Mikania micrantha, Kunth. H.B.K (Asteraceae) or mile-a-minute is a weed of Neotropical origin in 17 Pacific Island countries. It is becoming increasingly regarded as an invasive weed in Papua New Guinea and is now the focus of an Australian Government-funded biological control program. As part of the program, growth rates, distribution and physical and socio-economic impacts were studied to obtain baseline data and to assist with the field release of biological control agents. Through public awareness campaigns and dedicated surveys, mikania has been reported in most lowland provinces. It is particularly widespread in East New Britain and West New Britain Province. In field trials, mikania grew more than 1 metre per month in open sunny areas but slightly slower when growing under cocoa. The weed invades a wide range of land types, impacting on plantations and food gardens, smothering pawpaw, young cocoa, banana, taro, young oil palms and ornamental plants. In socio-economic surveys, mikania was found to have severe impacts on crop production and income generated through reduced yields and high weeding costs. These studies suggest that there would be substantial benefits to the community if biological control of mikania is successful.

Keywords: *Mikania micrantha, Growth Rate, Distribution, Physical and Socio-economic.*

INTRODUCTION

Mikania micrantha Kunth. H.B.K (Asteraceae), commonly known as mile-a-minute is a Neotropical invasive plant originating from South to Central America and the Caribbean. The weed has spread from its native range to many other regions and is now widespread in 17 Pacific Island Countries (PICs), including Papua New Guinea (PNG) (Waterhouse & Norris 1987). At a regional workshop on invasive alien species, it was ranked as one of the most important weeds of the region (Shine *et al.* 2003). Mikania was first reported in PNG in 1951 at Kerevat, East New Britain Province (PNG Plant Database) and found in three other provinces through subsequent weed surveys by NAQIA and AQIS staff (B. Waterhouse, AQIS pers. comm.).

As the common name suggests, mikania grows rapidly, and is one of the major weed invaders of subsistence gardens and tree crops in plantations in PNG. It forms a thick ground cover, outcompeting many plant species including food and cash crops such as sweet potato, aibika, taro, yams, bananas, cassava, vanilla, young cocoa and coconut, coffee, and oil palm. Its growth habit chokes the plants and smothers the vegetation, causing loss of production and localized death. It can interfere with the harvesting of tree crops like coconut, oil palm and cocoa. (Waterhouse & Norris 1987).

Mikania can be controlled through the use of herbicides or by manual means such as hand-pulling. However, these conventional methods of control are not practical as they are costly, time consuming and labour intensive. Biological control is seen as the only sustainable and cost-effective means to control this weed (Waterhouse & Norris 1987). A biological control program was first initiated in 2001, when the thrips *Liothrips mikaniae* was introduced into Solomon Islands and Malaysia but it failed to establish (Julien & Griffiths 1998; Evans & Ellison 2005).

As part of a renewed effort against mikania, an Australian Government-funded biological control

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program aiming to reduce the impact of *M. micrantha* in PNG and Fiji began in 2006 and involved the introduction of the rust fungus *Puccinia spegazzinii* and two butterfly species *Actinote anteas* and *A. thalia pyrrha* (Orapa *et al.* 2008). This paper reports on the distribution and growth of *M. micrantha* in PNG and the physical and socio-economic impacts of the weed. Information gained in these studies will be used in the biocontrol agent release program and to assess the benefits of the project.

DISTRIBUTION

Through the circulation of brochures and on-ground surveys conducted by the project and PNG provincial staff, mikania has now been reported in 13 lowland provinces (Fig. 1). It has also been reported in East Sepik Province (not shown) but the actual sites have not yet been confirmed. To date, mikania has not been found in Milne Bay Province despite several surveys having been conducted or Gulf Province where little work has been conducted. The largest infestations appear to be in East and West New Britain where project staff are located and are able to travel more easily. Mikania is also widespread in Central, Madang, Morobe and Manus provinces where project staff have undertaken field surveys (Fig. 1). While mikania has been reported in seven other provinces, thorough surveys of these and other provinces where the weed has not been reported, still need to be conducted to determine the actual distribution of mikania.

A preliminary CLIMEX model developed using the distribution of mikania in its native range shows that mikania has the potential to infest most parts of PNG, except the very high altitude areas and many wet lowland areas such as those found in Gulf Province (Fig. 1). Mikania has been located at Tabubil in Western Province which suggests that many other areas of similar altitude that are deemed by the model as less suitable, could actually be suitable for mikania. As a thorough survey of mikania in PNG has not yet been completed, the actual and full potential distribution of mikania cannot be determined.

GROWTH RATE

Growth measurements of mikania were undertaken by tagging plants at eight sites in East New Britain Province and two sites in West New Britain (Rigula and Dami). The sites covered different habitats, from under shade to full sunlight. In East New Britain, the length of the growing stem was recorded fortnightly, while in West New Britain, it was recorded weekly. As the plant's growing tips dried up and died they were over-handled, great care was taken during the measuring process. Dead stems were discarded from the analysis.

Growth rates of mikania varied from 5.6 cm/day in full sunlight to 1.9 cm/day in shaded areas or where mikania was growing under cocoa. The overall average growth rate of mikania for all sites was 3.5 cm/day or over 1 m/month.

THE PHYSICAL AND SOCIO-ECONOMIC IMPACT OF MIKANIA

The physical impact of mikania was determined through visual observations and field plot trials. In a field plot in West New Britain, young bananas were grown with and without the presence of mikania. Bananas in the control plot were weeded regularly and allowed to grow free of mikania while those in the test plot were not weeded.

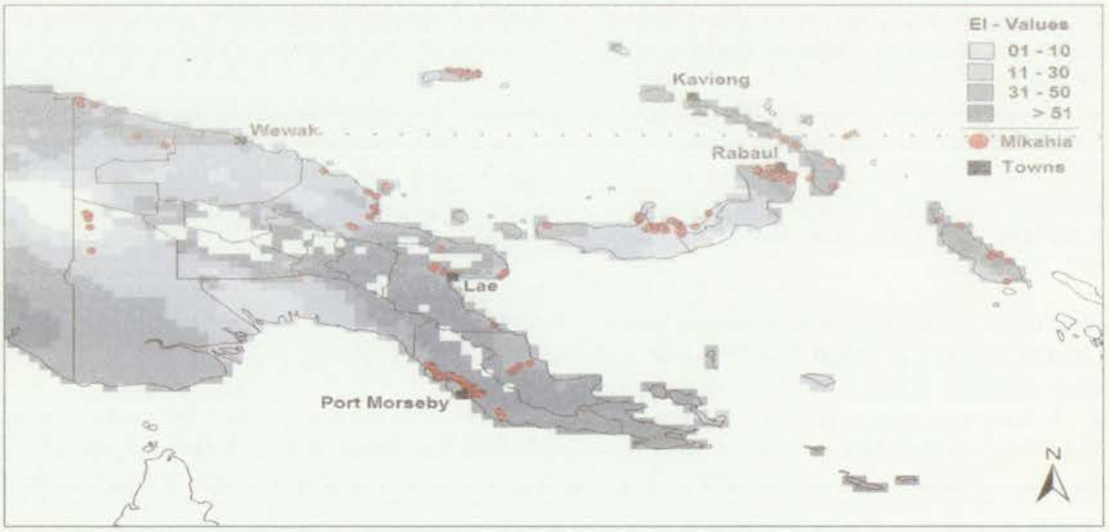
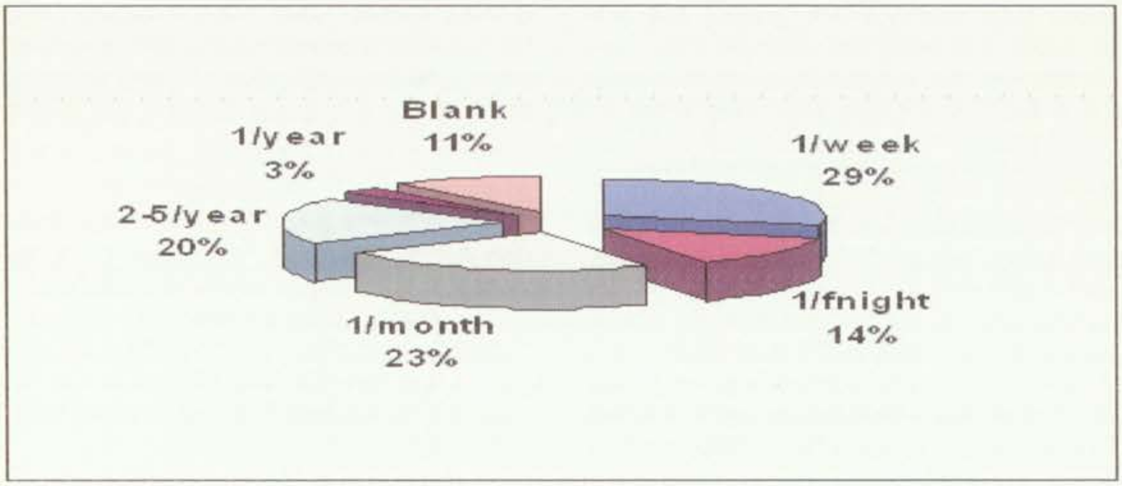


Figure 1: Map indicating where mikania is present in PNG and a preliminary CLIMEX model showing the areas where mikania is likely to occur if it continues to spread.



. **Figure 2**: The proportion of respondents who undertake control of mikania at various frequencies.

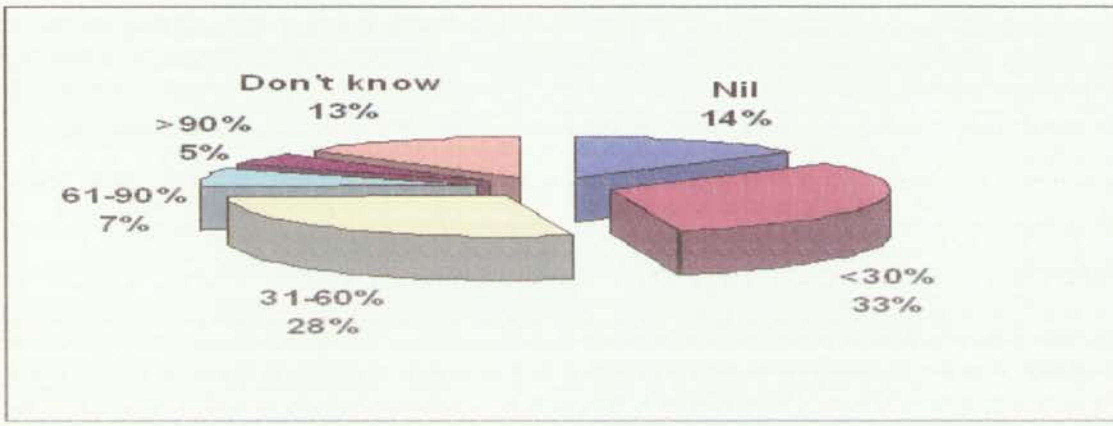


Figure 3: The proportion of respondents commenting on the effect of mikania on yield.

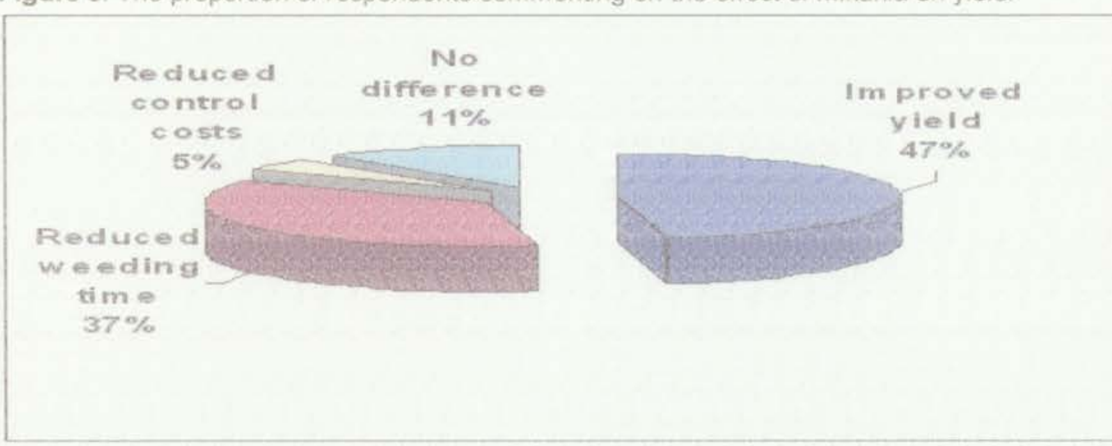


Figure 4: The proportion of respondents commenting on various benefits of controlling mikania.

Bananas left un-weeded eventually died, being smothered by mikania while the bananas in the control plot grew normally. At many sites throughout areas infested with mikania, plants smothered by mikania appeared in poorer condition than those without mikania. Anecdotal data found that cocoa plants covered in mikania had lower yields and it was thought that mikania interferes with flowering and the natural pollination by insects (J. Konam, PNG CCI, pers. comm.).

A questionnaire was developed to determine the social and economic impact of mikania on crop production, time spent weeding and income. Project staff conducted surveys in their own provinces and in provinces to which they travelled. The questionnaire was also sent to all other lowland provinces where mikania was reported for completion by provincial staff.

Over 270 responses covering 12 provinces were received, with the vast majority coming from East and West New Britain where project staff are based. Responses were well received from Central, Madang and Manus provinces where project officers were able to also visit. Less than 10 questionnaires were received from each of the other provinces where mikania was confirmed.

About 87% of respondents had mikania present on their blocks, while 82% of respondents with mikania, considered it as weed. Eighty-six percent of respondents stated that mikania climbs and competes with crops and 74% thought regular (at least once a month) control was warranted (Fig. 2). The principal method to control mikania was through hand-pulling (81% of respondents), with 47% using hired help.

Most respondents who had mikania present, believed that mikania reduces yield (72.9%, Fig. 3) and that its control would be beneficial through increased yield and reduced time weeding and control costs (88.7%, Fig. 4). Only 27% of respondents use mikania for medicinal purposes, such as in the treatment of cuts and wounds and less than 5% used mikania as a cover crop.

DISCUSSION

Mikania is becoming increasingly invasive in PNG, being present in most lowland provinces which have been surveyed. Its rapid growth rate is causing substantial problems for subsistence landowners and plantation managers alike by smothering crops and young trees, reducing productivity, food security, income and killing plants. Socio-economic surveys show that the negative impacts of mikania far out-weigh any benefits of the weed through its use as a cover crop or the treatment of cuts and wounds.

With food security and income being an important area of concern among farmers, the importance of finding cost effective control methods against this weed are clear. Particularly significant are the observations that there was a high labour cost involved in keeping land free from mikania and in farms where the weed was cleared, productivity rose significantly. Through the Australian Centre for International Agricultural Research (ACIAR)-funded biological control project, it is hoped that effective control of mikania can be achieved with the release of several biocontrol agents. As result indicated, labour requirement will be reduced while food production and income will increase.

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ADVANCING PAPUA NEW GUINEA'S FOOD PRODUCTION THROUGH THE USE OF INORGANIC OR MINERAL FERTILIZERS: A PERSONAL PERSPECTIVE

Joachim A.R. Pitala

ABSTRACT

Papua New Guinea has extensive inorganic, agricultural, forestry, fisheries and marine resources. About 80 % of the rural people rely on subsistence and semi-subsistence agriculture to produce food and cash crops. Many studies have established beyond doubt that there is a close relationship between fertilizer consumption and increased agricultural productivity. Applications of inorganic or mineral fertilizers have greatly increased food production in developed as well as in developing countries. With the perpetual increasing population of PNG, agricultural activities will certainly intensify which will result in the concomitant problems such as; shortages of cultivable lands, shorter fallow periods and declining soil fertility levels. To attain increased food production, the use of inorganic fertilizers and other improved agricultural technologies is unavoidable. PNG will definitely remain a subsistence level food producing country if the use of inorganic fertilizers is not encouraged and promoted.

Keywords: *Mineral fertilizers, inorganic fertilizers, organic fertilizers, agricultural production, food production, fertilizer consumption, soil fertility.*

INTRODUCTION

Papua New Guinea (PNG) compared to other developing countries, is fortunate to have extensive inorganic, agricultural, forestry, fisheries and marine resources and a generally favorable climate. Despite these favorable conditions, the agriculture sector had encountered many impediments and as such had not fared well [National Agriculture Development Plan (NADP), 2007]. The growth in agriculture is around 1% compared to the population growth of 2.7%.

About 80% of the rural people rely on subsistence and semi-subsistence agriculture to produce food and cash crops (NADP, 2007). Subsistence gardeners cultivate between 0.01 – 0.1 hectare of land while smallholder farmers, cultivate less than 5 hectares of land area. Most gardens are planted with crops for 1 or 2 years followed by fallowing; which ranges from 5 – 15 years. However, in some areas due to population pressure fallow periods have declined to less than 12 months (Hughes *et al*., 2009). The core feature of this farming system is that land is rotated rather than crops as is the practice in most intensive agriculture systems.

In spite of the fact that in the period 1998 to 2005, production of staple foods for subsistence and sale increased faster than population growth (Bourke and Allen, 2009), with the current population growth of 2.7%, land shortages and the concomitant shorter fallow periods are likely to increase significantly.

There is a general consensus among various people that the soils are generally fertile and the rainfall is sufficient to support the cultivation of a wide range of crops, both for domestic consumption and export markets. Most of these assertions are, however, based on patriotic sentiments rather than on long-term scientific studies. For example, Allen and Bourke (2009) indicated that in relation to sweet potato production more than 70% of the total land area is of low or very low quality and that most Papua New Guineans produce food from land of moderate to low quality. Therefore, such above sentiments should be treated with some degree of caution.

There have been cases of macronutrient deficiencies reported for most of the cash crops and micronutrients deficiencies in both tree crops and food crops have been reported to be widespread (Hartemink and Bourke, 2001; Southern, 1967). Hartemink and Bourke (2001), pointed out that much of the current agronomic work in PNG is devoted to crop cultivars and entomology but very little research is conducted on nutrient manage-

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ment strategies and nutrient deficiencies. They emphasized the fact that with further intensification of land use, soil fertility will be very much affected and nutrient deficiencies are likely to increase, particularly in food crops where inorganic fertilizers are not being used.

This paper discusses the need for the use of inorganic fertilizers in food production for improved yields; and quality to support a perpetual growing population and for possible export markets. In addition, the paper may perhaps stimulate thinking on the promotion of increasing use of inorganic fertilizers in PNG.

ents essential to normal growth and development of plants. Inorganic fertilizers have become an integral part of the agricultural economy of the developed countries but their use in developing countries including PNG is a comparatively recent occurrence.

Many studies have established beyond doubt the existence of a close relationship between fertilizer consumption level and increased agricultural productivity (FAO, 1984). Crop yield levels are generally higher in those countries where fertilizer consumption levels are also high (Figure 1).

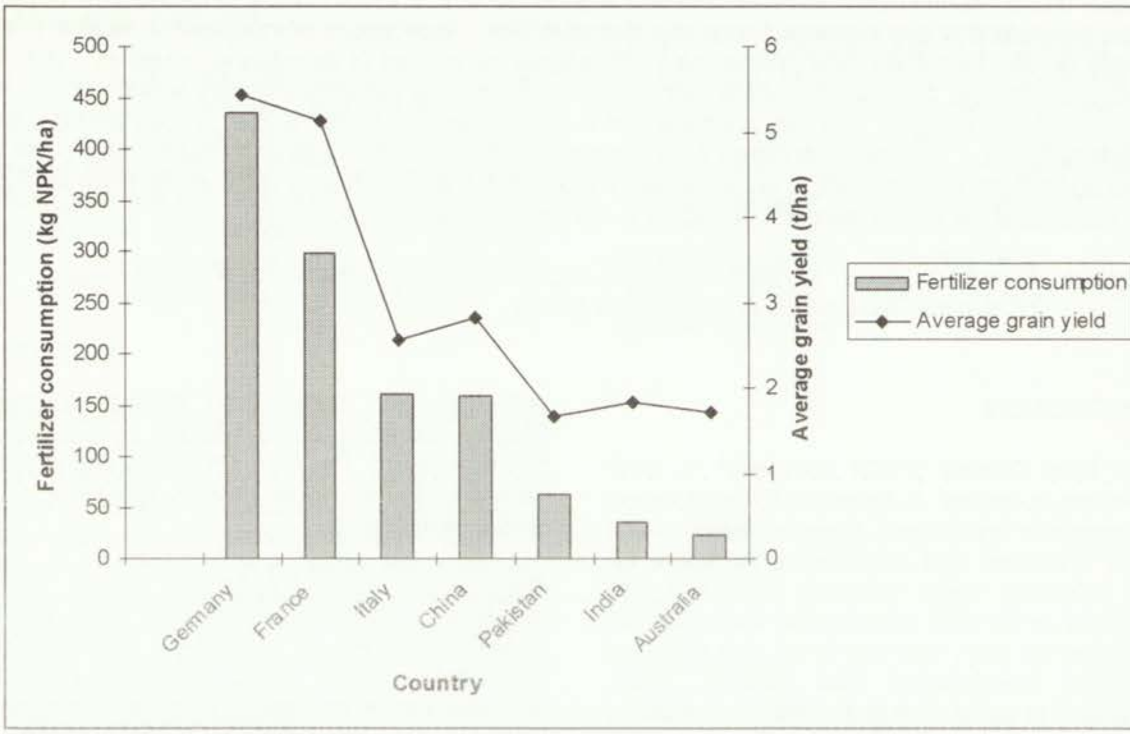

Figure 1: Fertilizer consumption and wheat yield (Adapted from FAO, 1984)

ROLE OF INORGANIC FERTILIZERS

Inorganic or mineral fertilizers are materials, either natural or manufactured containing nutri-

There is no doubt that the spectacular rise in crop yields has resulted from a combination of factors such as; crop improvement by breeding for high-yielding cultivars, improved farming methods, the use of pesticides and herbicides and last, but not the least, the application of inorganic fertilizers.

Table 1: Inorganic fertilizer consumption, yield per ha, production per head and the number of people supported by the production of 1 ha over a 180 year period in Germany. Production expressed in grain <<units>> which is equivalent to 1 t cereal grains (after Mengel and Kirkby, 1987).

Year	Number of people supported by 1 ha	Production per head, grain unit	Yield Tons/ha	Fertilizer consumption (kg NPK/ha)
1800	0.8	0.91	0.73	-
1875	1.3	0.92	1.20	3.1
1900	1.6	1.14	1.84	15.6
1925	2.1	1.09	2.28	43.9
1950	3.3	0.91	2.98	101.9
1975	4.6	0.95	4.43	233.5
1978	4.5	1.03	4.63	255.8

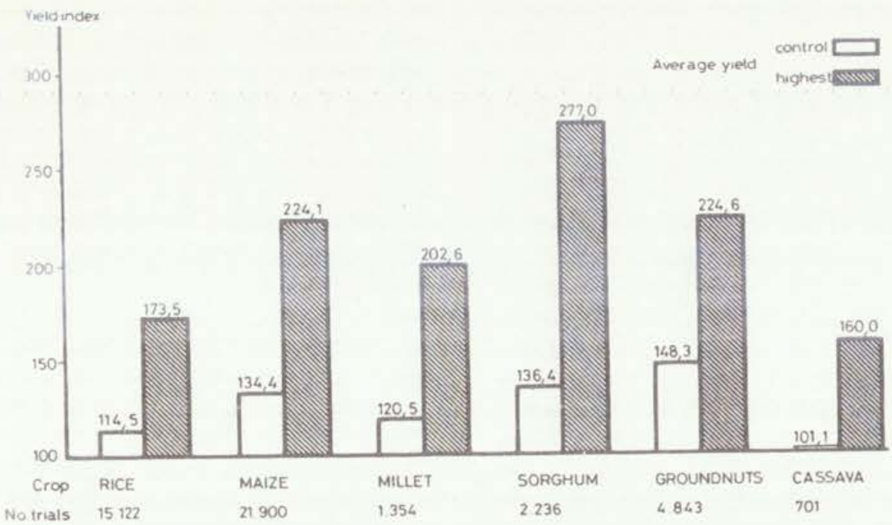

Figure 2: Crop response to fertilizers based on FAO/FP results (National average yield = 100) (Richards, 1979 from Mengel and Kirkby, 1987)

These factors are all interrelated. However, in order to establish high crop yields, adequate amounts of plant nutrients must be available in the soil.

In PNG, most soils are deficient in one or more plant nutrients and with the intensive use of farming lands, deficiencies of nutrients will certainly increase. Therefore, the differences to reach maximum potential have to be made up by inorganic fertilizer applications. The high yields of modern agriculture are thus, to a considerable extent due, to application of inorganic fertilizers. Table 1 shows the yield per hectare, fertilizer consumption as well as production per head and the number of people supported by production of 1 hectare of land. The Table clearly shows that at the beginning of the 19th century, 1 ha of farmland scarcely produced food for 1 person, however during 1978, 4.5 people could be fed from the production of 1 ha.

Amongst the various agricultural inputs, inorganic fertilizers, perhaps next to water, contribute to the maximum to increasing agricultural production. It has been estimated that about 50% of the increase in agricultural production witnessed during the last decade in developing countries is attributable to inorganic fertilizer use.

From an extensive FAO analysis of a large number of fertilizer trials conducted in developing countries, higher crop yield increases were

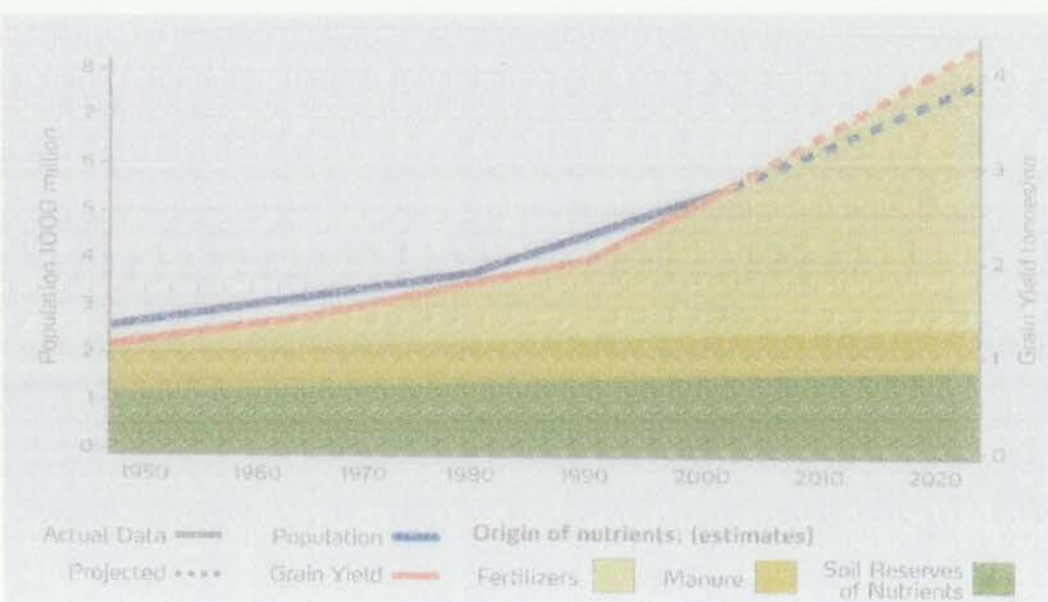

Figure 3: *Global trends in population growth, grain yield, and origin of plant nutrients (after Yara International, 2009)*

achieved as a result of inorganic fertilizer applications. (Figure 2).

Fertilizers are a key part of better farm management in improving, maintaining, or restoring soil fertility. Fertilizers promote plant and root growth which helps maintain or build organic matter in the soil. The wise use of fertilizers also prevents soil fertility decline and helps combat other forms of land degradation. Figure 3 shows the global trends in population growth, grain yield and origin of plant nutrients. It shows that whilst the soil reserve of nutrients and the use of manure are projected to remain as at present, the use of inorganic fertilizers will increase substantially and as a result, grain yield is projected to surpass the world population by 2020. While that is yet to be realized, the fact is that grain yield can not at present meet the world population's demand for grain.

FOOD PRODUCTION STATUS IN PNG

In PNG the NADP (2007) report showed that food crops including fruits, vegetables and nuts contribute 55% towards the total agriculture output. Bourke and Vlassak (2004), indicated that sweet potato dominates food production which accounts for 63.6% of the total food production output, followed by banana (9.7%), cassava (6%), yam (6%), Colocasia taro (5%), Kongkong taro (5%) and sago (1.8%). Highlighting the major differences in the structure of rural and urban diets, Gibson (2001) showed that about 65% of the rural population consume sweet potato compared to only 33% of the urban dwellers who consume sweet potato. However, 87% of the urban dwellers consume rice compared to 26% of the rural dwellers who consume rice. The same trend is also seen with wheat products.

It should be noted that the bulk of the food crops produced emanates from the subsistence and semi-subsistence producers. It is also quite apparent that food crops produced under these systems can not produce and supply food in the right quantity and quality to meet market demand. Furthermore, in the highlands there is evidence that the current indigenous soil-fertility management practices are gradually becoming unsustainable (Hughes *et. al.,* 2009) because of the increasing population pressure on gardening land areas.

In terms of grain crops production, Blakeney and Clough (2001) indicated that for rice, total production level in the year 2000 was estimated to be about 400 tonnes. Recent estimates however showed that since 2000, rice production levels from subsistence farmers have been increasing due partly to government support and partly as a result of more subsistence farmers engaging themselves in rice cultivation, that is, making more land available for rice production rather than as a result of higher yields per hectare. Average rice yields under subsistence production systems range from 1 – 1.5 t/ha. However, higher average yields of about 3–4 t/ha have been achieved when inorganic fertilizers were used (Dekuku *et al.*, 2002).

For wheat preliminary production data have shown that in the highlands region particularly in the Eastern Highlands and Enga provinces, yields of up to 2.0 t/ha had been achieved. However, with further intensive use of cultivable land and without the use of inorganic fertilizers, yields are expected to become significantly low.

Vegetables, fruits and nuts are considered as commercial food crops as they are grown primarily for sale. According to the NADP (2007) report, there are some 227,000 growers from the highlands producing and supplying between 5-6000 tonnes of fresh produce to Port Moresby markets. That is, each grower produces and supplies on average between 0.02–0.03 t of fresh produce annually which is insignificant. For PNG to attain high levels of vegetable and fruit production and to get quality products, inorganic fertilizers and other improved farming management inputs need to be used.

Bourke *et al.* (2009) showed that yields of root crops in PNG are as good as the best yields reported in other tropical locations, but they are lower compared to those of many sub-tropical locations were soil fertility is maintained by fertilizer applications and improved varieties. In addition, these authors pointed out that in some locations crop yields are very low due to population increases resulting in intensive use of land, thereby contributing to reduced soil fertility.

THE NEED FOR INORGANIC FERTLIZERS TO INCREASE FOOD PRODUCTION LEVELS FOR BOTH LOCAL CONSUMPTION AND MARKET DEMAND

Food production and supply is a competitive industry. For example, in the highlands food crops contributed 20% of the total income in 1996 and 25% in 2000 compared to coffee which contributed 33% of the total income in 1996 and 12% in 2000 (Allen *et.al.,* 2001). This scenario points out the importance of food crops sub-sector in providing relative stability in income of the rural farming households compared to those that rely mostly on export commodities, which in turn are dependent on weather conditions and price fluctuations in the world market. Despite these encouraging trends, the fact remains that subsistence food production can not sustain the demand for food for a rapidly growing population of PNG, particularly when one considers the present high population growth rate of 2.7%.

The NADP (2007) report highlighted five major constraints contributing to low level food production. These include:

- Poor land use
- Lack of technical know-how.
- Lack of production plans and effective programs dedicated to increasing food production in the districts.
- Shortage of production inputs which include, *Interalia*, the use of very little or no fertilizers and pesticides.
- Lack of an appropriate working credit system.

The NADP (2007) report also highlighted that one of the priority program areas for development is to improve supply of production units such as improved plant crop cultivars and varieties, seeds, chemical fertilizers and pesticides for commercial food production.

It is important to point out that the introduction of improved crop cultivars and varieties will require improved or higher farm management inputs in order for these crop varieties to produce at their genetic potential. This is clearly shown in Table 2 where the application of the NPK inorganic fertilizer resulted in higher grain yield and increased nutrient uptake in an improved rice variety compared to a local variety. Since PNG is beginning to cultivate many of the introduced improved crop varieties such as rice, it is necessary that applications of inorganic fertilizers, pesticides and other improved management techniques are used as well. Moreover, the nutrient content of inorganic fertilizers is known, predictable, in fixed ratios and readily available, allowing for precise delivery of nutrients to plants.

Table 2: Yield level and nutrient uptake of a local rice variety and the improved variety 1" (Kemmler, 1972).

Variety	Grain Yield	Nutrient uptake (kg/ha)		
	(t/ha)	N	P	K
Local	2.8	82	10	100
TN1	8.0	152	37	270

Data from long-term trials in India for rice and wheat, which are two of the most important crops that feed more than half of the world's population, show that when no fertilizer was used the grain yields were 1.75 t/ha and 0.99 t/ha for rice and wheat respectively. When inorganic NPK fertilizer was used, the yields increased significantly for both crops (Table 3).

Table 3: Yields of rice and wheat from long-term fertilizer trials in India (after Nambiar, 1994)

Fertilizer	Yield (kg/ha)	
	Rice	Wheat
No fertilizer	1.751	0.994
NPK fertilizer	3.607	3.342

FERTILIZER SUPPLY AND DISTRIBUTION

One of the strategies highlighted in the NADP (2007) report to improve supply of production inputs is to develop a cost effective procurement system for agricultural inputs like fertilizers and pesticides for commercial food production.

Procurement constitutes the first step in the entire fertilizer distribution chain. At present PNG does not have a domestic fertilizer production capability. Therefore, most of the inorganic fertilizers are imported from abroad, mostly by private companies. Often these fertilizers are stored in warehouses owned by these companies which are located in the urban centers. The movement of fertilizers from towns to the farmers' set-ups is thus non-existent. This is further exacerbated by the poor road network systems and exorbitant transport costs which make it impossible to move the fertilizers to the farmers' easy reach.

In many developing countries, the main channels of distribution are the cooperatives, private traders and state boards or other public sector agricultural agencies. These channels are absent in PNG and private traders distribute them only to the main urban centers. They do not distribute them to farmers.

For PNG to increase its level of commercial food production, the supply and distribution systems of fertilizers must be addressed and that should have been highlighted in the NADP (2007) report.

FERTILIZER QUALITY CONTROL

It is common knowledge that best results are usually obtained from the application of fertilizer only when it posses the requisite chemical composition and acceptable physical characteristics in terms of production shape, size, moisture content and storage characteristics.

The overall resource limitation of farmers in PNG and their lack of knowledge relating to the quality of fertilizer bought, makes it all the more important to have some sort of regulatory system through which quality of fertilizers can be fully guaranteed.

CREDIT

Most food crops farmers in PNG do not have the required capital to establish warehousing facilities on their own, thus demonstrating the necessity to store fertilizers at intermediate points. Therefore, dependence on external finance is unavoidable. Availability of credit to facilitate distributors' operations is necessary. There is also a greater need for credits to be made available to farmers to enable them to purchase fertilizers. The government should take an active responsibility in this regard.

FERTILIZER USE AND THE QUALITY OF THE ENVIRONMENT

Inorganic fertilizers have played a significant part in achieving higher agricultural production in both developed and developing countries. There is however a growing concern among different people with the increasing use of inorganic fertilizers and the potential side effects that could have on the environment. This is a very important subject and therefore it is necessary to look at it from different perspectives. These include looking at the fertilizer needs of modern agriculture, the relevant fertilizer-soil-plant interactions and the possible effects on human environment.

Problems from inorganic fertilizers can occur under conditions where:

- Excessive nutrient is applied than the crop requirements, either over the whole field or over part of the field especially in cases where the fertilizer might be spread unevenly.
- A deficiency in one nutrient is left uncorrected which may lead to unbalanced nutrition and poor utilization of other nutrients.
- Nutrients applied in manures are not considered when applying fertilizer.

The problems that can then occur include; leaching of nitrate into aquifers or surface waters, loss of phosphorus-enriched soil particles to surface waters that can contribute to eutrophication, and loss of ammonia or nitrogen oxides to the atmosphere by volatilization and denitrification.

However, when used correctly inorganic fertilizers can improve and protect the environment in several ways. These include:

- Improved productivity from cropped land avoid the need to destroy further areas of natural forest and grassland.
- Sustained green crop growth vital for maintenance of the atmosphere.
- Reduced losses of soil due to wind and water erosion. Small particles of soil can be easily eroded from bare areas of a farmland. Many of these particles can end up in water ways with a potential of causing pollution of surface waters. Erosion can thus be reduced by the maintenance of green crop cover with active healthy root system.
- Improved crop rooting systems which can make better use of both the soil's nutrient supply and applied fertilizers. This reduces the risk of nutrients entering ground water.
- Land reclamation and safe disposal of degradable wastes is improved by fertilizers encouraging active crop growth.
- Increased soil organic matter through incorporation of greater amounts of crop residues associated with higher crop yields.

Thus, using the correct amounts of inorganic fertilizers and applying them in right amounts to satisfy plants demand, and by taking appropriate measures to control runoffs, some of the associated environmental problems can be minimized.

ORGANIC FERTILIZER NUTRIENTS

Generally organic materials influence plant nutrient availability by:

- Providing plant nutrients, however, the nutrients content is very variable and often low.
- Providing a source of carbon and energy for microbial activities.
- Controlling net mineralization-Immobilization patterns.
- Increasing soil organic matter, which can improve soil structure, water storage and cation exchange capacity of soils.

It should be noted however that all sound farming practices such as crop rotation, the use of green manure crops, retention of crop residues and minimum tillage can also help to maintain or improve organic matter levels, thereby contributing to soil conservation.

Although, there are examples of increased crop yields as a result of the combined application of inorganic fertilizers and organic fertilizer materials like farm yard manure, in many Asian and African countries, organic fertilizer materials such as animal manures and crop residues have competing uses and the problem therefore is one of a shortage rather than the surplus. Furthermore, the systems produce very little biomass, and much of what is produced, is consumed by grazing animals and deposited elsewhere. The return of organic matter to the soil is thus negligible.

For subsistence gardening, composting may meet some of the food requirements of a family unit. However, composting cannot meet the food demand of a fast growing population like that of PNG. Application of organic fertilizers can supply some of the plant nutrients but not in large quantities. They are simply not available in adequate amounts to meet the crops demand. In addition, they can not supply all of the 16 elements essential for healthy plant growth. In fact, most of these organic fertilizers have too many nutrient imbalances. They are also bulky hence handling and transportation are usually difficult and costly. There have been numerous examples that; of all the different components of input, inorganic fertilizer use alone has shown to rapidly and easily give higher agricultural production. No other sources of nitrogen, phosphate and potash are available in sufficient amounts to satisfy total world requirements for plant nutrients. Increasing use of inorganic fertilizers is, thus, essential to satisfy world-wide demands for food and, in this respect, PNG is no exception.

CONCLUSION

As pointed out by Hartemink and Bourke (2001), as PNG's population increases the use of land will further intensify which will result in soil fertility problems, and nutrient deficiencies are also likely to increase. PNG will certainly remain a subsistence level food producing country if the use of inorganic fertilizers is not encouraged and promoted.

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THE CRITICAL NATURE OF ANAEROBIC PHASE IN COCOA MICRO-FERMENTATION METHODS TO REPRODUCE OPTIMUM COCOA FLAVOUR POTENTIAL SIMILAR TO LARGE SCALE FERMENTATION

Noel Y.Kuman and Neil Hollywood

ABSTRACT

Successful cocoa fermentation is defined by development of the optimum flavour potentials of cocoa. Cocoa flavour precursors are developed during fermentation. The initial anaerobic phase of the microfermentation process is demonstrated to be essential for proper development of cocoa flavour attributes.

Key words: *flavour characteristic, fermentation, anaerobic phase*

INTRODUCTION (FERMENTATION PROCESSES)

In a large scale cocoa fermentation process, a sequence of enzymatic and microbial activities and biochemical reactions are involved to produce desirable qualities of cocoa flavour. During fermentation, successive growths of microorganisms are observed beginning with fungal species, followed by yeast and bacteria species (Acetobacter, Lactobacilli and Bacillus species). Cocoa fermentation is a crucial biochemical process required in development of flavour precursors. Fermentation is regarded as being essential for initiating the reactions that lead to the formation of substances that confer characteristic of chocolate flavour (Lehrian and Patterson, 1983).

The flavour precursors (amino acids, peptides and reducing sugar) developed during fermentation undergoes Mallaird or non-enzymatic browning reaction during roasting to produce typical cocoa flavour compounds. There are 462 compounds found from several sources of cocoa and there is no single compound that produces an aroma that can be described as "cocoa" or "chocolate". It is more a balance of pyrazines, aldehydes, alcohols, volatile acids and esters, which make up the overall flavour (Macdonlad *et al.*, 1994).

The initial anaerobic phase in cocoa fermentation is crucial for flavour development. During the initial anaerobic phase in the first 24 hours of fermentation, pulp sugars are converted by yeast to ethanol, which is later converted into acetic acid by bacteria species. The conversion of ethanol to acetic acid is an exothermic reaction which increases the temperature of the fermenting mass. A combination of acetic acid levels and heat generated from the exothermic reactions during fermentation kill the cocoa beans causing a disruption of cell membranes; thus releasing enzymes and substrates which react to produce flavour precursors.

Similar processing conditions to large scale fermentation have to be reproduced when fermenting small quantities of beans (microfermentation) to produce desirable optimum flavour attributes. A reliable laboratory microfermentation method is required in breeding programs to address the critical problem of the small number of pods available from each genotype at any one time. Hence, the wet beans cannot be fermented as per normal commercial practice. A successful microfermentation method would allow rapid and reliable assessment of flavour potentials of genotypes. The method has to be less cumbersome, time and labour consuming and more reliable to reproduce basic physical and organic chemical attributes and microbiology similar to that of large scale fermentation.

Various microfermentation methods for processing small quantities of beans have been developed (Clapperton *et al.*, 1991; Quesnel and Lopez 1975; Challot, 1977; Perkins, 1982; Bridgland, 1984; Jacquet *et al.*, 1981). Most of these procedures produce beans of abnormal qualities, while other methods developed are cumbersome, time and labour consuming and unreliable.

From a detailed literature review (Hollywood, 1994); it was revealed that the anaerobic phase of microfermentation was ignored by most researchers when developing microfermentation methods to ferment small quantities of beans,

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though it is a critical factor that contributes towards production of optimum cocoa flavours similar to beans processed by large scale fermentation. Consequently, the microfermentation methods developed produce beans of abnormal qualities.

The work reported here was intended to validate the importance of anaerobic phase in large scale cocoa fermentation that needs to be reproduced in microfermentation methods to produce desirable cocoa flavour attributes similar to beans processed by large scale fermentation. This hypothesis was tested by microfermenting cocoa with or without an anaerobic phase in the first 24 hours of a microfermentation process described. The cocoa flavour profiles of the two treatments (with or without inclusion of anaerobic phase) were compared statistically to verify whether the anaerobic phase of fermentation is necessary in microfermentation process to develop desirable flavour attributes.

OBJECTIVE

The objective was to compare the flavour profiles of cocoa processed by a microfermentation method with or without anaerobic phase.

MATERIALS AND METHODS

Experimental Design

The cocoa genotypes assessed for flavour characteristics were collected from a cocoa breeding trial conducted at the Papua New Guinea Cocoa and Coconut Research Institute (PNGCCRI).

Sample collection & preparation

Treatment 1

Microfermenting cocoa under an anaerobic phase using an anaerobic jar inserted with a campy pak and microaerophilic gas generator.

A kilogram of wet beans was collected from Trinitario clones (K20) from a cocoa breeding trial. The beans were inoculated with 10 g pulp from day 1 commercial fermented beans and placed inside an anaerobic jar inserted with campy pak and microaerophilic gas generator to create an anaerobic phase in the first 24 hours of fermentation, mimicking a condition similar to a large fermentation. The beans were removed from the anaerobic jar after 24 hours and placed in a buchner funnel mounted on an erlenmeyer flask, which allowed draining of sweating and placed inside a thermostatically controlled incubator set at the following temperature range from day 0 (D0) to 6:(D6) D0-D1, 30 °C; D1-D2, 35 °C; D2-D3, 40 °C; D3-D4, 46 °C; D4-D5, 47°C; D5-D6, 47°C. The bean sweating collected inside the anaerobic jar and in the erlenmeyer flask were discarded. The moisture levels in the beans were maintained by sealing the buchner funnel with plastic wrappings. Aeration in the buchner funnel was controlled by stirring the beans daily. For both treatments, after six days of fermentation, the beans were solar dried (Hollywood *et al.*, 1996) for three days and drying was completed by drying the beans in cabinet dryer at 60 °C. The dried beans were cooled under room temperature before bagged and stored under dry condition for sensory assessment.

Treatment 2

Microfermenting cocoa without an anaerobic phase

For treatment 2, same procedure as for treatment 1 was applied except exclusion of the anaerobic phase of fermentation in the first 24 hours of microfermentation. Instead of placing the beans inside a campy pak with microaerophilic gas generator, the wet beans were placed straight into a buchner funnel mounted on an erlenmeyer flask and fermented after inoculation with 10 g pulp from day 1 commercial fermented beans. After fermentation and drying, the dried beans were bagged for sensory assessment.

Sample preparation

Approximately 2 kg of dried beans were collected from three replicates of each treatment. The sampled beans were dried inside an oven (Cotherm, New Zealand) at 115 °C for 15 min to standardize the moisture content of the beans to less than 7 %, cooled under room temperature before being emptied into a mixing container and thoroughly mixed. Any foreign materials and debris were removed. The samples were processed and packed following a procedure described by Sukha, 2001. The dried cocoa samples were sent to Queensland Department of Primary Industry (QDPI) and their basic flavour attributes were rated.

Flavour assessment procedure

Cocoa samples were assessed using standard rating test (AS2542.2.3-1988). Data were collected using a fully integrated software system Compusense five version 2.2 (Compusense Inc, Canada) and statistically analysed using appropriate techniques. The samples were rated for the basic flavour attributes of chocolate, acidity, bitterness, astringency and fruitiness.

Statistical Analysis

The data generated were analysed as a factorial using analysis of variance with tasters as a blocking factor and the two treatments assessed three times.

RESULTS & DISCUSSION

Table 1: Factorial analysis of variance, comparing cocoa flavours produced by microfermentation methods with or without an anaerobic phase.

Source	*Significant (p)*
Taster (Chocolate)	0.0050*
Taster (Acid)	0.0050*
Taster (Astringency)	0.0428 – NS
Taster (Bitterness)	0.0000*
Taster (Fruitiness)	0.0000*
Taster others (chemical, phenolic, overripe fruit)	0.1635 – NS

* Significant difference at 5 % level
NS No significant difference at 1 % level

Taster refers to a taste panel differentiating levels of flavour intensity between samples generated by two treatments.

Table 2: LSD pairwise comparisons of cocoa flavour produced by microfermentation methods with or without anaerobic phase.

Microfermentation method	Chocolate mean*
1	42.3
2	32.1
	Acid mean*
1	47.1
2	22.8
	Astringency mean NS
1	13.6
2	11.4
	Bitterness mean*
1	19.2
2	9.6
	Fruitiness mean*
1	54.2
2	27.1
	Others (chemical, phenolic, overripe fruit) mean NS
1	10.9
2	3.1

* Significant difference at 5 % level
NS No significant difference at 1 % level.

1. denotes microfermentation with anaerobic phase (treatment 1)
2. denotes microfermentation without anaerobic phase (treatment 2)

The analysis of variance and LSD pairwise comparisons of cocoa flavour intensities (Tables 1-2) indicate that the six variables analyzed showed significant (5 %) differences in their levels of flavours between treatment one and two except for astringency which was not significant. Chocolate and other flavours were significant at the 5 % level. Intensities of all flavours were higher for treatment one which is from beans processed by the micro-fermentation method; that include an anaerobic phase using anaerobic jar inserted with a campy pak and microaerophilic gas generator. Other flavours observed were described as overripe fruit, phenolic or chemical. The results indicate the need for an anaerobic phase in any micro-fermentation method as part of the initial fermentation process.

The initial anaerobic phase of the micro-fermentation process is crucial to reproduce the basic physical and organic chemistry attributes and microbiology of large scale fermentation. Exclusion of an anaerobic phase in cocoa fermentation would result in processing cocoa with undesirable flavours or the flavour potential of cocoa may not be fully developed. Successful microfermentation methods would allow rapid and reliable assessment of the flavour potential of genotypes to cater for small numbers of pods available from each genotype at any one time which may not be possible to ferment using normal commercial practice. The successful microfermentation method would support progressive breeding programs to select planting material with superior quality attributes for the industry.

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DEVELOPING A NEW SMALL-SCALE LABORATORY MICROFERMENTATION METHOD THAT CAN SUCCESSFULLY FERMENT SMALL QUANTITIES OF COCOA FOR A RAPID AND RELIABLE GENOTYPE FLAVOUR PROFILING

Noel Y. Kuman[1], Neil Hollywood[2]

ABSTRACT

A method of fermenting small quantities of cocoa in a thermostatically controlled incubator was developed. The method is referred to as CCRI microfermentation method. This method reproduces the basic physical and organic chemical attributes and microbiology similar to a commercial fermentation. Statistical analysis of data indicated no significant difference between cocoa flavours attributes generated by the microfermention and commercial fermentation methods.

Key words: *microfermentation, genotype, cocoa flavour attributes*

INTRODUCTION

Early production of cocoa in Papua New Guinea (PNG) was from the low yielding, largely unselected Trinitario variety which gave an average yields of 0.7 t/ha and 0.3 t/ha for large and small-scale holders respectively. In the early 1980s, the National Department of Primary Industry (DPI) developed and distributed new series of high yielding hybrids from Trinitario x Amazonian crosses with potential yields of more than 2 t/ha. Since then, more extensive breeding programs have been carried out by Papua New Guinea Cocoa and Coconut Research Institute (PNGCCRI), developing hybrid planting materials with substantially improved yields.

However, the major concern of the breeding program has been that as the genetic make-up of hybrids is modified to improve yield, concomitants changes may occur that alters their flavour profiles which may no longer meet end-users requirements. Some sections of the industry were concern that the introduction of hybrids has resulted in reduced levels of cocoa/chocolate flavours in PNG cocoa. To address this problem, sensory assessments by chocolate manufacturers have been incorporated into most breeding programs. However, some doubts have been cast on the reliability of the sensory data obtained.

Yield is determined by changes in pod production and this can be assessed from unprocessed cocoa. However, to assess changes in flavour profile, the wet bean must be fermented and dried so that chocolate tasters can be processed and evaluated.

A limitation in most breeding trias is that only a small number of pods are available from each genotype at any one time, hence the wet beans cannot be fermented as per normal commercial practices. Various procedures for processing small quantities of beans have been developed and tested (Clapperton et al., 1991; Quesnel et al., 1975; Challot, 1977; Perkins, 1982; Bridgland, 1984; Jacquet, 1981). But, most of these procedures produce beans of abnormal qualities.

However, one procedure that has been developed and widely used to ferment small quantities of cocoa is by placing a muslin or nylon mesh bag containing the wet beans into the centre of commercial size ferment (large cocoa mass) for normal duration of fermentation. This method has received criticism because of the likely effects of the larger mass of commercial ferment on the small samples. The transfer of liquid through the sample bag allows the characteristic of the larger mass to overwhelm those of the small samples. Such method of flavour assessment would result in selecting genotypes with undesirable flavour characteristic because the samples could be overpowered by those of the large mass. Under this condition, the true characteristic of the genotypes may not be identified at the initial stage of selection until commercial production which could result in serious losses to the industry if the geno-

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types selected have undesirable characteristics. Incorrect procedures may also cause rejection of progenies that may be promising.

Clapperton *et al.*, 1991 described a method of fermenting small quantities of cocoa in a bag placed in heap fermentation. This method has been demonstrated to give good assessment of flavour characteristic of genotypes. It has also been demonstrated to reproduce the flavour characteristic of genotype similar to commercial size fermentation. Although, this methodology has been well assessed and represents a valid technique, it is still cumbersome and time and labour consuming. Therefore, there is a need to develop a microfermentation method that allows rapid and reliable assessment of flavour potential true to their sensory properties, less cumbersome, time, labour consuming and reliable.

This paper discusses development of a new microfermentation method that reproduces flavour profiles similar to normal commercial fermented beans.

OBJECTIVES:

Develop a microfermentation method that can reproduce basic physical and organic chemical attributes and microbiology similar to a commercial fermentation. The method should be relatively cheap, rapid and reliable with the potential of high output to support breeding programs.

MATERIALS & METHODS

From a detailed literature review, the following important factors were considered critical to the designing of reliable and effective microfermentation techniques.

Temperature regime

In a commercial fermentation, the temperature of bean is generally between 24-30 °C at the start of fermentation and rises to 50-51 °C by the third and fourth day, and generally remains at this temperature until the end of fermentation. Therefore a similar microfermentation temperature regime is required.

Size and type of inoculums

The microflora occurring in microfermentation should be similar in type and level to that occurring in a commercial fermentation.

Organic acid and ethanol production

Organic acids and ethanol production need to be similar to that occurring in a commercial fermentation. These factors affect pH, titrable acidity (TA) and death and subsequent release of flavour precursors and enzymes in the cotyledon of the bean.

Moisture levels of beans

Moisture level must be maintained to prevent small quantities of beans from excessive drying during fermentation.

Regulating degree of aeration

Aeration regime affects both microbial and chemical processes during fermentation therefore it has to be regulated.

Adequate drying

Drying method is important during the fermentation process because the rate of moisture loss and time of oxidative process during drying greatly affects cocoa chemistry and flavour.

Genotypes

The selected cocoa genotypes assessed for their flavour characteristics were collected from a cocoa breeding trial conducted at Papua New Guinea Cocoa & Coconut Research Institute.

Microfermentation method

Following the preliminary assessment (Hollywood, 1994) of using different inoculums, manipulating of temperature regime, regulation of oxygen concentration and drying regimes; the following microfermentation method was developed.

A kilogram of wet beans was collected from each of the 13 Trinitario/Amazonian hybrid materials (Table 1). The beans were inoculated with 10 g pulp from a day 1 commercial fermented beans and placed inside an anaerobic jar with campy pak and a microaerophilic gas generator creating an anaerobic phase in the first 24 hours of fermentation. The beans were removed from the anaerobic jar after 24 hours and placed in a Buchner funnel mounted on an erlenmeyer flask which allows draining of sweating. The beans were placed inside a thermostatically controlled incubator set at the following temperature range

Cocoa genotypes were selected based on other quality characteristic (such as high fat content, large bean size and reasonable bean shell content and agronomical factors (such as high yielding, vigour and expressing a certain degree of disease resistance etc.

from day 0 to 6: D0-D1, 30 °C; D1-D2, 35 °C; D2-D3, 40 °C; D3-D4, 46 °C; D4-D5, 47°C; D5-D6, 47°C. The beans sweating collected inside the anaerobic jar and in the Erlenmeyer flask were discarded. The moisture level in the bean was maintained by sealing the Buchner funnel with plastic wrappings. Aeration in the Buchner funnel is controlled by stirring the bean daily. The fermented beans were solar dried (Hollywood *et al*., 1996) for three days and drying was completed in a cabinet dryer at 60 °C . The dried beans were bagged and stored for sensory assessment.

Sample collection & preparation

The dried beans collected from each genotype were dried in an oven (Cotherm, New Zealand) at 115 °C for 15 min to standardize the moisture content of the beans to less than 7 %, cooled under room temperature before being emptied into a mixing container and thoroughly mixed. Any foreign materials and debris were removed. The samples were processed and packed following a procedure described by Sukha, 2001. Approximately 2 kg of dried beans were sampled from each genotype collected over a crop season (12 months). The dried cocoa samples were sent to Nestle (UK) and their basic flavour attributes were rated.

Flavour profile assessment

Cocoa samples were assessed using standard rating test (AS2542.2.3-1988). Data were collected using a fully integrated software system Compusense five version 2.2 (Compusense Inc, Canada) and statistically analysed using appropriate techniques. The samples were rated for the basic flavour attributes of chocolate, acidity, bitterness, astringency, fruitiness and floral fragrant. The flavour rating scale is from 1-10, with 1 being weak and 10 being strong. The average flavour attributes of the selected genotypes and commercial fermented export quality beans were compared.

RESULTS AND DISCUSSION

Table 1: Basic flavour attributes of selected genotypes

Genotype	Chocolate Flavour	Acidity	Bitterness	Astringency	Fruitiness	Floral/ Fragrant
17/31	4.7	5.4	4.1	3.9	2.9	0.6
36-3/1	5.1	4.7	3.4	3.3	3.8	0.3
23-6/1	4.1	5.7	3.6	3.4	2.8	0.5
37-13/1	4.2	5.2	3.6	3.3	3.9	0.8
16-3/2	4.6	5.8	3.9	3.1	4.1	0.2
34-13/2	5.3	5.3	3.7	3.2	3.5	1.5
16-2/3	4.9	6.1	3.7	3.8	3.8	0.2
63-7/3	4.0	5.8	3.5	3.6	2.7	0.2
33-8/3	5.1	6.0	3.2	3.3	4.1	0.3
38-10/3	5.2	5.3	3.6	3.1	3.7	0.5
17-7/4	4.7	5.3	3.2	3.5	3.9	0.5
17-14/4	4.7	6.3	3.3	3.3	3.6	0.5
34-14/4	4.8	5.9	3/6	3.5	4.0	0.4
***Control mean**	**4.9**	**5.0**	**3.4**	**3.5**	**3.5**	**0.3**
Significant (p)	*0.20*	*0.03*	*0.03*	*0.2*	*0.5*	*0.10*

*Control mean represents mean flavour sensory attributes of commercial fermented PNG export cocoa assessed over the years by Nestle, UK. All flavour results including the 13 genotypes were evaluated by Nestle, UK. All genotype samples showed no significant difference at 1 % level against the control sample.

The results (Table 1) indicate that there is no significant difference in flavour of samples generated by microfermentation method described as compared to conventional fermentation which is indicated by the *p* values ($p > 0.005$). Many of the other previously developed microfermentation methods produced undesirable results when compared to this method. The difference between this method and other previously developed methods is the exclusion of anaerobic phase in the initial phase of fermentation. The inclusion of anaerobic phase in the first 24 hours of fermentation has demonstrated to be essential for the development of proper cocoa flavour attributes.

The development of flavour begins from the start of the fermentation process. During the initial anaerobic phase, pulp sugars are converted to etha-

Conventional fermentation box (120 x 90 x 90 cm)2 recommended for cocoa fermentation by Papua New Cocoa Board nol by yeast, which is later converted into acetic acid by bacteria species. The conversion of ethanol to acetic acid is an exothermic reaction which increases the temperature of the fermenting mass. The initial temperature of bean is generally between 24-30 °C at the start of fermentation and increases to 50-51 °C by the third and fourth day, and generally remains at that temperature until the end of fermentation. A combination of acetic acid levels and heat generated during fermentation are responsible for killing the cocoa beans causing a disruption of cell membrane thus releasing enzymes and substrates which react to produce flavour precursors.

For this microfermentation method, an anaerobic condition is created by using an anaerobic jar inserted with a campy pak and microaerophilic gas generator. The use of inoculums (10 g pulp from a day 1 commercial fermented beans) supplied the initial microflora required to initiate the fermentation process. Also the temperature regime was regulated artificially using thermostatically controlled incubator from 30 to 37 °C to generate temperature regime similar to normal fermentation since small quantities of beans microfermented can not generate sufficient heat to kill the beans. The daily turning of the beans promotes aeration which is necessary for ethanol to be converted into acetic acid. The plastic wrapping of the Buchner funnel keeps the microfermented beans moist hence prevents excessive drying that would lead to beans producing undesirable flavours. The beans were dried initially on a solar dryer to promote slow drying which allows sufficient time for continuation of oxidative reactions after fermentation to promote flavour developments and also allow adequate time for evaporation of acids from the bean cotyledon thus reducing bean acidity.

The microfermented method developed reproduces basic physical and organic chemical attributes and microbiology of a commercial fermentation. The method is relatively cheap, with the potential of high output to support the rapid breeding programs. The method is used for rapid and reliable assessment of flavour potential of genotype assessment.

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PRODUCTION OF SWEET POTATO (*IPOMOEA BATATUS* (L.) LAM) POLYCROSS HYBRIDS

Maia Wamala and Shamsul Akanda

ABSTRACT

A poly-cross nursery was established at the Agriculture Farm of the Papua New Guinea University of Technology to develop the poly-cross hybrids of sweet potato with high yield and superior agronomic characters. Twenty five segregating poly-cross hybrids developed from 20 selected sweet potato parental clones showed high variability in terms of tuber shape, tuber skin colour, tuber flesh colour, yield and yield components. Poly-cross hybrids showed vigorous growth and tuber yield increase ranging from 6.5% to 15.6% with higher tuber biomass ratio compared to parental clones. The hybrids showed significantly higher vine length, tuber number, tuber weight and tuber biomass ratio. However, the average vine weight was significantly higher ($p \leq 0.01$) in case of parental clones compared to the hybrids. About 65% ($r^2 = 0.649^{**}$) of the yield variability in hybrids were accounted for by the yield in parental clones. The hybrids showed significant positive correlations between tuber weight and tuber biomass ratio (0.39), tuber weight and tuber number (0.51**), but a very strong negative correlation (-0.89**) between vine weight and tuber biomass ratio.*

Key words: *Sweet potato, poly-cross hybrids*

INTRODUCTION

Sweet potato is one of the major staple food crops in Papua New Guinea (PNG). Breeding and improvement of sweet potato plant in major growing regions had been based on germplasm introduction, induced mutation, hybridization and selection. Hybridization through natural crossing of genetically variable parental clones in poly-cross nurseries has been the common method practiced in PNG and other tropical regions (Tumana and Kessavan, 1987). Poly-crossing is done to generate better hybrids that are superior in terms of tuber yielding ability as well as resistant and/or tolerant to varying ranges of abiotic and biotic stresses. Hybrids are also selected based on other superior agronomic, physiological and horticultural characters, including tuber: biomass ratio, high tuber dry matter and early maturity. Due to large number of hybrids generated through hybridization by poly-crossing, an efficient method of selection to handle these segregating progenies in their F_1 generation is necessary to select desirable hybrids (i.e. clonal selection) which can be maintained vegetatively. It is noted that due to long exposure of current parental clones to pest and diseases; producing clean poly-cross hybrids from true seeds at early generation is vital (Tumana and Kessavan, 1987). Keeping this in view, an experiment was conducted to produce hybrid seedling progenies with superior agronomic characters.

MATERIALS AND METHODS

Sweet Potato Germplasm Collection

Twenty clones originally from National Agricultural Research Institute (NARI) were selected based on improved tuber yield and other agronomic performances, including leaf scab and sweet potato weevil resistance for inclusion in the poly-cross nursery to produce seedling progenies.

A total of 350 seeds were collected from maternal parents. Due to constraints and difficulties in handling many seedlings, only 60 seedlings were raised and the rest of the seeds were reserved and stored as germplasm collection in the seed form for future sweet potato improvement programs. Seeds were scarified with concentrated sulphuric acid (H_2SO_4) for 20 minutes for softening the seed coat to improve germination (Steinbauer, 1937). The scarified seeds were sown in September 2005 in seed trays containing sterilized organic soil. The seedlings derived from each of the clones at F_1CG_1 were further multiplied to obtain more planting materials for further evaluation at clonal generation two (F_1CG_2).

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Experimental Site

The poly-cross nursery was established at the Agriculture Department Farm of the PNG University of Technology, Lae, during May to August 2004 and April 2005. The farm is situated in the north central coast of PNG mainland at an elevation of 65 m.a.s.l and between latitude 6° 41' South and a longitude of 146° 98' East. The site is classified as lowland per humid climate (McAlpine and Keig, 1983) with an annual rainfall of 4,700 mm and the minimum and maximum temperatures of 23^0 C and 30^0 C.

Experimental Design

A randomized complete block design was used with 20 sweet potato parental clones planted randomly in four replicated blocks. The total land area of 465 m² (15m × 31m) was further divided into four blocks, each measuring 31 m × 3 m. Each variety was planted on a raised bed of 3 m × 1 m width × 0.2 m height. In each plot, seven cuttings (30 cm of apical portion) from each of the 20 selected parental clones were planted 50cm apart between rows and within plants. Similarly, 25 selected progenies were also grown alongside the parents in a progeny row selection manner. The selected progenies were given the accession code names as MUIB (MAIA UNITECH IPOMOEA BATATAS) with the accession number.

Data Collection

Data were collected on plant vine and tuber characteristics, including leaf color, shapes, margins, leaf area and tuber textural characteristics for each of the seedling progeny. The above ground parts including vines and leaves were weighed and recorded. Tuberous roots and pencil like roots were washed, counted and weighed. The tubers were dried in an oven for six days and the dry weights taken. Leaf area for the progenies were measured using the Leaf Area meter, while vine and leaf texture were examined morphologically by observing the leaf colors of both mature and young leaves. Tuber skin colors were also examined by observing the outer skin color and inner tuber flesh color by cutting the flesh of each progeny. Vine length for each progeny was measured using a meter ruler, while vine fresh weight was weighed using an electronic balance. Tuber Biomass partition for each clone was determined using the following formula:

$$\text{TUBER BIOMASS RATIO} = \frac{\text{TOTAL TUBER WEIGHT}}{\text{TOTAL TUBER WEIGHT} + \text{TOTAL TOP WEIGHT}}$$

Data Analysis

The data collected on different parameters were analyzed using analysis of variance (ANOVA) with the MINITAB 15 Software Package and Microsoft Excel. Tuber weight of the offsprings were regressed on the corresponding parameter of the parental clones to determine the effect of parental clones on the offspring. Simple correlation coefficients were also calculated between the pairs of values for tuber number, tuber weight, vine length, vine weights and tuber biomass ratio for the offspring and the parents. Standard statistical procedures including pair mean comparison using the Duncan Multiple Range Test (DMRT) was also used to compare differences between treatment means as applicable.

RESULTS

The details of tuberous roots and other horticultural characteristics of the progenies selected from the parent in the progeny row selection are presented in Table 1. Progenies differ greatly in tuber shapes ranging from round to long/round and long. The progenies fall into three more or less distinct groups: MUIB 007, 009, 015, 016, 026, 035, 037 and 049 with round tuber; MUIB 001, 005, 011, 013, 014, 028, 031, 033, 034, 044, 045, 047, 048, 057, 058 and 059 with long/round tubers; and MUIB 004 as long tuber.

There were also wide variations for tuber skin color and tuber flesh color. Majority of the progenies have white tuber skin color and the rest were of yellow, red, pink, brown, orange and the combination of light to reddish pink color. The tuber flesh color varied widely among the progenies and the majority of the progenies fall into yellow and white color followed by yellow/purple.

The placement of tubers was either compact or spreading type (Table 1). A great majority (60%) of the tubers were of compact type, while the rests were spreading type. Results on vine length of the parents and offspring are presented in Table 2. The vine length of the parental clones ranged from 300 cm to 550 cm. The vine lengths in the case of offspring ranged from 350 cm in MUIB 013 to 650 cm in MUIB 034. All the offsprings had longer vines compared to their corresponding parental clones. On the average, the offsprings had longer vines (478 cm) than the parental clones (319.2) and the mean vine length difference was significant at $p \leq 0.01$ (LSD).

The tuber numbers for both the parents and offspring varied widely. The tuber numbers for the parental clones ranged from three to five. However, the tuber numbers for the offspring ranged from the lowest of three in MUIB 0016 and 037 to the highest of six in MUIB 004, 011, 013, 015, 033, 034 and 057 (Table 2). In most of the cases, the tuber numbers for the offspring were higher than the corresponding parental clones except MUIB 016, 026, 031, 037, 0.44 and 059, where the tuber numbers were equal for both the offspring and the parental clones; and for MUIB 009 had four tubers compared to five for the corresponding parent. The mean tuber number for the offspring (4.92) was higher than the corresponding mean tuber numbers of parental clones (3.96) and the difference in mean was significant at $p \leq 0.05$ (LSD).

There were wide variations among the parents and offspring for total tuber weight (Table 2). The tuber weights for the parents ranged from 460 g in Kabakaba to 1780 g in SI 172. On the other hand, the tuber weights for the offspring ranged from 430 g in MUIB 001 to 2110 g in MUIB 011. The tuber weights were always higher for the offspring than their corresponding parental clones with the exceptions of MUIB 001, 004, 016, and 028, where the tuber weights were slightly higher for the parental clones. The mean tuber weight of the offspring (1354 g) was much higher than the parental mean tuber weight (1108 g) and the difference was significant at $p \leq 0.01$ (LSD).

Table 3 shows the treatment mean comparisons for the tuber weights among the offspring. The results indicate that wide variations exist in the yielding abilities of the offspring. The highest yield (2110 g) was observed in the case of MUIB 011 and the lowest yield being 430 g in MUIB 001 and they differ significantly at $p \leq 0.05$ (DMRT). The tuber weights of MUIB 011, 013, 031 and 058 did not differ significantly at $p \leq 0.05$ (DMRT), but were significantly higher than MUIB 001, 004, 014, 016 and 026. However, the mean tuber weights of MUIB 001, 016 and 026 did not differ significantly.

The results for the vine weights for both the parents and offspring are presented in Table 2. Large variations exist both in the parental clones and the offspring in terms of vine weight. The vine weight of the parents ranged from 2440 g to 6300 g; whereas the vine weights of the offspring's ranged from 145 g in MUIB 026 to 3690 g in MUIB 001. In all the cases, the offspring had lower vine weights than the corresponding parental clones. The mean vine weight of the offspring's (907.89 g) was much lower than the mean vine weight of the parents (4600 g) and the difference of the means is significant at $p \leq 0.01$ (LSD).

Table 1: Tuberous root characteristics of the selected hybrid progenies

Progeny	Tuber shape	Tuber skin color	Tuber flesh color	Placement of tubers
MUIB 001	Long/round	Yellow	Yellow	Compact
MUIB 004	Long	Red	White	Compact
MUIB 005	Long/round	Copper color	Light yellow	Compact
MUIB 007	Round	White	Yellow/Purple	Spreading
MUIB 009	Round	Pink	Yellow	Spreading
MUIB 011	Long/round	White	White	Spreading
MUIB 013	Long/round	Light pink	Orange	Spreading
MUIB 014	Long/round	White	Orange	Compact
MUIB 015	Round	Brown	White	Compact
MUIB 016	Round	Yellow	Orange	Compact
MUIB 026	Round	White	Yellow/Purple	Spreading
MUIB 028	Long/round	White	White	Spreading
MUIB 031	Long/round	Pink	White	Compact
MUIB 033	Long/round	Orange	Orange	Compact
MUIB 034	Long/round	White	White	Spreading
MUIB 035	Round	Pink	Yellow	Compact
MUIB 037	Round	White	Yellow	Compact
MUIB 044	Long/round	Light pink	Yellow	Spreading
MUIB 045	Long/round	Pink	White	Spreading
MUIB 047	Long/round	White	Yellow	Compact
MUIB 048	Long/round	Reddish pink	Yellow	Spreading
MUIB 049	Round	White	White	Compact
MUIB 057	Long/round	Light pink	Orange	Compact
MUIB 058	Long/round	Brown/Yellow	Orange	Compact
MUIB 059	Long/round	Pinkish	Yellow	Compact

The tuber biomass ratio of the parental clones ranged from 0.071 to 0.311; however, the biomass ratio for the offspring ranged from 0.104 in MUIB 001 to 0.788 in MUIB 026 (Table 2). The tuber biomass ratios of the offspring were always higher than the corresponding parental clones except for MUIB 001. Overall, the mean of the tuber biomass ratio for the offspring (0.624) was much bigger than the mean of the parental clones (0.197) and the difference of the means was significant at $p \leq 0.05$ (LSD).

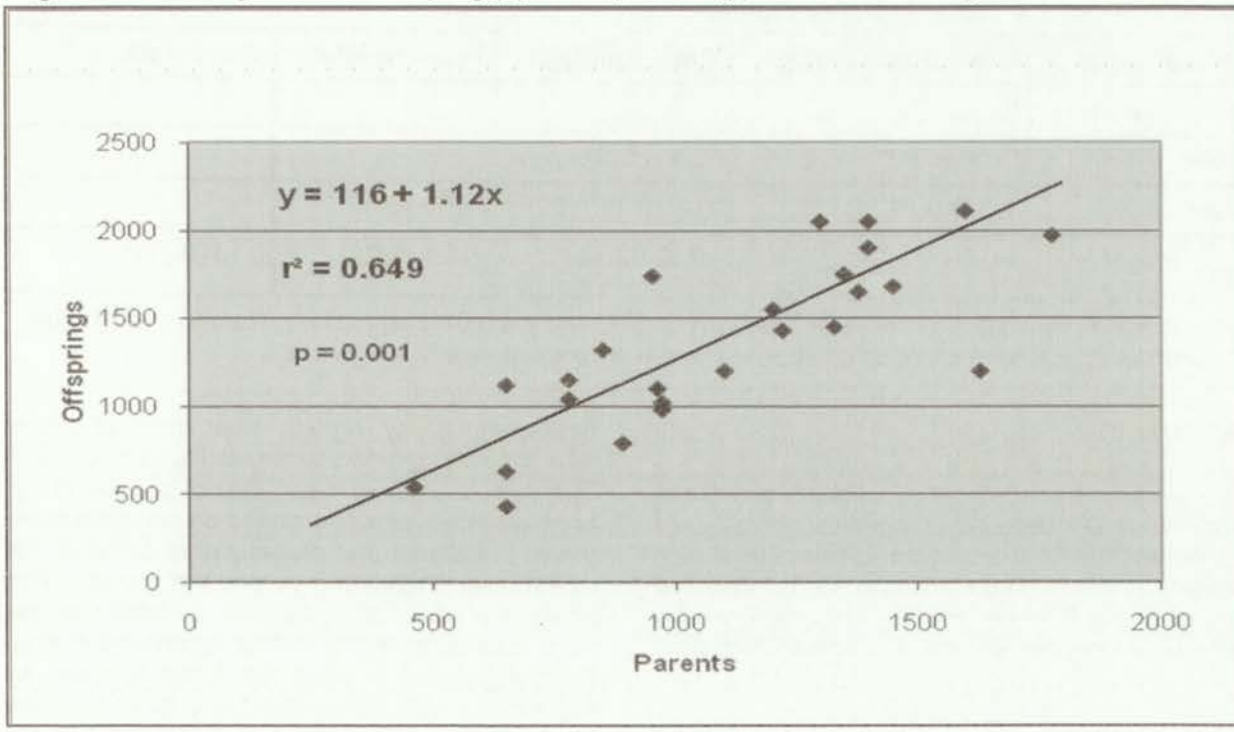
Table 2: Tuber weight, tuber number, vine length, vine weight and tuber: biomass ratio of parental clones and offspring

Maternal parental clones	Selected progeny (offspring (O)	Vine length (cm)		Tuber number		Tuber weight (g)		Vine weight g)		Tuber: biomass ratio	
		P	O	P	O	P	O	P	O	P	O
RAB 32	MUIB 001	400	540	3	4	650	430	4250	3690	0.133	0.104
K9	MUIB 004	350	400	4	6	890	790	3340	875	0.210	0.474
K9	MUIB 005	300	450	4	5	780	1150	5045	750	0.134	0.605
L676	MUIB 007	450	500	3	5	1400	1900	6300	2200	0.182	0.463
L676	MUIB 009	400	430	5	4	1200	1550	4340	890	0.217	0.635
L676	MUIB 011	350	400	4	6	1600	2110	5980	1200	0.211	0.637
L676	MUIB 013	300	350	4	6	1400	2050	4990	750	0.219	0.732
L676	MUIB 014	450	500	4	5	970	980	4780	690	0.169	0.587
L676	MUIB 015	400	540	5	6	1350	1750	5050	950	0.211	0.648
L676	MUIB 016	550	500	3	3	650	630	4680	340	0.122	0.649
Kabakaba	MUIB 026	350	430	4	4	460	540	5995	145	0.071	0.788
L43	MUIB 028	300	400	4	5	1630	1200	6070	750	0.212	0.615
SI-172	MUIB 031	400	450	5	5	1780	1970	4050	685	0.305	0.742
RAB 36	MUIB 033	450	500	5	6	1330	1450	4140	855	0.243	0.629
RAB36	MUIB 034	500	650	5	6	1450	1680	5990	550	0.195	0.753
RAB 36	MUIB 035	430	560	4	5	970	1020	4970	995	0.163	0.506
RAB 36	MUIB 037	450	500	3	3	850	1320	5220	980	0.140	0.574
KAV 57	MUIB 044	500	550	4	4	960	1100	5240	540	0.155	0.671
KAV 57	MUIB 045	450	550	3	4	1220	1430	4500	450	0.213	0.761
L696	MUIB 047	300	400	3	5	1380	1650	3985	560	0.257	0.747
L696	MUIB 048	400	500	4	4	650	1120	3030	755	0.177	0.597
L696	MUIB 049	300	450	4	5	780	1040	2980	525	0.207	0.665
NUG 5	MUIB 057	350	400	4	6	950	1740	4035	890	0.191	0.662
L329	MUIB 058	450	500	3	5	1300	2050	3600	1200	0.265	0.631
L329	MUIB 059	400	500	5	5	1100	1200	2440	480	0.311	0.714
Mean		**319.2**	**478****	**3.96**	**4.92***	**1108**	**1354****	**4600**	**907.8****	**0.197**	**0.624***

P = parent, O = offspring

*, **, offspring means are significantly different at $p \leq 0.05$ and $p \leq 0.01$ (LSD), respectively from the corresponding parental means.

Figure 1: Linear regression for offspring (o) on the parental (p) tuberous root weight



The result of the linear regression of the tuber weight of the offspring on the tuber weight of parental clones is presented in Fig 1. The parental clones accounted for 65% of the tuber yield variability of the offspring (r^2 = 0.649**).

The correlation coefficients for tuber weight, tuber number, vine length, vine weight and tuber biomass ratio both for the parental clones and offspring are presented in Table 4. In the case of offspring, tuber number was positively correlated to tuber biomass ratio (0.13) and tuber weight (0.51**) but negatively to vine length and vine weight; and was significant only for tuber weight. Vine length was negatively correlated to tuber number, tuber weight and tuber biomass ratio, though none of them was significant. Tuber weight also had a significant (0.39*) correlation with tuber biomass ratio. Vine weight had a negative correlation (-0.89**) with the tuber biomass ratio, tuber number (-0.02) and tuber weight (-0.06) but was positively correlated to vine length (0.15). Similar was the trend with the parental clones except that the correlation coefficients between tuber number and tuber biomass ratio was much higher; and it was much smaller (0.49*), but was positive between vine weight and tuber biomass ratio compared to their corresponding offspring values.

Table 3: Treatment means comparison for offspring tuber weight.

Offspring	Tuber weight (g)
MUIB011	2110 a
MUIB013	2050 ab
MUIB058	2050 ab
MUIB031	1970 abc
MUIB007	1900 bcde
MUIB015	1750 cde
MUIB057	1740 cdef
MUIB034	1680 defg
MUIB047	1650 efgh
MUIB009	1550 fghi
MUIB033	1450 ghij
MUIB045	1430 hijk
MUIB037	1320 ijkl
MUIB059	1200 jklm
MUIB028	1200 jklm
MUIB005	1150 klmn
MUIB048	1120 lmno
MUIB044	1100 mnop
MUIB049	1040 nopq
MUIB035	1020 opq
MUIB014	980 qr
MUIB004	790 qrs
MUIB016	630 rst
MUIB026	540 stu
MUIB001	430 tuv

Means followed by the same letters in a column do not differ significantly at p ≤ 0.05 (DMRT).

Table 4: Correlations among tuber number, tuber weight, tuber biomass ratio, vine length and vine weights for the offspring and parental clones

Components	Tuber biomass ratio	Tuber number	Tuber weight	Vine length
Tuber number	0.13(0.37)			
Tuber weight	0.39*(0.71)**	0.51**(0.30)		
Vine length	-0.16(-0.15)	-0.21(0.17(0.08)	- 0.17 (0.08)	
Vine weight	- 0.89**(0.49**)	- 0.02 (-0.10)	-0.06 (0.24)	0.15 (0.12)

*, **, correlation coefficients are significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. Numbers within the parentheses are the correlation coefficients for the parental clones.

DISCUSSION

In sweet potato crop improvement programs, screening of seedling progenies from poly-crosses is the first step towards selection of high yielding cultivars. The seedlings are first selected based on the tuberous root formation followed by selection for other desirable agronomic characters.

Highly significant differences were observed for tuber yield and related vine characters on the poly-cross hybrids (off-springs) as compared to parental clones. The selected sweet potato genotypes raised through poly-crossing showed wide variations in plant vine and tuberous root characteristics indicating that progenies were highly segregating and assortment in F_1 generation since parents of sweet potato are highly heterozygous. This confirmed the findings of Tumana and Kessavan (1987), Bang (1987) and Anders (1983).

Tuber numbers for the off-springs were significantly higher with an average of 4.9 (≈ 5.0), while parental clones produced an average tuber number of 3.9 (≈ 4.0). The increase in tuber number in off-springs could be attributed to clean seedlings without virus originating from the true seeds. Tumana and Kessavan (1987) reported that increase in tuber yield from the poly-cross hybrids is due to clean seedlings without virus originating from the true seeds. It was also noted by the same authors that the parental clones have been long exposed to wide ranges of virus strains and other pathogenic organism contributing to low tuber yield.

High Tuber: biomass ratio indicates partitioning ability (Tumana and Kessavan, 1987; Bang, 1987), i.e. the portion of total biomass which assimiates sources is highly converted to edible tuberous roots. Partitioning was the highest in the poly-cross hybrids compared to parental clones. It does appear that many poly-cross hybrids generated from poly-cross mating process have high partitioning ability, though other parental clones also showed high partitioning ability (Bang, 1987). The comparisons of tuber yield of poly-cross hybrids with their parental clones on per plant basis grown in parents and progeny rows showed that hybrids significantly out-yielded the parents. This allows the selection of the hybrids based on the tuber bearing ability for further agronomic evaluations. Significant positive correlation between tuber number with tuber weight and tuber biomass ratio indicated that high tuber yielding clones are related to high tuber number and weight with less vine weight. This study also revealed that sweet potato improvement adapted for wide range of environment through poly-crossing is feasible. Tumana and Kessavan (1987) also reported similar feasibility for improving sweet potato performance under lowland conditions.

CONCLUSION

Twenty five hybrids were produced from 20 selected parental clones through poly-crossing. Wide morphological variation was observed in all selected progenies on the vine characteristics especially on leaf textures ranging from purple to green leaves. Leaf shapes also ranged from deeply lobed, slightly lobed to simple leaf shapes. All the poly-cross hybrids out yielded the parents raising the feasibility of sweet potato improvement through poly-crossing. The selected clones were also noted for high tuber partitioning ratio which was related to production of bigger tubers with less vine weight and biomass.

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TILLER DYNAMICS IN INDICA AND TROPICAL JAPONICA RICE FROM TRANSPLANTING STRESSED SEEDLINGS UNDER IRRIGATED CONDITIONS

Stanis Malangen

Abstract

An experiment was conducted at JICA, Tsukuba, Japan from April to October 2009 to elucidate the effect of transplanting stress on the growth and development of two rice varieties; IR – 64 (Indica) and a Tropical Japonica (Demadola). Four different transplanting options and the two varieties were tested in a factorial experiment of randomized complete block design with 3 replicates. Tiller production was higher for Indica varieties. It was also evident that though total tiller production was high for the different stress levels for the Indica variety; tiller mortality was also high; resulting in slightly higher effective tiller numbers compared to the normal planting. Stem elongation or rhizomes with multiple nodes were observed in Indica seedlings that were severely damaged thus resulting in higher production of tillers. The increase in the production of high effective tiller number could increase the yield of rice for farmers who apply very little or no inputs at all in their rice production.

Key words: *tillers, tiller numbers, effective tillers, non-effective tillers, rhizomes*

Introduction

Rice (*Oryza sativa L*) has many advantages over most of the traditional staple food crops in the Pacific Region. Rice is easy to store, does not perish during transportation to distant locations, consumption of small volumes is enough to satisfy the human appetite compared to the traditional root crops and is considered a novel food (Malangen and Komolong, 2007). It has great potential for food security for these Island countries where the population is expanding with high urban migration and rapid genetic erosion on traditional staples.

In Papua New Guinea (PNG) rice is predominantly cultivated as a subsistence crop under upland conditions (Sajjad, 1995 and 1998). The commonly grown rice varieties are Indica and Javanica commonly referred to as Tropical Japonica FAO (2009) are directly dibbled into the field amongst other crops or planted as a mono-crop in small to medium plots. The yields are generally low due to poor germination, soil fertility, and competition from weeds.

Rice yields can be increased in many ways. The two main ways are by planting improved high yielding varieties and by adopting proper agronomic practices to achieve their potential yield. Generally the yield of hybrid rice varieties is 10% - 15% more than the improved inbred varieties (Alam, *et al* 2009). Proper planting is an important management practice which can increase the yield of rice. Some farmers in PNG have adapted to transplanting seedlings under upland rain fed conditions due to better competition against weeds and their high survival rate. Mitchell *et al* (2004) found that rice transplanted produce 6% more yield than rice direct seeded. The International Rice Research Institute (IRRI) also reported that transplanted rice generally produce more tillers than direct seeded crops IRR1 (2009).

Studies have shown that Indica rice varieties tend to still grow even if their seedlings are slightly damaged during transplanting compared to the Japonica and Tropical Japonica formerly known as Javanica varieties. While a study by Urayama *et al* (1989) found that Traditional Indica Varieties when exposed to stress at transplanting produce higher tillers numbers than the improved Indica varieties. The production of high tiller numbers could increase the yield of rice for farmers in PNG who apply no or very low inputs in rice production.

This study was planned to determine whether transplanting stressed seedling increases tiller production in Indica and Tropical Japonica rice varieties.

National Agricultural Research Institute Papua New Guinea

Materials and Method

Design of Experiment

This experiment was conducted at the Tsukuba International Center (TIBC) Ibaraka in Japan in a glass house from April to October 2009. Two rice varieties, an Indica (IR- 64), and a Tropical Japonica (Demadola) rice variety denoted as V_1 and V_2, respectively were used in this experiment.

Thirty day old seedlings (4-5 leaf stage) were transplanted on the 15^{th} of April into pots filled with mountain soil. The two varieties were planted under 4 different stress levels (treatments). The 4 stress levels are 1: Planted upright (Control), 2: Planted horizontal to the soil surface. 3: Planted with stem completely bent at 90 ^{0}C and 4: planted with stem completely snapped: denoted as (T_1), (T_2), (T_3) and (T_4), respectively. Each treatment has 6 pots transplanted with a single seedling. The experimental design is a two-factor experiment in Randomized Complete Block (RCB) with 3 replications.

For soil fertility, NPK (6-9-6) fertilizer was applied at a rate of 100kg ha^{-1} of Nitrogen split application (60 kg at basal and 40 kg top dressing). Phosphorous (P_20_5) (0-17.5-0) and Potassium (K_2O) (0-0-60) fertilizer was applied at a rate of 100 kg and 110 kg ha^{-1} respectively

Data Collection and Statistical Analysis

Growth Observation.

Days from transplanting to ripening stage, plant height (cm), number of tillers, leaf area (cm^2) (measured with leaf meter, AAM-8 Hayashi Co. Ltd Japan), Chlorophyll content or SPAD value (measured with a Chlorophyll meter, Minolta Co., Ltd) and Dry matter content (after drying plants sample at 80 ^{0}C for 48 hours) were determined.

Yield Observations

In each replication 3 pots were used for yield analysis. Harvesting date varied according to treatments. Grains were selected using salt solution of 1.06, specific gravity and grain weight per pot was determined at 14% moisture content. Panicle number, average spikelet number per panicle, ripening ratio (%) and 1000 grain weight (g) were used to calculate the yield per pot.

Statistical Analysis

Analysis of variance (ANOVA) was performed using Excel for each treatment and means were separated using Least Significant Difference (LSD).

Results.

Though both growth and yield observations were made, only the growth observations results is presented and discussed specifically on tiller production in relation to stress.

The average heading dates of the 2 varieties were similar at days after transplanting (DAT) but within the treatments their heading dates varied accordingly. V_1T_2 and V_2T_2 have the same heading date at 99 (DAT) as V1T1 and V_2T_1. Followed by V_1T_3 and V_2T_3 at 101 (DAT) and V_1T_4 and V_2T_4 at 114 (DAT) respectively. T_4 took longer to heading because of the stress. The more severe the stress the longer the crop takes to heading. (Table 1)

V_1 is the shorter of the two varieties with an average height of 111.84 cm while V_2 is a tall variety with an average of 167.76 cm at harvest. V_2T_4 was shorter in height at all stages of growth (DAT) (Fig. 1) compared to the other treatments in V_2 due to the serve stress. Tropical Japonica Varieties are generally tall in height compared to Indica varieties. Therefore in this trail, V_1 is shorter in height as it is an improved Indica variety.

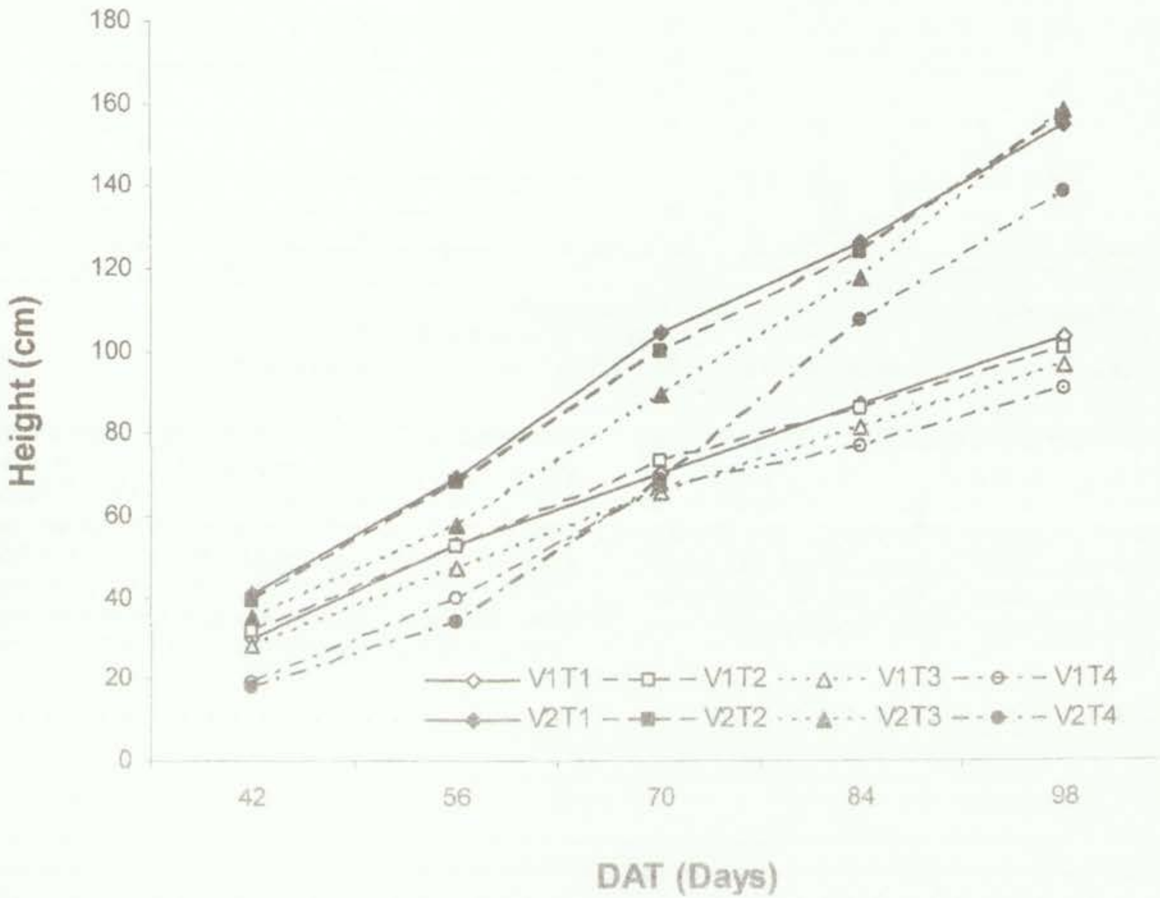
As for the chlorophyll content (SPAD values), there was a significant difference at 42 DAT (Fig. 2). V_2T_4 has a lower SPAD value than all the other treatments (Fig. 2). But at 84 (DAT), it has the highest value until harvest. V_2T_4 was

Table 1. The 80%-heading dates of the two varieties under the different stress levels

V_1				V_2			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
22/08	22/08	26/08	6/09	22/0	22/08	26/08	6/09

Date of transplanting was on the 15^{th} of May.
V_1 = IR-64: V_2 = Demadola, T_1 = control, T_2 = planted horizontal to the soil surface,

Fig. 1: Plant height at days after transplanting (DAT)



V_1 = IR-64: V_2 = Demadola, T_1 = control, T_2 = planted horizontal to the soil surface,
T_3 = Planted with stem completely bent at 90 ^{0}C, T4 = planted with stem completely snapped

heavily stressed; therefore it took longer to recover as evident from delayed heading date and as a result its SPAD value was low before 70 DAT. At 84 DAT has recovered and was in its peak stage of growth while the other treatments have reached their peak of growth 70 DAT and their SPAD values were decreasing.

Tiller Number Hill $^{-1}$.

The two rice varieties showed significant difference in tiller production at 70, 84, 94 and at harvest (DAT) which ranged from 1 to 36 tillers number hill^{-1} (Table 2). Tiller number increased sharply with age reaching maximum at 84 DAT and then decreased irrespective of variety. The rate of increase, however, varied depending on variety, treatment and the stage of growth (Figure 2). The maximum tillering occurred during 56 to 84 days DAT. Variety V_1 produced the maximum number of tillers in all stages of DAT. The lowest number of tillers was observed for V_2. It also produced the lowest tiller number hill $^{-1}$ in all stages (DAT). It was revealed that tiller mortality of V_1 was high (Fig. 2), even though it produced higher number of tillers at harvest. Tillering capacity differs in different cultivars, even within sub species level, Japonica, Tropical Japonica. Therefore in this experiment a significant difference in the tiller capacity was observed.

Table 2. Effect of variety and stress on tillers number hill^{-1} at different Days after transplant (DAT).

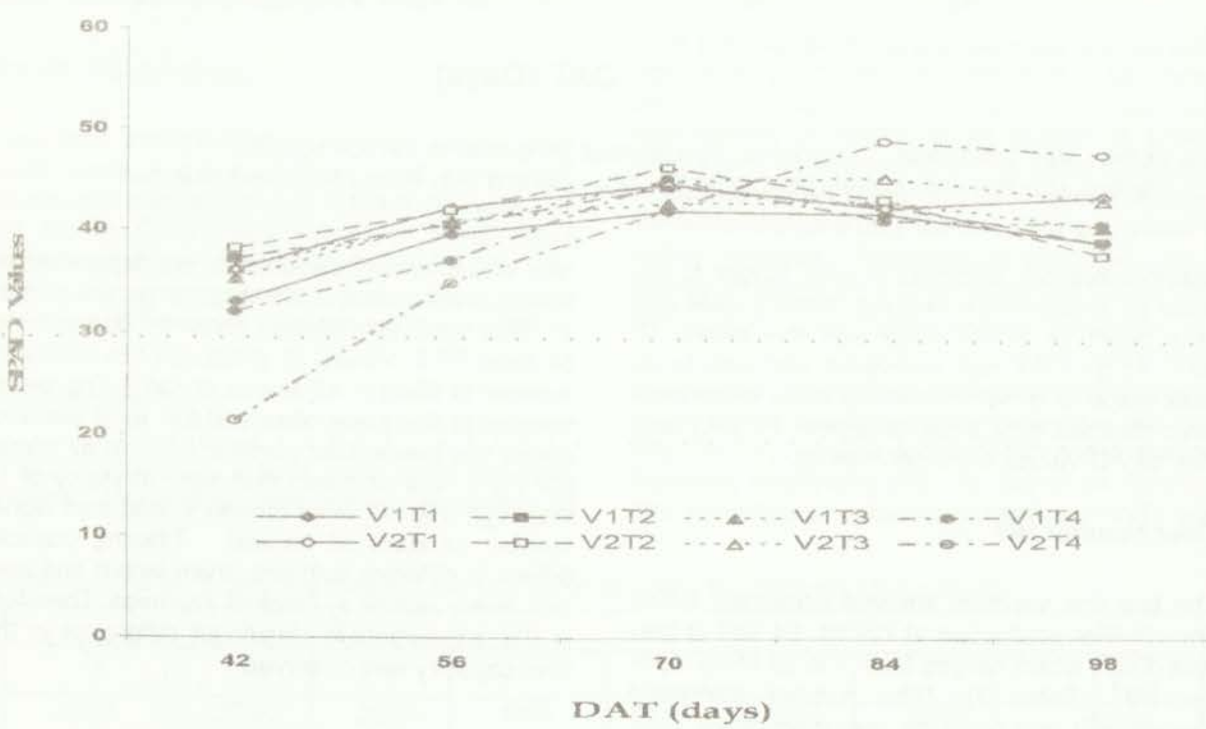
Tillers hill $^{-1}$ (no.) at different DAT							
Treatments		42	56	70	84	98	At Harvest
V1	T1	2	10	24	32	23	24
	T2	3	13	34	37	22	25
	T3	2	7	26	33	24	27
	T4	1	5	20	33	25	27
V2	T1	1	5	15	11	9	9
	T2	2	4	10	12	9	9
	T3	1	3	9	10	8	8
	T4	1	2	7	8	7	7
Variety		ns	ns	**	**	**	**
Stress		ns	ns	*	ns	ns	ns
Variety x Stress		ns	ns	ns	ns	ns	ns

*, ** significant different at $p<0.05$ and $p<0.01$ levels respectively.
V_1 = IR-64: V_2 = Demadola, T_1 = control, T_2 = planted horizontal to the soil surface
T_3 = Planted with stem completely bent at 90 ^{0}C, T4 = planted with stem completely snapped.

Interaction Effect of Variety and stress levels:

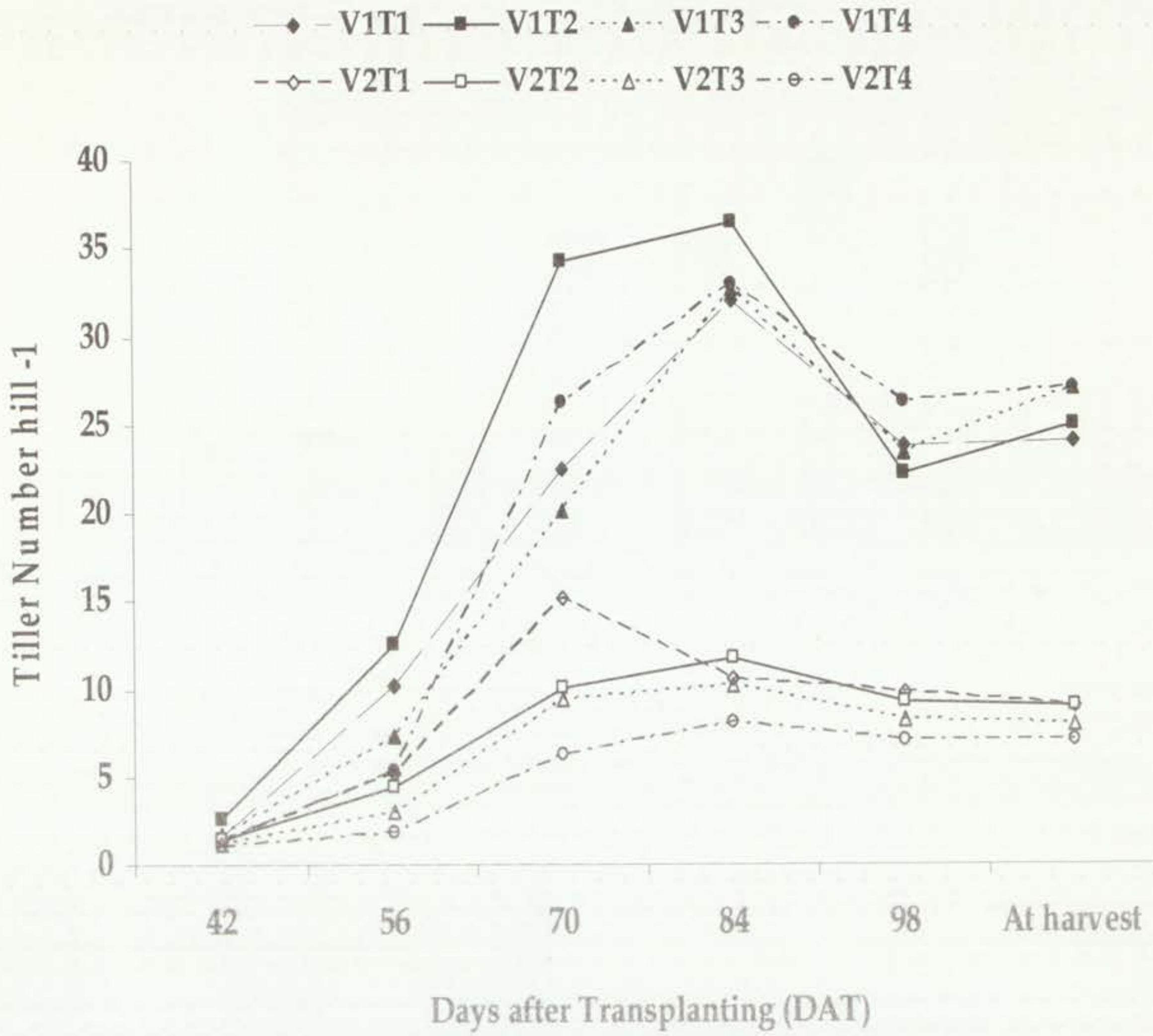
The interaction effect of variety and stress levels showed no significant influence on tiller production at all stages (DAT) though there was significant difference between the varieties. The maximum tiller production for the improved variety V_1, at 84 DAT was in the order, T_2, T_4 and T_3 (Fig, 3) compared to T_1. While for V_2, they were in the order T_2, T_3, and T_4 respectively. T_1 produced higher tiller number than T_4 for V_2. For V_1 there was increase in total tiller production for all the stress levels. V_1T_2 produced (116%), V_1T_3 (103%) and V_1T_4 (103%) more tillers than V_1T_1 respectively. As for V_2 tiller production decreased accordingly to the stress levels. But the total num-

Fig. 2: SPAD value after transplanting (DAT)



V_1 = IR-64: V_2 = Demadola, T_1 = control, T_2 = planted horizontal to the soil surface,
T_3 = Planted with stem completely bent at 90 ^{0}C, T4 = planted with stem completely snapped.

Fig. 3: Tiller numbers hill $^{-1}$ at the different growth stages



V_1 = IR-64: V_2 = Demadola, T_1 = control, T_2 = planted horizontal to the soil surface, T_3 = Planted with stem completely bent at 90 ^{0}C, T4 = planted with stem completely snapped.

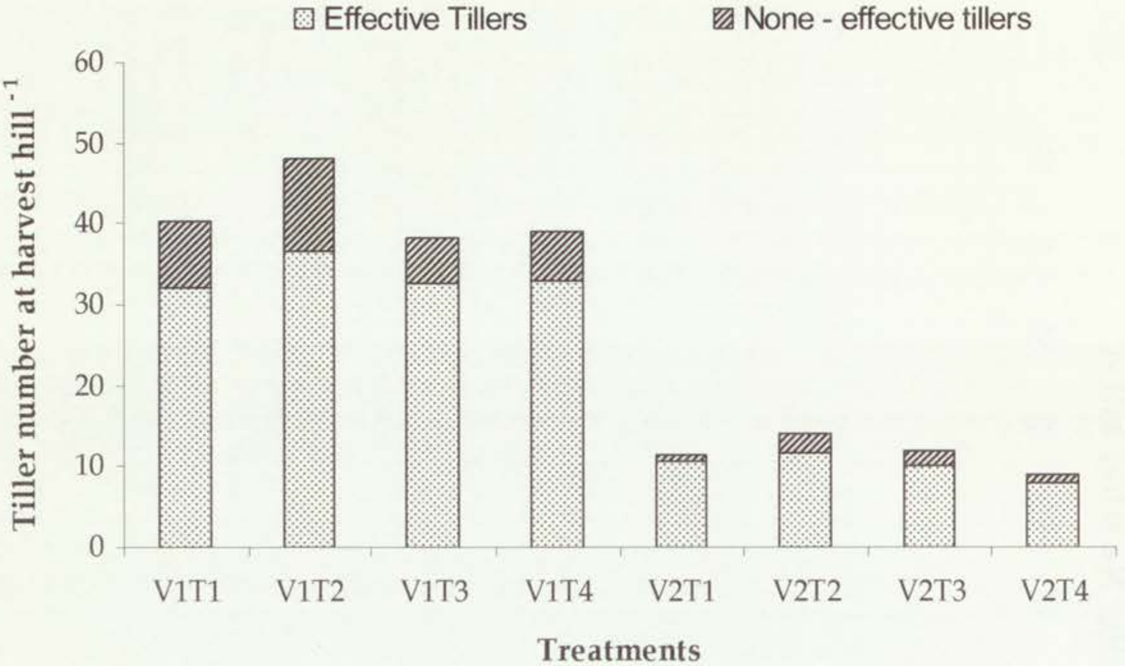
ber of tiller production tends to decrease with the severity of the stress (Fig. 3). Seedlings of Indica varieties slightly stressed at transplanting produces higher number of tillers according to this study.

DISCUSSION

The results from this experiment is too preliminary to make any recommendations, because there are no significant difference within the stress levels and the interaction effect. This could be due to the experiment conducted in glass house and the sample size being very small. Seedlings exposed to stress produce higher tiller numbers than severely stressed and the normal method of transplanting. A similar study done by Urayama *et. al* (1989) also found that Indica varieties produce higher tiller when stressed compared to The climatic condition could have an adverse effect on the tiller production in various conditions and weather patterns. But from this preliminary study conducted under irrigated condition, it is evident that Indica varieties produce high tiller numbers than the Tropical Japonica (IRRI 2009). Tillering capacity differs in different cultivars, even within sub species level, Japonica, Tropical Japonica. Therefore in this experiment a significant difference in the tiller capacity was observed.

It is also evident that stressed seedling produced higher tiller numbers though their mortality rates are high. The numbers of effective tiller numbers produced are high. Severely stressed seedlings produce tillers on multiple nodes due to stem elongation (rhizomes) resulting in slightly higher

Fig. 4: Effective and non-effective tillers at harvest affected by the stress levels.



V_1 = IR-64: V_2 = Demadola, T_1 = control, T_2 = planted horizontal to the soil surface,
T_3 = Planted with stem completely bent at 90 ^{0}C, T4 = planted with stem completely snapped.

effective tiller numbers. Stressed seedlings also took longer time to head, depending on variety and stress levels.

In PNG where inputs into rice yields are very low and with more farmers now transplanting rice seedlings under upland/lowland rain fed conditions, this finding could be further investigated by using the landrace varieties to compare their adaptability to stress and tiller production against the improved varieties in their specific locations. The production of high number of effective tiller would result in higher yield.

Appendix

1. Ryzhome (stem elongation)

2. Tillers from two internodes with heavy root production

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INTENSIVE LIVESTOCK PRODUCTION: LESSONS LEARNED AND FUTURE PROSPECTS [1]

Alan R. Quartermain [2]

ABSTRACT

The focus of this paper is the commercial production of poultry and pigs permanently confined in some kind of housing. Data on livestock numbers and production indicate low levels of commercial pig meat production compared to that from traditional systems. The opposite holds true for poultry products. There is significant production of broiler chickens by independent growers, mainly sold in the live bird markets. The demand for meat and eggs is expected to continue to grow at about five percent per year due to population increases and factors to do with urbanization, incomes and aspirations. Papua New Guinea conditions are favourable for intensive production, especially by smallholders. There are minimum sizes of operation for practicality but the economics of scale are not important. Local production of feeds is feasible making good use of local resources but quality feeds will never be cheap. The concepts of nucleus estates and vertical integration are appealing but implementation is problematic. A number of lessons from past experiences with intensive systems give guidelines for best practice. It is concluded that the bulk of desired growth in livestock production over the next 10-20 years can come from smallholders and this will be profitable for them.

Keywords: *Broiler chickens, egg production, pig production, meat demand, smallholders, integration, best practice*

INTRODUCTION

Intensive animal production can be regarded as any system of keeping animals under close confinement. There is a range of systems from cattle in feedlots to chickens or rabbits in cages. Even the grazing of animals confined at high stocking rates on pasture as practiced for example in the New Zealand dairy industry can be regarded as intensive, as distinct from free range grazing systems. For the purpose of this discussion, interest is in the commercial production of animals permanently confined in some kind of housing and will be restricted to the production of broiler chickens, eggs and pig meat.

PRODUCTION AND DEMAND

In 2002 an attempt was made to summarise information and estimates on livestock numbers and production in Papua New Guinea (PNG) and the findings were published (Quartermain 2002). These estimates are reproduced in Table 1. The reasoning behind the estimates is clearly set out in the NARI Nius article and need not be repeated here.

What is important to note is the low level of commercial pig meat production compared to production from traditional pig keeping, although the latter is often very intensive. This is in contrast to the situation with poultry meat and eggs with traditional production estimated as being very low. What needs to be noted here is the very significant production of commercial broilers for the live bird trade by farmers not fully integrated into the large scale commercial sector. These numbers are not expected to have changed significantly over the last eight years.

However, it is expected that the demand for meat in PNG will grow at the rate of about five percent per year (Quartermain 2001). This is due to population increase at around 2.5 percent and a number of factors associated with urbanization, availability of cash and the search for improved diets. If such increase is to happen, much of it must come from intensive, commercial production. This is a world wide phenomenon. Consumption of meat in developing countries increased about five fold from the early 1970s to the mid 1990s. This is part of what has been termed the "Livestock Revolution". This is ongoing since consumption levels in the developing

1. Paper presented at a workshop on "Revitalisation of Commercial Livestock Production in Laloki Catchment", 23-24 February 2005, Laloki Provincial High School, Central Province, Papua New Guinea, facilitated by the Technical Assistance Screening and Management Unit, Nucleus Agro Enterprises Project, Asian Development Bank.
2. Papua New Guinea University of Natural Resources and Environment

Table1. Livestock numbers and production

Species	Component	Number	Production
Pigs	Village	1.8 million	27, 000 t
	Commercial	23, 500	1, 000 t
Cattle	Large-scale ranch	63, 000	2, 300 t
	Smallholder	17, 000	600 t
Sheep	Smallholder	15, 000	54 t
Goats	Smallholder	20, 000	72 t
Swamp buffalo	80 percent feral	4, 000	
Chickens	Commercial broilers		17, 500 t frozen
	Broilers live sales		6, 000 t carcass
	Commercial layers	200, 000 hens	54 million eggs
	Village	1.5 million	1, 858 t carcass
			6 million eggs
Muscovy ducks	Household	10, 000	
Rabbits	Household	15, 000	112 t

countries are nowhere near those in developed countries and populations continue to increase. Population growth, income growth and urbanization are driving these changes. The demand for livestock products is expected to double again in the next 20 years. Projections for the three main meat products are 3.9, 2.9 and 2.4 percent per year for poultry, beef and pork (Delgado et al. 2003). We might expect demand in PNG to exceed these figures because the country is lagging behind many other larger developing countries in income growth and the population continues to grow at a very high rate.

SYSTEMS AND SCALE OF PRODUCTION

Conditions in PNG are extremely favourable for the intensive production of meat and eggs to meet these projected increases in demand. PNG has an abundance of natural resources, either in the shape of crop residues and surpluses or of land, to support animal production as well as an enviable low disease risk status. There is currently relatively good support for research but there is a need to ensure on-going strength in the National Agriculture Quarantine and Inspection Authority for effective disease monitoring and border surveillance. In addition, many studies have shown that as long as smallholders value their own labour less than market wage rates, small family farms are typically more efficient at generating profits per unit of output than are large production operations, even with poultry production which is usually considered to have large "economies of scale". Smallholders therefore can and do compete, especially in PNG where there are serious management problems with large-scale operations. However, there are minimal sizes of operation to be viable in commercial markets rather than simply for household or local village uses, and these need to be defined. Some forms of vertical cooperation (rather than vertical integration) are necessary to ensure input supplies, and access to credit, technical information and secure markets will not always be problems for smallholders. Smallholder production must be supported by policies and strategies to ensure such access.

For broilers, the minimal size of operation is generally dictated by the fact that day-old chickens are sold in boxes of 50. Similarly, a smallholder layer operation might have a minimal size of 150 birds in lay in order to have 50 replacement growers coming through at any one time. For pigs, a minimal size might be 12 sows and one boar for efficient use of the latter, unless he can be shared which is generally not a good idea. Simple farm budgets calculated using a range of assumptions suggest that if the ratio of the sale price of one kilogram of pork carcass, dressed chicken or eggs to the average cost price of one kilogram of purchased feed is in the range of 6-10 then profitability is assured, provided reasonable production targets are met and nothing goes drastically wrong. Such ratios are favourable for smallholders in PNG unless they are too isolated to purchase prepared feed. Local ingredient feed options are being developed for such situations and for those willing to do the extra work involved. What is important to understand here is that there is no such thing as "cheap feed". Feeds adequate to achieve acceptable levels of productivity and profitability can be produced in PNG using mainly PNG materials and at a lower cost than imported feed. But they are not and cannot be cheap. Farmers cannot manage their units badly, fail to achieve acceptable productivity, and then blame their lack of profit on the cost of feed.

The concepts of "nucleus estates" and "vertical integration" are clearly appealing to planners, politicians and corporate business. Capital investment can be attracted by an integrated package and hence avoid the problems associated with providing credit to independent small-scale operators. There have been attempts in the past to group pig fattening units around a nucleus breeding unit but these have failed due to the kinds of management problems discussed later in this paper as well as problems with financial management and inability to realize unrealistic expectations with respect to output and profitability. One idea worth considering is to have a group of contract farmers breeding pigs and producing weaners, which would then be purchased at adequate and acceptable prices for finishing in a nucleus fattening unit. If the nucleus were also supported by its own breeding unit, such an arrangement would have substantially lower risk for investors.

The only really successful integrated business using the nucleus estate concept is Niugini Tablebirds. Ilimo Farms had a similar structure but failed for a variety of reasons which had little to do with the ability of contract farmers to grow chickens. Tablebirds has been successful because of strict central management, adequate financing, excellent training and support for staff and the contract growers, adequate but manageable sizes of grower operations and realistic expectations of profits to be earned by participants. The keys to success in any livestock production business are forward planning and realistic expectations of feed supplies at pre-arranged prices, farmer training and extension support, negotiated profit margins and, of course, care and attention to the needs of all animals. However, in considering this type of investment it should be born in mind that the impact will be localized and limited to a relatively small number of participants. Nevertheless there will be employment opportunities and stimulation of the local economy.

LESSONS FROM THE PAST

A number of lessons can be learnt from past and on-going failures of farmers to meet acceptable production targets. These can be itemized as follows giving guidelines for "best practice". They apply across species and production systems.

- It is essential to identify and assess the sustainability of markets and feed supplies before starting anything else. Forward planning is necessary even for a simple batch-in batch-out broiler operation but is absolutely essential for the longer term pig breeding or layer chicken enterprises.

- Given the uncertainties of sales on the live animal market it is necessary to develop flexibility to allow for feeding animals cheaply at maintenance levels after they have reached market weight. It may not be possible to sell 50 live broilers in one day or pigs may be held to get a higher price. However, common sense dictates that finished animals cannot be held too long before sale. Forward planning may allow for the targeting of known periods of increased demand such as Christmas.

- If, inadvertently, feed is short for reasons beyond the farmer's control, short term measures should include the targeting of animals most at risk such as brooding chickens, young pigs prior to and post weaning, and breeding sows. Other animals can be put "on hold" for short periods without disaster.

- The importance of good feed storage and handling cannot be stressed enough. This is an area of operation which is often overlooked and can lead to total failure. Food must be kept dry and cool, preferably stacked off the floor and away from a wall, and protected from rats. The supply must be regularly cycled so that the oldest feed is always that being used. No feed should be kept for longer than two weeks. Also, during the actual feeding operation, do not waste feed by using inappropriate containers or feeding too much at once. With pigs it is necessary to ensure that each animal gets its share of the feed at each feeding.

- The continuous supply of water and access to drinking water by all animals at all times is another essential husbandry necessity. In the PNG climate, laying birds in particular will immediately cease production if deprived of water for even one day.

- Emphasis in the provision of information and training needs to cover all of the points raised here, but there is a clear need to concentrate on care and survival of the young, including especially the brooding of chicks and the husbandry of piglets during the first three weeks of life and during weaning.

- A major problem encountered with pigs is the demand made by buyers or others for the sale or gifting of breeding stock. Breeders need to avoid the unwanted sale or disposal of gilts or young boars selected for breeding and of breeding sows or boars in good condition. One solution is to divide the piggery into two sections, one open to the public with animals for sale and one closed for breeding stock.
- While the maintenance of cleanliness or hygiene is important in all livestock operations, it is of particular importance in intensive production units. We are not only concerned about animal health and pleasant working conditions, but also about waste disposal. Requirements concerning the avoidance of environmental pollution are only going to get more restrictive with public awareness and regulation. It is no longer simply a matter of washing effluent into the nearest river or gully. Of course, solid wastes such as chicken litter are used, can be used and should be used as fertilizer but there are implications for handling and labour. Disposal of liquid wastes is more problematic. There are solutions but these have capital and operational costs. The important point is that provisions must be considered and built into the planning and setting up of intensive units and not left until real problems emerge.

CONCLUSIONS

In conclusion it can be stated with some confidence that the demand for meat and eggs will continue to grow rapidly over the next 10-20 years or until such time as population growth slows down and PNG becomes a developed country. A high proportion of this demand will need to be met by intensive production from chickens and pigs. The bulk of this production can be met by smallholders and will be profitable for them, thus maximizing and spreading benefits throughout the community. Naturally there will need to be concurrent development of feed milling facilities, hatcheries and abattoirs, but these too can be small-scale and strategically located. There will always be room for larger scale, vertically integrated enterprises and nucleus estate type arrangements but their impact will more than likely be restricted to servicing the needs of the larger urban complexes.

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SUBJECT INDEX

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g - gram

kg - kilogram
t - tonne
l - litre
ml - millilitre
ha - hectare
mm - millimetre
cm - centimeter
M - metre
a.s.l. - above sea level
yr - year
wk - week
h - hour
min - minute
s - second
k - kina
n.a. - not applicable or not available
n.r. - not recorded
var - variance
s.d. - standard deviation
s.e.m.- standard error of difference
d.f. - degrees of freedom

Levels of significance

n.s. - not significant
* - 0.01 $p < 0.05$
** - 0.001 $p < 0.01$
*** - $p < 0.001$

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