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CONTENTS

ONION CULTIVAR SELECTION FOR THE LOWLANDS OF CENTRAL PROVINCE IN PAPUA NEW GUINEA

John W. Sowei[1]

ABSTRACT

Selected bulb onion cultivars bred in Australia, New Zealand, Japan and the United States were evaluated for production potential under tropical lowland conditions in Papua New Guinea (PNG). Cultivars Rio Enrique, Tropic Brown, Dessex, Yellow Granex, Pira Ouro, Texas Early Grano and Rio Bravo have been identified and recommended for production in the area. Total marketable yield obtained from transplants ranged from 32.1 to 43.6 t/ha. In the lowlands of Central Province, the most suitable planting time is from February to June. However, some cultivars may have potential for late-season planting in July and August.

Key Words: *Onion, Cultivar, Evaluation, Lowlands, Central Province, Papua New Guinea.*

INTRODUCTION

Onion *(Allium cepa)* is a new crop of great economic potential for small-holder farmers in Papua New Guinea (PNG). Currently, PNG relies heavily on imported onions from Australia and New Zealand (NZ) for its domestic consumption. Figures available from July 1987 to June 1988 show that of the 2135 tonnes imported, 1501 tonnes were of Australia origin and the remaining 634 tonnes were from NZ (Wiles, unpublished). At current prices, it is estimated that 5000,000 kina is spent annually on imported onions.

Unconfirmed reports suggest that early missionaries to Manus (2°S) brought some seeds for trial purposes in the 1960s to see if onions could be grown under local conditions. It was not until the 1980s that the Department of Agriculture and Livestock imported some seed material for trials at Laloki (Bull and Bourke 1983; Bull 1985). From these trials, three cultivars were recommended for production in the lowlands of PNG, especially in areas around Port Moresby. Further trials were conducted at Kuk Research Station (1550 m) to identify potential cultivars for high altitude areas. Subsequently, two cultivars were released for production in the highlands (Gunther 1985; Pitt 1988 a).

Small-holder vegetable growers, especially in the highlands, have tried growing fresh bulb onions with some success. The fresh onion bulbs are sold locally. Potential onion growing areas in the highlands and lowlands are those with a distinct dry and wet season. Pitt (1988 a) identified Banz and Minj (Western Highlands); Kainantu, Henganofi and Goroka (Eastern Highlands) as places with a relatively cooler climate which should permit production throughout the year. Potential lowland areas for onion growing are those immediately outside Port Moresby in Central Province (Bull and Bourke 1983; Bull 1985).

The Department of Agriculture and Livestock (DAL) through its Research Division commenced an onion cultivar evaluation program in 1991. The aims of these trials were:

(1) to evaluate the increasing number of new seed material being sold indiscriminately by retailers in PNG without any knowledge of their performance under local conditions, and

(2) to determine a suitable time of planting.

Many onion cultivars developed for temperate or sub-tropical conditions may not necessarily perform well under PNG conditions. Generally, the trails aim to select cultivars that can be promoted for local production; selected cultivars would eventually replace imported onions and capture some economic benefits for local producers.

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Results from this 'elite' cultivar trial would form the basis for a final selection from the cultivars that had been evaluated previously during 1991 and 1992 (Sowei *et al.* unpublished). This report discusses the results from the 'elite' cultivars evaluated at Laloki Agricultural Research Station, Central Province, PNG.

MATERIALS AND METHODS

Nine elite selections of brown onions from the screening and cultivar trials (Kurika *et al.*, unpublished) were evaluated against the two recommended cultivars *viz* Gladalan Brown and Superex (Table 1). The trial was laid out in a completely randomized design (CRD) with 4 replications on a clay loam soil at Laloki Agricultural Research Station (9° S), situated about 15 km from Gordons, Port Moresby, at an altitude of 30 m.

The seedlings were raised in a seed-bed mix of 2 parts black soil, 1 part river soil and 0.5 parts fine sand. The soil was steam sterilized for 2 hours and sieved to obtain a fine mix. Sieved chicken manure droppings obtained from a nearby layer shed were applied at 500 kg/ha, and NPK (12:12:17:2) at the recommended rate. The mixture was watered every day for 1 week before sowing on April 29, 1993. The seeds germinated within 1 week and were maintained for 4 weeks under 50% shade cloth. The seedlings were transplanted at a spacing of 7.5 cm between plants and 30 cm between rows on June 22, 1993.

Plots of 1.5 m x 1.5 m were prepared manually after the field was ploughed using a tractor. Fertilizers (chicken manure and NPK (12:12:17:2)) were applied at recommended rates 1 week before transplanting. Plots were irrigated using watering cans and a lawn sprinkler every day until full establishment at 3 weeks; thereafter watering was done every second day.

Preventative spraying using Benlate (R) and Dithane (R) at 20 grams per 10 litres of water was applied to control purple blotch *(Alternaria porri)*. This treatment, carried out at 2 weeks intervals, started during the last week of May when the seedlings were still in the nursery and continued until leaf fall. On the other hand, onion thrips *(Thrips tabaci)* were controlled by applying Orthene (R) at 10 grams per 10 litres of water. Plots were kept weed free by manual weeding.

After maturing, the onions were field cured before harvesting in September, 1993 (Plate 1). Some late maturing and thick-neck plants were harvested and the tops removed before curing. The onions were graded into large (>50 g) and small (<50 g) bulbs and weighed. Data were subjected to an analysis of variance using a statistical software package, MSTAT Version 4.0.

Storage Observations

After yield measurements were taken, 20 large marketable bulbs were selected from each cultivar for storage observation. The aim was to see how well these bulbs can store under ambient temperature and relative humidity. Bulb weights were monitored weekly for 8 weeks (Table 2).

RESULTS AND DISCUSSION

Yields obtained on the trial (Table 1) indicate that cultivar Rio Enrique produced the highest total marketable yield with large bulbs (>50 g) comprising 97% of that yield. Notwithstanding, the yield of large bulbs of Rio Enrique was not significantly greater than that of the control Gladalan Brown and Superex. However, Rio Enrique produced a significantly greater yield of large bulbs than six of the other eight introduced cultivars. The only cultivars that had a lower large bulb yield than the control cultivar Gladalan Brown were Early Yellow Premium and Early Lockyer Brown which produced low yields of large bulbs (18.0 and 13.3 t/ha, respectively). The latter cultivar is not suitable for early planting, while Early Lockyer Brown developed premature bulbs in the nursery and did not yield well after transplanting into the field.

From the storage observation, it was found that the incidence of fungal rot caused by *Aspergillus niger* was low. Cultivars Superex and Early Yellow Premium had 5% of the bulbs infected while Pira Ouro and Rio Bravo had 10% of the bulbs infected. All other cultivars remained uninfected throughout the 8 weeks storage.

The rate of water loss during storage is a useful guide to determine the keeping quality of onions. Woodman and Barnell (1937) observed that high rates of water loss during drying after harvest were characteristic of non-keeping onions, whereas onions with good storage characteristics lost little water. In this study, water (weight) loss over the storage period for the cultivars tested was monitored over 8 weeks (Table 2). From the seven selections, cultivars Tropic

Brown, Dessex, Yellow Granex and Texas Early Grano lost from 2% to 4% of the moisture content. The highest yielding cultivar in this trial, Rio Enrique, lost 25% of the original weight. This could be related to the bigger bulbs used. Stow (1975) reported that the larger bulbs showed the greatest total loss of weight throughout the storage period. Similar observations were made by Jayabharathi (1989) using *Allium cepa* var. *aggregatum* cultivar Co. 4.

TABLE 1: **Yield of Onion Cultivars Evaluated at Laloki Agricultural Research Station**

Cultivar	Source	% Dry Matter	Large Marketable Bulbs (t/ha)		Small Marketable Bulbs (t/ha)		Total Marketable Yield (t/ha)	
Rio Enrique	Rio Colorado, USA	6.6	42.3	a	1.3	a	43.6	a
Gladalan Brown *	Yates, Australia	7.0	35.2	ab	2.3	ab	37.5	ab
Tropic Brown	Yates, New Zealand	7.4	34.0	ab	4.4	ab	38.3	abc
Superex *	Takii, Japan	7.3	33.4	ab	5.2	ab	38.6	abc
Dessex	Sunseeds, USA	7.7	30.9	abc	4.8	ab	35.7	abcd
Yellow Granex	Sunseeds, USA	6.9	29.4	abc	4.5	ab	33.9	abcd
Pira Ouro	Agroceres, Brazil	11.1	28.4	abc	4.4	ab	32.8	abcd
Texas Early Grano	Yates, Australia	7.6	27.9	abc	10.1	ab	38.0	abcd
Rio Bravo	Rio Colorado. USA	7.6	27.0	abc	5.1	ab	32.1	bcd
Early Yellow Premium	Sunseeds, USA	6.3	18.0	bc	6.7	ab	24.7	cd
Early Lockyer Brown	Yates, Australia	5.2	13.3	c	5.6	b	18.9	d

* = Control Cultivars
LSD (0.05) Large Bulbs = 16.20 t/ha
CV = 38.58%
Yield in each column followed by the same letter are not significantly different by DMRT (p=0.05).

Although the percent loss in dry weight during storage was greatest for large bulbs, they stored better than smaller ones. On the contrary, Karmarkar and Joshi (1941) and Tendaj and Rodkiewicz (1992) reported that small bulbs tend to loose water more quickly than large bulbs. However, in a review by Mondal and Paramanik (1992) a recommendation to use small bulbs suggests that they may be good keepers.

Marketable yields of onions obtained in the present trial are higher than those obtained in the screening trial (0.13 to 10.2 t/ha) and in the cultivar trial (4.25 to 24.0 t/ha) during the 1991 season (Kurika *et al.*, unpublished). The comparatively low yields obtained in the screening trial were attributed to a severe infestation of purple blotch.

It is generally accepted that all cultivars of the common onion are long-day plants (Call 1986), which tend to form bulbs in long days (Austin 1972).

Daylength plays a very important role in the adaptation of onion cultivars, and is determined by both the time of year and latitude of the production area (Call 1986; Darley 1986).

In the lowlands of Central Province, Bull and Bourke (1983) and Bull (1985) were able to evaluate and release the cultivars Texas Early Grano, Yellow Granex and Red Creole. This indicates that 'long-day' and 'intermediate-day' cultivars bred for temperate regions (Australia, NZ and the USA) can be grown successfully under tropical lowland

TABLE 2: **Water Loss from Bulbs Stored for 8 Weeks**

Cultivar	Weight (kg)							
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Rio Enrique	4.43	3.41	3.39	3.39	3.37	3.36	3.34	3.33
Gladalan Brown	3.40	3.38	3.36	3.35	3.34	3.33	3.32	3.30
Tropic Brown	4.03	4.01	3.99	3.98	3.97	3.96	3.95	3.93
Superex	2.22	2.20	2.18	2.17	2.15	2.14	2.12	2.00
Dessex	3.38	3.36	3.34	3.33	3.31	3.29	3.26	3.24
Yellow Granex	3.39	3.37	3.35	3.34	3.33	3.32	3.31	3.29
Pira Ouro	2.26	2.24	2.22	2.19	2.17	1.98	1.97	1.96
Texas Early Grano	3.33	3.30	3.28	3.27	3.26	3.25	3.24	3.23
Rio Bravo	2.67	2.63	2.61	2.59	2.57	2.24	2.23	2.21
Early Yellow Premium	2.85	2.83	2.81	2.80	2.77	2.59	2.58	2.57
Early Lockyer Brown	3.23	3.20	3.18	3.17	3.16	3.14	3.12	3.11

TABLE 3: **Mean Monthly Temperatures Recorded at Laloki Research Station in 1993**

Month	Mean Minimum	Mean Maximum
January	27.5	32.9
February	26.5	32.7
March	27.3	32.9
April	26.9	32.6
May	26.3	32.3
June	26.0	32.4
July	24.7	31.7
August	19.7	31.7
September	22.3	32.4
October	24.1	32.9
November	25.8	31.8
December	24.3	32.9

PLATE 1: **Harvesting Onions at Laloki in September, 1993**

PLATE 2: **Marketable Bulbs of Cultivar Rio Enrique**

conditions at Laloki, Central Province.

Onions grown under different latitudes and seasons have had to adapt to changing daylength and temperatures, the two most important factors responsible for bulbing. The bulbing process is triggered by a critical minimum daylength, which may vary from 12 to 13 hours for 'short-day' types to 16 hours for extremely 'long-day' types (Darley 1986). Thus, onion cultivars can be classified into 'long-day', 'intermediate-day' and 'short-day' types depending on their bulbing response to daylength.

Probably of more significance under short-day tropical conditions is the effect of temperature on the physiological development and bulbing of onions. It is generally accepted that in the temperate regions, daylength is the primary factor in bulb initiation and that the role of temperature only enhances or delays the bulbing process (Heath 1945; Call 1986; Sinclair 1989). Brester (1989) showed that bulb development is accelerated by an increase in temperature. In the tropics and sub-tropics, seasonal variation in daylength is small but average temperatures are often high (Abdalla 1967; Bourke 1983). Fluctuations in daily mean minimum and mean maximum temperatures throughout the duration of the trial (June to September) ranged from 19.7^0 C to 32.4^0 C (Table 3).

The role of temperature in bulb development of onions was studied by Abdalla (1967) and Heath (1945). Temperature was considered by Abdalla (1967) to have a catalytic effect on onion bulbing. Heath (1945) found that higher temperatures (16-27^0 C) enhanced bulbing and that lower temperatures delayed bulbing. Higher temperatures reduce the minimum daylength required for bulbing to commence (Sinclair 1989), but quantitative differences among cultivars in their tendency to commence bulbing are dependent on the combined effect of photoperiod and temperature (Abdalla 1967).

Furthermore, high temperatures may retard physiological processes including cell enlargement at the leaf bases of onion and carbohydrate translocation; they may also initiate a change from cell division to cell expansion at the leaf bases through a hormonal mechanism (Abdalla 1967). This mechanism explains why onions form bulbs more quickly and mature early at high temperatures (Grodel and Gunther 1985; Call 1986; Sinclair 1989; Brewster 1990; Culley 1993).

Other cultural practices such as planting density, soil moisture regime, nutrient supply, time and depth of planting affect bulb formation and characteristics (Call 1986; Sinclair 1989; Brewster 1990).

All the cultivars used in this trial (Table 1) are 'long-day' and 'intermediate-day' types with the exception of cultivar Superex, a 'short-day' type from Takii Seeds, Japan. Therefore, it is highly likely that temperature, other than daylength, is responsible for the adaptation of these cultivars under short-day tropical conditions at Laloki, Central Province. The yields reported in this trial are comparable to those obtained by Culley (1993) for a direct sown crop under sub-tropical conditions in the Lockyer Valley (27°S), South East Queensland. Other commercial yields under Australian conditions are given by Rogers (1977). Under small-holder management conditions in PNG, yields of 20 t/ha are possible (Wiles 1992); there are lower than the average yield of 29 t/ha obtained in the present trial.

In the lowlands of Central Province, the time of sowing is very important as reported by Bull and Bourke (1983), Bull (1985), and Wiles (1992). The most suitable time of sowing is from February to June, although some cultivars may be suitable for a later planting (July to August). Observations from a field planting at Laloki in August 1993 showed some promising cultivars - YHO37, Tropic Ace, Haemek, Aldobo, YHO34 and Hojem (Sowei, unpublished). However, these cultivars should be further tested. Yields of an early season crop (February to March planting) could be maintained with adequate spraying to control purple blotch, a serious problem during the wet season.

Short day-length and high temperatures experienced during the dry season tend to promote premature bulbing of the seedlings in the seed-bed. Premature bulb formation in the seed-beds was particularly evident in the low-yielding cultivars Early Lockyer Brown and Early Yellow Premium. The critical daylength enhanced by high temperatures was probably responsible for the rapid bulb development and early maturity of cultivar Early Lockyer Brown. It was evident at transplanting that some of the seedlings had formed bulbs in the seed-bed. Selective transplants were used but bulbs developed rapidly. Hence, maturity was also very early. Cultivar Early Yellow Premium is probably not suitable for late planting (May to June).

Preventative spraying with fungicides (Benlate (R) and Dithane (R)) at recommended rates was able to control purple blotch. However, it was observed that cultivars with dark green waxed leaves had more resistance than those with light green non-waxy leaves to purple blotch. For example, the cultivars Rio Enrique, Pira Ouro and Gladalan Brown had more tolerance to the disease than Superex. Currah and Proctor (1990) reported that some onions bred in Brazil (Baia Periforme group) have characteristic waxy dark green leaves and can tolerate pink root rot *(Pyrenochaeta terrestris)* and purple blotch. Cultivar Pira Ouro was developed by onion breeding at the University of Sao Paulo for the tropical north-east region of Brazil. The Pira series were derived from Baia Periforme lines which have a high dry-matter content (Currah Proctor 1990). This is consistent with the high dry-matter and good keeping quality of Pira Ouro reported in this trial.

There were also differences in the bulbing habit. The cultivars Superex, Early Lockyer Brown, Early Yellow Premium and Dessex formed bulbs earlier than the other early bulbing types, whereas Pira Ouro and Gladalan Brown formed bulbs late in this trial. The extended length of the growth period meant bigger plants and subsequently a larger bulb size. This is probably why cultivar Rio Enrique produced more large bulbs than small bulbs (Table 1 and Plate 2).

It was reported by Grodel and Gunther (1985) that cultivars Early Lockyer Brown and Early Lockyer White formed bulbs in the seed-bed at Kuk (1550 m). However, Wiles (1991, unpublished) found that these cultivars had satisfactory yields at Tambul (2240 m). The cooler temperatures at Tambul (8.5^{0}C - 19.0^{0}C) could have lengthened the growing period for bulb development and maturity. Similar results were obtained by Culley (1993), from a direct sown crop, while evaluating a range of 'short-day' hybrids including Early Lockyer White for production in the Lockyer Valley (27^0 S), South East Queensland, Australia.

CONCLUSIONS

Yields obtained in this 'elite' cultivar trial have indicated that suitable hybrids from Australia, New Zealand and the United States can be grown successfully under tropical conditions in the lowlands of Central Province, PNG.

Seven cultivars, Rio Enrique, Tropic Brown, Dessex, Yellow Granex, Pira Ouro, Texas Early Grano and Rio Bravo have been selected, which should be promoted to the growers in the lowlands of Central Province. This program needs to be extended to other potential production areas such as Tapini in the Central Province and Kainantu in the Eastern Highlands Province with a relatively good market access. It is anticipated that this program will promote commercial onion production to eventually replace imported onions on the domestic market.

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REGENERATION AND RESIDUAL STAND AFTER WOKABAUT SOMIL OPERATIONS IN SEASONALLY INUNDATED FOREST NEAR LAE, PAPUA NEW GUINEA.

Bas Louman, Michael Hasagama, Constin Bigol, and Patrick Gamuna[1]

ABSTRACT

This study compares undisturbed seasonally inundated lowland rain forest with the same forest 6-8 months after completion of commercial wokabaut somil operations, and with similar forest 6-8 months after conventional logging took place. The results suggest that the commercial wokabaut somil operation reduces the basal area of the total standing stock, the number of trees in the lower diameter classes, and the number of species present in the area directly affected by the operations. The authors conclude that the operation will not be sustainable, unless better felling practices are adopted and TSI measures are implemented following harvesting. While the basal area of the residual stock was greater, and regeneration more abundant in the conventionally logged area than in the wokabaut somil area, the latter operation showed greater harvesting efficiency and less felling damage to the trees in lower diameter classes.

Keywords: *Workabaut somil, Residual stand, Regeneration.*

INTRODUCTION

The Wokabaut Somil (WS) is a small sawmill consisting of a beam along which moves an engine with two circular saws, mounted perpendicular to each other and sawing timber into planks of present sizes. The mill is usually dismantled and hand carried into the forest, where it is placed over the trees to be sawn. WS operations in Papua New Guinea (PNG) have expanded enormously over the past decades but very little is known about the effect of these operations on the immediate forest environment. Louman (1992) suggests that sustainability of a WS operation may be achieved, depending on the specific natural and socio-economic environment in which it takes place.

For tree harvesting to be sustainable, care has to be taken that the harvested trees are succeeded by healthy younger trees and seedlings. While these aspects have been studied in PNG in relation to conventional logging (CL) operations (Buenaflor (unpublished FAO report 1989), Johns (1987), Nir, (1992), Saulei (1984), Saulei and Lamb (1991), Sopu and Arentz (1990), and Vigus (in press)), "a dearth of validated information regarding the development of PNG forest following harvest" still exists (Cameron and Vigus, unpublished reports for the World Bank, 1993, pl Section 1).

In addition, none of the above mentioned studies investigates regeneration and residual stands following the type of operation related to the use of small portable sawmills.

This study, therefore, helps filling a gap in the existing knowledge on impact of tree harvesting systems on the PNG lowland rain forest. The present paper summarises the results of a study into the sustainability of the operations of a WS in a seasonally inundated forest, focussing on felling damage assessment and regeneration studies.

The project area

The study site of 90 hectares is located approximately 25 km West of Lae City on the banks of the Garagos Creek (see map 1). The altitude of the area is approximately 120 m.a.s.l. The climate is wet tropical with an annual rainfall approximately 3000 mm well distributed over the year. Temperatures range from 23° C to 32° C. The soil of the study site is little differentiated, with an alkaline, sandy loam A-horizon overlying a gleyic subsoil. The vegetation can be classified as seasonally inundated alluvial lowland rain forest. The canopy height of the forest is between 25 and 30 meters. Canopy species and

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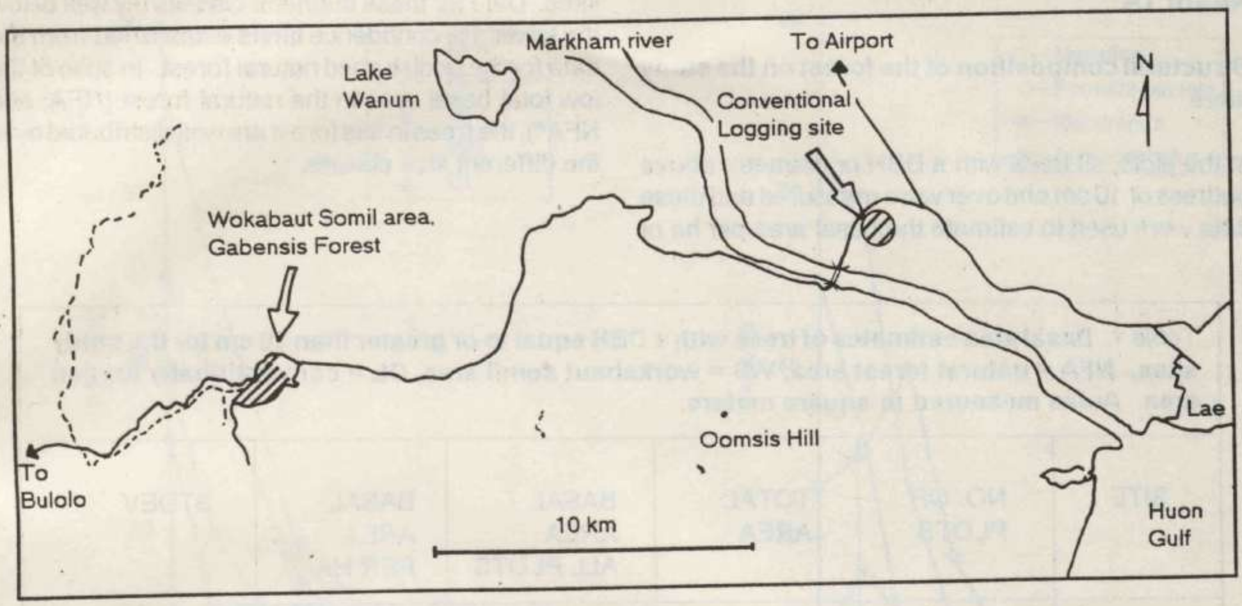

Map 1. **Location of the study sites: A = Gabensis area with wokabaut somil operations, B = Markham area with conventional logging operations.**

genera commonly found in the area are: *Anthocephalus chinensis* (Lamk) A. Rich. ex Walp., *Intsia bijuga* (Colebr.) O. Kuntze, *Macaranga* Thouars spp., *Myristica* Gronov. spp., *Nauclea* Merr. spp., *Octomeles sumatrana* Miq., *Pometia pinnata* J.R. Forster & J.G. Forster, *Pterocarpus indicus* Willd., *Sterculia* L. spp., and *Terminalia* L. spp Palms, rattans and woody lianas are abundant.

A WS has operated in the area for two years prior to the study. Harvest is market oriented, rather than based on silvicultural planning. The result is a mosaic of forest patches cut at different intensities: from heavily cut, locally clear felled areas to nearly untouched areas, the latter having few trees of commercial value. In general, trees are felled in a patch of forest. Then the WS is set-up alongside a felled tree. The other logs felled in that patch of forest are pulled toward the mill using a hand winch. This procedure usually creates more or less circular gaps in the canopy. Canopy cover increases slowly with increasing distance from the centrally located sawmill.

METHODOLOGY

Three circular plots with a 30 m radius were established in areas 6-8 months after the WS ceased operation in those sites. The plot had the original location of the mills as centre. They were used for sampling the vegetation density in terms of basal area of trees above 10 cm DBH. Within the same plots a circle with 20 m radius was marked, which was used for a complete regeneration count.

Similar plots were established in undisturbed forest (NFA), using mature commercial trees as the central point for each plot. Information obtained from these plots was compared to data collected during an inventory of 5.7 ha out of the total 90 ha of the study site. For statistical analysis of the inventory data, it was assumed that the trees in each size class were normally distributed over the area. Out of the 57 plots of 0.1 ha each, only those were used that had at least one potential harvestable tree in it (i.e DBH > 50 cm). A total of 35 plots met this criterion.

In all the sub-plots, regeneration was identified to genus level. Individual plants were counted, and it was established whether the plants were seedlings, or regenerated from stumps.

A comparative analysis was done using the same methodology in a conventionally logged over area (CL) in similar forest, approximately 12 km West of Lae. Trees had been harvested 6-8 months prior to the study.

RESULTS

Structural composition of the forest on the study sites

In the plots, all trees with a DBH or diameter above buttress of 10 cm and over were measured and these data were used to estimate the basal area per ha of sites. Data for these diameter classes lay well below the lower 1% confidence limits established from the data for the undisturbed natural forest. In spite of the low total basal area in the natural forest (NFA, and NFA*), the trees in this forest are well distributed over the different size classes.

Table 1. **Basal area estimates of trees with a DBH equal to or greater than 10 cm for the study sites. NFA = natural forest area, WS = workabaut somil area, CL = conventionally logged area. Areas measured in square meters.**

SITE	NO. OF PLOTS	TOTAL AREA	BASAL AREA ALL PLOTS	BASAL AREA PER HA	STDEV
NFA	3	8482.3	9.55	11.3	1.522
WS	3	8482.3	4.06	4.8**	0.227
CL	3	8482.3	6.97	8.2**	0.253
NFA*	35	35000		19.4**	0.810

* based on data from 6.3% inventory of study area.
** significantly different at 1% level.

the different sites. Table 1 shows the basal area estimates for each site. The basal area, in particular of the undisturbed forest, is very low (11.3 m^2/ha). The high standard deviation of the undisturbed forest figures indicate a low level of reliability of the data. For that reason the inventory data of the same forest are included, showing a higher basal area (19.4 m^2/ha) and a lower standard deviation (0.81). Unfortunately no undisturbed patch of forest of sufficient size was left in the conventionally logged area to be able to compare basal areas. The data for the WS site and CL site (4.8 and 8.2 m^2/ha respectively) indicate that the WS operation studied extracts significantly more trees per ha than the conventional operation at a 1% significance level. Both basal area estimates differ significantly from the data obtained in the inventory of the undisturbed forest.

Figure 1 summarises data on diameter distribution of the trees in the circular plots of 30 m radius for each study site. The Figure shows the lack of trees in the 10-40 cm diameter classes relative to the frequencies in the other diameter classes for both the logged over

Floristic composition of the forest on the study sites

Table 2 indicates the occurrence of 11 major tree genera and species in the different study areas. Appendix A indicates the occurrence of all species in each site. These data confirm the higher harvesting intensity in the WS area. Six to eight months after harvesting only an average of 6 (range 5-9) species were present per circular plot, compared to an average of 10 (9-11) species in the circular plots in the CL area, and of 18 (15-20) species in the NFA.

REGENERATION

Table 3 shows the main results of the regeneration counts in the different size. Regeneration from seedlings was most abundant in the NFA with an average of 481 seedlings of 31 species per plot, followed by the CL area with 315 seedlings of 20 species. While the WS area only had an average of 170 seedlings and 12 species per plot. These figures

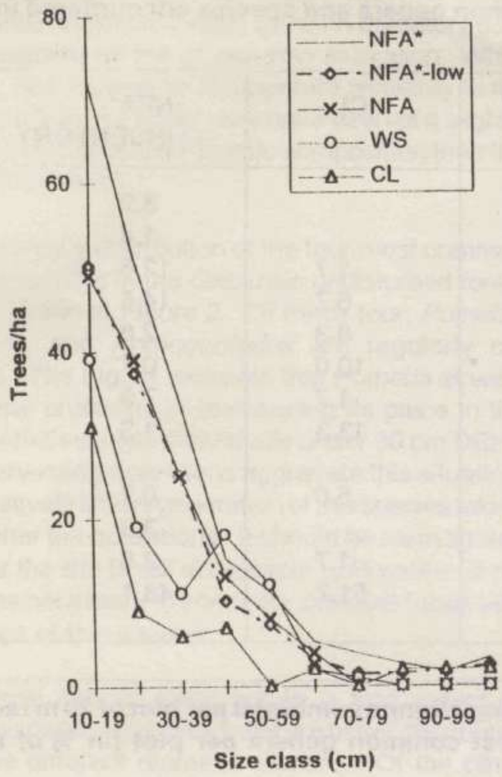

Figure 1: **Frequency distribution of all species combined for each site studied. (*) based on data from Appendix B, NFA*-low indicates the 1% lower limits of the NFA* data**

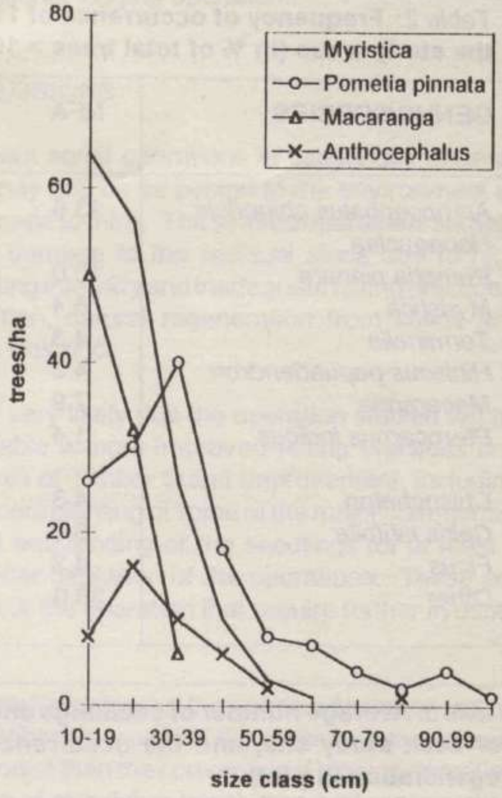

Figure 2: **Frequency distribution of four most common species in the natural forest of the Gabensis study site (data from Appendix B).**

amount to 3828, 2507, and 1353 seedlings per ha. respectively.

Regeneration from stumps averaged nil, 31, and 48 plants per plot for the respective sites. Including this generation from stumps, regeneration in the WS area was significantly less than in both the NFA and CL areas (at 10% level).

Noteworthy is the abundance of *P. pinnata* in the undisturbed forest and it's relative lack (less than 7.5% of seedlings) in the other sites. *Myristica* occurs throughout the plots, while *Neonauclea* Merr. is abundant in the WS site but hardly occurs at all in the other sites. Regeneration of *Elaeocarpus* L. is also abundant in the WS sites, both for stumps and seedlings.

DISCUSSION

Wokabaut somil operations as studied in the seasonally swampy forest near Gabensis in the Morobe Province resulted in great reduction in basal area of standing trees in all diameter classes, but in particular in the smaller diameter classes. This indicates severe felling damage to the potential residual stand or systematic cutting of undersized species.

Conventional logging also resulted in reduced basal areas, but to a lesser extent than that occurred in the studied wokabaut somil operations. Figure 1 data indicate more severe damage to the residual stand than in the wokabaut somil site, while more trees of the larger size classes have been left standing, explaining the higher basal area.

Table 2: **Frequency of occurrence of 11 most common genera and species encountered in the study areas (in % of total trees > 10cm DBH).**

GENUS/SPECIES	NFA	WS	CL	NFA* INVENTORY
Anthocephalus chinensis	13.6	4.9		3.9
Neonauclea		25.5		1.4
Pometia pinnata	10.0	3.9	1.7	12.6
Myristica	6.4	7.8	6.7	14.5
Terminalia	4.3	9.8	8.3	2.8
Hibiscus papuadendron	4.3		10.0	0.7
Macaranga	7.9	3.9	1.7	7.9
Pterocarpus indicus	1.4	4.9	13.3	1.3
Chisocheton	4.3		5.0	0.7
Celtis latifolia	5.0	1.0		3.3
Ficus	4.3		1.7	2.8
Other	38.6	38.2	51.7	48.1

Table 3: **Average number of seedlings and regenerating stumps combined per plot of 20 m radius for each study site, and the occurrence of the most common genera per plot (in % of total regeneration in plot).**

PLOT	NFA	WS6-8	CL
1	783	196	271
2	300	233	264
3	360	226	503
MEAN	481	218	346
STDEV	263.25	19.66	136.01
LOW 10%	286.22	203.79	245.37
HIGH 10%	675.78	232.88	446.64

Note:
At 10% significance level
NFA and WS are different
CL and WS are different
NFA and CL are NOT different

Plot	Most common genera	% of regeneration per plot
NFA		
plot 1	*Pometia*	14.3
	Chisocheton	10.5
plot 2	*Medusanthera*	9.3
	Myristica	8.7
	Pometia	7.7
plot 3	*Pometia*	13.1
	Ficus	10.6
	Manilto	9.2
WS(6-8)		
plot 1	mixed	
plot 2	*Myristica*	12.8
	Elaeocarpus	12.0
	Terminalia	11.2
plot 3	*Elaeocarpus*	14.1
	Neonauclea	14.1
	Myristica	9.7

Plot	Most common genera	% of regeneration per plot
CL		
plot 1	*Dysoxylum*	11.4
	Semecarpus	8.1
	Nauclea	8.1
plot 2	*Vitex*	16.4
	Hibiscus	10.4
	Syzygium	8.4
plot 3	*Macaranga*	11.5
	Barrintonia	10.3
	Polyalthia	9.5
	Syzygium	8.5
	Hibiscus	8.5

Some caution should be taken, though, in the interpretation of these data, since no inventory data were available for the CL site prior to logging. While the site was chosen for its apparent similarity to the Gabensis site, the forest may have been of a slightly different structural and floristic composition than the Gabensis forest.

The frequency distribution of the four most common species existing in the Gabensis undisturbed forest area is shown in Figure 2. Of these four, *Pometia, Myristica,* and *Anthocephalus* are regularly cut species. The Figure indicates that *Pometia* already has some problems in maintaining its place in the forest (relatively few individuals under 30 cm DBH). Tree harvesting operations aggravate this situation, with relatively little regeneration of this species taking place after the operations. It should be investigated whether the site is still acceptable to *Pometia*. If so, it may be necessary to enrich the cut-over forest with seedlings of this species.

The same can be said, but to a less extent of *Anthocephalus*. *Myristica* trees are better distributed over the different diameter classes. Of the other commercial species present in the undisturbed forest. *Dracontomelon dao* (Blanco) Merr. & Rolfe *Intsia bijuga, Octomeles sumatrana, Planchonella* Pierre sp., and *Pterocarpus indicus* seemed to have a lack of trees in the lower diameter classes, resulting in very flat to climbing frequency distribution curves (compare data in Appendix B). Regeneration of these species may need to be encouraged, if their presence in the future harvestable stock is desired. This may be of greater necessity in the WS area than in the CL site, due to poorer regeneration in the former site.

In general, regeneration is low in the sites studied. In forests in New Britain average regeneration counts of 30,000 seedlings per ha. have been obtained (Vigus, in press), while Saulei (1984) found up to 40,000 seedlings per ha. after clear felling. The seasonal swampiness of the areas studied is probably the main cause for the lack of generation. This aspect would need further investigations to see whether any type of tree harvesting operation should be carried out in such an area.

The site selected by the sawmill owner appears to be barely suitable for this type of operations. Unfortunately, wokabaut somil owners will often have to resort to these second or third rate sites, since these are the sites normally left untouched by previous, conventional logging operations.

CONCLUSIONS

Wokabaut somil operations in seasonally swampy areas may not be as benign to the environment as one is made to think. The studied operations showed severe damage to the residual stock due to high harvesting intensity and inadequate felling practices. In addition, natural regeneration from seeds and stumps was poor.

It is not very likely that the operation studied will be sustainable without improved felling practices and measures of Timber Stand Improvement, including enrichment planting of some of the major commercial species and tending of the seedlings for at least 2 years after cessation of the operations. These are aspects of the operation that require further in depth study.

This study indicates that the wokabaut somil operation in the Gabensis area had a greater negative impact on the forest than the conventional logging operation in terms of remaining basal area and regeneration from seedlings and stumps, both in species composition and number. On the other hand, the residual stand had a relative greater number of young trees (diameter classes 10-40 cm) in the WS area than in the CL area, indicating that harvesting had been more efficient, that less felling damage occurred per felled tree, and that therefore the potential for timber production from the residual stock is greater in the wokabaut somil area. Thus wokabaul sawmilling in Gabensis has good prospects for the next crop in 25-30 years time, but what happens thereafter will completely depend on the ability of the sawmill owners to improve regeneration in the area.

ACKNOWLEDGEMENTS

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Map 1; Location of the study sites: A = Gabensis area with wokabaut

APPENDIX A

Frequency of occurrence (% of all trees above 10 cm DBH) of all genera in all study sites. NFA = natural forest area, WS = wokabaut somil area, CL = conventional logging area.

GENUS/SPECIES	NFA	WS	CL
Alstonia	0.7	2.6	3.3
Anthocephalus chinensis	13.6	2.6	
Antiaris	0.7		
Artocarpus incisus			1.7
Campnosperma sp.		5.1	
C. brevipetiolatum		5.1	
Cananga odorata	2.1		
Chisocheton	4.3		5.0
Celtis latifolia	5.0		
Cerbera floribunda	0.7		6.7
Denrocnide peltata	2.9		
Diospyros	0.7	10.3	
Duabanga moluccana		2.6	
Dysoxylum			3.3
Elaeocarpus	0.7	2.6	
Endospermum medullos	1.2		
Evodia elleryana	0.7		
Ficus	4.3		1.7
Firminiana	0.7		
Gmelina	1.4		
Gnetum gnemon	1.4		5.0
Hernandia origera	2.1		
Hibiscus papuadendron	4.3		10.0
Homalium foetidum	0.7		
Intsia bijuga	0.7	2.6	3.3
Macaranga	7.9		1.7
Maniltoa	2.1		
Medusanthera	3.6		
Myristica	6.4	2.6	6.7
Nauclea	0.7		5.0
Neonauclea		46.2	
Octomeles sumatrana	2.9		
Palaquium	0.7		
Pimeleodendron amboinicum			8.3
Pisonia	2.9	2.6	
Pittosporum	0.7		
Polyalthia oblongifolia			1.7
Pometia pinnata	10.0		1.7
Pterocarpus indicus	1.4	5.1	13.3
Pterocymbium	0.7		
Rhus titensis	1.4		
Semecarpus			3.3
Sloanea	0.7		
Sterculia			1.7
Syzygium	0.7	2.6	
Terminalia	4.3	5.1	8.3
Tristiropsis	3.6		
Vitex cofassus	0.7		
Vitex quinnata			5.0
Other	1.0	5.1	11.7

APPENDIX B

Inventory data Gabensis, 1994. 5.7 ha of seasonally inundated alluvial rain forest. Frequent distribution by size class.

SPECIES	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	>100	TOTAL
	DBH-CLASSES (cm)										
Aglaia	8	8	4								20
Aleurites			2								2
Alstonia chinensis	2		8	1							11
Anthocephalus	8	16	10	6	2			1			43
Artocarpus	10	2	10	1	2		1				26
Bischofia				1						1	2
Buchanania	6			1	1						8
Calophyllum	4	2									6
Campnosperma	4	2	4	3		1		1			15
Cananga	8	8	8	4							28
Canarium	10	4	4	3	2	1	1				25
Celtis	12	10	8	4	3						37
Cerbera		2	2	1							5
Chisocheton	2	2	2		2						8
Chrysophyllum		2									2
Cryptocarya		6				1					7
Dendrocnide	10		2								12
Diospyros		2									2
Dracontomelon			2	1	3	1	1	1	2	1	12
Dysoxylum	8	2		1	1						12
Elaeocarpus	2		4								6
Endospermum	4	6									10
Euphorbiaceae		2									2
Evodia	2	2									4
Ficus	26	2		1			1	1			31
Garcinia	6	4		1							11
Gardenia	2										2
Glochidion	2	2	2								6
Gnetum gnemon	4	4									8
Gordonia	2										2
Hernandia	4										4
Hibiscus	2	2	4								8
Homalium	2						1				3
Horsfieldia	12		4								16
Intsia bijuga		2	2	2	1	2	1				10
Kingiodendron	2	4									6
Litsea	8	12	4	1							25
Macaranga	50	32	6								88
Maniltoa	4		2	1							7
Maranthis		2									2
Medusanthera	8										8
Miscellaneous	14	6		1	1						22
Myristica	64	56	26	10	3	1				1	161
Nauclea	6	2	2	3	2	1					16
Neonauclea					2		1				3
Octomeles sumatrensis	2	4			2					3	11
Palagquium				1							1
Pimeleodendron	18	14	12	1							45
Planchonia		2									2
Planchonella	2	4		1			1				8
Polyalthia			4	2	4			1			11
Pometia pinnata	26	30	40	18	8	7	4	2	4	1	140
Protium	4					1					5

Appendix B continued

SPECIES	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	>100	TOTAL
	DBH-CLASSES (cm)										
Pterocarpus	2			3	2	2		4	1		14
Rubiaceae			2								2
Semecarpus	4										4
Sloanea	6	6	2		1	1	2		1		19
Sterculia	14	8	8	2	2						34
Syzygium	4	2		1	1						8
Terminalia	8	8	2	6	3	1		2		1	31
Thespesia	22										22
Vitex		2		1	1	2	1			3	10
TOTAL	430	286	194	83	49	22	15	13	8	11	1111

THE POPULATION DYNAMICS OF THE BORER, *SESAMIA GRISESCENS* WALKER (LEPIDOPTERA: NOCTUIDAE), ON SUGARCANE IN THE RAMU VALLEY OF PAPUA NEW GUINEA.

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ABSTRACT

*The top borer, **Sesamia grisescens**, is a serious pest of sugarcane at Ramu, Papua New Guinea. Borer populations were sampled at the Ramu Sugar plantation for 147 weeks, from 1986 to 1989. Populations increased during the North West monsoon and declined during the drier part of the year. Life stages were strongly synchronized during the period of study and this was attributed to nitrogen boost to the population at the start of the North West Monsoon. Additionally, a field trial showed a strong correlation between rates of nitrogen applied and percent stalks bored by **S. grisescens**. From the available evidence, natural enemies exerted little control over borer populations, however discrete life stages provide scope for augmentative releases of natural enemies in the future.*

Key Words: *Sesamia, Sugarcane, Nitrogen, Natural enemies, Life stages.*

INTRODUCTION

The sugarcane borer, *Sesamia grisescens* Walker (Lepidoptera: Noctuidae), is known from mainland Papua New Guinea (PNG) and offshore islands (Szent-Ivany and Ardley 1962; Bourke 1968; Anon 1969; Bourke *et al.* 1973). Adult females lay their eggs beneath the sheaths of younger leaves of the sugarcane stalk, after hatching the larvae bore into the terminal internodes of the stalk where they feed gregariously. Larval feeding eventually results in the death of the apical meristem causing a characteristic deadheart. *S. grisescens* will attack sugarcane at any stage of growth. There are 7 larval instars and the final instar pupates within the sugarcane stalk. The mean time from egg to adult is 60 days (Young and Kuniata 1992).

Sugarcane, *Saccharum officinarum*, is the main host plant, although the wild pit pits *Saccharum robustum* and *S. spontaneum* are also attacked and destroyed by Ramu Stunt disease (Eastwood 1990). As a result 4,700 hectares had to be planted with disease resistant varieties in the last half of 1986. Over 4,000 hectares were planted to variety Cadmus. This plant crop was severely damaged by *S. grisescens* between January and June 1987 (Kuniata and Sweet 1991; Young and Kuniata 1992). Studies on the population dynamics of the borer were started in order to predict future outbreaks and formulate control measures.

Sugar grown at Ramu is rainfed with the growing season extending from November to May during the North West monsoon. Fields are planted to a plant crop followed by 2 ratoon crops. Harvesting, planting and ratooning is carried out continuously between June and November. The time from planting or ratooning to harvest is 11 to 13 months.

MATERIALS AND METHODS

Ninety fields were sampled for borer life stages each month. The estate was divided into 9 sections with 10 fields being selected at random from each section. Individual fields were sampled by selecting 20 rows at random and then cutting 9 stalks systematically from each row, making a total of 180 stalks per field (Elliott 1977). The sugarcane sampled ranged

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in age from 6 weeks to 48 weeks.

Stalks were cut longitudinally with a knife and the numbers of larvae and pupae recorded, additionally the terminal leaves were examined for the presence of egg masses (Young and Kuniata 1992). A subsample of each life stage was returned to the laboratory for parasite emergence. Numbers of adult borers were estimated by means of 3 light traps, each consisting of a fluorescent black light and 2 m X 2 m calico sheet. The traps were separated by a distance of 2 kms. The work was carried out between July 1986 and May 1989.

A trial was established on a plant crop during 1988 to determine the response of *S. grisescens* populations to varying rates of nitrogen fertiliser. There were 6 treatments, with urea applied at 0, 30, 60, 90, 120 and 150 Kg N/ha and 3 replicates of each treatment. At harvest 50 stalks were cut at random from each plot. Stalks were split open with a knife and scored for *S. grisescens* damage. Leaf 4 was sampled from 5 stalks per plot, taking the spindle as leaf 1. The leaf samples were analysed for total nitrogen using the Kjeldahl method.

RESULTS

Over the 147 weeks of the study populations of *S. grisescens* started to increase with the onset of the North West monsoon and declined during the drier part of the year (Figs. 1 & 2). Numbers of larvae peaked during May 1987, August 1988 and May 1989, while pupal numbers peaked during April 1987, July 1988 and June 1989. The populations showed strongly synchronized or discrete life stages (Fig. 3). The exception was the period between late October 1987 and mid March 1988, where populations were too low to detect any changes. This period was preceded by the worst drought on record at Ramu when only 13 mm of rain fell between mid May 1987 and the first week of October 1987. The period between population peaks ranged from 7 to 10 weeks for larvae and 5 to 11 weeks for pupae. This is in broad agreement with Young and Kuniata (1992), who reported a generation time of 7 to 11 weeks in the field. Egg masses ranged from 0 to 5.2 per 100 stalks and zero counts were recorded for 80 of the 147 weeks. The light traps were ineffective in estimating the adult population recording zeros in most of the 147 weeks.

Two species of parasitoids, *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) and *Enicospilus* sp. (Hymenoptera: Ichneumonidae), as well as an entomogenous fungus *Beauveria* sp., were recorded from *S. grisescens* larvae. Parasitism by *C. flavipes* ranged from 0 to 68 percent and a mean parasitism of 12 percent per month with larval numbers and percent parasitism being statistically unrelated (Fig. 4). During June 1988 parasitism by *Enicospilus* sp. reached 10 percent but the mean monthly parastism was less than 1 percent, with zero parasitism recorded for 16 months. Up to 2 percent of larvae were attacked by *Beauveria* sp. No parasites were recorded from either eggs or pupae, although there was evidence of egg predation.

The earwig, *Chelisoches morio* Fabricius (Dermaptera: Chelisochidae), was recorded feeding

Table 1. **Effect of nitrogen on stalk damage by *S. grisescens*.**

Kg N per Hectare	Percent foliar N	Percent stalks bored by *S. grisescens*
0	2.08	61.4
30	2.13	62.5
60	2.44	65.2
90	2.43	73.0
120	2.53	76.1
150	2.50	80.4

on early instar larvae. The nitrogen fertiliser trial showed that the proportion of stalks bored increased with increasing rates of nitrogen applied per hectare (Table 1). There was a highly significant positive correlation between percent stalks bored by *S. grisescens* and rates of nitrogen applied ($r = 0.98$, $p < 0.001$. $df = 4$, $Y = 59.5 + 0.14X$). Additionally, there was a significant correlation between percent foliar nitrogen and rate of nitrogen ($r = 0.90$, $p < 0.05$, $df = 4$, $Y = 2.1 + .003X$), however the correlation between percent stalks bored and percent foliar nitrogen was not significant correlation between percent foliar nitrogen was not significant.

DISCUSSION

The synchronized life stages of *S. grisescens* as well as the relationship between high populations and rainfall point to fluctuations in the nutrition of the borer. Phytophagous insects have a high protein content yet the host is predominantly composed of carbohydrate (Norris 1991). Spectacular increases in populations of phytophagous insects are often associated with increased levels of available nitrogen (McNeill and Southwood 1978; White 1969 and 1978). McNeill and Southwood (1978) view this nitrogen boost to phytophagous populations as a rise in the rate of increase due to higher growth rates, survial or reproduction or a combination of all three. Setamou *et al.* (1993), working with *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) on maize, found that the intrinsic rate of increase and net reproductive rate were positively related to leaf and stem nitrogen. Our data on increasing rates of nitrogen suggests a similar response for *S. grisescens* on sugarcane, although the lack of a significant correlation between leaf nitrogen and *Sesamia* damage suggests that leaf nitrogen might be a poor indication of stalk nitrogen in sugarcane.

Rapidly multiplying meristematic tissues are usually high in soluble nitrogen, that is amides and amino acids (McNeil and Southwood 1978). *S. grisescens* larvae feed predominantly in the soft internode tissue of the sugarcane stalk, just below the meristem (Young and Kuniata 1992). When the sugarcane stalk is growing rapidly the nitrogen content of the meristematic and surrounding tissue would be higher than at times of slow or no growth. It is reasonable to conclude that *S. grisescens* populations would be sensitive to changes in the nitrogen content of this tissue.

The start of the North West monsoon would initiate an increase in cane growth and the nitrogen content of stalk tops. Eggs laid at this stage would produce a generation of larvae with a high rate of growth and survival by comparison with larvae born during the preceding dry months. It is probable that the generation of larvae which fed on enchanced levels of nitrogen was the start of a series of discrete generations which continued throughout the growing season (Figs. 1 & 2).

It could be argued that harvesting the crop was the reason for the population crashes during the dry season, by removing the borer's food source. This is an unlikely explanation, since *S. grisescens* can attack cane at any age and harvesting removes the crop over 5 months as well as overlapping with planting and ratooning (Young and Kuniata 1992). Therefore borer populations would not have run short of food.

From the available evidence natural enemies made little impression on borer populations over the period of study. The most important parasite was *C. flavipes*, however the level of sampling was not sufficient to allow an accurate assessment of its contribution to larval martality. *C. morio* has been recorded feeding on eggs and larvae of *S. grisescens* in the laboratory but its importance in the field is not known (unpublished data).

The data points to a nitrogen induced increase in population growth allowing borer populations to escape the controlling effects of natural enemies (McNeill & Southwood 1978). Additionally, discrete generations present problems for parasites in as much as the relevant host stage may not be available when the female parasite is ready to oviposit. Discrete generations do however allow scope for augmentative releases of laboratory reared parasites when the target host stage is abundant.

Further research is required on the influence of natural enemies on borer populations at Ramu, in particular the construction of life tables.

Prior to 1986, 90% of the estate was planted to variety Ragnar and, while *S. grisescens* was always present populations never reached the levels found on variety Cadmus during the first half of 1987. It may be that Cadmus is a more favourable host to the borer than Ragnar. The susceptibility of different varieties of sugarcane to attack by *S. grisescens* requires further investigation.

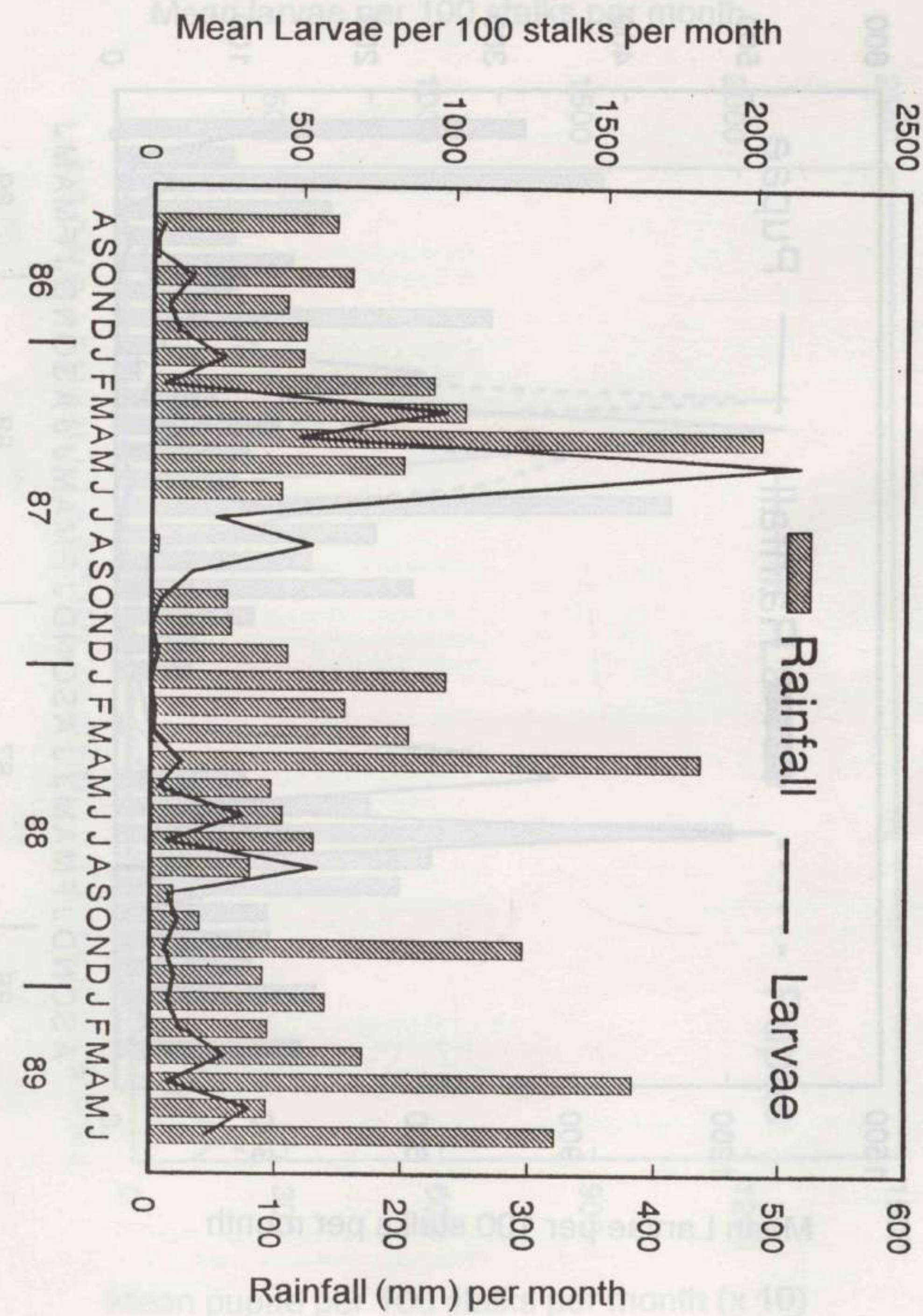


Figure 1. **Numbers of *S. grisescens* larvae and monthly rainfall, August 1986 to June 1989.**

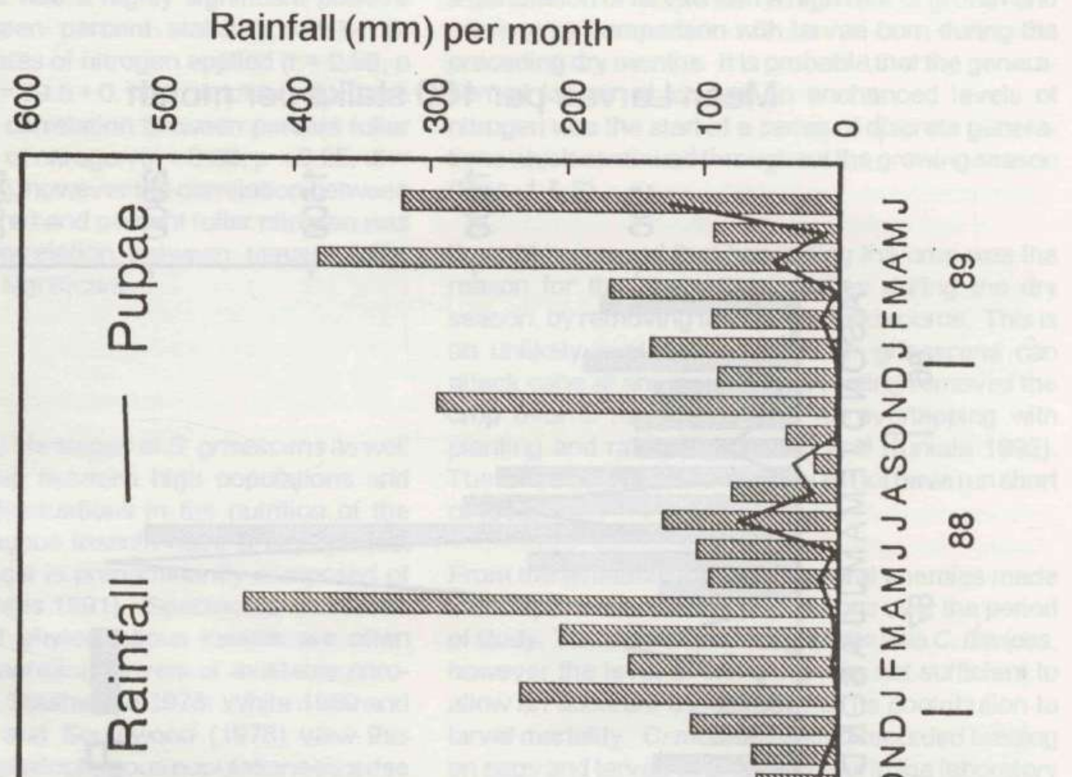


Figure 2. Numbers of *S. grisescens* pupae and monthly rainfall, August 1986 to June 1989.

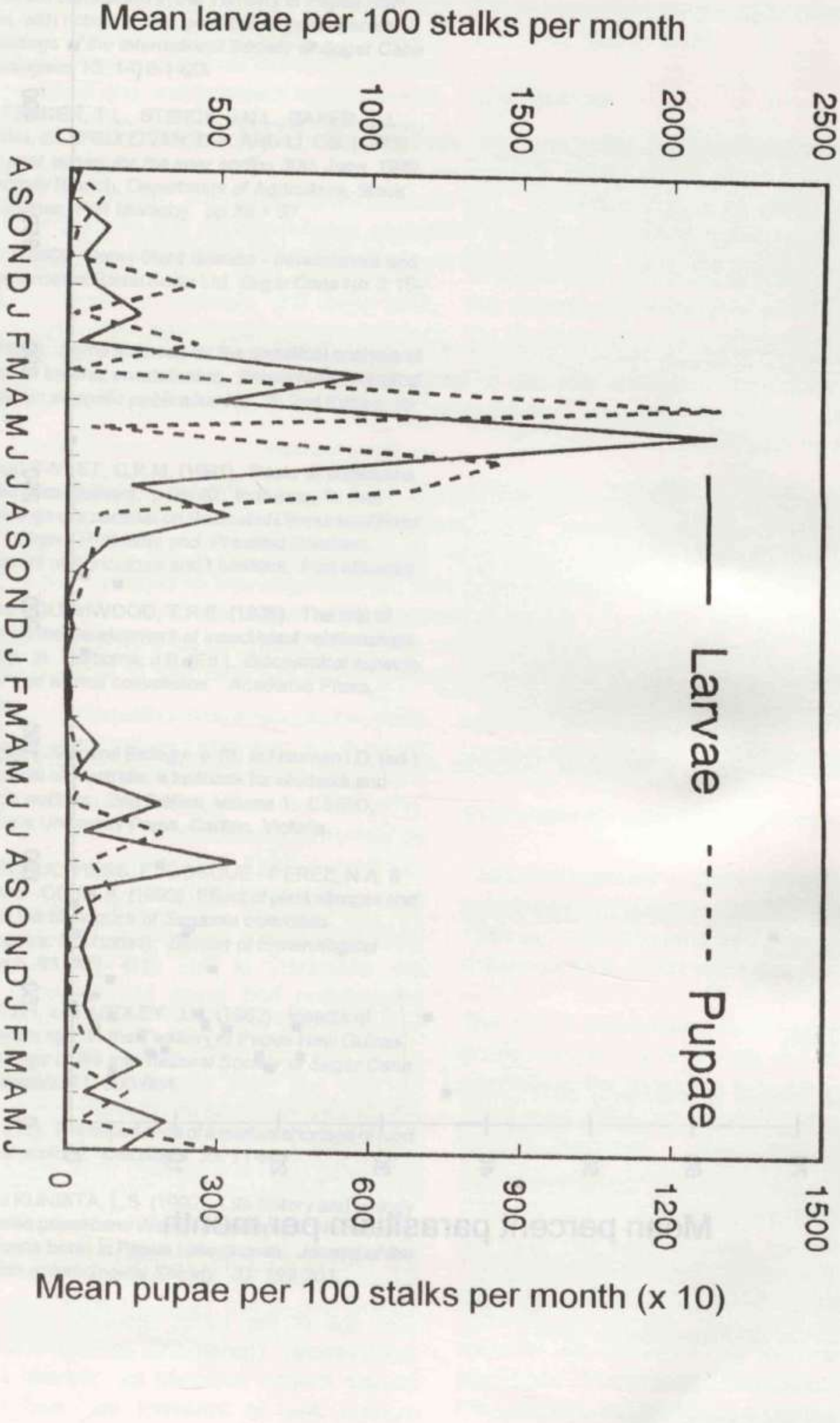
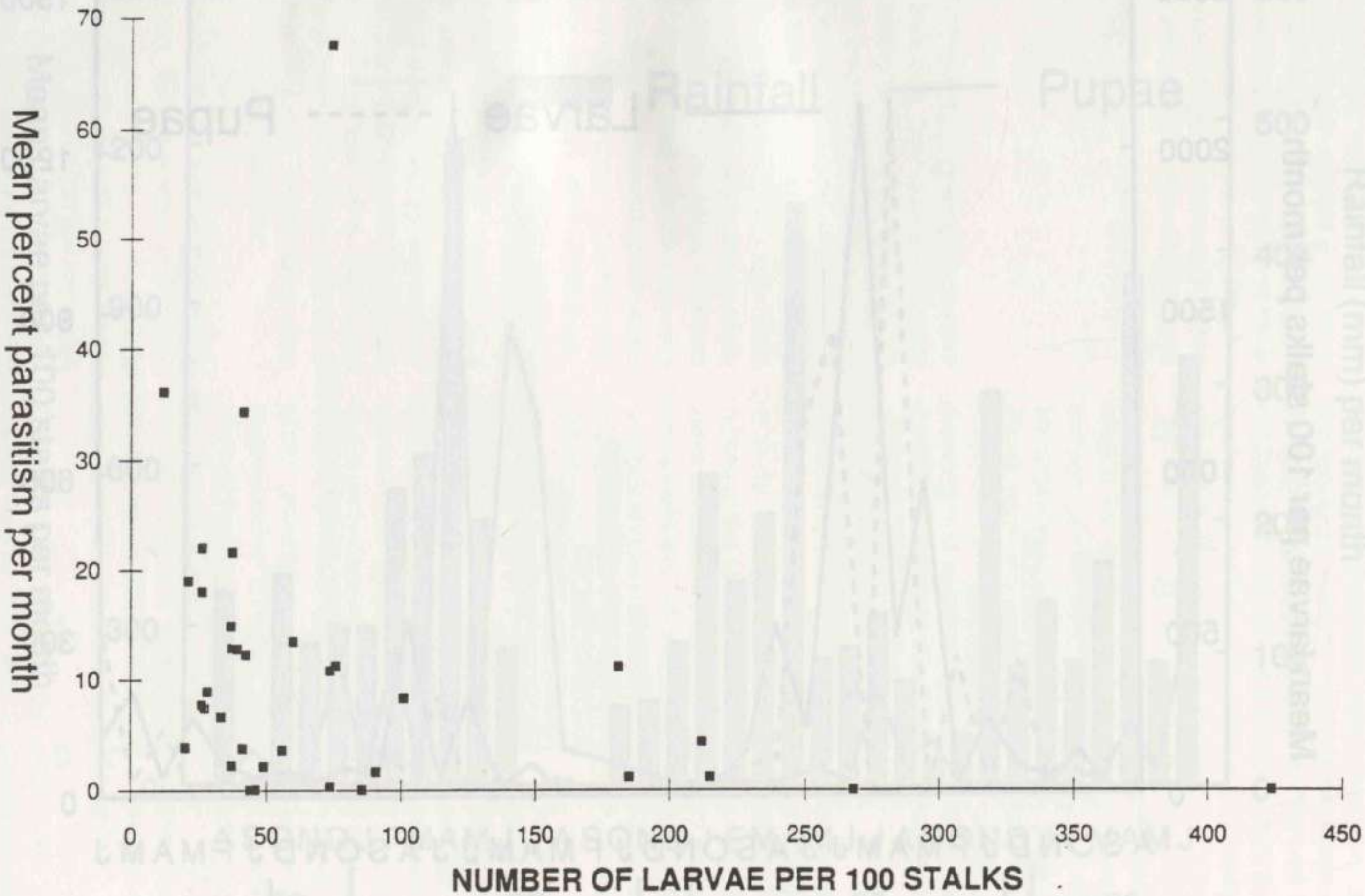


Figure 3. Numbers of *S. grisescens* larvae and pupae, August 1986 to June 1989.

Figure 4. **The relationship between the density of *S. grisescens* larvae and parasitism by *C. flavipes.***



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A REVIEW OF PROPERTIES, NUTRIENT SUPPLY, CULTIVATION AND MANAGEMENT OF VOLCANIC SOILS, WITH PARTICULAR REFERENCE TO PAPUA NEW GUINEA.

Matthew B. Kanua[1]

ABSTRACT

Soils derived from volcanic ash are called andisols. Andisols have good physical properties and are able to resist erosion because of the stable nature of dominant clay minerals such as allophane in them. However, they have a poor ability to supply nutrients. The dominance of allophane, allophane - organic matter complexes, and dependency of cation and anion exchange mechanism on soil pH contribute to the poor chemical fertility of volcanic ash soils. Such features give peculiar characteristics to andisols and make their management difficult.

Intensive weathering of the ash on volcanic soils has resulted in losses of Si and bases. Si may combine with Al or Fe to form allophane, imogolite, gibbsite or halloysite, depending on the stage of weathering and prevailing climates. These clay minerals form complex associations with organic matter, and together they influence the charge characteristics of andisols.

The review of research on this soil type indicates that the principle constraints to agricultural production are likely to be imposed by chemical properties. The specific chemical problems of weathered andisols are high P-fixation, low pH, low available K, Mg, Ca, low BS(%), low ECEC, deficient B, Mo, Zn and suboptimal levels of Mn, Cu and Fe. The evidence is overwhelming that the management of organic matter is the key to sustaining agriculture on this soil type. It results in increasing the magnitude of the negative charged sites, enhances the ECEC, supplies a wide range of macro and micro nutrients, as well as maintaining the soil physical and chemical fertility. The review identifies pitfalls in the management of andisols and discusses practical and cost effective ways of tackling them.

Keywords: *Papua New Guinea, Andisols, Volcanic ash soils, Organic matter, Soil fertility management*

A. PROPERTIES AND NUTRIENT SUPPLY IN VOLCANIC SOILS

1.0 INTRODUCTION

A comprehensive review of research on Central American volcanic soils going back to the 1960s was carried out by Sanchez (1973). Since that review there have been quite significant advances in the understanding of the chemistry and behavior of this soil type. A significant development has been the advancement in the classification of this soil type, previously within the Order inceptisols (Sub order andepts), to the Order andisols (Wada 1985).

The bibliography shows that many scientific man years of research have been invested in the study of the chemistry of this soil type but little of this information has been translated to appropriate management practices. Therefore it has been the aim of this work to review research conducted so far on this soil type with the objective of deriving management practices relevant and suited to Papua New Guinea (PNG) where a significant proportion of cultivated soils are derived from volcanic ash.

2.0 THE VOLCANIC ASH SOILS OF THE TROPICS

The soil is the basic resource base of farmers everywhere. Constraints to food production in the tropics maybe imposed by climatic conditions, or maybe due to inherent soil and management

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problems. Ash derived soils are reported not only to sustain some of the tropics most productive and stable agricultural systems, but also support heavy densities of human and animal populations (Oades *et al.* 1989). The capacity of these soils to supply nutrients for sustainable agriculture seems to differ amongst different ash derived soil types. It is essential that constraints and/or beneficial attributes of andisols are reliably identified and understood if optimum and sustainable production is to be obtained from them.

2.1 Soil Taxonomy

Ten Soil Orders were proposed and used in the USDA soil classification system. Soils derived from volcanic ash are known as andisols, and these until the 1980s were within the Order inceptisols (Suborder andepts). Recent developments in soil classification have led to raising andepts to Order level of andisol (Wada 1985). Hereafter, andisol is used to encompass Great Group soils of volcanic origin currently under inceptisols because the andisol nomenclature at Great Group level has not been formally ratified. Andisols and volcanic ash soils (VAS) are used interchangeably throughout this report.

2.2 Distribution of Andisols in the Tropics

Andisols are associated with volcanic eruptions which occurred many thousands of years ago. Each has a localised distribution but overall they are geographically widespread throughout the world (Fig. 1). Their generalised area distribution relative to other major tropical soils is given in Table 1. Andisols occupy 43 million hectares (ie. 0.86%) of total tropical soils (Table 1), and about 124 million hectares (0.84%) of the world land surface (Leamy *et al.* 1981).

A significant proportion of cultivated soils of tropical America, the Caribbean, Columbia, Peru, Ecuador, Bolivia, Japan, PNG, New Zealand and Indonesia are derived from volcanic ash. A review of the distribution of andisols in other parts of the world is given elsewhere (Leamy *et al.* 1981). The distinctive properties of different types of ash derived soils are primarily a function of the climates under which the soil is formed. VAS of the drier tropics differ in parent materials and geologic age, and are formed under extreme climates than those of the humid tropics (Wada 1985; Mitzota & Chappelle 1988).

2.3 Distribution of Andisols in PNG

Figure 2 shows the distribution of andisols in PNG. This soil commonly occurs in association with other major soil types (Bleeker 1983). The following distributional grouping maybe generally made at the soil Great Group level.

Andaquepts

Andaquepts are volcanic soils formed under poorly drained conditions which have limited landuse potential. They are also relatively rare in occurrence but are found in a wide variety of climates and at altitudes from sea level to 2000 m. In the highlands this soil may be associated with hydrandepts and on the lowlands they may grade into both eutrandepts and dystrandepts (Bleeker 1983).

Vitrandepts and Durandepts

These are typically lowland soils near active volcanoes. They are in their early stages of soil formation and are least weathered, dominant in sand, weakly acid, and with bulk densities higher than 0.8g cm^{-3} (Wada 1985). Vitrandepts occur extensively on Northern, New Ireland, New Britain and Madang provinces (Karkar Island). These soils are highly susceptible to erosion. Durandepts have a limited distribution on New Guinea mainland and coastal areas (e.g Madang province).

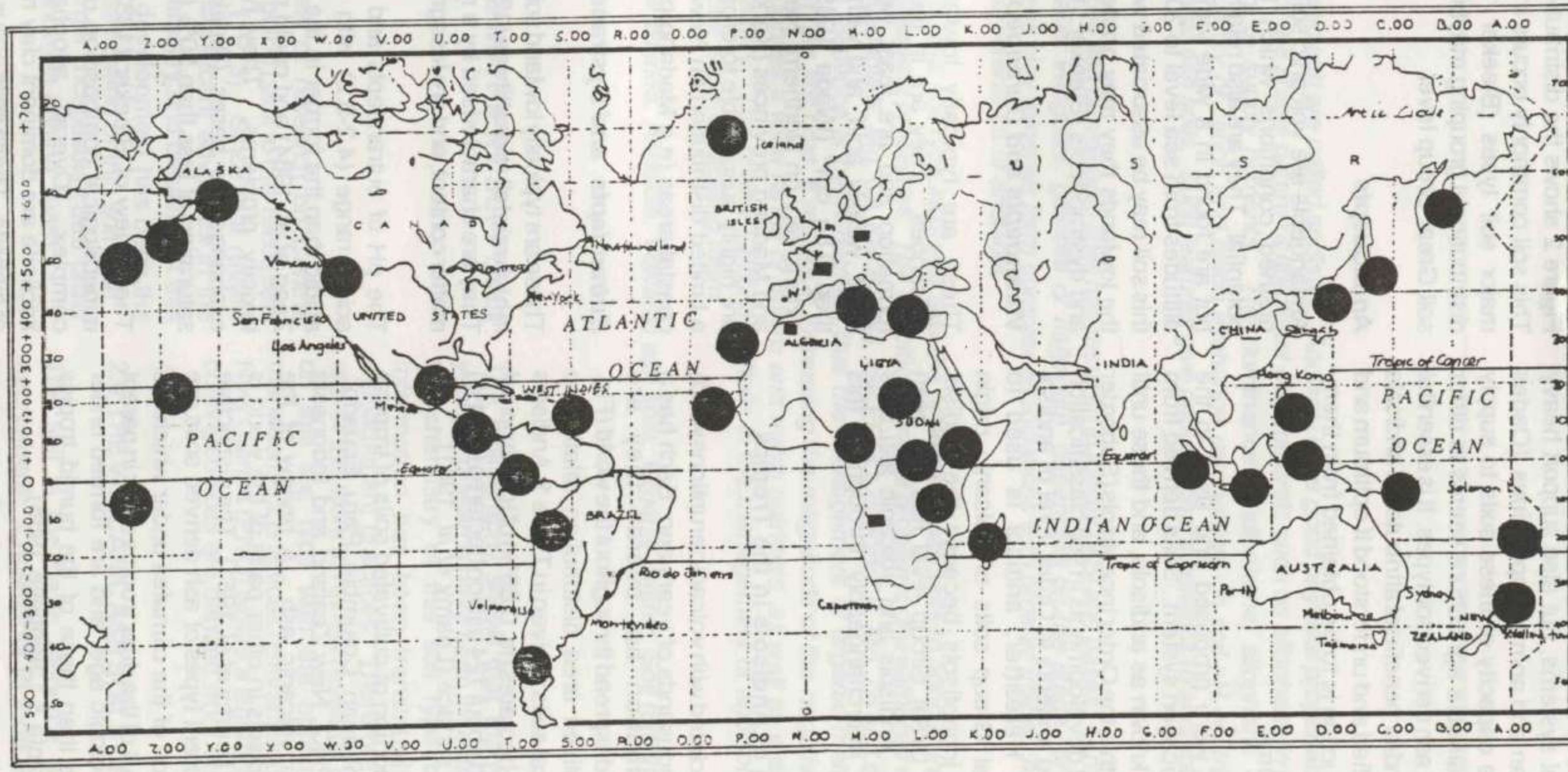
Eutrandepts and Dystrandepts

These are typically lowland soils but occur extensively in high rainfall mid-altitude (1200-1500 m.a.s.l) areas. They are characterised by a medium to high organic matter content, and are less gravelly than vitrandepts.

The pH of eutrandepts and dystrandepts is in the acidic range (4.2-5.2) with the latter being more acidic than the former in the upper profiles (Vander Zaag *et al.* 1984) and could pose serious Al and Mn toxicity problems. They have low to moderate exchangeable bases (Bleeker 1983) and a base saturation of less than 50% (Wada 1985).

The review of Bleeker (1983) shows that the clay mineralogical composition of these soils are quite complex. Overall, allophane, halloysite and/or kaolinite are dominant clay minerals with low levels of gibbsite. These soils occur mainly on Bougainville, New Britain and Northern province in the lowlands,

Figure 1. **Map of the worldwide distribution of Andisols (Scource: Norman et al, 1984).**



Areas of major occurrence are indicated by circles, and those of minor occurrence by squares.

Table 1: **Generalised distribution of soils in the tropics**

Soil Associations dominated by	Tropical America (m/ha)	Tropical Africa (m/ha)	Tropical Asia (m/ha)	Tropical Australia (m/ha)	Total (m/ha)	Proportion of tropics (%)
Oxisols	502	550	15	-	1067	21
Ultisols	320	135	286	8	749	15
Entisols	124	300	75	93	592	12
Alfisols	183	550	123	55	911	18
Inceptisols	240	156	169	3	532	11
Vertisols	20	46	66	31	163	3
Aridisols	30	704	23	33	790	16
Mollisols	65	-	9	0	74	2
Andisols	31	1	11	0	43	1
Histosols	4	5	27	-	36	1
Spodosols	10	3	6	1	20	-
TOTAL	1493	2450	810	224	4977	100

Source: Norman *et al.* (1984)

and Southern and Simbu provinces in the highlands. Despite P-fixation being a major constraint, much of the cocoa, oil palm and robusta coffee is produced on these soils and on vitrandepts.

Hydrandepts

Hydrandepts are the dominant highland soils and occur in high rainfall areas between 1500-3000 m.a.s.l. These soils are highly weathered and devoid of silicates.

They are characterised by high organic matter (OM) content with concomitant high C/N ratios (>15) and low bulk densities. Moisture content of these soils rarely falls below field capacity. The pH ranges from 4.5-5.5, but is not associated with the usual Al and Mn toxicity problems encountered by other soil types at these range of pH. Exchangeable bases are low.

Allophane, gibbsite and to a lesser extent halloysite are the dominant clay minerals in hydrandepts (Bleeker 1983). P-fixation is high resulting in widespread P-deficiency. Hydrandepts occur throughout the highland provinces occupying a total of some 25,000 km^2 (Radcliffe 1985) and sustain heavy human and livestock populations and agricultural activity. Harding (1984) listed hydrandepts as a common arabica coffee soil above 1500 m.a.s.l in PNG.

3.0 PROPERTIES OF ANDISOLS

3.1 Clay Mineralogy

Allophane, Imogolite, Gibbsite and Halloysite

The climates of the humid tropics favours rapid weathering. Andisols are developed from the weathering of ash which was deposited from volcanic eruptions many thousands of years ago. The weathering results in the loss of silicon and bases by leaching and in the accumulation of active Al and Fe in the weathered products (Wada 1985). The active Al combines with Si in the absence of OM to form different classes of non-crystalline and crystalline minerals. The dominant and most important are allophane, imogolite, gibbsite and halloysite (Wada 1985; Wada 1981; Parfitt 1978; Tan 1981). In the presence of OM, a strong bonding is formed between Al and humus (Wada 1981; Tan 1981). These materials have distinctive effects on chemical and physical properties of andisols.

Allophane and imogolite are non-crystalline aluminosilicates, which are formed under similar conditions. They are found in lower horizons where OM is deficient or low (Wada 1985). Once allophane is formed it has a high affinity for OM and interacts with it to form organic complexes which resist decomposition and result in the accumulation of organic materials in VAS. Allophane influences the charge characteristics of andisols. In the absence of

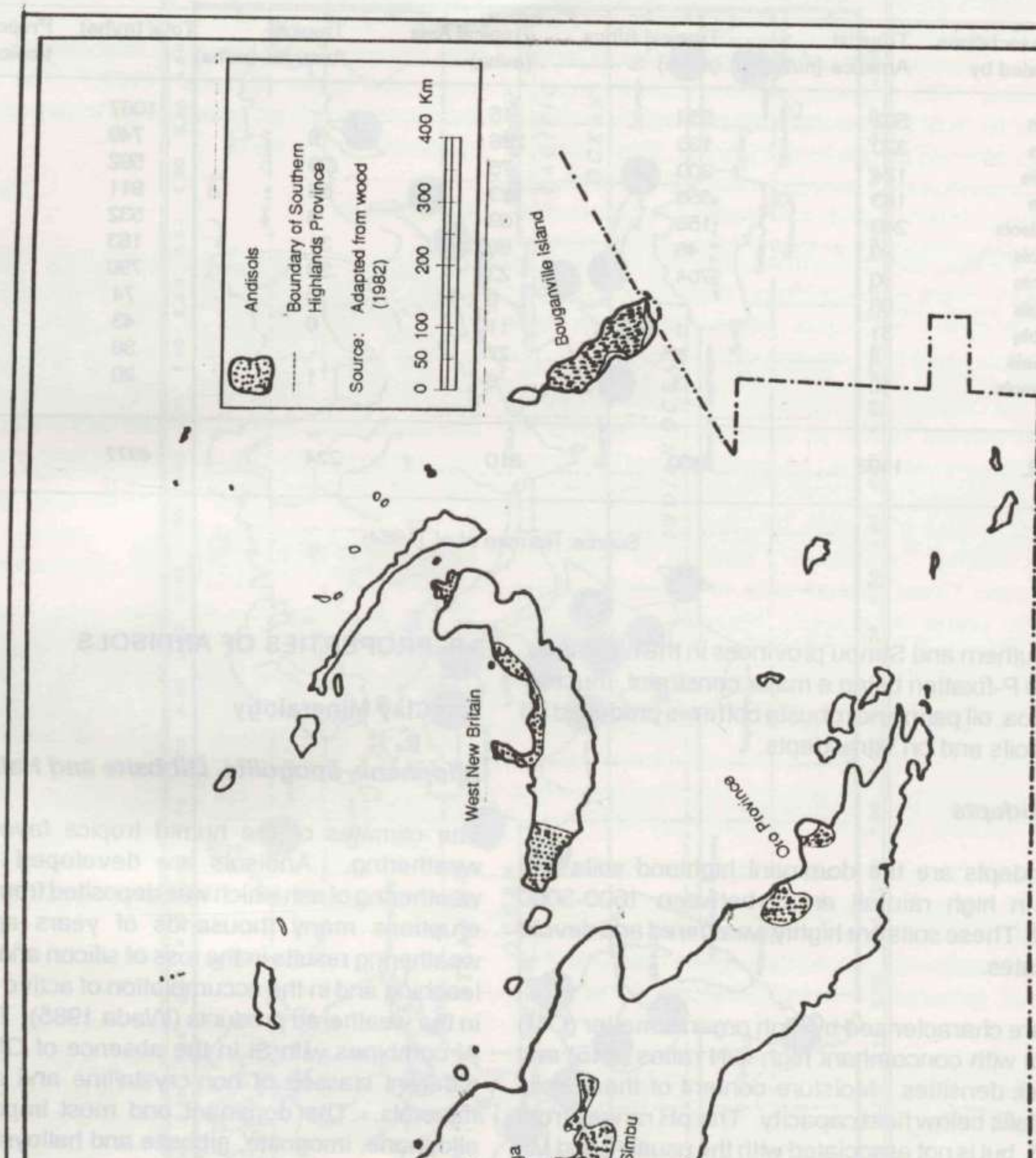


Figure 2. **Distribution of Andisols in Papua New Guinea. (Source: Radecliffe, 1985).**

allophane and imogolite, especially in the high rainfall tropical areas, Al and Fe hydroxides may be abundant (Wada 1985). This may result in an abundance of gibbsite relative to other clay minerals because it is formed of Al and Fe oxides (Tan 1981). Alternatively, the Al may form complex associations with OM, if present. In the warmer lowland tropics halloysite is plentiful because allophane is short lived and is transformed to halloysite (Wada 1985). Such transformation from the allophanic to the halloysitic stage can take upto 15,000 - 30,000 years (Carating 1991).

Little or no halloysite may be present in the high rainfall highland areas. Both gibbsite and halloysite are important clay minerals in highly weathered VAS. An abundance of halloysite usually represents either an advanced stage of weathering or a mixing of non-ash materials (Mitzota & Chapelle 1988). The coexistence of gibbsite and allophane in PNG andisols is documented by Bleeker (1983), Radcliffe & Gillman (1985) and Chartres *et al.* (1985).

In one study the presence of amorphous and poorly crystallised clay materials made mineralogy tracing and its interpretation difficult in some PNG soils (Bleeker 1983). Despite this, other data seem to suggest a distinct altitudinal differentiation in the distribution of allophane, imogolite, gibbsite and halloysite in PNG andisols (Chartres *et al.* 1985; Radcliffe and Gillman 1985). Allophane dominates highland soils (>2000 m), gibbsite between 1200-2000 m and halloysite those below 1200 m. The presence of imogolite, relative to other minerals is not well established. In highland hydrandepts, the order of dominance is allophane > gibbsite > halloysite. This is comparable with a lowland (540 m) typic hydrandept in West Java where weathering resulted in mixed gel > allophane > imogolite > gibbsite in that order of mineralogical dominance (Goenadi 1991). The special properties of VAS are a consequence of the properties of these clay minerals and they determine the soil electric charge and influence the physical and chemical properties of VAS.

3.2 Physical Properties

A good description of the physical properties of volcanic soils rich in allophane is given by Carating (1991) and Leamy *et al.* (1981). Typically, andisols have deep dark to very black top soils. In humid tropical climates the colour may be less dark but more dark brown to dark-red brown. The dark black colour is derived from the ash which is predominantly black. The A horizon is often deep (> 100 cm) and associated with high OM levels (>70%), thus making this profile humus rich, with excellent physical properties. The soil is well structured, friable and easy to work (Radcliffe 1985).

The high OM level in the A horizon is a special and important feature of andisols (McMahon 1987). This has resulted in other distinctive properties such as high C/N ratios (15-20), low BD (0.4 - 0.7g cm^{-3}) and very high CEC (Leamy *et al.* 1981). A particular characteristic is the water holding capacity of andisols, which can be twice that of more common tropical soils, with the water held at considerably lower tensions than most (Sanchez 1976).

Most of PNG highland soils form under freely drained moisture conditions (Radcliffe 1985). Wallace (1971) reported field moisture contents of highland VAS to be in the range 80-190%. He also reported that the effects of drying these soils resulted in an irreversible change in structure and plasticity, implying that the soil is vulnerable to permanent structural damage if a bad drought is experienced.

The B horizon is often brown to yellowish brown in colour. Subsoils are also often friable and permeable, but weakly structured (Radcliffe 1985). The presence of imogolite in andisols is thought to be associated with the puffy, loose, very soft and often extremely friable nature of subsoils, inspite of the high moisture holding capacity of this soil (Leamy *et al.* 1981).

Allophane is naturally stable. Its association with OM results in high aggregate stability, good infiltration in the top soil and high permeability in the subsoil. These properties are said to give andisols resistance to erosion (Leamy *et al.* 1981; Sanchez 1976; Wada 1985). Despite the good structural stability, there is a critical limit beyond which exposure to heavy pressure and compaction, can result in structural deformation and change in strength (Leamy *et al.* 1981). Studies in USA on a VAS heavily compacted by machinery in logging operations have confirmed significant impairment to soil structure and increased bulk density (Geist *et al.* 1989). This implies that the potential for intensive mechanised agriculture on volcanic soils may be limited.

3.2.1 Bulk Density (BD)

Except for young VAS of vitric nature (eg vitrandepts), the usually quoted range of BD (0.4-0.7 g cm^{-3}) for VAS are the lowest of all soils. The high OM content is responsible for high porosity, and the relative lightness of this soil type results in a low BD.

3.2.2 Organic matter

The organic components of soils originate from above and below ground biomass. The breakdown of this biomass is influenced by the quality or nature of the material, soil temperature, moisture, soil acidity, soil microbial population, and in agricultural systems, human and animal activity. In most tropical ecosystems the OM in the soil is rapidly attacked by micro-organisms and depending on N supply, is subject to quick decomposition and mineralisation. Hence, OM is a reservoir for N, P, K, S and other macro and micro nutrients.

In tropical VAS it seems temperature, in particular diurnal fluctuations in soil temperature, moisture and clay mineralogy (Wood 1989) have a more profound effect on soil microbial processes and significantly affect OM breakdown and mineralisation. The literature agrees on some basic facts of OM breakdown. These are (i) OM accumulates to high levels in the cool highland environments of the tropics, and decreases with increased temperature (Wada 1985; Yoo 1984; Goh 1981); (ii) the activity of soil fungi, actinomycetes and other micro-organisims decreases with increased altitude, resulting in an extraordinary build up of immobile OM in the upper profiles of VAS (Tate & Theng 1981; Lozoane *et al.* 1974, cited by D'Souza 1986). OM in this form is complexed with allophane and Al, and becomes resistent to microbial decay (Tate & Theng 1981; Oades *et al.* 1989; Goh 1981), and (iii) low temperatures, low micro faunal densities and high levels of OM in complex associations are suggested to interact in ways which lowers and/or inhibits OM mineralisation and hence nutrient supply to crops.

Soil carbon and N mineralisation rates for soils high in clay and allophane was reported lower than other soils which lacked these materials (Goh 1981; Sanchez 1976; Vander Zaag *et al.* 1984; Oades *et al.* 1989). The actual cause of OM resistance to microbial decomposition remains unknown. It is generally attributed to at least three main causes and represents fertile areas of research (Tate & Theng 1981, Goh 1981):

1. Micro-organism inactivity due to aluminum toxicity.

2. The complex OM - allophane bonding makes OM inaccessible to extracellular enzymes and decay organisms. This may come about either because OM is entrapped within clays, or because clay minerals have a range of effects on microbial processes in soils (Wood 1989; Goh 1981; Vander Zaag *et al.* 1984).

3. Reactive sites on OM are inactivated, probably due to formation of coatings over organic compounds.

The formation of complex associations between allophane and OM constituents is a phenomenon common in andisols, and is said to influence soil electric charge.

3.3 Chemical Properties

3.3.1 Charge characteristics & pH

On permanent or constantly charged soils, the electric charge on the soil surface of soil clay particles arises from isomorphous substitution of ions, as occurs when Mg^{2+} replaces Al^{3+}. The soils under review are called variable or pH-dependent charged soils, such as those derived from volcanic ash.

For these soils the charge at which the positive (H^+) ions equal negative (OH^-) ions is called the **Point of Zero Net Charge (PZNC)** (Fig.3). The pH determined here is called the pH at Zero point of charge (pHo). The difference between pHo and field pH (i.e pHo-pH) determines not only the actual net charge of the soil, but also the magnitude of that charge (Radcliffe & Gillman 1985). Hence, at low pH (acidic conditions), andisols exhibit net positive charge and at high pH (alkaline conditions) they exhibit net negative charge (Sanchez 1976). A decrease in soil pH and ionic concentration will result in a corresponding decline in exchangeable bases in andisols. For andisols pHo is often lower than the field pH, resulting in a net negative charge in field situations, but it could be net positive or even a zero charge (Sanchez 1976). Typically andisols are above pH 5.5 (Sanchez 1976).

OM is a variable - charged material (Oades *et al.* 1989) and affects the charge characteristics of VAS. OM content can be negatively correlated with pHo (Fig 4). The agronomic implication of this is that if OM is reduced, as would occur under intensive tillage, the pHo will increase. When this occurs the pHo-pH will result in a positive charge (anionic), and therefore a reduction in ECEC. Similar relationships have been reported for Australian Oxisols (Oades *et al.* 1989).

The dominant factors determining the variable charge nature of andisols, among other influences (see Parfitt 1981; Wada 1985) are:

1. the concentration of cation and anions in the solution, which is determined by the difference between the pH at Zero point of charge (pHo) and field soil pH (ie. pHo-pH);

2. organic matter content; and

3. clay mineralogy, in particular the influence of allophane, imogolite, halloysite and gibbsite (Wada 1981; 1985).

Despite the dominant role of pH, OM and clay mineralogy, some isomophous replacements of ions does occur, especially by small amounts of permanent charge arising from differences in clay mineralogy (Oades *et al.* 1989), or due to lack of OM (Wada 1981), and can interfere with the charge on exchange sites (Sanchez 1976). For example, Radcliffe & Gillman (1985) found that alluvially resorted VAS had a lesser potential variable charge than airfall VAS. In the former there would be less allophane due to weathering, and greater depletion of OM.

3.3.2 Cation exchange capacity (CEC) and base saturation (BS)

The CEC of a soil is an important characteristic related to soil fertility and management. In variable charged soils the CEC, for example of andisols, is often quoted as very high. This is however, an over estimation because the number of cation exchange sites on variable charged soils is determined by the difference between pHo-pH (see Fig 3). As can be seen from Figure 3 the magnitude of negative sites in andisols is small. This has given rise to measurement and interpretation problems, not only of CEC but also for BS (Sanchez 1976). It is very important that agronomists have a correct understanding of these features. Firstly it will facilitate accurate interpretation of soil analytical data, and secondly help identify the appropriate management of nutrients in this soil. Clarifications on this has been provided elsewhere (Kanua 1991).

3.3.3 Anion exchange capacity (AEC)

The important anions in the soils are chlorides, phosphates, silicates, nitrates and sulphates. Relative to cations, relatively few anions, particularly of NO_3 and to an extent Cl, are held by weak electrostatic attraction on clay minerals (Parfitt 1978). Some anions, such as phosphates and sulphates, are strongly held by clay minerals in complex associations, for which reviews on the mechanism of adsorption involved are given elsewhere (Parfitt 1978).

VAS anion fixation, particularly of phosphates, is an important consideration. For phosphates and to an extent nitrogen, a mere statement of their available quantity is an insufficient assessment of the total P & N status. In VAS, P-fixation is very high and nitrogen mineralisation is very low due to high C/N ratio. Therefore determination of the available P and total N must be accompanied by their measurements of anion fixation capacity (Bellamy 1986). These are routinely carried out by commercial laboratories. Generally determination of AEC is less important than ECEC for andisols because, in the field, these soils exhibit negative charge.

4.0 SUPPLY OF NUTRIENTS IN VOLCANIC SOILS

Nitrogen: The organic fraction of the soil phase is the main source of N, P and S. Nitrogen level in VAS', particularly hydrandepts, is often higher than in vitrandepts. Radcliffe (1985) and Wood (1984) reported high levels of total N in highland VAS. In most VAS C/N ratio is high with significant amounts of organic carbon (>1%) and N in the B-horizon which is considered typical of andisols (Sanchez 1976; Bleeker 1983). This results from organic complexes formed from the binding of OM with allophane. However, plants take up N in the form of nitrates. Nitrate - N is also the ion most readily leached from the soil but may not be entirely lost from the system. In a dystrandept significant amounts of Nitrate-N were found in lower profiles (Matson *et al.* 1987) and may be recouped by deep rooting crops.

Phosphorous: Total P-level may be very high but because over 90% of this is locked in the allophane, little is present in the form available to plants, making this nutrient the most limiting for crop production. High P-fixation is one of the diagnostic features of andisols. Al-humus complexes and allophane are considered to be the major materials contributing to the phosphate absorption in andisols (Wada 1985).

The important sources of P are the weathering parent material and the organic fraction of soils. The former depends on the rate of weathering and climatic factors, while the latter depends on biological mineralisation. There is some evidence that organic P is less readily fixed in VAS dominated by halloysite (Bleeker 1983). The management of this nutrient is an important consideration in this study and elsewhere (Kanua 1991).

Potassium: Total K level and the labile pool K in VAS depend, among other factors on the degree of weathering (Graham & Fox 1971 in Sanchez 1973) and organic matter mineralisation, and is closely related to the dominant clay minerals (Hombunaka, 1989). Potassium levels are generally high and better supplied in young VAS (eg. vitrandepts) than hydrandepts . Moss and Coulter (1964) reported considerable amounts of K fixed by the allophane on West Indian volcanic soils but Hombunaka (1989) showed that K-fixation values differ according to methods of measurement, hence, experimental values obtained cannot be compared between methods or between soils.

The critical level of exchangeable K was cited as 0.10 meq per 100g soil for tropical agriculture (Boyer 1972 quoted by Radcliffe 1985). The top horizon of VAS in the PNG highlands are slightly higher but subsoil values are consistently below this critical value (Radcliffe 1985). Of the major elements, K is the most easily leached in VAS, but in other soils, particularly those dominant in 1:1 clay minerals it is the most tightly held nutrient (Mengel & Kirkby 1987).

K-availability to plants depends on its relation to other cations, in particular Ca and Mg. Limited evidence from a PNG VAS (Preston 1990) suggests that the interaction of K with other cations and OM may make this element more available to plants. On the other hand cationic imbalance arising from high Ca/K or Mg/K ratios in the exchange complex, the latter being more common in highland VAS and the former possibly common on calcarious soils, can result in K being made unavailable to plants. This has been reported for a Guatemalan volcanic soil (Tergas & Popenoe 1971) and for PNG by Wood (1984).

4.1 Other Nutrients

The micronutrient status of andisols is not well documented. The excellent review of workers in Central America (Sanchez 1973) is acknowledged and cited extensively here.

Magnesium: Magnesium levels were reported to be low in hydrandepts (Radcliffe 1985), especially in the B-horizon. Low levels of this element with other cations, in particular Ca, often lead to lowering the ECEC of the soil.

Calcium: Ca^{2+} together with Mg^{2+} and K^{+} are the nutrients most readily leached, the rate of leaching increases with annual rainfall and consequently lower the ECEC of the soil (Sanchez 1976). In andisols Ca is leached (Mahilum *et al.* 1970) in the more water soluble carbonic acid which is formed in the presence of CO_2, a by-product of OM decomposition (Mengle & Kirkby 1987).

Sulphur: Most of the S in tropical soils is derived from the OM, whereas in the industrialized world, it is derived from industrial waste and rain water. Like phosphates, a VAS high in allophane and OM will have a high total S-level (Sanchez 1976) because the SO_4 is derived from the organic fraction. The mineralisation of S is however slow, probably because OM is intimately associated with allophane or due to resistance to OM mineralisation by the biological microflora. Mineralised SO_4 is fixed by the allophane anyway, and some are leached making this element available for plant uptake at very low levels in VAS. However, reported levels of SO_4-S from Rwanda (Vander Zaag *et al.* 1984) and PNG (Radcliffe 1985) andisols are adequate. The relative strength at which S is adsorbed and held by the clay is less than phosphate (Sanchez 1976).

Boron: Boron is confirmed deficient in VAS of Hawaii (Fox 1988) Mexico (Sanchez 1976), Chile (Schalscha *et al.* 1973) and PNG (Radcliffe 1985; Bourke 1980). Allophane has a high affinity for boron, making this element together with phosphates and sulphates well retained in VAS.

Zinc: Bajwa (1984) reported widespread Zn deficiency in soils derived from volcanic ash in the Philippines. Radcliffe (1985) reported possible deficiency of Zn in highland VAS. Critical limits of Zn is around 0.4 - 0.6 ppm, and coffee is reported (Bleeker 1983) to suffer from suboptional levels in PNG. Cox (in Sanchez 1973) cited Zn deficiencies in a Costa Rican VAS. Zn deficiency on citrus grown on vitrandepts in New Britain has been confirmed (Bourke 1983).

Aluminum: High levels of exchangeable Al are associated with soil acidity and become a special problem for management of agriculture on many tropical soils. The recorded pH of many VAS are in the acidic range (4.5-5.5), but this is seldom associated with a level of exchangeable Al likely to induce toxicity problems. For example, Radcliffe (1985) and Wood (1984) reported exchangeable Al levels to be only moderate, and not sufficient to induce toxicity problems. However, in a peat soil with volcanic ash influence, Al toxicity significantly reduced yield of maize (Macfarlene & Quin 1989). In another volcanic soil Hombunaka (1989) reported high Al saturation of the ECEC but this did not affect growth of coffee.

Manganese: Radcliffe (1985) reported Mn levels in hydrandepts to be lower than the quoted critical limits of 2-3 ppm. He noted this may indicate possible deficiency of this element. Mn deficiency symptom on plants may be confused for Fe (e.g. Bleeker 1983). Tea grown in organic peat soils have been reported to suffer from Mn deficiency (Bleeker 1983), but has not been confirmed for tea grown in a VAS in the Southern highlands. A limed Columbian VAS was reported to decrease the uptake of Mn by Coffee (Cox in Sanchez 1973). Citrus and robusta coffee grown on a young volcanic soil in New Britain showed Mn deficiency symptoms (Bourke 1983).

Molybdenum: The status of molybdenum in VAS is not clear, but Cox (in Sanzhez 1973) reported that it may be low. Hawaiian and Columbian VAS were reported (Cox in Sanchez 1973) to be low in Mo and suggests this could affect crop production. Cauliflower grown on a VAS at Tambul (PNG) produced the characteristic 'whip tail' Mo deficiency symptom (Mueller, unpubl). In general VAS with low pH (eg. dystrandepts) are likely to suffer from Mo deficiencies.

Copper: Cu deficiency is reported in some andisols (eg, Wada 1985) and is ascribed to stable Cu-OM complex association, as well as inherent low status of this element. Bourke (1983) reported significant sorghum yield response to applied Cu on vitrandepts in New Britain but cautioned that there was limited response to this nutrient in further trials. Tea grown in a highland VAS was confirmed deficient of Cu from foliar analysis (Bourke 1983).

Iron: Levels of Fe in VAS is reported to be adequate (Cox in Sanchez 1973). Fe deficiencies of crops were reported for PNG in soils other than VAS (Bourke 1983).

5.0 NUTRIENT LOSSES IN VOLCANIC SOILS

Plant nutrients are lost from the soil nutrient base in various ways. Nutrient removal by the crop is one contributor. The others being through leaching, run-off and soil erosion.

5.1 Erosion

PNG andisols are ranked very low on a soil erodibility risk class (Bellamy 1986; Bleeker 1983). The detailed study of soil erosion by Humphreys (1984) in PNG was conducted on soils other than volcanic ash. His conclusions were that, even though current rates of soil erosion on bare plots were not excessive, other forms of soil loss, viz; mass movement, rilling, gulling and soil creep, could be substantial. In Tari, on a steep (22-25% slope) garden VAS, Wood (1985) reported that losses were moderate and approached the rate of soil formation (10-15 t ha^{-1} yr^{-1}). These data were not related to crop yield lose.

Soil lost by erosion on a cultivated Japanese VAS was found to range from 9.5 to 15.5m^3 ha^{-1} yr^{-1}, but on pasture established sites was 3.0 to 7.4m^3 ha^{-1} yr^{-1} (Wada 1985). Sanchez (1976) cites evidence of little or insignificant surface erosion and run-off from Guatemalan and Colombian VAS. He attributed this to high permeability of these soils. El-Swaify (1977) using rainfall simulation experiments, evaluated the relative susceptibility of five Hawaiian soils. A entic eutrandept was the most susceptible to erosion but the range of variation was very high even within the andisol group. Another subgroup, typic hydrandept was rated least susceptible and an hydric dystrandept with a typic eutrandept moderately susceptible.

In general, soil erosion on VAS is insignificant and negligible. Most erosion research do not relate soil lose to crop yield lose, probably because the relationship between erosion and productivity is not direct. Despite this, the data provided by Wood (1985) suggests that intensive cultivation of VAS on steep slopes could result in fertility decline through erosion of topsoil. In a poorly fertilized VAS, even small nutrient losses in erosion could have serious implications for crop production.

5.2 Leaching and Run-off

Substantial amounts of NO_3, Ca, K and Mg were shown to be lost to leaching in high rainfall Columbian andisols (Sanchez 1976). Phosphate losses were negligible, probably because it is strongly held by the allophane - OM complexes. No data on micronutrient losses to leaching were provided. Kano (cited by Wood 1984) analysing nutrient contents of rivers flowing through volcanic regions found high levels of bases which he attributed to intensive leaching of bases from the ash deposits. Losses of topsoil by erosion, and nutrients by run-off and leaching, was concluded by Wood (1984) to aggravate soil fertility decline on VAS cultivated on steep slopes in the highlands of PNG. The overall effect of leaching, especially of bases, is the lowering of the ECEC and decrease in pH.

B. CULTIVATION AND MANAGEMENT OF VOLCANIC SOILS

6.0 CULTIVATION OF VOLCANIC SOILS

6.1 Changes in Soil Physical Properties with Cultivation

The deterioration of soil physical properties with cultivation is recorded for many soils of the tropics. Evidence from cultivated Japanese VAS shows that with cultivation, OM content falls and structural systems deteriorate. This is more marked in the warmer southern regions (Wada 1985). Cultivation on PNG VAS was reported to cause little change in soil physical properties (Wood 1985). Wood (1985) reported higher infiltration rates, lower B.D, higher porosity and a greater proportion of water stable aggregates than would normally be experienced with other soils. Radcliffe (1985) noted that the combination of high aggregate stability and infiltration in the topsoil, and permeability in the subsoil gave these soils resistance to erosion and stability to soil structure.

The evidence from Japan contradicts that reported for PNG. A possible explanation is that the regular use of composed material in PNG VAS helps to maintain soil structure and avoids the depletion of soil physical fertility (Kanua 1991). Productivity on VAS measured by sweet potato as test crop throughout the highlands (Goodbody 1983; Floyd *et al.* 1988; Preston 1990) appears to be comparable with yields obtained elsewhere (e.g. Tusno 1970) but not conclusively so. This is despite the greater intensity of land use on VAS than on non-ash derived soils, probably because of their good and stable physical properties. For the moment, soil physical properties do not appear to impose constraints to crop production on PNG VAS.

6.2 Changes in Soil Chemical Properties with Cultivation

The principle constraints to agricultural production on VAS are likely to be imposed by chemical properties. The specific chemical properties of weathered andisols that are likely to limit production on VAS are:

- low availability of phosphates and high P-fixation,
- deficiencies of B, Zn, Mn, Mo and possibly other nutrients,
- low ECEC; and
- low base status and therefore low pH.

Under low pH (acidic) conditions micronutrients such as Zn, Cu and Mn can be in excess. In such situation high levels of Zn for instance, can suppress uptake of P and Fe (Mengle & Kirkby 1987). In general, despite such behavior of micronutrients, their uptake rate is pH dependent and seems to be highest in the mild acidic to neutral pH range (Mengle and Kirkby 1987 see also section 4.1).

Bleeker (1983) showed that so long as crop production on VAS is maintained by continuous fresh compost application, soil chemical fertility (% organic Carbon, % Nitrogen and CEC), with the exception of soil pH, is not drastically reduced on hydrandepts compared to a non VAS (humitropept). Radcliffe (1985) concluded that these problems would become more apparent with intensity of cropping. Wood (1979; 1984; 1985) presented similar conclusions on VAS in Tari and Karamui.

In Tari, Wood (1985) reported exponential decline of exchangeable K with cultivation time. It is noteworthy that K, the nutrient most heavily demanded by crops like sweet potato and coffee, declines sharply over the first five years of cultivation and continues to do so as garden age increases more in the VAS than the non-ash soils. He also obtained highly significant negative correlations between exchangeable Mg, Ca, CEC, % BS and total N on garden age on the soils derived from volcanic ash. The decline in soil chemical fertility with garden age was also associated with a decline in sweet potato yield. This decline in VAS was markedly lower than for other soils. Similar results were obtained on a vitrandept, yield of sweet potato tubers declined from 20-28 t ha^{-1} in the first cropping year to less than 5 t ha^{-1} after 33 years

(Bourke 1977).

The data reported by Wood (1984) for another VAS showed a decline in exchangeable Ca, Mg, total exchangeable bases, % BS and soil pH with cropping time. He noted that there was a gradual increase in soil nutrient content with long fallows on these soils, but that the rate of nutrient recovery was slower than the decline which occurred with cultivation. Similar data from Korean VAS showed that extractable Al decreased in the topsoil but increased markedly in the subsoil with length of cultivation in citrus orchards (Yoo 1984). Yoo also showed that % OM was weakly correlated with extractable Al in the topsoil but the variables were strongly correlated in the subsoil with more than 30 years cultivation.

6.3 Crop Responses to Fertilizer Application

The easiest but not necessarily the cheapest way to solve soil fertility problem is by the addition of inorganic fertilizer. The alternatives are to use organic manure or to practice shifting agriculture. The choice becomes limited under increased land pressure. Under such situations increased crop yields per unit of land area will depend on increased resource investment. To optimise returns from organic and inorganic fertilizer investment, crop responses to these amendments in andisols must be known.

It is highly likely that amendments of nutrients identified at suboptimal or deficient levels in VAS, will give crop yield responses. However, the response of an applied nutrient depends on the soil clay mineralogy and the relative crop requirement for the nutrient and to some extent soil temperature (Fox 1979). These factors become important in fertilizer recommendations so that major economies in fertilizer use are made. These aspects are now considered.

6.3.1 Inorganic fertilizer response

Most studies have shown that because of the high P-fixation capacity and slow mineralisation of OM, VAS are responsive to the addition of major nutrients (N,P,K). The relative magnitude of the effect of N, P & K, as well as Ca, Mg and S, and other nutrients does, however, vary among ash derived soil types.
Nitrogen response: The effect of N in Chilean volcanic soils (Trumaos) on the yield of wheat and beet (Almeyda 1969), and PNG highland VAS on the yield for sweet potato (D'Souza & Bourke 1986a) were limited. The inherently high N-levels in these soils is the reason for this lack of response. However, VAS low in OM are likely to respond to N-application, as reported for a vitrandept (Bourke 1977) and for a young volcanic soil in East Java (Soedarjo *et al.* 1988). Nitrogen tends to promote vegetative growth of crops like beet and sweet potato. In high rainfall areas, anionic (nitrate) or urea, rather than cationic (ammonia) N-fertilizer is recommended (Arana 1969). This is because the NH^+_4 ion has a strong ability to displace Ca, Mg & K in the soil, which are then lost to leaching.

On a highly fertile andic dystropept, applications of 200 kg ha^{-1} yr^{-1} of each of N (ammonium sulphate) and K (K_2O) did not, at first give any significant coffee (green bean) yield responses (Harding 1993). However in the final year of this five year fertilizer experiment there were indications of significant yield responses.

Phosphorus response: Using survey data of sweet potato gardens on hydrandepts in PNG, Goodbody & Humphreys (1986) obtained highly significant positive linear correlations for first harvest yields on soil pH, available P and P retention. Higher yields resulting from increasing P retention is unlikely. However, raising soil pH and increasing available P can both be achieved from a heavy application of phosphatic fertilizers. This finding suggests that P application on andisols, particularly hydrandepts, is likely to give a response.

Crop response to applied P is fairly well established because of the low level of available P in VAS. Almeyda (1969) reported wheat, beet, rape and potato responses to P on Trumaos soils. Almeyda also reported residual effects of P applied two years earlier on beet and clover yield on this soil. However, the residual response was in part attributed to localised placement of P rather than broadcasting, the effect was greatest for beet. Appropriate methods of fertilizer P application are required especially in high rainfall areas because availability of P in the soils fluctuates over the season according to the rainfall pattern (Arana 1969).

Floyd *et al.* (1988) found significant sweet potato responses to fertilizer P and K application on PNG highland VAS. The response of P relative to K, was greatest on these soils, and proved inconsistent with the belief that sweet potato has a low P requirement (Fox 1979). However, Floyd *et al.* (1988) found that the crop response to applied P was reduced by increased mycorrhiza activity. D'Souza and Bourke (1986a) obtained only a small response from P relative to K in Nembi Plateau, and attributed this to low levels of K on the studied soils.

Manuelpillai *et al.* (1981) reported an increasing response to P on three successive soybean crops in a West Javan hydric dysterandept, the response was greatest on the third crop. In East Java Soedarjo *et al.* (1988) reported significant maize yield responses to P_2O_5 on a young VAS.

Potassium response: Beet did not respond to K on Trumaos soils whereas potatoes did (Almeyda 1969). Maize did not respond to K on a young VAS in East Java (Soedarjo *et al.* 1988). Application of K_2SO_4 had little effect on wheat, but where there was a response, it was mainly attributed to S and only to a lesser extent K (Almeyda 1969). Coffee grown in VAS must be adequately supplied with K for which this crop has a high demand (Hombunaka 1989). Manuelpillai *et al.* (1981) reported good response to lime and K by soybean grown on dystrandeps in West Java.

Tusno and Fujise (cited by Tusno 1970) noticed that in Japanese VAS, exchangeable K was high in the subsoil, and this, coupled with deep rooting tuberous roots, was responsible for giving high average sweet potato yields. In field experiments with deep K placement, they found that K alone was not effective but that the combined effect of K and N gave better sweet potato yields. They observed that N and K together were required to keep roots healthy for a longer period of time, rather than K alone.

Maximum tuber yields of sweet potato are achieved at a lower fertilizer N:K ratio (i.e, <1:3) (Norman *et al.* 1984), but this is modified with intensity of land use. A higher ratio of K:N is likely to give yield response on intensively used sites, as reported for an Oxisol in Sierra Leone (Geoffrey-Sam-Aggrey 1976).

Other nutrients: The critical limit for B is around 0.3-0.5 ppm. Hydrandepts of PNG were quoted to be lower than this value (Radcliffe 1985), indicating that crop response to this nutrient is likely. This was confirmed by D'Souza & Bourke (1986) with responses by *Casuarina oligodon* to B-application. Boron applied to sweet potato suppressed tuber yield. Vine yield was significantly increased by the application of B, Mg, Zn, Mn, Co and S on a VAS, but except for B, foliar analysis did not confirm an increased uptake of these nutrients (D'Souza & Bourke 1986a).

As in the case of P (Arana 1969) seasonal flushes of SO_4 in VAS have been reported (Radcliffe 1985) and this is probably due to alternating wet and dry seasons in this region. This means that seasonal crop responses to native S are likely. A maize yield response to sulphur was recorded on a young volcanic soil in East Java (Soedarjo *et al.* 1988).

Al and Mn toxicity can be a common problem on acid soils but is not generally reported for VAS. Rather, suboptimal levels of these elements are reported for VAS. In only one case in PNG, it was reported (Macfarlene & Quin 1989) that Al toxicity reduced maize yields significantly on a peat soil highly influenced by volcanic ash. In contrast citrus and robusta coffee grown on a young VAS in New Britain showed Mn deficiency symptoms (Bourke 1983). In citrus, combined Mn and Zn foliar spray removed Mn deficiency symptoms, indicating a positive Mn * Zn interaction because Mn application in the absence of Zn, did not completely remove the symptom.

For most of the heavy metal cations (Cd, Co, Zn, Cu and Pb), andisols containing high amounts of allophane and imogolite will have a high adsorption capacity for these (Wada 1985). Therefore crop responses to these nutrients are highly likely. However, information on crop species requirements of these elements is scanty.

6.3.2 Organic fertilizer responses

In Japanese VAS compost application was reported to significantly increase sweet potato yield, and improve soil aeration and maintain favourable soil moisture levels during tuber bulking time (Tusno 1970). Floyd *et al.* (1988) found linear responses to sweet potato yield with increasing compost rates on seven ash derived soils in PNG. The maximum yield attained was about 17 t ha^{-1} with 100 t ha^{-1} of *Ischaemum polystachyum* grass. The practical constraint in exploiting the linear yield response is the problem of gathering large quantities for fresh material. Elsewhere in this area D'Souza and Bourke (1986b) recorded quadratic response curves of tuber yield on compost rates for three different composting materials.

Some of the commonly used organic manures in the study area are mixed grass, sweet potato vines and coffee pulp. In experiments, pig manure, *Azolla* fern, *Ischaemum* grass and coffee pulp have been used (D'Souza and Bourke 1986b; Floyd *et al.* 1988). The quantity and quality of nutrients supplied by these materials differ between species (Table 2). Chemical

Table 2: **Nutrient supply by some commonly available composting materials in the highlands of PNG**

Compost material	Application rates (t/ha) (Fresh weight)	Nutrient levels kg/ha N	P	K	Reference
Ischaemum grass	10	38	5	36	D'Souza & Bourke (1986 b)
	20	75	10	73	D'Souza & Bourke (1986 b)
	30	113	14	109	D'Souza & Bourke (1986 b)
	40	151	19	145	D'Souza & Bourke (1986 b)
	100(a)	251	33.5	251	Floyd *et al*.,(1988)
Azolla pinnata	30	40	5	30	D'Souza & Bourke (1986 b)
Pig manure	20	113	64	79	D'Souza & Bourke (1986 b)
Coffee pulp	30	73	5	139	D'Souza & Bourke (1986 b)

(a).Floyd *et al.* (1988) also reported values for S, Ca, Mg, Na, Fe, Mn, Zn, Cu and B; these were 44.6, 114.6, 75.3, 1.95, 4.2, 5.2, 1.3, 0.2 and 0.2 Kg ha^{-1} respectively.

analysis data for *Ischaemum* grass shows fairly high levels of major nutrients and gives a reasonable balance of other macro and micro nutrients. Regression equations relating quantity of *Ischaemum* grass (X) and supply of major nutrients calculated from the data in Table 2 are:

Nitrogen = 33.15 + 2.33X (r=0.97)
Phosphorus = 3.82 + 0.312X (r=0.98)
Potassium = 29.7 + 2.347X (r=0.98)

Average nutritive contents of the other manures are also given. Pig manure is a good source of N and P but low in K, while coffee pulp is a rich source of K, moderately high in N and low in P. Traditionally organic materials are applied mixed (Kanua & Rangai 1988), a practice which serves to maintain the balance of nutrient supply to plants. Quantities of applied manure can vary from 10 to 40 t ha^{-1} fresh weight. A economic rate of application was set at 20 t ha^{-1} (D'Souza and Bourke 1986 b).

6.3.3 Residual response of organic & inorganic fertilizer

Floyd *et al.* (1988) found no beneficial residual effect of compost on sweet potato yield. Residual compost manuring effects may be augmented or enhanced by a nominal inorganic fertilizer application. Since OM has a wide C/N ratio in highland VAS (e.g hydrandepts), the prospects for lowering this by fertilizer nitrogen application needs to be investigated.

Data on residual effects on crop yield from inorganic manuring are very limited. Fertilizer P application is said to have good residual effects. However, this appears to be a function of the application method. An initial heavy P - application is reported to give satisfactory residual effects over a number of crops.

6.3.4 The role of Vascular Abascula Mycorrhiza (VAM)

The role of mycorrhiza in the nutrition of cassava, yam and Irish potato roots has been frequently reported (Norman *et al.* 1984). Such associations are important particularly for P uptake, and to a lesser extent for K and S.

Floyd *et al.* (1988) reported that a parameter 'Relative Phosphate (total tuber) yield' of sweet potato (i.e yield at zero fertilizer/maximum or estimated yield * 100) was better related to the soil phosphate requirement (SPR) when the inter-site differences in VAM infection were first accounted for. By multiple regression equations they showed that sweet potato response to applied P is reduced by increased VAM infection. Hence, one of the important factors determining potential site yield (i.e control plots) in these soils is the degree of VAM activity which was related by the multiple regression equation:

Site Yield = 9.1 + 0.96 VAM (%) 3 * 10^{-9} SPR^3(ug g^{-1} soil).

Thus the equation shows a higher site control yield (i.e zero fertilizer treatment) was associated with higher VAM infection than expected from site phosphate requirement. These studies indicate that there are important compost * fertilizer P * VAM interactions in the soils and warrant further research.

6.3.5 Nutrient interactions

Preston (1990) investigating compost (C) * fertilizer interaction on sweet potato tuber yields in PNG highland VAS, recorded significant C * K effect on one site. C * N interaction significantly increased vine yield. Unpublished data from elsewhere in this region (Chatteris 1987 - reported by Preston 1988) showed no C * fertilizer interactions. Significant positive C * P effect on the growth and yield of beans and maize, and to a limited extent for cabbages on VAS in the Southern highlands was reported by Floyd *et al.* (1987). Despite the significant interaction effects, the magnitude of response was attributed primarily to fertilizer P application. On a andic dystropept, Harding (1993) reported significant N * K effect on coffee (green bean) yield and showed that high top soil exchangeable K levels were maintained at a lower fertilizer N:K ratio. On a Japanese VAS, sweet potato yield on zero N plus compost treatment plots was comparable with that of ammonium sulphate treated plots. Better yields were obtained when compost and ammonium sulphate were combined.

The fertilizer study of Floyd *et al.* (1988) found no interaction between P * K on the yield of sweet potato. The rates of fertilizer - P used were 0, 250, 500 and 1000 kg ha^{-1} as triple super phosphate. This is equivalent to 0, 52.5, 105, 210 kg P ha^{-1}. Goodbody (1983) obtained highly significant sweet potato yields on similar soils high in OM (7.5%) with an application of 50 Kg P_2O_5 ha^{-1}. In a trial on a VAS elsewhere in this region, Kanua (1990) found significant P * K (and non significant N * K or N * P) effect on sweet potato yield. In the latter study, the rates of phosphate were 0, 25, 50 and 100 kg ha^{-1}. In the light of the major role of mychorriza in the phosphate nutrition of sweet potato in VAS (Floyd *et al.* 1988), it seems likely that lower rates of P application may give a response by positively interacting with the VAM populations. At higher rates of applied P, VAM activity seems suppressed to the extent that even the uptake of K appears affected, resulting in limiting any beneficial interaction effects.

6.3.6 Liming volcanic soils

Liming is usually not a management option but a necessity in correcting soil acidity. Its application results in an increase in the soil pH, with a concomitant decrease in extractable Al levels. Increase in soil Ca and Mg is a secondary benefit and depends largely on the liming material used. The increase in pH will make native anions and cations available to crops. But increase above pH 5.6 is not beneficial in most situations as it results in precipitation of anions and renders them unavailable to plants (Sanchez 1976).

The data from a liming study conducted on a peat soil with volcanic ash influence by Macfarlane & Quin (1989) in PNG showed that liming up to 18 t ha^{-1} on this peat-ash mixed soil (pH 4.8) did not increase the yield of the first maize crop as did phosphate broadcasted at 2060 kg P ha^{-1} (i.e. at zero lime). Application of 2060 kg ha^{-1} alone, as well as satisfying fixation capacity of the soil and increasing the soil P concentration, also increased the soil pH. Such high P-rates are not, however, economically feasible for small farmers. Despite this, a residual maize crop yielded comparably with the first crop on the 2060 kg P ha^{-1} plot. This means that the effect of a initial heavy application of P can be spread over a number of succeeding crops. Broadcast and placement of P in the second planting on this site produced results that were not conclusive. In general, yields were not significantly different between the two methods of P-application (Macfarlene & Quin 1989). Despite this maize yields obtained at a lower level of lime (6 t ha^{-1}) with banded 1000 kg P ha^{-1} was found comparable with yields obtained at 2060 kg P ha^{-1} broadcast.

In a 7.5 years study on the residual effect of liming andisols, Mahilum *et al.* (1970) found that silicon based liming material ($CaSiCO_3$) had a superior effect in reducing exchangeable Al. In this study Ca^{2+} was readily leached away, only negligible amounts were recovered at 1.2 m depth after seven years. This rapid leaching of Ca^{2+} was reported to be responsible for a subsequent decrease in pH. Similar results were obtained by heavily liming another VAS (Rixon & Sherman 1962). In the latter study a significant increase in CEC was contributed by P-application but liming had no effect. On a volcanic ash influenced andic dystropept, Harding (1993) reported that ammonium sulphate fertilizer applications significantly lowered the soil pH. This N - induced acidification was responsible for increasing the leaching of K, Mg and Ca. Liming a Brazillian volcanic soil increased the buffering capacity of the soil but also induced a decrease in the intensity factor, the latter if left unchecked could lead to K-deficiency (Hombunaka 1989).

7.0 MANAGEMENT OF WEATHERED (ANDIC) ANDISOLS

The data reviewed indicate that inherent soil chemical properties of andisols will impose constraints to foodcrop production. In particular the evidence is overwhelming that due to low ECEC in highland VAS, there is limited capacity to retain cations at the field soil pH. It follows that future management of this soil lies in finding ways of raising ECEC. It has been suggested (Radcliffe 1985), that this can be achieved either by raising the soil pH or by decreasing the pHo. The practical ways of achieving this in the field require investigation.

7.1 Raising Soil pH by Liming

In the absence of other data it seems that liming hydrandepts and other more weathered andisols high in allophane is unlikely to give the desired results. However, liming eutrandepts and dystrandepts which are acidic lowland andisols may give a positive response. No data are available at present to suggest otherwise and should be tested in the field.

One reason why liming may not be the preferred management option is that the low K-level is likely to be worsened by an imbalance created by an influx of Ca or Mg, giving high Ca:K or Mg: K ratio. Also raising pH above 5.6 can result in precipitation of anions and worsen the P and S problems of some highland soils (Sanchez 1976). Fox (1981) notes that greater precision is required in controlling pH of variable charged soils than of permanent charged soils.

Despite this the limited data of Macfarlane & Quin (1989) suggests that possible beneficial effects of lime and economic rates of P may be achieved at application rates lower than those used in their study. Moderate quantities of lime are required to raise pH of variable charged soils to about 5.0 in order to reduce Al toxicities (Fox 1981). Exploiting beneficial interaction effects between phosphate and lime represents a fertile area of research.

7.2 Lowering the pHo

We are left with the proposition that lowering the pHo is an agronomically practical option. The two ways of achieving these are, 1) addition of OM and 2) addition of anionic fertilizers (Radcliffe 1985).

7.2.1 Lowering the pHo by organic matter management

OM plays a role in lowering the pHo and increases the magnitude of negative charge in variable charged soils. However, OM levels are already high in VAS, and the prospects for additional increases to ECEC resulting from additional OM inputs may be insignificant. Despite this, the weight of evidence reviewed suggests that the management of OM is still the key to crop production in VAS. There is also the scope for exploiting beneficial OM * inorganic fertilizer interactions.

Mechanisms involved in composting response

The small amounts of available information reviewed indicates that the principle mechanisms controlling yield responses to composting is the chemical and clay mineralogical properties of andisols. The direct effects of compost on the supply of nutrients are:

1) its role in reducing P-fixation by forming complex associations with allophane,

2) since OM is negatively correlated with pHo, it lowers the pHo and thereby increases the ECEC of the soil,

3) as a consequence of 2) losses of bases to leaching are reduced,

4) OM supplies a more balanced nutrition (see Table 2) and supplies it slowly in available form over the growth period (Tusno 1970),

5) it seems that the traditional practice of compost mounding in the PNG highlands ensures nutrients supplied by decomposing material are directly taken up by plants, without going through a soil phase (Floyd *et al.* 1988).

Consistent with 4) and 5) above, Floyd *et al.* (1988) found increased efficiency of use of P and K supplied as compost than as inorganic fertilizer. However this increased efficiency was modified by differences in soils, particularly P-fixation and base nutrition in VAS. Moreover, in the same study Floyd *et al.* (1988) found that site control yield of sweet potato increased with increased VAM infection. Thus, in concluding they speculated that important interactions between compost* fertilizer* VAM could be involved. Despite all their data they were not able to separate the nutrient effects from any physical benefits of compost.

7.2.2 Lowering pHo by addition of anionic fertilizers

Inorganic amendments of anionic, rather than cationic fertilizers, such as phosphate and silicates, are thought to be most effective in lowering pHo (Radcliffe 1985; Mahilum *et al.* 1970), and the concomitant increase in ECEC. In particular, the addition of phosphatic fertilizers, as well as satisfying fixation capacity of the soil, will also increase the soil pH and the available P-level. The benefit of silicate fertilizers (e.g Ca - silicate) is that phosphate adsorption is decreased and P-desorption is increased (Fox 1974). This results in an increased concentration of P in the soil solution, as well as supplying moderate amounts of Ca and Mg.

Whether these amendments should be applied in splits or in concentrated bands, or in a large initial 'blanket' application is not clear. The limited evidence from this review is inconsistent and does not agree on a single method, but it seems band or split application may be preferred over broadcasting or 'blanket' application for economic reasons. For vegetable production on VAS in PNG, recommended fertilizer application was applied within the planting holes or in bands (Crittenden & Quin 1987). Precise placement of fertilizer seems the sensible option for small farmers. A blanket application of large quantities of phosphatic fertilizers is considered an economic investment, but this is not likely to be adopted by small farmers. In the split or concentrated band application, the applied P saturates the adsorption sites in the immediate vicinity and makes P available to plants grown within that area. Each method needs testing in field trials before recommending the best technique. The technical and economic feasibility of achieving this also requires investigation.

The data on the economics of inorganic fertilizer use is scanty. In PNG, Floyd *et al.* (1988) demonstrated that P-application resulted in uneconomic yield increases for sweet potato, while K gave economic yields for the majority of the VAS used in their study. Despite the fact that applied P is uneconomic to sustain maximum sweet potato yields, limited evidence suggests that good yields of the first crop and response by subsequent crops to residual P over a number of seasons, may more than compensate for the high cost of a single P application. In other P - deficient soils such as ultisols and oxisols, applications of 20 to 80 kg P ha^{-1} sufficiently fertilized crops in rotation, its residual effect lasted two years and gave high economic returns to P-fertilization.

7.3 Inorganic Fertilizer Management

Experimental evidence of the response of the staple crop sweet potato and a number of other crops to nutrients is given in Table 3. In general the responses are inconsistent, probably due to differences in soil and varietal characteristics. Despite this, responses to P and to an extent K, are well established for highland VAS. N is not limiting, a lack of response, except on a vitrandept, confirms this. The requirement for N may be to facilitate and enhance micro-organism activity in the breakdown of OM. It seems the future management of N lies in exploiting beneficial nutrient interaction effects (see Table 3). If these can be confirmed in future trials, practical implications for agricultural management are good.

The data available on other nutrients show that Mg, Ca, B, Zn, Mo, Mn and to a lesser extent, Fe and Cu are either deficient or are at suboptimal levels in andisols worldwide. Crop responses to these nutrients are highly likely. Data on the response to these nutrients in PNG andisols is scanty, and represents a priority area for research.

7.4 Management of Soil Organisions

Apart from the role of VAM in the P-nutrition of crops, other soil organisms such as fungi, actinomycetes, earthworms, termites and micro-organisms are also important in soil formation. Little is known about their specific roles in forming volcanic soils in the cooler tropical highland areas. The review shows that in VAS the activity of soil fungi and actinomycetes decrease with altitude implying that the activity of other soil organisms is also likely to be low.

Local PNG farmer's believe that by placing compost inside earth mounds the soil temperature is raised sufficiently to activate the meso and micro floral activity. This belief is consistent with scientific evidence reviewed (see 3.2.2) and can lead to rapid OM-breakdown and mineralisation. These aspects represents fertile areas for further research.

Table 3: **Crop response to organic and inorganic fertilizer application on volcanic ash soils**

Nutrient	rate Kg ha^{-1}	Crop	Response	Country	Reference
N	300	Wheat	*	Chile	McMahon (1987)
	100	S.potato	**	PNG (Enga)	Preston (1990)
	-	S.potato	**	PNG (ENBP)	Bourke (1977)
P	400 (P_2O_5)	Wheat	**	Chile	McMahon (1987)
	120 (P_2O_5)	Beet	**	Chile	McMahon (1987)
	100 (P_2O_5)	S.potato	**	PNG (Enga)	Preston (1990)
	2060 (P_2O_5)	Maize	**	PNG (SHP)	Macfarlene & Quin (1989)
	- (P_2O_5)	Maize	**	East Java	Soedarjo *et al.* (1988)
	75	S.potato	*	PNG (Nembi Plateau)	D'Souza & Bourke (1986a)
	500-1000	S.potato	**	PNG (SHP)	Floyd *et al.* (1981)
	-	Soy bean	**	West Java	Manuelpillai *et al.* (1981)
K	75	S.potato	**	PNG (Nembi Plateau)	D'Souza & Bourke (1986a)
	200-360	S.potato	*	PNG (SHP)	Floyd *et al.* (1988)
	-	Soy bean	*	West Java	Manuelpillai *et al.* (1981)
	-	Coffee	*	PNG	Hombunaka (1989)
S	-	Maize	*	East Java	Soedarjo *et al.* (1988)
B	1.5	*C.aligod on*	*	PNG (Nembi Plateau)	D'Souza & Bourke (1986a)
N * P	150 N, 400 P_2O_5 64 N, 100 P_2O_5 120 N, 180 P_2O_5	Wheat Rape Clover	** ** **	Chile Chile Chile	McMahon (1987) Almeyda (1969) Almeyda (1969)
N * K	-	S.potato	*	Japan	Tusno (1970)
P * K	50 P, 150K	S.potato	**	PNG (Gumine)	Kanua (1990)
Mn * Zn	-	Citrus	*	PNG (Keravat)	Bourke (1983)
Compost (C)	67 t/ha	S.potato	**	PNG (Enga)	Preston (1990)
	100 t/ha	S.potato	**	PNG (SHP)	Floyd *et al.* (1988)
Pig manure	20 t/ha	S.potato	**	PNG (Nembi Plateau)	D'Souza & Bourke (1986b)
Coffee pulp	30 t/ha	S.potato	**	PNG (Nembi Plateau)	D'Souza & Bourke (1986b)
C * K	6.7 t/ha C 100 K	S.potato	**	PNG (Enga, Tuluma)	Preston (1990)
C * P	-	Maize	*	PNG (SHP)	Floyd *et al.* (1987)
P * Ca (1)	300 P_2O_5 4000 CaO_3	Wheat	-*	Chile	Almeyda (1969)
Lime	2,500 $CaCO_3$	Alfalfa	*	Chile	Almeyda (1969)
	6 - 18 t/ha	Maize	-*	PNG	Macfarlane & Quin (1989)
	$CaSiCO_3$	Soy bean	*	West Java	Manuelpillai *et al* (1981)
Lime * P_2O_5(2)	6 t/ha 1000 P_2O_5	Maize	*	PNG (Kuma, SHP)	Macfarlane & Quin (1989)

* - positive, small response
** - highly significant response
-* - significant negative response
(1)- The P * Ca interaction is negative at high P_2O_5 levels only. P-alone is effective
(2)- Results were not conclusive but a Lime * P positive interaction is highly likely at lower rates of these materials.

8.0 CONCLUSION

Crop production on VAS in the PNG highlands is governed essentially by rainfall and soil type. High rainfall regimes are responsible for the rapid leaching of bases. This results in lowering the pH and ECEC. It was suggested that in cooler highland regions the interaction of high OM levels, coupled with low microfaunal population and low temperatures, results in complex processes which may inhibit both OM mineralisation and nutrient supply to plants. In addition VAS high in allophane retain important anions such as phosphates and sulphates, and micronutrient cations such as B, Mo and Zn, and render them unavailable to plants. All these factors together contribute to giving VAS their peculiar characteristics and make their management difficult.

Against the backdrop of a harsh soil and agroclimatic environment, traditional management seems to have developed practices specifically to curb these problems. The compost-mounding and improved fallow planting (Kanua & Rangai 1988) are examples of these. The information reviewed show that OM plays a vital role in maintaining soil physical and chemical fertility. As well as sustaining soil aggregate stability and other physical benefits, OM supplies a wide range of nutrients, and makes them directly available to crops. Coupled with this it plays the role in increasing the magnitude of the negative charge sites, and hence ECEC.

It must be concluded that the traditional practice of compost-mounding is an important activity, and that the key to the management of highland VAS in PNG lies in the continuous application of organic materials. To improve this qualitatively, requires the supplementation of compost vegetable materials, perhaps through a selective planted and/or simultaneous fallow. Despite the fact that data on inorganic fertilizer response in andisols is somewhat inconsistent, there is scope for exploiting beneficial organic * inorganic fertilizer interaction to augment crop responses to organic manuring.

Crop diversification seems a logical proposition for farmers. Maize would be an ideal candidate (see Floyd 1985), but the low chemical fertility of this soil means that the production of maize or any other introduced crop will have to be supported by heavy fertilizer applications. The alternative is to continue to rely on low nutrient requiring crops such as sweet potato and other tuber crops. The traditional system of crop variety selections has resulted in varieties suited to different soil situations, and are particularly adapted to low levels of nutrient supply. Their yield is not high and substantial improvement in soil nutrient status will require the introduction of new varieties to make full use of the changing conditions. Farmers appear to be satisfied with their current level of production using their present soil and crop management practices. The need for improved crop varieties and for better management practices will become apparent when increased population pressure increases the demand for more food, and therefore more cultivable area.

9.0 ACKNOWLEDGEMENT

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10.0 ACRONYMS

AEC	- Anion Exchange Capacity
BD	- Bulk Density
BS	- Base Saturation
C	- Compost
CEC	- Cation Exchange capacity
ECEC	- Effective cation Exchange Capacity
m.a.s.l	- meters above sea level
OM	- Organic Matter
pHo	- Point of Zero Charge
PNG	- Papua New Guinea
PZNC	- Point of Zero Net Charge
SPR	- Soil Phosphate Requirement
USDA	- United States Department of Agriculture
VAM	- Vascular Abascula Mycorhiza
VAS	- Volcanic Ash Soils
*	- Multiplication (eg. C * K).

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INFLUENCE OF DIFFERENT N, P, K DOSES ON YIELD & YIELD COMPONENTS OF TWO STANDARD RICE VARIETIES OF PNG, UNDER LOWLAND FIELD CONDITIONS.

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ABSTRACT

Influence of 6 doses of N, P, K on yield and yield components of two PNG standard varieties Wantok & Tambu was studied under lowland field conditions, separately. Under no fertilizer treatment, the yield was the least, for both the varieties, while highest yeidl for Wantok and Tambu was recorded under N, P, K (kg./ha.) doses of 100:50:50, 120:60:60 and 140:70:70; and 120:60:60 and 140:70:70 respectively. Doses of 100:50:50 and 120:60:60 seem to be optimum for Wantok and Tambu respectively. The influence of all the doses on yield and yield component of both the varieties has also been presented.

Keywords: NPK doses, lowland field, yield and its components.

INTRODUCTION

The two PNG standard rice varieties i.e. Tambu and Wantok were developed through the recombination breeding techniques during 1986 (Kim, 1986; Kim and Kriosaki, 1986). Unfortunately their nuritional requirements were not determined.

Grain and Rice Research and Development Project was initiated to develop both the modern High Yielding Varieties (HYV's) and cost effective Agronomic practices, during 1990. Although both the varieties possess many undesirable traits such as eating and milling recovery etc., yet they have ideal semi dwarf plant postures.

The miracle rices of 60s were developed using Dee Gee Woo Gen & I Go Tse dwarfing gene sources. The use of donors for semi dwarf plant postures set the dawn of Green Revolution in the Asian countries in particular and world at large. The resultant recombinants possessed short, thick and sturdy culms short erect leaves, responsiveness to added fertilizers, high tillering potential, resulting in increased yields (International Rice Research Institute, 1968; Tanaka *et al.* 1969).

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We envisaged that since these two varieties possess the semi dwarf plant posture they may be fertilizer responsive. In PNG, a fertilizer rate of 100-150:50:50 Kg./ha. of N, P, K respectively has been recommended by Wohuinangu and Kap, 1980 in their review paper on, Review on Rice Research.

We conducted the present study to optimize the fertilizer rate for semi dwarf varieties under lowland field conditions. The results of the study are presented in the paper.

MATERIALS AND METHODS

Two separate experiments on Wantok and Tambu were conducted with the following N, P, K fertilizer treatments (kg/ha.).

T1= 0- 0- 0
T2= 60-30-30
T3= 80-40-40
T4=100-50-50
T5=120-60-60
T6=140-70-70

Twenty days-old field grown nursery of both Wantok and Tambu was transplanted on 3.5.1991, at a plant to row distances of 20 cm., using seedlings per hill. All P, K, & 40% N was applied at the time of transplanting. The two top dressings were accomplished with N (30 % each) after 20 and 40 days after

Table 1: Influence of different doses of NPK on yield components of rice variety Wantok, under lowland field condition at Bubia Agriculture Research Centre, during 1991.

Doses	Yield t/ha.	Plant height (cm.)	No. of productive tillers/hill.	Panicle length (cm.)	No. of grains per panicle	Spikelet fertility %	Flag leaf area (cm.sq.)	Thousand grain weight (g)
0-0-0	4.7c	80.0b	7.2b	23.9a	114.1e	82.0b	22.8c	20.0b
60-30-30	6.2b	81.2b	8.2b	24.0a	124.6d	91.7a	25.6b	20.0b
80-40-40	7.1b	86.2a	10.9a	24.3a	129.9c	92.8a	25.7c	20.4b
100-50-50	8.1a	86.3a	11.8a	24.6a	132.0b	93.5a	26.5b	20.9b
120-60-60	8.3a	87.6a	12.4a	25.1a	135.5a	94.2a	27.1a	21.3a
140-70-70	8.8a	87.9a	13.1a	25.2a	137.0a	94.7a	28.5a	23.1a

Figures in columns, followed by different letters are significant 5% level of significance according to DMRT.

Table 2: Influence of different doses of NPK on yield and its components of rice variety Tambu, under lowland field condition at Bubia Agriculture Research Centre during 1991.

Doses	Yield t/ha.	Plant height (cm.)	No. of productive tillers/hill.	Panicle length (cm.)	No. of grains per panicle	Spikelet fertility %	Flag leaf (cm.sq.)	Thousand grain weight (g)
0-0-0	5.2c	80.0c	6.0c	23.4b	116.2c	80.0b	22.7d	23.1c
60-30-30	6.1b	83.4b	6.3c	23.7a	118.3c	92.7a	24.5c	23.4c
80-40-40	6.5b	85.5b	9.2b	24.0a	122.4b	93.3a	25.0b	25.5b
100-50-50	7.0b	87.6b	10.2a	24.3a	125.9b	94.0a	26.1b	25.6b
120-60-60	7.5a	88.5a	11.5a	24.6a	129.3a	94.8a	27.7a	26.7a
140-70-70	8.8a	92.5a	12.8a	24.7a	134.2a	95.3a	30.5a	26.7a

Figures in columns, followed by different letters are significant at 5% level, according to DMRT.

the transplanting date respectively. The experiments were conducted using Randomized Complete Block Design (RCBD, with three replications). The plot size was 10 m.sq. The other normal cultural practices were followed during the growing periods of experiments.

The data on yield was recorded by harvesting a net area of 6 sq. m. per treatment per replication per experiment. The data on yield components were recorded on 25 guarded plants per treatment per replication per experiment.

EXPERIMENTAL RESULTS

YIELD

The results of the study (Tables 1 & 2) indicate that under no fertilizer treatment, the yield was the least, for both the varieties, while the highest yield for Wantok and Tambu was recorded under 100-50-50; and 120-60-60 and 140-70-70 (at par with each other); and 120:60:60 and 140:70:70 (at par with each other) respectively. Doses of 100-50-50 and

120-60-60 seem to be the optimum for Wantok and Tambu respectively.

PLANT HEIGHT

For Wantok, plant height was maximum under 100:50:50 and 120:40:60 doses followed by rest of the doses of fertilizer, while least no. of tillers were produced under no fertilizer and 60:30:30 doses. For Tambu, the three highest doses produced the mazimum no. of tillers followed by 80:40:40, 60:30:30 and no fertilizer doses (non significant with each other).

NO. OF PRODUCTIVE TILLERS PER HILL

Wantok produced maximum no. of productive tillers per hill under the highest four doses of fertilizer, while least no. of tillers were produced under no fertilizer and 60:30:30 doses. For Tambu, the three highest doses produced the maximum no. of tillers followed by 80:40:40, 60:30:30 and no fertilizer doses (non significant with each other).

PANICLE LENGTH

Panicle length of Wantok was non significant under all the doses of fertilizer. While for Tambu, under no fertilizer treatment, the panicle length was significantly less, compared to rest of the doses. Except no fertilizer, panicle length under all the rest of the doses was non significant.

NO. OF GRAINS PER PANICLE

Different doses of fertilizer affected both the varieties similarly. The maximum grains per panicle were produced by the highest two doses, followed by rest of the doses in decreasing order, for both the varieties.

PANICLE FERTILITY %

Exactly similar effect of different doses of fertilizer were observed for both the varities. The minimum value for the trait was recorded for no fertilizer, while the trait was at par among the rest of the doses, for both the varieties.

FLAG LEAF AREA

Maximum flag leaf area was recorded for the last highest two doses for both the varieties, while the minimum value for the trait was recorded for no fertilizer treatment.

THOUSAND GRAIN WEIGHT

The maximum value for the trait was observed under the highest doses for both the varieties under study. The second highest dose of fertilizer for Tambu has also influenced trait the maximum (at par with the highest dose).

DISCUSSION

For Wantok, the three highest dose of complete fertilizer of N, P, K affected yield and its components, the maximum. But for Tambu, only two highest doses affected yield and yield components, the most. It is extremely interesting to note that under the three highest doses, the yield and almost all the yield components are non significant. Similarly for Tambu, only last two highest doses have affected yield and yield components, the most. Therefore, from the result of the study, a clearer picture has emerged that, N, P, K doses of 100:50:50 and 120:60:60 has affected the yield and yield components of Wantok and Tambu respectively, the most.

CONCLUSION

It may safely be concluded from the results of the study that N, P, K doses of 100:50:50 and 120:60:60, Kg./ha. for Wantok and Tambu respectively may be recommended for lowland rice cultivation in the country.

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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 mean
s.e.d.	- standard error of difference
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