ISSN 0256-954X

Papua New Guinea

Journal of Agriculture, Forestry and Fisheries

(Formerly the Papua New Guinea Agriculture Journal)

EDITOR: REUBEN SENGERE VOLUME 40 NUMBER 1&2, DECEMBER, 1997

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PAPUA NEW GUINEA

JOURNAL OF AGRICULTURE, FORESTRY AND FISHERIES

(Abbr. Key Title = P.N.G. j. agric. for. fish.)

(Formerly the Papua New Guinea Agriculture Journal)

Published by the Department of Agriculture and Livestock (DAL)

Editor: Reuben Sengere (DAL, Konedobu)

Honorary Consultant Editor: Professor Ray Kumar (UPNG)

Department of Agriculture and Livestock, P. O. Box 417, KONEDOBU, Papua New Guinea.

Published Biannually

		Airmail	Surface Mail
Annual Subscriptions:	Australia/Asia/Pacific	K32.50	K30.50
	Other countries	K45.30	K38.56
	Domestic	K23.62	K23.02

(Prices are subject to change without notice)

DAL PRINTSHOP, HOHOLA, PORT MORESBY

Cover Design by Jackson Kaumana

PAPUA NEW GUINEA

JOURNAL OF AGRICULTURE, FORESTRY AND FISHERIES

(Formerly the Papua New Guinea Agriculture Journal)

Vol. 40 No. 1 & 2 December, 1997

CONTENTS

SOIL CHEMICAL PROPERTIES UNDER PRIMARY FOREST AND COFFEE IN THE KUTUBU AREA OF PAPUA NEW GUINEA

Toli Kunu and Alfred E. Hartemink*

ABSTRACT

This paper presents some preliminary investigations in the topsoil (0-0.2 m) chemical properties under primary forest and arabica coffee in the Kutubu area (Southern Highlands). The coffee gardens were established from primary forest about 3 years prior to the soil sampling in 1996. Most of the arabica coffee in the Kutubu area is not fertilized and overall the coffee is growing poorly. Both soils under forest and coffee had moderate to low fertility levels with strongly to moderately acid soil reactions (pH H_2O: 4.7 to 5.4). There was little difference in the chemical fertility between the topsoils under forest and coffee although exchangeable calcium and base saturation were significantly higher under coffee possibly as a result of the ash addition after the forest was slashed and burned. All soils had extremely low levels of available phosphorus but high total P-levels. Nutrient deficiencies, in particular P and micronutrients, may be factors explaining the poor coffee performance in the Kutubu area but additional research is required.

Keywords: *primary forest, soil fertility changes, arabica coffee, phosphorus, Lake Kutubu area*

INTRODUCTION

The first arabica coffee (*Coffea arabica*) plantation in Papua New Guinea was probably established near Wau in 1928. In 1937, arabica coffee was planted on the Highlands Agricultural Experimental Station at Aiyura and from there coffee was planted throughout the highlands provinces (Harding *et al.* 1986). Coffee production rose from 42,000 bags green beans (60 kg/ bag) in 1960/61 to 1,100,000 bags in 1993/94 (Anon 1994). Most of the coffee in Papua New Guinea is produced by smallholders and it is the major source of income for one-third of the population (Harding *et al.* 1984).

Besides having a well established coffee industry, Papua New Guinea has vast areas of primary forests which cover about 80% of the country. Annually about 113,000 ha of primary forest are cleared for logging, mining, agricultural projects and shifting cultivation (FAO 1995). A large part of the deforestation is required for the expansion of agricultural land to feed the rapidly growing population, and the planting of cash crops such as arabica coffee. In the Eastern and Western Highlands there are vast areas where coffee is a dominant crop but in the Southern Highlands relatively little coffee is grown despite various attempts to encourage coffee growing in this province (Harding *et al.* 1986). In recent years, however, a large number of farmers have planted arabica coffee in the area around Lake Kutubu. Most of these new plantings were made after cutting and burning the primary forest.

There is a fair body of literature on the changes which take place in the soil when forest is cleared and crops are planted, and excellent summaries can be found in Nye and Greenland (1960), Sanchez (1976), Lal (1986) and Lal *et al.* (1986). The burning of the vegetation and the production of ash increases the soil pH and the levels of exchangeable calcium and magnesium which is particularly beneficial in acid soils. Also, the available phosphorus and potassium levels increase after burning. The organic matter and soil nitrogen contents increase slightly after burning because of the addition of the partially burned vegetation. All nutrients decrease gradually with cultivation due to a combination of losses and crop uptake and removal.

For the Kutubu area where coffee cultivation is expanding, virtually nothing is known on changes in soil

*University of Technology, Department of Agriculture, PMB, Lae, Papua New Guinea and corresponding author.

chemical properties when forest is cleared. The objectives of the research presented in this paper were (i) to investigate differences in soil chemical properties between primary forest and coffee gardens, and (ii) to identify possible soil chemical constraints affecting coffee production in the Kutubu area.

MATERIALS & METHODS

The site

The soil samples were taken in the Foi area (6°23' S, 143°20' E), north of Lake Kutubu along the main Mendi-Kutubu road in the Southern Highlands of Papua New Guinea. Altitude of the sampled sites was approximately 900 m a.s.l. and in the classification of agro-climatic zones of Papua New Guinea by Gurnah (1992) the area around Lake Kutubu is Premontane Perhumid (Zone II). No detailed climatic data were available for the sampled sites but average rainfall at Lake Kutubu is about 4,500 mm yr^{-1} with a mean annual temperature of 23.1°C (CSIRO 1965).

Most of the soils north of Lake Kutubu have been developed from volcanic deposits on limestone and they are generally acid with low base saturation. Similar soils have been described by Harding (1984) at Ialibu (profile no. PH001-R400) where a strongly acid soil with high aluminium saturation in the subsoil was formed on limestone. The soil at Ialibu was classified as an Andic Humitropept which is equivalent to Haplustands in the more recent Soil Taxonomy version (Soil Survey Staff 1994) or Umbric Andosol in the FAO-Unesco classification (1988).

Soil sampling and analysis

Soil samples were collected under primary forest and coffee gardens in March 1996. Sampling sites were at Kunufalu, Aliago, Iputaba, Tanuga, Gesege turn off, Inu Junction, Yaipa, and Tubaga. The coffee gardens were established from primary forest in 1993 and some were intercropped with food crops during the first few seasons. None of the coffee gardens had been fertilized. Sampling procedures were the same in the forest and coffee gardens, as follows: The mulch layer (O-horizon) was removed from the soil whereafter a mini-pit of 0.2 m depth was dug using a spade. From these pits about 0.5 kg soil was taken from the 0-0.2 m soil horizon. In total, 10 such pits were dug in an area of 50 m by 50 m. The soil was bulked and a subsample of about 2 kg was taken to the National Analysis Laboratory in Lae for analysis. Soils were air dried, ground and passed through a 2 mm sieve. For total P determinations the samples were ground to pass through 150 mesh.

Soil samples were analysed at the National Analysis Laboratory in Lae following standard procedures as described in Page *et al.* (1982). The following methods were used: pH H_2O in 1:5 suspension of soil and water; pH KCl in a 1:5 soil and 1*M* KCl solution; electrical conductivity in a 1:5 suspension of soil and water; organic carbon by $K_2Cr_2O_7$ and H_2SO_4 oxidation; available P by NH_4F and HCl extraction (Bray I); total P by perchloric acid digestion; exchangeable cations Ca, Mg, K, Na and CEC after percolation with 1 *M* NH_4OAc followed by spectrophotometry (K, Na), AAS (Ca, Mg) and titration (CEC); and exchangeable acidity (H, Al) extraction by 1 *M* KCl. In addition, pH-NaF was measured in a 1:50 soil and 1*M* NaF solution at the laboratories of the Department of Agriculture. The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable calcium, magnesium, potassium, sodium and exchangeable acidity (hydrogen and aluminium).

RESULTS

At Inu Junction and Aliago, soil samples were taken in primary forest and an adjoining coffee garden. The distance between the two samplings was less than 100 m. At Inu Junction, the soil sample was taken in a forest with large trees and undergrowth of ferns. In the adjoining coffee garden, the forest was cleared in 1993 and coffee was planted intercropped with sweet potato (*Ipomoea batatas*), sugar cane (*Saccharum* sp.) and banana (*Musa* sp.). The coffee showed stunted growth in this garden.

Differences in soil chemical properties between the forest and the coffee garden were marginal (Table 1). Both soils were strongly acid with moderate amounts of organic carbon and extremely low levels of available phosphorus. The soil under coffee had, however, slightly higher levels of exchangeable bases and CEC, and as a result, a lower aluminium saturation. The pH-NaF is close to 9.4 in both soils.

At the Aliago site, the forest consisted of large trees including pandanus species and ferns undergrowth. In

Table 1. **Soil chemical properties (0-20 cm) of paired samples under primary forest and coffee in the Kutubu Area**

	Inu Junction		Aliago	
	primary forest	coffee garden	primary forest	coffee garden
pH water (1:5)	4.8	4.9	4.7	4.9
pH KCl (1:5)	4.7	4.6	4.0	4.2
pH NaF (1:50)	9.2	9.0	8.8	8.8
EC (µS cm^{-1})	24	59	82	94
organic C (g kg^{-1})	29	38	38	38
Total N (g kg^{-1})	2.7	2.6	3.5	4.0
C/N	11	15	11	10
Available P (mg kg^{-1})	1	traces	1	2
Total P (mg kg^{-1})	860	1100	1300	1100
CEC ($mmol_c$ kg^{-1})	68	98	146	211
Exchangeable Ca ($mmol_c$ kg^{-1})	5	17	18	77
Exchangeable Mg ($mmol_c$ kg^{-1})	4	5	8	24
Exchangeable K ($mmol_c$ kg^{-1})	0.7	1.2	1.8	4.5
Base saturation (%)	15	24	19	50
Exchangeable Al ($mmol_c$ kg^{-1})	1.2	1.6	17.9	5.9
Al saturation (%)[a]	15	8	42	7

Table 2. **Soil chemical properties (0-20 cm) under primary forest and coffee in the Kutubu Area (values reported are the arithmetic mean ±1 SD)**

	primary forest (*n*=5)	coffee gardens (*n*=5)	difference
pH water (1:5)	5.0± 0.22	5.0± 0.24	n.s.
pH KCl (1:5)	4.4± 0.26	4.5± 0.24	n.s.
pH NaF (1:50)	9.1± 0.5	8.9± 0.3	n.s.
EC (µS cm^{-1})	52± 28	69± 24	n.s.
organic C (g kg^{-1})	3.9± 0.86	3.9± 0.14	n.s.
Total N (g kg^{-1})	3.0± 0.52	3.2± 0.53	n.s.
C/N	13± 2.0	12.6± 1.8	n.s.
Available P (mg kg^{-1})	0.6± 0.5	1.0± 1.0	n.s.
Total P (mg kg^{-1})	1152± 220	1116± 229	n.s.
CEC ($mmol_c$ kg^{-1})	107± 29	142± 48	n.s.
Exchangeable Ca ($mmol_c$ kg^{-1})	10± 6	41± 28	*P*=0.05
Exchangeable Mg ($mmol_c$ kg^{-1})	5± 3	11± 10	n.s.
Exchangeable K ($mmol_c$ kg^{-1})	1.2± 0.4	2.1± 1.5	n.s.
Base saturation (%)	15± 4	36± 18	*P*=0.04
Exchangeable Al ($mmol_c$ kg^{-1})	6.2± 6.7	6.5± 6.2	n.s.
Al saturation (%)[a]	28 ±13	17±17	n.s.

[a] **Aluminium saturation was calculated as: Al/ECEC = Al/ (Ca, Mg, K, Na, H, Al)*100**

1993, some of the forest was cleared for growing coffee which performed poorly in 1996. As was found at Inu Junction, both soils had a low pH, extremely low available P and moderate amounts of organic C (Table 1). Levels of exchangeable bases as well as the CEC were higher under coffee than under primary forest. Under coffee, aluminium saturation of the ECEC (Effective Cation Exchange Capacity) was 7% whereas this was 42% under primary forest.

In total five soil samples were taken in coffee gardens and five under primary forest. Mean values of the soil chemical data for both land-use systems are given in table 2. Variation in soil chemical parameters was considerable as can be seen from the standard deviations. Despite this variation both exchangeable calcium and base saturation were significantly higher in the soils under coffee but no significant differences were found in other soil chemical properties.

A striking feature of both the soils under forest and coffee is the extremely low available phosphorus level ($\leq$ 2 mg P kg^{-1} soil). Total levels of phosphorus ranged from 860 to 1600 mg kg^{-1}. Although the data are only few, total P tended to increase at higher organic C contents.

Some soils had a moderately high pH in NaF which is generally an indication of the presence of allophane and aluminium. The hydroxyl groups of the various components in soils enriched with volcanic deposits containing active aluminium, react strongly with fluoride ions, the so-called ligand exchange (Mizota & van Reeuwijk 1989). The ligand exchange between F^- and OH^- result in a rapid increase in pH (Uehara & Ikawa 1985). This was found in some of the soils of the Kutubu area, and 2 of the 10 sampled soils had a pH NaF ^{3} 9.4.

DISCUSSION

Despite variation in the soil analytical data both soils under coffee and primary forest had a moderate to low fertility with moderate levels of aluminium saturation. Soils under tropical forest are commonly, but not always, acid with a low fertility (Wild 1989). A large part of the soil fertility is found in the above and below ground biomass i.e. the forest. For example Grubb & Edwards (1982) found in a lower montane forest in the Eastern Highlands of Papua New Guinea 835 kg N ha^{-1}, 49 kg P ha^{-1} and 699 kg K ha^{-1}. These nutrients become partly available following the slashing and burning of the forest vegetation. Under coffee, levels of exchangeable calcium and the base saturation was significantly higher. This is likely to be due to the addition of ashes containing several salts, including carbonates, hydroxides and silicates, which raise the soil pH and levels of exchangeable bases (Wild 1989). As the slashing and burning of the forest vegetation had taken place 3 years prior to the soil sampling, the effect of the ash addition had almost disappeared due to losses and crop removal.

Most of the P in the Kutubu soils under primary forest and coffee was not extractable by NH_4F and HCl and levels of available phosphorus were extremely low ($\leq$ 2 mg kg^{-1}). Total phosphorus was, however, between 860 and 1600 mg kg^{-1} which is high to very high (Landon 1991). The soils have a high P retention capacity which is common in soils of the Southern Highlands (Radcliffe & Gillman 1985). Indeed the pH-NaF of the soils was between 8.5 and 9.8 which may be a clear indication that the soils are derived from volcanic ash. Although most of the phosphorus may be fixed in inorganic compounds, some phosphorus is in the organic form which is likely to be an important source of plant-available phosphorus as was also found in other tropical soils with cropping systems receiving little or no fertilizers (Beck & Sanchez 1994).

At all sites it was observed that the coffee was growing poorly. The pH of the soils is below optimal for coffee, which is generally believed to be between 5.2 and 6.0. It should be noted, however, that some arabica coffee is successfully grown in soils with pH 4.6 (Wrigley 1988). The organic C content is low but total levels of N are generally sufficient. Levels of exchangeable bases are moderate and also the aluminium saturation is probably not limiting arabica coffee production since it can tolerate aluminium saturation up to 80% (Sanchez 1976). Micronutrient deficiencies, notably boron, are widespread throughout the soils under coffee in the highlands of Papua New Guinea (Harding *et al.* 1986) and may perhaps explain why the coffee is growing so poorly in this part of the Southern Highlands. Other explanations may be unfavourable soil physical properties (e.g. limited rooting depth, impeded drainage) and the occurrence of pests and diseases but data to support this are not available.

It can be concluded that there were only marginal differences in soil fertility between primary forest and coffee gardens in the Kutubu area. Although several factors may be limiting high yielding coffee cultiva-

tion, levels of phosphorus and micronutrients are likely to be suboptimal for arabica coffee, particularly when the coffee is young.

ACKNOWLEDGEMENTS

Mr Fred Grieshaber of the National Analysis Laboratory in Lae is kindly acknowledged for the help in soil analysis. Toli Kunu wishes to thank Chevron's training department for assistance received to conduct this study. The useful comments from two anonymous reviewers are kindly acknowledged.

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BIOMASS PRODUCTION AND NUTRIENT UPTAKE OF TARO ROOTS

A.E. Hartemink*, M. Johnston, P. John, W. Julius and A. Kerru

ABSTRACT

*Information on biomass production and nutrient uptake of roots in tropical tuber crops is scarce. In this paper data are presented on nutrient uptake of taro roots (*Colocasia esculenta*) in relation to corm yield and above ground biomass on a Typic Tropofluvents in the humid lowlands near Lae. Fertilized (100-50-100 kg NPK ha^{-1}) and unfertilized plants (n=4 each) were harvested at 126 days after planting (126 DAP=mid-season) and 231 DAP (harvest). Root biomass at 126 DAP was 0.26 t ha^{-1} (15% of total biomass) in the unfertilized plots and 0.52 t ha^{-1} (13% of total) in the fertilized plots but at 231 DAP root biomass was similar (~0.50 t ha^{-1}). Root nutrient concentrations at 126 DAP was similar in both plots but N, Ca and S significantly declined in the unfertilized plots at 231 DAP whereas B increased with 18 mg kg^{-1} ($p<0.01$). In the fertilized plot P, K, Mg, Mn and Cu had decreased at 231 DAP but Zn had significantly ($p<0.01$) increased. Nutrients in the root biomass as a fraction of the total nutrient uptake were similar at 126 DAP for both treatments. At 231 DAP, however, the fraction of nutrients in the root biomass was considerably lower in the fertilized plots. Nutrient uptake by roots at harvest was 5 kg N, 1 kg P, 25 kg K, 5 kg Ca, and 3 kg Mg ha^{-1} for both fertilized and unfertilized conditions. The study has shown that taro roots contain considerable amount of nutrients but that a much larger proportion of plant nutrients is allocated to the roots under unfertilized conditions.*

Keywords: *taro, roots, nutrient uptake, nutrient concentration, fertilizer*

INTRODUCTION

Root biomass production and nutrient uptake receive little attention in most field studies with food crops. The reasons for this omission are obvious: the root system is hidden from direct observation and the quantification of roots is tedious and difficult because of problems in extracting roots from the soil. It is also complex because of the spatial and temporal variability of roots in the soil matrix. Despite these problems, various destructive and advanced non-destructive methods have been developed to study roots of field crops (Taylor *et al.* 1991) in addition to sampling schemes for their quantification (van Noordwijk *et al.* 1985). Much of the research on roots has been conducted in the temperate regions and information on root biomass and its nutrient content of tropical crops is limited. This is particular the case for tropical root and tuber crops (Goenaga and Chardon 1995; Jacobs and Clarke 1993).

Root and tuber crops are the major source of dietary energy for many people in the Pacific Islands countries (de la Peña 1996). In Papua New Guinea, sweet potato (*Ipomoea batatas*) is the main staple crop (Allen *et al.* 1995) although taro (*Colocasia esculenta*) is usually the first crop planted after the forest or fallow vegetation is cleared (Moles *et al.* 1984). It is generally grown under upland conditions and no irrigation or fertilizers are applied. Most smallscale farmers in Papua New Guinea grow taro for one season only because of an increase in the incidence of pests and diseases, weeds and/or the depletion of soil nutrients. These factors usually result in low yields in successive seasons. Inorganic fertilizers are a viable option to sustain and improve taro yields since taro commonly responds well to fertilizers (de Geus 1972; Kabeerathumma 1992). Smallscale farmers use little inorganic fertilizer because of low nutrient use efficiency (Noordwijk and de Willigen 1991) with the associated risk that investments in fertilizers will not be profitable (McIntire 1986). An important step to increase the efficiency of fertilizers in order to improve yields is an understanding of the nutrient uptake and

*University of Technology, Department of Agriculture, Private Mail Bag, LAE, Papua New Guinea and corresponding author.

allocation within the taro plant during a growing season. We therefore conducted an experiment which aimed to quantify root biomass production and nutrient uptake of fertilized and unfertilized taro. In order to make an accurate estimation of root dry weight, destructive measurements were made whereby whole taro plants were dug up.

MATERIALS AND METHODS

The site

The research took place on the experimental farm of the University of Technology in Lae. The experimental farm (6°41'S, 146°98'E) is located at an altitude of 65 m a.s.l. and annual rainfall is about 4400 mm y^{-1} which is fairly well distributed throughout the year. Average daily temperature is 26.3°C, with an average minimum of 22.9°C and an average daily maximum of 29.7°C. Annual evaporation (US Class A pan) is 2139 mm, and rainfall exceeds evaporation in each month (McAlpine *et al.* 1975). The climate is classified as Af (Köppen) i.e. a tropical rainy climate with driest month over 60 mm rain. During the experiment (23 March until 13 November 1996) 2605 mm of rain was recorded.

The soil at the farm is well drained and classified as a sandy, mixed, isohyperthermic Typic Tropofluvents (USDA Soil Taxonomy) or Eutric Fluvisol (FAO-Unesco). Airdried and sieved (2 mm) topsoil (0-0.23 m) had the following properties: pH (1:5 soil:water suspension) = 5.9, organic C = 23.8 g kg^{-1}, P-Olsen = 12 mg kg^{-1}, total N = 2.0 g kg^{-1}, CEC (1 *M* NH_4OAc, pH7) = 126 $mmol_c\ kg^{-1}$, sand = 790 g kg^{-1}, and clay = 80 g kg^{-1}, bulk density = 1.10 t m^{-3}.

Experimental setup and management

The site at which the experiment was conducted had been under pasture for 8 years and was ploughed in January 1996. Four blocks each with two plots (5.6 x 9.5m) of taro (*Colocasia esculenta* (L.) Schott. var. *esculenta*) local cultivar Nomkoi were planted on 23/3/1996 at a spacing of 0.5 by 0.8 m (25,000 plants ha^{-1}). Planting material consisted of corm apical portions from main plants from which the petioles had been cut 0.25 to 0.30 m above the corm to remove the leaf lamina. In each block one randomly selected plot was fertilized with 100 kg N ha^{-1} (sulphate of ammonia) given in equal amounts at 49 and 79 DAP (=days after planting), and 50 kg P ha^{-1} (triplesuperphosphate) and 100 kg K ha^{-1} (muriate of potash) as a basal dressing at planting. Fertilizers were broadcast over the plot and slightly incorporated into the topsoil. The other plot was not fertilized. Weeding was done manually at regular intervals and weeds were not removed from the plots. Biocides were used to control hawkmoth (*Hippotion celerio* L.) and taro leaf blight (*Phytophtera colocasiae*).

Sampling and nutrient analysis

In the mid-season (126 DAP) and at harvest (231 DAP) a row of four taro plants was randomly selected in both the fertilized and unfertilized plots to determine above and below ground biomass production and nutrient uptake. Due to the large amount of work involved in root washing and sorting, only 4 plants were sampled per treatment at the two sampling times. The plants were pulled up and divided into corms and leaves (including petioles). No distinction was made between main and sucker plants and for each plant, corms or leaves of the main plants and suckers were combined into one sample. The samples were washed with distilled water and ovendried at 70°C for 72h which after dry weight was recorded. The dried plant parts were ground (mesh 0.2mm) prior to nutrient analysis.

For the root biomass determination, an area equal to the plant spacing (0.5 x 0.8m) was pegged out around each taro plant which has been called the unit soil area by Noordwijk *et al.* (1985). Pits were dug to observe the rooting depth of the taro, and in the mid-season and at the harvest the taro had not rooted deeper than 0.15 to 0.18 m. All soil to a depth of 0.2 m (0.08 m^3) was collected in plastic bags and taken to the laboratory. The roots were washed from the soil with pressurized water on a 0.5 mm sieve. The sieved root and organic debris material were put in plastic trays filled with water whereafter the floating roots were handpicked the same day. After washing the roots with distilled water, they were immediately ovendried to avoid loss of nutrients (Misra 1994).

Nutrient analysis of root, corm and leaf biomass samples was conducted at the laboratories of the Department of Agriculture of the University of Queensland. One subsample was digested in 5:1 nitric:perchloric acids and analyzed for P, K, Ca, Mg, S, B, Mn, Zn and Cu using inductively coupled plasma atomic emission spectrometry (ICP AES-Spectro Model P). A second subsample was digested according to the Kjeldahl procedure and analyzed for N on an

Alpkem Rapid Flow Analyser Series 300.

RESULTS

Biomass

Fertilized taro had significantly ($p<0.05$) more total biomass than unfertilized taro at both sampling times which in the mid-season (123 DAP) was due to the larger root and leaf biomass (Table 1). There had been little corm development in the mid-season and differences in the corm weight of fertilized and unfertilized taro were not significant. At harvest (231 DAP), however, the difference in total biomass was due to the greater corm and leaf biomass in the fertilized taro. The root biomass was similar for both fertilized and unfertilized plants at harvest and approximately 50 g m^{-2}. In fertilized taro, maximum root biomass was achieved by the mid-season (52 g m^{-2}) whereas root development was still occurring in the mid-season unfertilized taro (26 g m^{-2}). At 126 DAP root biomass was 15% and 13% of the total biomass in the unfertilized and fertilized taro, respectively. At harvest, the proportion of roots of the total biomass was 10% in the unfertilized taro and 4% in the fertilized taro. The CV% of dry root weight were between 6 and 24% at 126 DAP and between 1 and 14% at 231 DAP. The variation in root measurements was larger in fertilized taro.

The dry matter content of all plant parts increased from the mid-season to the end of season and was unaffected by fertilizer except for mid-season sampling when the roots of fertilized taro had a slight but significantly higher dry matter content (Table 1).

Nutrients

Nutrient analysis showed that the Ca concentration was significantly lower in taro roots ($p<0.001$) at the end of season compared to the mid-season for both unfertilized and fertilized taro (Table 2). At harvest, B and Zn concentrations had significantly ($p<0.01$) increased from the mid-season in unfertilized and fertilized taro roots respectively. Potassium concentration in the roots were similar at 126 DAP and 231 DAP and not affected by fertilizer. In the mid-season fertilizers increased the concentration of Mg, S, B, Mn and Cu but decreased the concentration of P and Zn. At harvest, there was no effect of the fertilizer applications on the nutrient concentration except for S which was 0.5 g kg^{-1} higher in fertilized roots.

The K, Ca, Mg, Mn and Cu concentration in the taro corms were all lower at the end of season than in the mid-season for both unfertilized and fertilized taro (Table 3). At harvest, the concentration of N and S was significantly lower in the corms of fertilized taro only. Fertilizers decreased the nutrient concentration of P and Zn in the mid-season, and N, K and Zn at harvest. Striking is the effect that fertilizer decreased P and Zn concentration in both roots and corms in the mid-season.

Table 1. **Biomass production and dry matter content of unfertilized and fertilized taro at 126 and 231 DAP.**

	plant part	mid-season (126 DAP) unfertilized	fertilized	at harvest (231 DAP) unfertilized	fertilized
dry weight (t ha^{-1})	roots	0.26	0.52***	0.51	0.50
	corms	0.82	1.21	2.53	6.99*
	leaves[1]	0.67	2.13*	2.00	3.64*
	total	1.75	3.86*	5.04	11.13*
dry matter content (%)	roots	4	5***	12	11
	corms	21	19	30	30
	leaves[1]	8	7	16	16

[1] **leaf biomass includes petioles**

*,**,*** **indicates significant difference between fertilized and unfertilized taro at $p<0.05$, 0.01 and 0.001 respectively.**

Table 2. Nutrient concentration in unfertilized and fertilized taro roots at 126 and 231 DAP

Nutrient	Unit	Unferilized		Fertilized		Fertilizer effect[1]	
		126 DAP	231 DAP	126 DAP	231 DAP	126 DAP	231 DAP
N	g kg^{-1}	13.0	11.4*	14.1	10.6	ns	ns
K	"	2.1	2.2	1.8	2.2*	-	ns
K	"	52.7	48.9	47.7	46.3	ns	ns
Ca	"	14.0	10.7***	14.4	11.0**	ns	ns
Mg	"	5.9	5.9	7.1	6.0*	+	ns
S	"	1.2	1.5*	2.3	2.0	+++	ns
B	mg kg^{-1}	12	30**	25	25	+	ns
Mn	"	77	84	120	94*	++	ns
Zn	"	91	105	63	114**	--	ns
Cu	"	42	39	62	29**	+	ns

***,**,* indicates significant difference at p<0.001, 0.01 and 0.05 between mid season (126 DAP) and at harvest (231 DAP)
[1] indicates level of significant difference between fertilized and fertilized taro at 126 and 231 DAP;
+++,++,+ indicates fertilizers increased nutrient concentration significantly at p<0.001, 0.01 and 0.05 respectively;
--, - indicates fertilizers decreased nutrient concentration significantly at p<0.01 and 0.05 respectively;
ns = not significant.

Table 3. **Nutrient concentration1 in unfertilized and fertilized taro corms at 126 and 231 DAP**

Nutrient	Unit	Unferilized		Fertilized		Fertilizer effect[1]	
		126 DAP	231 DAP	126 DAP	231 DAP	126 DAP	231 DAP
N	g kg^{-1}	8.3	5.8	14.5	4.5**	+	-
K	"	2.6	2.1**	1.9	1.8	--	ns
K	"	20.9	17.0*	19.0	13.0**	ns	-
Ca	"	5.8	3.6*	4.9	3.1*	ns	ns
Mg	"	1.4	0.8**	1.3	0.8**	ns	ns
S	"	0.5	0.4	0.8	0.4***	+	ns
B	mg kg^{-1}	4	16**	13	17	ns	ns
Mn	"	40	24*	43	21*	ns	ns
Zn	"	68	37**	28	27	---	-
Cu	"	18	11*	19	9***	ns	ns

***,**,* indicates significant difference at p<0.001, 0.01 and 0.05 between mid season (126 DAP) and at harvest (231 DAP)
[1] indicates level of significant difference between fertiliezed and fertilized taro at 126 and 231 DAP;
+++,++,+ indicates fertilizers increased nutrient concentration significantly at p<0.001, 0.01 and 0.05 respectively;
--, - indicates fertilizers decreased nutrient concentration significantly at p<0.01 and 0.05 respectively;
ns = not significant.

Although variation was large, it was found that roots of fertilized taro at 126 DAP had taken up significantly larger ($p<0.01$) amounts of all major nutrients (Table 4). This was due to the greater biomass (Table 1) and higher concentration of most nutrients (Table 2). The total nitrogen content in the corm was higher in fertilized taro (14 kg ha^{-1}) than in unfertilized taro (5 kg ha^{-1}). Overall in the mid-season fertilized taro had taken up significantly more N, Ca, Mg and S. The fraction of nutrients taken up by the roots expressed as a proportion of the total uptake was, however, not different between fertilized and unfertilized taro at 126 DAP. The uptake of N and P in roots was about 7 to 12% of the total uptake whereas 13 to 22% of the total

Table 4. **Nutrient content (kg ha^{-1}) of roots, corms and leafs of unfertilized and fertilized taro at 126 and 231 DAP**

	plant part	unfertilized taro			fertilized taro		
sampling period		N	P	K	Ca	Mg	S
mid-season	roots	3	<1	13	4	2	<1
(126 DAP)	corms	5	2	17	4	1	<1
	leaves[1]	19	5	46	8	1	1
	total	27	9	76	16	4	2
at harvest	roots	6	1	25	5	3	1
(231DAP)	corms	13	5	42	8	2	1
	leaves[1]	34	10	80	21	3	2
	total	53	16	147	35	8	4

,**, indicates significant difference between fertilized and unfertilized taro at $p<0.05$, 0.01 and 0.001 respectively**
[1] leaf biomass includes petioles

Table 4. **contd.**

	Plant part	fertilized taro					
sampling period		N	P	K	Ca	Mg	S
mid-season	roots	8**	1***	25**	8***	4***	1**
(126 DAP)	corms	14**	2	22	6	2	1
	leaves[1]	63	9	119	29*	5*	4
	total	85*	13	166	42*	10*	5*
at harvest	roots	5	1	23	5	3	1
(231DAP)	corms	31*	12*	86*	23	5*	3**
	leaves[1]	55	18	106	46	6	4
	total	91	31	215	74*	15*	8*

,**, indicates significant difference between fertilized and unfertilized taro at $p<0.05$, 0.01 and 0.001 respectively**
[1] leaf biomass includes petioles

K, Ca and S uptake was present in the roots at 126 DAP. The amount of Mg in the roots accounted for 36 to 38% of the total Mg in the taro plants in both treatments.

At the end of season, there were no differences in the amount of nutrients taken up by the roots of fertilized and unfertilized taro. On a whole plant basis, however, fertilized taro took up significantly ($p<0.05$) more Ca, Mg and S than unfertilized taro. The proportion of nutrients taken up by the roots was similar for unfertilized taro at 126 DAP and 231 DAP. However, nutrient uptake in the roots as a proportion of the total uptake decreased between 126 and 231 DAP for both fertilized and unfertilized taro, notably for Ca (from 18 to 7%) and Mg (from 36 to 20%).

DISCUSSION

Fertilized taro produced twice as much biomass than unfertilized taro. Differences were already pronounced in the mid-season when fertilized taro had three times more leaf biomass and two times more root biomass. At harvest, however, root biomass was not different and about 0.50 t ha^{-1}. This root biomass is much larger than that recorded by Goenaga and Chardon (1995) who found between 0.14 to 0.31 t ha^{-1} for fertilized and drip-irrigated taro in Puerto Rico. Goenaga and Chardon (1995) also found that root biomass accumulation was complete within 120 DAP and did not change thereafter. Our research suggested the same for fertilized taro but showed that unfertilized taro had not fully developed its root system by 126 DAP. The advantages of the rapidly developed root system are obvious and can be simplified as: the more roots, the better shoot growth (Noordwijk and Willigen, 1991) which our data confirmed. As whole plants were dug up variation in root biomass measurements was relatively low (CV%<24) compared to other destructive sampling techniques like core samples and pinboards (Noordwijk *et al.* 1985; Taylor *et al.* 1991).

It was found that fertilizers reduced the concentration of P and Zn in both corms and roots at the mid-season whereas it increased the level of S. The increase in S concentration may be due to an increased S availability due to the addition by the sulphate of ammonia (114 kg S ha^{-1}). The significant decrease in P concentration may be caused by dilution in the plants which occurs when the rate of uptake is slower than the rate of biomass accumulation. The same may hold for the decrease in Zn concentration.

In our experiment we found that large amounts of nutrients are taken up by the roots and only small differences were found between fertilized and unfertilized taro at harvest. Some caution is, however, needed in the interpretation of the nutrient data of the roots as traces of soil may have adhered to the roots and nutrients may be washed from the roots with separation (Misra 1994). Nitrogen in the roots at harvest was 8 kg ha^{-1} (9% of total uptake) and 5 kg ha^{-1} (6%) for fertilized and unfertilized taro respectively. This is much higher than found by Gliessman (1982) who recorded 0.5 kg N ha^{-1} in the taro roots at harvest which was 2% of the total uptake. The difference is large and may be partially explained by differences in taro cultivars (Goenaga and Chardon 1995; Jacobs and Clarke 1993) and the growing conditions. Very little P was found in the roots ($\leq$ 1 kg ha^{-1}) and the majority of the P was in the leaves (including petioles). Potassium was found in large quantities in taro roots and up to 25 kg ha^{-1} was recorded. This may be an underestimation as K is easily lost from roots with washing. Misra (1994) found that wet separation (washing) of Eucalyptus roots resulted in a 24% loss of K. Magnesium was not taken up in large quantities in taro roots under unfertilized conditions (3 kg ha^{-1} at harvest) but it accounted for about 36% of the total Mg in the taro plants. In fertilized taro, about 20% of the total Mg taken up was found in the roots at harvest. In the mid season, the proportion of Mg in taro roots was highest (36-38% of total uptake). These data are much higher than those found by Kabeerathumma *et al.* (1985) who found 5% of the total Mg in the taro roots.

CONCLUSIONS

Root biomass in fertilized taro was fully developed by the mid-season whereas only half of the final root biomass was formed in unfertilized taro at this time. At harvest root biomass of fertilized and unfertilized taro was 0.50 t ha^{-1}. The amounts of nutrients in the roots of fertilized and unfertilized taro was similar at harvest: 5 kg N, 1 kg P, 25 kg K, 5 kg Ca, and 3 kg Mg ha^{-1}. The study has shown that considerable amounts of nutrients are allocated to the roots of taro but that the proportion of nutrients in the roots was much larger for unfertilized taro.

ACKNOWLEDGEMENTS

The authors are indebted to Spencer Poloma and Maquin Maino of the University of Technology in Lae for technical assistance. The research was partly funded through ACIAR Project 9101 (Diagnosis and correction of mineral nutrient disorders in root crops of the Pacific) and support from Drs F.P.C. Blamey and J.N. O'Sullivan of The University of Queensland in Brisbane is kindly acknowledged.

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EVALUATION OF LEAF BLIGHT RESISTANT TARO (*COLOCASIA ESCULENTA*) VARIETIES FOR BUBIA, MOROBE PROVINCE, PAPUA NEW GUINEA.

T. Okpul[2], A. Ivancic[1, 2] and A. Simin[2].

ABSTRACT

*Thirty five taro (*Colocasia esculenta *(L.) Schott) varieties resistant to taro leaf blight (TLB) (*Phytophthora colocasiae *Racib.) were evaluated at Bubia Agricultural Research Centre, Lae, Papua New Guinea, for yield components and eating quality in comparison with the locally preferred cultivar, Numkowec. The main factors affecting eating quality were presence of conspicuous corm fibre and acridity. Leaf blight resistant varieties AN 65, 17, 50, 32, 46, 21, 12 and AN 20 had acceptable eating quality. Their corm yield ranged from 300 g/plot (AN 50) to 570 g/plot (AN 21). However, their corm yield was not significantly different from that of Numkowec (430 g/plot). These resistant varieties are recommended to farmers in the Lae area based on their resistance to TLB and their similarities in corm yield and eating quality to Numkowec.*

Keywords: *Taro, variety evaluation, eating quality, taro leaf blight resistance.*

INTRODUCTION

Taro, *Colocasia esculenta* (L.) Schott (Araceae), is an important traditional crop in the Asia-Pacific region. In Papua New Guinea (PNG) it is a dietary staple for communities up to 2200 m a.s.l. (Oksapmin - Telefomin area), in which the farming system is predominantly taro-based. Conversely, it is cultivated as an additional seasonal crop to altitudes as high as 2740 m (Bourke 1982). Taro is now being cultivated as a semi-commercial crop.

Taro production in PNG has been declining over the last decades. This decline is due to the crop's susceptibility to insect pests and diseases and other agro-economic problems (Bourke 1982).

Taro leaf blight (TLB), caused by *Phytophthora colocasiae* Racib., is an important disease of the crop. It has been reported to cause up to 50% reduction in corm yield in PNG (Cox and Kasimani 1988).

Many fungicides have been reported to be effective in controlling the disease (Bergquist 1972, 1974, Gollifer and Brown 1974, Aggarawal and Methrota 1987, Cox and Kasimani 1988, Ghosh and Pan 1991). However, use of chemicals is usually hazardous and costly to the user and the environment. Development of new races of pathogens with resistance to the fungicides can also result from their use.

Varietal improvement of agronomic traits and resistance and/or tolerance to pests and diseases can provide a practical solution to controlling the disease, and also to alleviating the declining trend in taro production. Genetic improvement of the crop has been described recently by Ivancic, Simin and Tale (1994).

The aim of this study was to evaluate for yield and eating quality 35 TLB resistant taro varieties developed at Bubia Agricultural Research Centre (BARC), near Lae, PNG.

MATERIALS AND METHODS

The trial was carried out between June and December 1995 at BARC. The centre is situated at an altitude of 20 m and receives a mean annual rainfall of 2870 mm.

In the experiment, the most preferred local cultivar, Numkowec (syn. Numkoi) (Akus *et al.* 1991), was compared to 35 of TLB resistant varieties. Numkowec

[1] Present address: Faculty of Agriculture, University of Maribor, Vrbanska 30, 2000 Maribor, SLOVENIA.
[2] Bubia Agricultural Research Centre, P O Box 1639, Lae, Papua New Guinea.

is susceptible to TLB. The resistant varieties were selected on a single plant basis for TLB resistance, yield and eating quality from the first cycle of breeding (cycle-1 population) of the recurrent selection programme carried out a BARC (Ivancic, Simin *et al.* 1994).

The genotypes used were replicated three time in a Randomized Complete Block Design. Plots were 5 m x 3.6 m with net plot size of 4.2 m^2. Plants were spaced 1.2 m between rows and 1.0 m between plants. Weeds were controlled using a rotovator between rows and manually between plants. A dose of 50 Kg N/ha in the form of Urea was applied after three months to boost growth. *P. colocasiae* spore suspension was prepared following the method of Ivancic, Kokoa *et al.* (1994) and was inoculated on to the leaf laminae fortnightly to reconfirm the plant's resistance.

RESULTS

Significant differences ($P<0.05$) were observed in corm yield (Table 2). Of all the resistant varieties, only AN 25 (800 g/plot) significantly out-yielded the locally most preferred cultivar, Numkowec (430 g/plot) in mean corm yield. AN 31 was the only variety with a significantly lower yield (mean of 240 g/plot) than Numkowec.

The number of suckers was significantly different ($P<0.05$) between varieties (Table 3). However, the co-efficient of variation was very high (40.5%). This was due to the occurrence of different plant forms in different varieties which differ in their suckering tendency and general corm morphology (Figure 1). Forms observed were simple corms with stolons, simple corms with side shoots, simple corms with both stolons and side shoots, and multiple-headed (or branched) corm with no suckers. Separation of the four forms into sub-groups resulted in a decrease in the co-efficient of variation. Nevertheless, the variation range (maximum - minimum) was still high. Varieties which had simple corms with stoloniferous suckers had a variation range of 18.56 suckers and a co-efficient of variation of 28.16% (Table 4).

Table 1. **Aspects of texture, taste preference, fibre content and acridity used to determine preference scores for taro varieties.**

Score	Texture	Preference	Fibre	Acridity
1	Firm, dry	Most liked		
2	Friable, dry	Liked		
3	Soft, sticky	Disliked		
4	Firm, sticky	Most disliked		
5	Spongy			
			Present/Conspicuous	Present
			Absent/Inconspicuous	Absent

Harvesting was done six months after planting. Yield and yield components were measured. Analysis of Variance was carried out for total (biological) yield, corm yield, cormel yield and number of suckers.

Presence of corm cortex fibre, texture and acridity were assessed in evaluating eating quality. Corm samples of 500 - 600 g fresh weight (chopped up into 50 - 100 g pieces) of each variety were peeled (removing all tissues surrounding the corm cortex), bagged separately in onion bags and boiled in excess water for 20 - 30 minutes. A panel of 15 people were used to assess eating quality based on the preference scale shown in Table 1.

The eating quality of the varieties was assessed relative to that of Numkowec (Table 5). Numkowec has inconspicuous corm cortex fibre, firm and dry texture and no acrid taste. The traits which mainly affect

Table 2. **Mean corm yields of 36 taro varieties**

Variety	Mean corm wt. (g/plot)	Variety	Mean corm wt. (g/plot)
AN 25	800	AN 36	390
AN 49	580	AN 68	390
AN 21	570	AN 34	390
AN 22	540	AN 36	380
AN 12	530	AN 20	370
AN 42	520	AN 32	360
AN 9	480	AN 46	350
AN 65	480	AN 19	350
AN 8	470	AN 23/2	350
AN 4	460	AN 33	340
AN 10	460	AN 16	330
AN 43	450	AN 11	310
NUMKOWEC	430	AN 5	300
AN 17	420	AN 50	300
AN 3	410	AN 6	280
AN 51	410	AN 37	280
AN 54	410	AN 29	270
AN 7	390	AN 31	240

Table 3. **Mean number of cormels (suckers) on 36 taro varieties.**

Variety number	Mean sucker	Variety	Mean sucker number
AN 38	31.06	AN 7	12.03
AN 68	24.47	AN 50	11.31
AN 43	23.92	AN 9	11.53
AN 19	23.56	AN 8	10.78
AN 49	20.53	AN 10	10.78
AN 16	18.94	AN 20	10.61
AN 54	17.39	AN 3	10.19
AN 22	16.89	NUMKOWEC	9.70
AN 17	16.53	AN 11	9.21
AN 4	16.31	AN 65	8.36
AN 36	15.78	AN 6	7.22
AN 29	13.92	AN 42	5.97
AN 51	13.70	AN 33	5.86
AN 21	13.19	AN 31	5.75
AN 23/2	12.55	AN 34	4.64
AN 5	12.50	AN 46	3.89
AN 12	12.44	AN 37	3.61
AN 32	12.11	AN 25	0

LSD (0.05), C.V. = 40.4%

Figure 1. **Suckering habits and corm morphology of some taro varieties; (a) simple corm with side shoots, (b) simple corm with stolons, and (c) corm with multiple heads.**

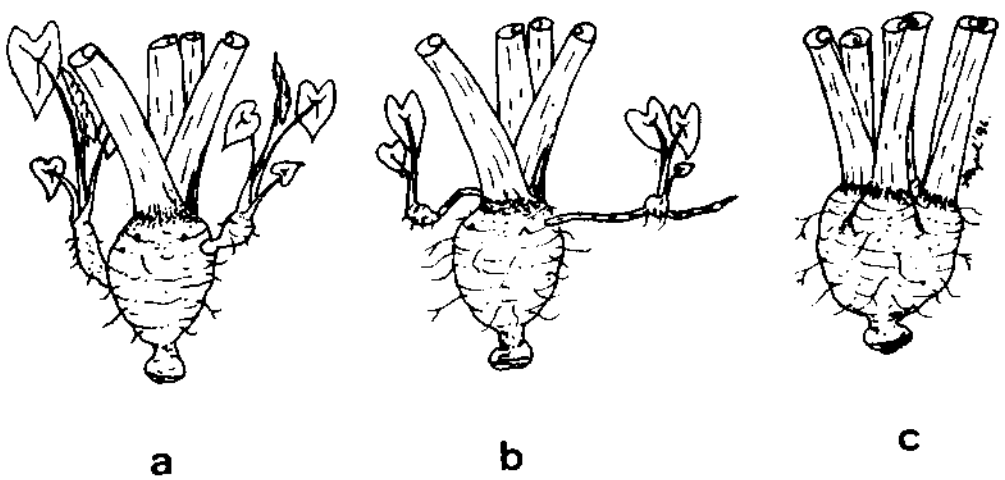

Table 4. **Variability in number of suckers after separation of varieties into their different suckering habits.**

Suckering form	N	Mean	S. Dev.	C.V. (%)	Min.	Max.
Stolons	12	19.27	5.43	28.16	12.50	31.06
Stolons & side shoots	9	11.90	3.27	27.43	5.75	16.89
Side shoots	14	8.52	3.13	36.78	3.61	13.19

eating quality are presence of conspicuous corm fibre and the acrid taste. The varieties with acceptable quality were AN 65, 17, 50, 32, 46, 21, 12, and AN 20. Their corm yields, ranging from 300 g/plot (AN 50) to 570 g/plot (AN 21), were not significantly different from that of Numkowec (430 g/plot).

DISCUSSION

In this study, the corm yields of eight TLB resistant varieties with acceptable eating quality were not significantly different from that of the susceptible, standard cultivar, Numkowec. Any influence of the disease on the corm yield of Numkowec was not detected in this study, although it is known that a linear relationship exists between TLB intensity and yield components (Paiki 1996).

Eating quality is affected by presence of noticeable corm cortex fibre and an acrid taste which is related to the presence of calcium oxalate crystals (Strauss *et al.* 1979). Most varieties with unacceptable eating quality in this study expressed one or more wild and

Table 5. **Eating quality assesments of taro varieties based on corm fibre content, texture and acridity giving a preference score of 1 (highest) to 5 (lowest).**

Variety	Quality Characteristics			
	Fibre	Texture	Acridity	Preference
AN 3	+	3	+	3
AN 4	-	1	-	3
AN 5	+	4	+	4
AN 6	-	1	+	3
AN 7	+	4	+	4
AN 8	+	3	+	3
AN 9	+	3	+	4
AN 10	+	3	+	3
AN 11	+	4	+	4
AN 12	-	2	-	2*
AN 16	+	4	+	4
AN 17	-	1	-	1*
AN 19	+	4	+	4
AN 20	-	1	-	2*
AN 21	-	1	-	2*
AN 22	-	3	+	3
AN 23/2	+	3	+	3
AN 25	+	4	+	4
AN 29	+	4	+	4
AN 31	+	4	+	4
AN 32	-	1	-	2*
AN 33	+	1	+	4
AN 34	+	3	+	3
AN 36	+	5	+	4
AN 37	+	4	+	4
AN 38	+	3	+	3
AN 42	-	3	+	3
AN 43	+	1	+	4
AN 46	-	2	-	2*
AN 49	+	3	+	3
AN 50	-	2	-	2*
AN 51	+	4	+	4
AN 54	+	4	+	4
AN 65	-	1	-	1*
AN 68	+	1	+	3
NUMKOWEC	-	1	-	1

* **Acceptable preference scores**

or semi-wild type characteristics, these being small corms, high concentration of calcium oxalates (as reflected by their acridity), stoloniferous suckers (Ivancic *et al.* 1995), and conspicuous corm cortex fibre.

The expression of these wild traits may be attributed to the influence of wild germplasm in the parent genotypes. The varieties used were selected from the population of the first cycle of recurrent selection which consisted of segregating offsprings resulting from random mating between susceptible cultivars and resistant wild and semi-wild varieties. Hence, the fact that some of the resistant varieties retained some wild-type characters could explain the observation that their resistance to TLB did not result in a superiority in corm yield over that of the susceptible, standard cultivar Numkowec. It may also have caused the variation observed between and within the different suckering types. Suckering ability cannot be compared in this study because of the variation between the varieties in the forms of the corms and their suckering habits.

Taro varieties AN 65, 17, 50, 32, 42, 21, 12 and AN 20 are recommended to farmers in the Lae area based on their resistance to TLB and the similarities in corm yield and eating quality to Numkowec. However, further testing of the performances and consumer acceptability of these varieties under different agro-ecological regimes and with different ethnic groups in PNG is needed.

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EFFECT OF CONTAMINANTS IN TISSUE CULTURES OF TARO (*COLOCASIA ESCULENTA*)

Tony G. Gunua[1]

ABSTRACT

*Taro (*Colocasia esculenta *var.* esculenta *(L.) Schott) is easily cultured* in vitro. *Twenty five genetically different taro clones from the breeding program at Bubia Agriculture Research Centre, Lae, (Papua New Guinea) were cultured* in vitro *on modified Murashige and Skoog (MS) minimal organic medium. Endogenous contamination in taro tissue culture is not being properly acknowledged therefore this study was initiated to assess the type and rate of contamination. The rate of contamination was 56% of the total shoot tips cultured. When visually assessed, 16% of red, orange or yellow and 24% of clear or milky white coloured bacteria or yeast were observed which came out from the base of the explants. Fungal contamination on the media accounted for another 16% of the total cultures. It was shown that the presence of micro-organisms in cultures affected explants, eventually result in death when contaminated cultures were not transferred onto fresh medium. It was concluded that detection methods should be incorporated at all stages of tissue culture to avoid losses due to endogenous micro-organisms.*

Keywords: Colocasia esculenta, *endogenous contamination, tissue culture*

INTRODUCTION

The shoot tip of taro (*Colocasia esculenta* L. Schott.) can be easily cultured *in vitro*. The tissue culture method has enabled studies on plant physiology (Yam *et al.* 1990 a, 1990 b), metabolism, morphogenesis (Mostafa *et al. 1976*; Yam *et al.* 1990 a, 1990 b; Yam *et al.* 1991) and has enhanced elimination of plant pathogens (Jackson *et al.* 1977), preserve plant germplasm in limited space, help germplasm exchange and rapid micro propagation (Chng and Goh 1994) of plant tissues. Although several reports of taro tissue culture are available, information on plant losses during *in vitro* culture caused by microbial contaminants has hardly been given attention. Information of *in vitro* contaminants of food crop including taro in this country are yet to be identified and documented.

At Bubia it was found that micro organisms can live within plant tissues for longer periods *in vitro* without being pathogenic and show up in cultures during short environmental changes. The presence of micro-organisms in cultures may inhibit growth rate and decrease the potential of *in vitro* propagation. Contaminants could become pathogenic *in vivo* when the plants are introduced into another climate. Furthermore, metabolites of the contaminants could be toxic to the culture during short climate changes in the growth room. Leifert *et al.* (1991) mentioned that losses of plants from microbial contaminants outweighs other bacterial contamination observed in *in vitro* cultures. Deleterious pathogenic micro organisms which exist endogenously *in vivo* and are not detected and removed could become a treat during tissue cultures.

Because of the usually high death rate of taro explants in tissue cultures this investigation was initiated to record and describe casual endogenous microorganisms. The paper reports on contaminants observed on twenty five genetically different F1 taro hybrids in tissue cultures at the Bubia laboratory.

MATERIALS AND METHODS

First generation hybrid taro clones from the breeding program at Bubia Agricultural Research Centre served as explant sources. Meristem shoot tips of about 2 to 3 cm in diameter without the outmost whorl of petioles were washed with tap water. Hereafter they were

[1]Bubia ARC, P O Box 1639, LAE, Morobe Province, Papua New Guinea.

submerged into a sterilent (Sodium hypochlorite; Household bleach; marvo - Linn brand) of 20% and 10% for 10 and 20 minutes respectively followed by 3 rinses of sterile distilled water before isolation. Shoot tips of 0.2 cm in diameter and 1.0 cm in height were isolated aseptically onto a growth medium after the excess tissues were removed at each decontamination stage. One explant of each hybrid was grown on Murashige and Skoog (MS) (1962) minimal organic medium containing 0.3 mg/l NAA and 1.0 mg/l BAP (E' Medium). They were kept under 16h days, a light intensity of 2.5 m W cm^2 (provided by 40 W GroLux fluorescent tubes) at median temperatures of 22 to 26°C. Though isolation and identification were not done, percentage contamination, description of contaminants, time of appearance after isolation and the site of contamination were noted. The contaminants were described as bacteria, yeast and fungi using the C.A.B edition of Plant Pathologists Pocketbook (1983) based on their morphological characteristics.

RESULTS

Observations of contamination made on the isolated taro clones *in vitro* is shown in Table 1. Out of the 25 taro shoots cultured 56% were contaminated by micro organisms. Of the affected shoots, 16 and 24% were

Table 1. **Cultured taro clones alongside observations of contamination.**

Taro clone Name	Time of detection after isolation (days)	Type of micro-organism (visual observance)	Colour of micro-organism	Site of contamination (explant/ media)	Time at death of explant (days)	Number affected (%)
AN1-1 AN21-1 AN22-1 AN24-1	4 - 5	fungus	initial white, then grey 4-5 days later	media	14-21 after outgrowth of fungus	16
AN2-1,AN3-1 AN9-1, AN11-1	10 -14	bacteria/ yeast	red/orange/ yellow	explant base under the media	14 - 21 after detection	16
AN10-1 AN12-1 AN13-1 AN17-1 AN23-1 AN25-1	2 - 3	bacteria/ yeast	clear initial then milky white	explant base under media	21-24 after detection	24
AN4-1,AN5-1 AN6-1,AN7-1 AN8-1 AN14-1 AN15-1 AN16-1 AN18-1 AN19-1 AN20-1	0	0	0	0	0	44

Note: Cultures that had no contamination are indicated with zero (0)

affected by red, orange, clear and milky white bacteria or yeast respectively. The other 16% contamination was due to a fungus on the media. The red, orange and yellow contaminant occurred as slimy exudate, firstly observed after 10 to 14 days of isolation at the base of the explant in the growth medium. Contaminated cultures changed growth medium colour from colourless to yellow 7 to 14 days after detection. The highest contamination were due to the bacteria or yeast that appeared as shiny colourless exudate at the base of the explant 2 to 3 days after culture initiation. The contaminants changed the growth medium colour to milky white after 21 days of detection. Fungal contamination first seen as white mycelium on the media, changed colour to grey/brown after 4 to 5 days and then eventually became black. The growth vile was covered with fungal mycelium within a week. All explants in contaminated cultures died when not transferred onto clean medium.

DISCUSSION

Most contamination problems arise when tissue culture methods used are inefficient in: sterilisation of explants, detection of micro-organisms in *in vitro* culture, aseptic handling of explant and the sterilisation of culture vessel, instruments and media. Contamination of 40% from the base of the taro shoot explants in this experiment suggest that several of the methods were not efficiently executed.

Improper handling and transferring of explant could be possible reasons for the fungus contamination. The frequent occurrence of the same bacteria or yeast like micro-organisms on several of the cultures suggests that these two types are common endogenous micro-organisms in taro at Bubia. The investigation cannot distinguish micro-organisms' specificity or preference to occur in particular clones. Since only one explant per clone was cultured, firm conclusions cannot be drawn.

Contaminants pathogenic to plants *in vivo* staying latent for longer periods when introduced into plant tissue cultures, must be considered a threat in the tissue culture of taro. Early detection of latent contamination is therefore essential to prevent losses due to such contaminants. Bacterial contaminants were isolated from established plant cultures which had been *in vitro* for longer than 12 months (Leifert *et al.* 1991). Bacteria or yeast contaminants observed in this experiment occurred within one month after isolation. The variation in emergence of contaminants in the cultures suggests that screening for contaminants or detection methods should be incorporated at all stages of tissue culture so that losses due to latent micro-organisms (esp. bacteria) can be avoided. The explants in the contaminated cultures eventually died, confirming deleterious effect of micro-organisms on explants in tissue cultures.

If investigations on endogenous micro-organisms in taro were to be carried out, emphasis should be put to identify, describe, and document these micro-organisms. Studies should also be done to find out the relationship of these micro-organisms to taro and their affinity for specificity or preference on the taro varieties.

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FOLIAR DISEASES OF TARO IN THE WAHGI VALLEY OF THE WESTERN HIGHLANDS PROVINCE OF PAPUA NEW GUINEA

Tony G. Gunua[1]

ABSTRACT

*Foliar diseases of taro (*Colocasia esculenta *(L.) Schott) in three areas of the Wahgi Valley in the Western Highlands of Papua New Guinea was investigated. Alomae Bobone Virus Complex (ABVC), Ghost Spot (*Cladosporium colocasiae *Saw.) and Dasheen Mosaic Virus (DMV) diseases were detected at all sites. ABVC and Ghost Spot affected between 70 - 100% of varieties. Taro Leaf Blight (*Phytophthora colocasiae *Rac.) disease was not found at any of the sites.*

Keywords: Foliar diseases, Colocasia esculenta, *Wahgi Valley*

INTRODUCTION

Taro (*Colocasia esculenta* (L.) Schott.), an important staple tuber crop in many parts of Papua New Guinea, has declined in production (Bourke 1982). Factors such as soil fertility decline, pests, diseases and the growing of other higher yielding tuber crops have contributed to the decline of taro production. Nevertheless taro is currently one of the most expensive tuber crop in Papua New Guinea. Diseases could be contributing to the decline in production as has occurred in other taro growing areas. The foliar diseases that are considered to be economically important are: Taro Leaf Blight (TLB), Alomae Bobone Virus Complex (ABVC), Dasheen Mosaic Virus (DMV), Ghost Spot and some others. A survey was done in the Wahgi Valley during the first week of April 1996 to observe the status of these diseases in randomly selected gardens. Information gathered may caution and guide farmers, extension workers and researchers when transferring taro germplasm from one region to another.

MATERIALS AND METHODS

Location

The Wahgi Valley is located in the Western Highlands Province. The Valley floor is found at 1400 to 1800 metres altitude. The sites visited were Domil, Kopolong and Barawahgi. The former two sites are at 1500 to 1600 m and the latter at about 1450 m a.s.l.. Three gardens were randomly selected in each village. Sizes of gardens at Kopolong and Domil were in the range of 6 - 7 m^2 whereas Barawahgi was about 4 - 5 m^2. Other crops such as banana (*Musa* cvs.), sugarcane (*Saccharum officinarum* L.), saiyor (*Rungia klossii* S. Moore), sweet potato (*Ipomoea batatas* (L.) Lam.) and highlands pitpit (*Setaria palmifolia* (Koenig) Stapf) were being grown among taro. Disease incidence and severity assessment were made and the different varieties grown were recorded. The gardens selected had taro of about four to five months old.

Disease Assessment

The disease incidence (DI) and severity on individual plants were visually assessed. Symptoms descriptions of ABVC and DMV used by Jackson (1978), Zettler and Jackson (1979) and Shaw *et al.* (1979) were used to visually assess the two parameters. A key and formula modified from Anon. (1947) was used to calculate the two parameters. For disease incidence calculations, the number of plants affected was expressed as a percentage over the total of each variety. The formula used is:

$$DI = \frac{(\text{Total number of plants - Non diseased plants}) \times 100}{\text{Total number of plants}}$$

[1] Bubia ARC, P O Box 1639, LAE, Morobe Province, Papua New Guinea.

To quantify the intensity of disease presence on the plants, half of all the varieties grown were assessed. The surface area affected and types of symptoms shown were assessed for individual leaves. Scores of 1, 2 and 3 were given for less, moderate and severe symptoms respectively. The sum of the scores over total number of leaves multiplied by 3 expressed as a percentage is the severity of the disease of that variety. The formula is:

$$DS = \frac{\text{Sum of all scores} \times 100}{\text{Total number of leaves} \times 3}$$

Disease severity (DS) of ABVC and DMV was calculated using the above formula but scores given were based on types and stages of development of symptoms expressed. Mild, moderate and severe symptoms of leaf crinkling, mottling, puckering, rolling, stunting etc. were given scores of 1, 2 and 3 with signs +, ++ and +++ respectively. The disease rating legend is given in Appendix 1.

RESULTS

Taro Leaf Blight disease caused by the fungus *Phytophthora colocasiae* Rac. was not detected at the sites visited although the disease was reported to be present in the area (Kokoa 1991). Ghost spot caused by *Cladosporium colocasiae* Saw. affected all

Table 1. **Taro Leaf Diseases Incidence and Severity at the three locations**

Location	Taro variety number	Diseases							
		DI	TLB DS	Ghost DI	Spot DS	ABVC DI	DS	DMV DI	DS
Kopolong	1p	0	0	30	+	100	+		
	2	0	0	100	++	80	++		
	3d	0	0	80	++	100	+		
	4	0	0	-	-	20	+		
	5t	0	0	80	+	100	++	20	+
Domil	1p	0	0	10	+	100	+		
	2	0	0	-	-	-	-		
	3d	0	0	100	++	100	++		
	4	0	0	60	+	100	++		
	5	0	0	-	-	60	+		
	6	0	0	100	++	100	+		
	7	0	0	100	+	60	+		
	8	0	0	-	-	-	-		
	9t	0	0	100	++	100	++	50	++
Barawahgi	1t	0	0	100	++	100	++		
	2d	0	0	100	+	100	+		
	3	0	0	100	+	100	+		

Note: **a/ Letters after taro variety number indicate the same variety at different locations.**
b/ DI = disease incidence expressed as a percentage
c/ DS = disease severity
+ = mildly affected,
++ = moderately affected
+++ = severely affected. ***(See appendix 1)***

the varieties at Barawahgi and more than 70% of varieties at Kopolong and Domil. Older leaves were more vulnerable to this disease, especially those of the green pigmented varieties.

Dasheen Mosaic Virus (DMV) disease was observed at Kopolong and Domil on the same variety. The symptoms observed at the former location was only main vein chlorosis with feathery pattern of mosaic on some of the lateral veins. Symptoms at the Domil location were moderately severe showing leaf curling with distorted chlorotic feathery pattern of mosaic, crinkling and puckering. The pattern seemed to be coupled with ABVC.

Alomae Bobone Virus Complex (ABVC) disease incidence was about 78% at Domil and 100% at Kopolong and Barawahgi. Two dark purple pigmented varieties grown at the former location showed no visible symptoms of ABVC on any plant. Apart from those two varieties, most characteristic symptoms of ABVC viz., mid leaf crinkles, leaf puckering, severe leaf crinkle and thickening of lateral veins, were seen on all varieties grown at the three sites. The most severe symptoms of ABVC such as leaf rolling, enlarged stunted outgrowth of leaf petiole, severe stunting of youngest leaf with rolled up lamina and death were not observed.

The intensity of ABVC disease symptoms was much higher in the commonly grown taro varieties.

DISCUSSION

A high incidence of ABVC and Ghost spot was recorded at all three sites. Only one taro variety showed symptoms of DMV at two locations. Taro leaf blight was not detected at any of the sites although the disease was recorded at Kuk Agriculture Research Station at an altitude of 1590 m above sea level in 1986 (Kokoa 1991). The higher altitude of above 1400 m and lower day and night humidity could be possible reasons for the absence of the disease. Ghost spot (*Cladosporium colocasiae* Saw.) was reported to be endemic in the country (Shaw 1984; Muthappa 1987; Kokoa 1991).

ABVC disease is likely to be the most serious at these sites in the near future as common varieties are substantially affected. The higher intensity of ABVC symptoms expressed on the commonly grown taro varieties could be due to the viruses build up over time. The disease is presently seen to be the most serious after Taro leaf blight in the wet lowlands of the country but may become important. Varieties that showed no or little symptoms should be collected and used in breeding for ABVC tolerance.

Ghost spot showed similar patterns at the sites but is of less significance as it only affects older leaves. The effect of the disease on the performance and yield of taro is, however, unknown.

Generally ABVC and Ghost spot incidence and severity were similar at the three sites. It shows that the diseases' intensity and development is similar throughout the Waghi valley.

Farmers in the area should be encouraged to use suckers as planting material in new gardens to reduce virus spread by planting material. Fungicidal control on Ghost spot is uneconomical as the disease does not cause appreciable losses (Trujillo 1967).

ACKNOWLEDGEMENT

I thank the staff of CIS Barawahgi, DPI Officers of Banz and Nondugl for their sound reception and help.

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Appendix 1

	Disease Rating Scale	
Diseases	**Score**	**Sign**
Ghost Spot *Cladosporium colocasiae*		
1 - 20 % of leaf area affected	1	+
21 - 50 % of leaf area affected	2	++
> 50 % of leaf area affected	3	+++
Alomae Bobone Virus Complex (ABVC)		
Localised mild symptoms of leaf crinkling, puckering and rolling.	1	+
Moderate symptoms of leaf crinkling associated with thickening of lateral veins, puckering and vein rolling, clearing etc.	2	++
Both the above with severe stunting and out-growth of petiole and stunting of youngest leaf with rolled up lamina and death eventually.	3	+++
Dasheen Mosaic Virus (DMV)		
Mild localised mosaic symptoms	1	+
Moderate symptoms covering nearly half of the leaf.	2	++
Severe mosaic and distortion symptoms affecting the entire leaf.	3	+++

GENERATION OF TARO (*COLOCASIA ESCULENTA*) PLANTING MATERIAL USING TREATED SPLIT CORM APICES

P. Taramurray and I.C. Onwueme*

ABSTRACT

Scarcity of planting material is a problem in taro cultivation. A field experiment was conducted that compared unsplit apical corm portions ("huli") with huli split longitudinally into two portions. There were five treatments: unsplit huli; split huli; and split huli treated with acetylene, wood ash, or coconut milk, respectively. Untreated split huli established just as rapidly as intact huli, but split huli treated with the substances established more slowly. Leaf area at 6 or 14 weeks after planting was higher for the intact huli than for any of the split huli treatments. The intact huli also yielded significantly more than each of the split huli treatments, which did not differ from one another. Split huli produced as many side corms as the intact huli, thereby making them effective for producing future planting material. The implications of the results are discussed, and it is suggested that the yields from split-huli plantings could be increased by planting them at higher density.

Keywords: *Taro, taro planting material, split taro corm, huli.*

INTRODUCTION

One of the most persistent problems in taro production is the scarcity of planting material. The problem is experienced both by the subsistence farmer and the commercial producer of the commodity, and it has placed severe restrictions on the expansion of hectarages. Larger planting pieces give higher yields (Bourke and Perry 1976), but they tend to exacerbate, rather than to solve, the perennial problem of scarce planting material. This is because the use of larger planting pieces entails using a greater quantity of planting material per hectare.

Through the use of tissue culture and other tools of biotechnology, it is possible to achieve dramatic increases in plant numbers. However, these techniques require sophisticated infrastructural support, and are unlikely to become generally available to farmers for many years to come. The search must therefore, continue for farmer-level, low technology methods of achieving reasonably rapid increase in plant numbers of taro. Various effort have previously been made in this direction. Some unpublished work at Bubia in Papua New Guinea (Akus, Niangu, Boksou & Ghodake, personal communication) involved splitting of the corm in various ways and treating them with wood ash. Soto and Arze (1986) split tannia corms transversely and longitudinally before planting the pieces, but the results were inconclusive. Moreover, there were no definite attempts to stimulate greater suckering or development of the corm pieces.

The use of the taro corm proper, whether intact or subdivided, as planting material is clearly uneconomical since the corm is the main edible part of the taro. The Pacific Islands practice of using the apical portion of the corm, with the basal portions of the petioles still attached, has much to recommend it. The search for low-technology, rapid multiplication for taro must still confine itself to the huli, without encroaching on the main body of the corm.

The objectives of these experiments were:

a. to evaluate the effect of longitudinal splitting of the huli on performance of the huli halves as planting material;

*Agriculture Department, PNG University of Technology, LAE, Papua New Guinea and corresponding author.

b. to see if commonly available low-technology substances, and plant-growth hormones (namely wood ash, acetylene and coconut milk) could boost the productivity or suckering ability of split huli.

The main experiments were carried out in the field, with a back-up glasshouse experiment intended to observe the morphological and developmental effects of the various treatments.

MATERIALS AND METHODS

Suckers of taro (*Colocasia esculenta* (L.) Schott cv Nomkoi) had their corms removed 1 cm below the petiole base of the oldest living leaf. The petioles were then cut off 20 cm from their attachment to the corm. The resulting planting material made up of the apex of the corm and the bases of the petiole is called a "huli" (Onwueme 1978). Huli for the experiment were selected to be of uniform size, weighing 100-120 g and having a basal circumference of 5 cm.

For the field experiment, there were five treatments as follows:

A. Huli split longitudinally into two halves;
B. Huli split in half and fumigated with acetylene;
C. Huli split in half and dipped in wood ash suspension
D. Huli split in half and dipped in coconut milk;
E. Intact huli (not split).

Fumigation with acetylene was achieved by placing the split huli in a large bin. About 10 g of calcium carbide were placed in a small container in one corner of the bin. A few drops of water were added to the calcium carbide, and the lid of the bin was closed. The acetylene generated by the calcium carbide was allowed to incubate with the huli for about 15 hours.

Wood ash was derived from burning a mixture of tropical hardwoods. A slurry of the ash was prepared by mixing two volumes of ash with one volume of water. The bases of the huli were then dipped in the slurry for 12 hours prior to planting. Coconut milk was obtained from green coconuts. The huli were dipped in the milk for 15 hours prior to planting.

After the huli had been treated, they were planted out in the field. Field layout was a randomised complete block design, with four replications and twenty plants per plot. Spacing was 50 cm x 50 cm, giving a planting density of 40,000 setts per hectare. The soil was sandy loam, and the field had been fallow for the previous two years after a crop of sweet potato. No fertilizer was applied. The season's rainfall approximated 3200 mm. Average daily temperature was about 26°C, with average daily minimum and maximum of 23°C and 30°C, respectively. The crop was mulched with oil palm leaves, and required only one weeding throughout the season. Harvesting was done at 32 weeks after planting (WAP).

Establishment counts were taken weekly for the first four weeks after planting. A plant was considered established when the lamina of at least one leaf had completely unfurled from its rolled-up position. Leaf area was determined at 6 and 14 WAP, respectively, using non-destructive methods. At 6 WAP, leaf area was determined by use of a transparent sheet ruled into 2 cm x 2 cm squares. The sheet was placed over each leaf and the number of squares counted. At 14 WAP, leaf area was estimated by measuring the distance from the leaf apex to the point of junction between the petiole and the lamina, and then using the formula outlined by Bourke *et al.* (1976) to calculate the leaf area.

The field experiments were supported by a glasshouse experiment, performed four times, in which the effects of the various treatments on the growth and development of the huli were observed. The various treatments were as follows:

a. split-huli fumigated with acetylene for 2 or 5 days and then kept with the basal portion dipping in water indefinitely;

b. split-huli dipped in coconut milk for 2 or 5 days and then kept in water;

c. split-huli kept in water for 3 days, then acetylene or coconut milk for 2 days and then back to water;

d. split-huli kept in water indefinitely;

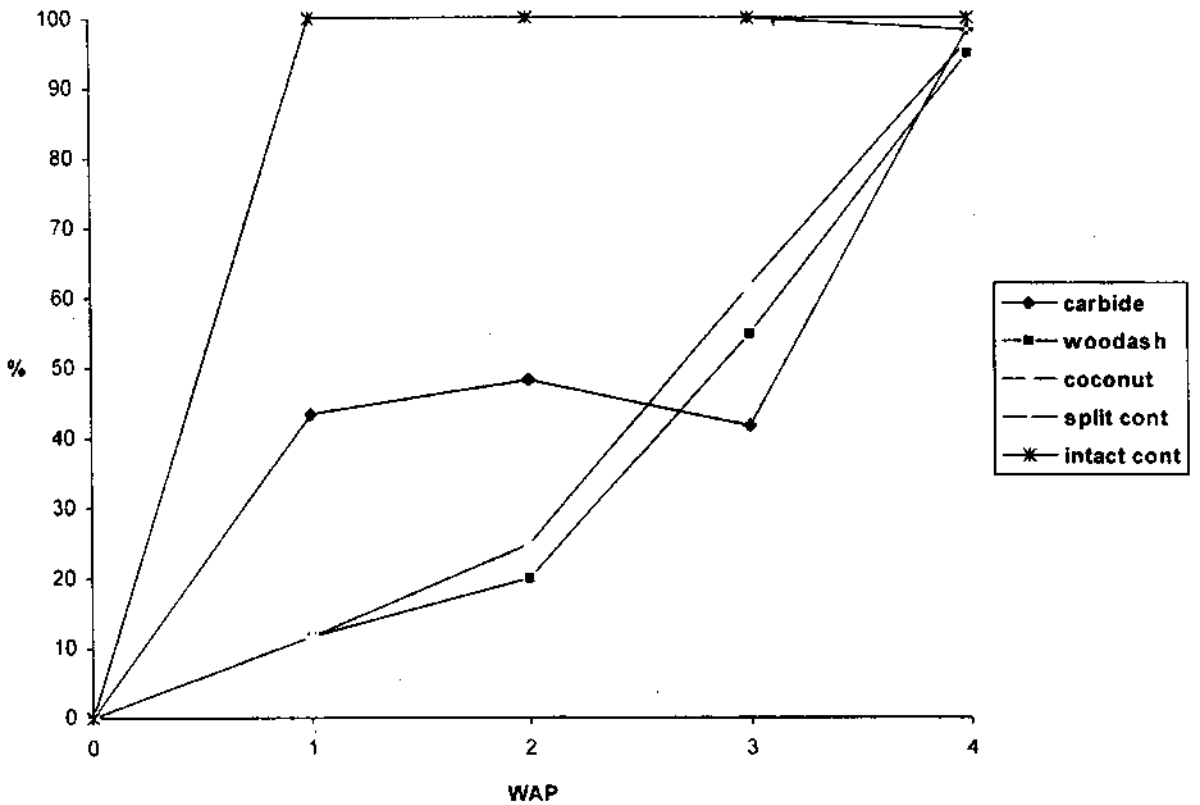
e. Intact huli kept in water indefinitely.

RESULTS

Establishment

The patterns of field establishment for the various treatments are shown in Figure 1. The acetylene,

Figure 1. **Pattern of field establishment (defined as the unfurling of at least one leaf lamina on the plant) at various times after planting. The number of established plants is expressed as a percentage of the total number of setts planted.**



wood ash and coconut milk treatments retarded field establishment. While the untreated split huli and the untreated intact huli achieved 100% establishment by 1 WAP, the other treatments did not reach a comparable level of establishment till after 4 WAP. This suggests that splitting *per se* did not delay the establishment of the huli, but that the other superimposed treatments caused a delay in establishment.

Leaves and suckers

In both 6 WAP and 14 WAP, the intact huli had a significantly higher leaf area than the other treatments (Table 1). These other treatments did not differ significantly from one another. The number of leaves per stand at 6 WAP all the treatments, including the intact huli, did not differ significantly from one another in terms of the number of leaves per stand. The coconut milk and acetylene treatments produced more suckers (i.e. side shoots) at 14 WAP than any of the other treatments.

Yield

The yield results for the field experiments are shown in Table 2. The intact huli yielded significantly higher than

Table 1. **Leaf area, leaf number and daughter sucker numbers for the various treatments. In each column, values followed by the same letter are not significantly different from one another.**

Treatment	Leaf area/stand (cm^2) *6 WAP*	*14 WAP*	Number of leaves/stand *6 WAP*	*14 WAP*	Number of suckers/stand *14 WAP*
Split huli	137.0a	904a	2.68a	4.85a	1.0a
Split huli (acetylene)	182.4a	998a	2.26a	6.02a	1.3b
Split huli (wood ash)	262.6a	693a	2.55a	4.90a	1.0a
Split huli (coconut milk)	104.8a	989a	2.75a	4.33a	1.5c
Intact huli	438.2b	1827b	3.18b	4.68a	1.1a
Least sig. difference (p<0.05)	23.2	186	1.5	Not sig.	0.19

Table 2. **Yields of main corms, side corms, and total corms for the various treatments. In each column, values followed by the same letter are not significantly different from one another.**

Treatment	Main corm kg/ha	Side corm kg/ha	Total yield kg/ha	Main corm g/plant	Total corm g/plant	Side corm % of total	Number of side corms/plant
Split huli	8,242	3,660	11,900	226	327	30	21
Split huli (acetylene)	9,412	5,342	14,754	246	388	36	32
Split huli (wood ash)	8,128	4,444	12,570	243	376	34	27
Split huli (coconut milk)	7,280	2,966	10,246	206	292	28	21
Intact huli	20,388	2,282	22,670	503	599	10	23
Least sig. dif. (p<0.05)	3,412	Not sig.	4,866	93.3	162.4	13.4	Not sig.

all the other treatments in terms of main corm yield per hectare, main corm yield per plant, total corm yield per hectare and total corm yield per plant.

However, there were no significant differences in these yield parameters, between the various split huli treatments. The intact huli produced the lowest yield of side corms per hectare, but the differences between the treatments were not significant. The percentage contribution of the side corms to the total yield was significantly lower for the intact huli than for the various split huli treatments, but the numbers of side corms per plot showed no particular trends of differences between the treatments.

Glasshouse experiment

Observation based on the glasshouse experiments showed the following:

a. Acetylene treatment had a slightly promotive effect on the expansion and growth of the buds present on the huli.

b. In comparison with the control, root development was retarded by each of the substances used, namely coconut milk, acetylene and wood ash.

DISCUSSION

The above results have established that it is perfectly feasible to raise a crop of taro utilizing split huli pieces. Starting from a given number of huli, the number of plants is immediately doubled. Moreover, the results show that the split huli produced as many side corms as the intact huli, so its advantage for generating future planting material is maintained.

The main handicap to the use of split-huli would be in the low yield recorded. Even the untreated split-huli, which established just as rapidly as the intact huli, still yielded only about half as much as the intact huli. The low yield of all the split-huli treatments must have resulted from the low leaf area, as revealed in the results. Perhaps a strategy to improve the yield from split-huli on a hectare basis might be to plant them at a higher density than the intact huli.

The objective of identifying a farmer-level treatment to boost the performance of split huli was not achieved in these experiments. Treatment with acetylene, wood ash or coconut milk did not improve the yield and performance of the split huli over the untreated split huli.

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VASICULAR ARBUSCULAR MYCORRHIZAE - TREE ASSOCIATION OF VARIRATA NATIONAL PARK AND THE INFLUENCE OF VEGETATION TYPES

T. Mubyana[1] & S. M. Saulei[2]

ABSTRACT

A study to investigate the occurrence of Vasicular Arbuscular mycorrhizae among tree species of Varirata National Park was conducted at the University of Papua New Guinea. The study also investigated the influence of vegetation types, i.e., savanna, savanna-rain forest ecotone and rain forest on the VA mycorrhizae infection levels among the tree species. The infection levels were investigated using roots sampled from representative tree species. The roots were decolourized, stained and observed under the microscope to assess the levels of infections. The results of the study indicated that generally, all the tree species sampled were infected with the VA mycorrhizae. However, there was a high infection variation among the different tree species. A comparison of infection between the primary and secondary tree species indicated higher infection levels among the secondary tree species. With the highest infection observed among two secondary species, i.e., Leea indica *and* Rhus taitensis, *while the lowest were observed among the* Breynia cernua *samples. However, there was no significant difference within the same species across the three vegetation types. All the studied sites within the three vegetation types comprised of heavy clay acidic soils, with high organic carbon content ranging from 7.23% in the savanna to 11.91% in the savanna-rain forest. However, there was no correlation between the organic carbon levels and the infection levels. Overall, these results indicate that VA mycorrhizae infection levels vary with species and not vegetation types, and secondary tree species have a higher infection level in comparison to primary species.*

Key words: *VA Mycorrhiza, vegetation, rain forest, savanna, ecotone, infections, soils, carbon, Varirata National Park*

INTRODUCTION

Papua New Guinea possesses one of the last most valuable standing forests of the tropics. These forests are part of the circum Antarctica, South East Asia and endemic forest (Saulei 1993). Over 70% (36.2 X10^{6}ha) of the country's total land area is under forest cover ranging for swamps and lowland forests of coastal plains to the alpine and mossy forests of the highlands. However, due to shifting cultivation, logging and other developments, these forests are disappearing at an alarming rate (Saulei 1992). Thus efforts are being made to encourage reforestation through understanding some of the characteristics or factors involved in regrowth and regeneration of these forests. Some Fungi commonly known as mycorrhizae form symbiotic associations with many plants, ranging from the minute gametophytes of primitive non-vascular plants to trees. The association occurs among various types of terrestrial vegetations, from rain forests to savanna and to the regrowths of disturbed forests (Tinker 1980; Jackson and Mayson 1984). Generally mycorrhizae are believed to be associated with most trees. The association when in place results in increased uptake of nutrients such as Phosphorus, Zinc and Copper (Young *et al.* 1986). This association varies with tree species, climate, soils and topography.

Among the common tree families in the lowlands of Central Province are Lauraceae, Rubiaceae, Mrytaceae and Moraceae. The Lower montane include all of the above families and Fagaceae. Preliminary unreplicated studies on some of the above

[1] Now at: Institute For Soil, Climate & Water, Private Mail Bag, X79, Pretoria 001, South Africa.
[2] Biology Department, University of Papua New Guinea, P.O. Box 320, University, NCD, Papua New Guinea.

species of Varirata National Park in Central Province have shown that secondary tree species seemed to form a closer and much wider spread association with Vasicular arbuscular (VA) mycorrhizae than the primary tree species (Suruman 1996 unpublished). The park supports three different vegetation communities; rain forest, secondary forests and savanna woodland; the latter is now reverting back to natural forest. The southern portion of the Park is all rain forest while the northern part is covered with savanna woodland coupled with secondary regrowths.

Apart from the scanty unreplicated data, very little is known about the mycorrhizae-tree associations in Papua New Guinea. Thus, the objective of this study was to investigate the occurrence of vascular aburscular mycorrhizae (VAM) in dominant tree species of the Varirata National Park. The study also investigated variations in VAM populations between the different tree species among the different vegetation types. The study was carried out in two parts. The first part investigated the occurrence of mycorrhizae in both primary and secondary trees. The second aspect concentrated on the occurrence among secondary tree species, and the relationships with vegetation types.

MATERIALS AND METHODS

This study was conducted at Varirata National Park, 45 km southwest of Port Moresby (latitude 9° 26'S, and longitude 147(21'E). It is located on the Sogeri plateau, southeast of the Astrolabe Range (720 - 860 m above sea level). Several interconnecting creeks and tributaries dissect the Park and join the main Laloki river north of the area. The climate of Varirata National Park is very seasonal, receiving less than

Table 1. **Location and ecological classifications of the tree species sampled from the Park in the initial study.**

Family	Species	Ecological Classification	Location within Varirata National Park
Anacardiaceae	*Rhus taitensis*	Secondary	SE of Varirata Look out
Euphorbiaceae	*Bridelia macrocarpa*	Secondary	Picnic site 1, NE of main picnic
	Endospermum	Secondary	site SW of Rangers' camp
	Glochidion	Secondary	NE of Rangers' camp
	Macaranga	Secondary	Picnic Site 1, SE of Varirata lookout
	Mallotus	Secondary	Edge of savanna, NE of Rangers' camp
Leeaceae	*Leea indica*	Secondary	SE of Varirata Lookout & NE of Rangers' Camp
Melastomaceae	*Melastoma*	Primary	SE of Varirata Lookout & SW of Rangers' Camp
Rubiaceae	*Evodia*	Secondary	East of Rangers' camp
	Psychotria	Primary	SW of Rangers' camp
	Timonius timon	Secondary	NE & SE of Rangers' camp
	Wendlandia paniculata	Primary	SW of Rangers' camp

Table 2. Location and ecological classifications of the common secondary tree species sampled in the second study from the National Park.

Family	Species	Vegetation type	Height (m)	Location within the Park
Anacardiaceae	*Rhus taitensis*	Savanna	6	Varirata Lookout
	R. taitensis	Savanna	3	Picnic site 4
	R. taitensis	Savanna	4	Picnic site 3
	R. taitensis	Savanna/RF*	1	Picnic site 1
	R. taitensis	Savanna/RF*	1	East of Rangers' camp
Euphorbiacea	*Breynia cernua*	Savanna	2	Varirata lookout
	B. cernua	Savanna	4	" "
	B. cernua	Savanna	3	Picnic site 4
	B. cernua	Savanna/RF*	2	Picnic site 3
	B. cernua	Savanna/RF*	1	Picnic site 1
	B. cernua	Savanna/RF*	3	East of Rangers' camp. Tract to Varirata Lookout
	Glochidion	Savanna	7	Varirata Lookout
	"	"	2	" "
	"	"	2	Picnic site 4
	"	Savanna/RF*	<1	Picnic site 3
	"	" "	<1	Picnic site 1, East of Rangers' camp
	"	" "	3	New Rangers' camp
	"	" "	4	Tract to Varirata Lookout
	Macaranga	Savanna/RF*	3	Tract to Varirata Lookout, Picnic site 2
	"	" "	3	Picnic site 1, near Rangers' camp
	"	" "	3	Tract to Varirata Lookout
	"	" "	2	Tract to Varirata Lookout
	Mallotus	" "	3	Tract to Varirata Lookout
	"	" "	<1	East of Rangers' camp
Leeaceae	*Leea indica*	Savanna	3	Varirata Lookout point
	L. indica	Savanna	3	Varirata Lookout point
	L. indica	Savanna	2	Picnic site 4
	L. indica	Savanna/RF*	1	Picnic site 3
	L. indica	Savanna/RF*	1	Picnic site 1
Rubiaceae	*Evodia*	Savanna	5	East of Rangers' camp
	"	"	3	Varirata Look out
	"	"	2	Picnic site 4
	"	Savanna/RF*	10	Picnic site 3
	"	"	3	Picnic site 1, East of Rangers' camp
	"	"	5	Near Varirata Lookout
	"	"	15	Picnic site 2, near Rangers' camp
	"	"	10	Tract to Varirata Lookout
	"	"	12	Tract to Varirata Lookout

* RF - Rain forest

2000 mm of precipitation annually. The heaviest rainfalls occur from December to April, thus giving rise to a distinct wet season followed by a dry season. The index of seasonality was calculated to be 0.1 indicating strong seasonality (McAlpine *et al.* 1983). Temperatures oscillate from 19°C during the dry season to 30°C during the wet season, with a mean relative humidity of 80%.

Three representative sites from the vegetation types were selected for sampling. These were: savanna, savanna rain forest and the ecotone zone between savanna and rain forest. The savanna woodland vegetation is basically a secondary forest comprising trees and grasses with *Casaurina papuana, Evodia* spp. *Rhus taitensis, Macaranga,* spp., *Eucalyptus* (E. *papuana, E. tereticornis*) *Banksia dentata* and *Melaleuca leucadendron* being common. While *Imperata cylindria, Themeda australis* are common grasses. The rain forest found in the Park is that of lower montane which has a frequent occurrence of *Cryptocarya, Syzygium, Elaeocarpus, Sloanea, Castanopsis* and *Ficus.* The ecotone (transition zone) between Savanna and the rain forest is dominated by *Casaurina papuana, Rhus taitensis, Macaranga, Cryptocarya, Canthium, Evodia, Ficus* and *Aglaia.*

Root sampling

The dominant primary and secondary tree species of the National Park were selected for the first study are shown in Table 1. While the dominant tree families in the savanna, savanna - rain forest and the rain forest selected for the second study are given in Table 2. Three trees of each species were selected in each vegetation type. Approximately 5 g of fine (maximum thickness 5 mm) tree roots from the A horizon (top 30 cm) were obtained from each tree from each of the four cardinal directions. The 5 g samples from the four cardinal directions of the tree were mixed to yield the representative tree sample. In all, roots of three trees were sampled for each species per vegetation type. The roots were brought into the laboratory for staining. When it was not possible to stain the roots on arrival, the roots were rinsed under a gentle stream of water to remove excess soil and were then frozen and stored in small plastic freezer bags at -18°C until it was possible to stain them. The roots were only allowed to stay in their frozen state for a maximum of 2 weeks.

In order to aid in the understanding of the differences in the levels of mycorrhizal infections between species in the different vegetation types, soil samples from the A horizon of the three vegetation types were also collected. The soils were analysed for physical and chemical characteristics. The soil samples were air-dried and sieved to pass through a 2 mm sieve before measuring the characteristics. Soil pH was determined in 1:2 soil: water and 1:2 soil: 0.01 M calcium chloride ($CaCl_2$) suspensions. The pH was then measured using a pH meter. Particle size analyses of the soils were also carried out to determine the percentage of sand, silt and clay using the hydrometer method (Bouyoucos 1927). Textural classes were then determined using the textural triangle (Fitzatrick 1974). Soil organic matter levels were determined by oxidation of organic matter with a concentrated mixture of H_2SO_4 according to Walkley and Black procedure (Walkley 1974). The amount of organic carbon was then obtained by titration with $FeSO_4$ as out lined by Nelson and Somers (1982). Organic matter was calculated from organic Carbon by multiplying by 1.724 based on the assumption that organic matter contains 58% carbon (Nelson and Somers 1982).

Table 3. **Comparison of mycorrhizal infection in all primary and secondary tree species sampled**

Ecological Classification	Mean percentage of Infection (⁺ SD)
Primary	37.75⁺19.95
Secondary	46.94⁺21.69

Table 4. **Mean percentage* (+SD) of VAM infection levels on roots of different secondary tree species in the Variarata National Park.**

Species	Vegetation Type		
	Savanna	Savanna/Rain Forest	Rain Forest
Rhus taitensis	37.4+24.6	50.9+6.5	xxx
Leea indica	59.9+26.1	23.3+14.1	xxx
Glochidion sp.	10.3+1.9	20.6+11.3	17.4+11.1
Evodia sp.	16.6+12.0	9.6+0.6	3.9+2.8
Breynia cernua	8.0+3.3	34.5+13.7	xxx
Macaranga sp.	xxxx	0.33+0.1	7.56+0.7

*** Mean given is for three tree samples and each sample comprise of 3 slides/tree**
xxx Species not available in the vegetation type

Staining of roots

The presence of VA mycorrhizae on the roots was determined using the procedure described by Bevege (1968). The infection was measured by estimating the portion of the primary cortex occupied by the VA mycorrhizae. Approximately 1g of washed and thawed or fresh root sample was cut into approximately 1cm long segments. To remove the host cytoplasm and the nuclei, the roots were placed into 10% KOH and heated for 25 minutes without boiling. After which they were rinsed with sterile tap water to remove excess KOH. The roots were then soaked in 0.01N HCl to neutralize the remaining KOH. These roots were later stained by heating them in a staining solution consisting of 200 ml glycerol, 200 ml lactic acid, 200 ml distilled water and 0.30 g aniline blue for 10 - 15 minutes. The roots were then transferred to a 50% glycerol solution overnight to remove the excess stain.

Table 5. **Mean percentage of VAM infection levels in different vegetations at the Variarata National Park**

Vegetation type	Mean % VAM infection* +SD
Savanna	13.5+ 4.6
Savanna/Rain Forest	15.1+12.6
Rain Forest	10.7+ 4.0

***Mean VAM infection for two genera (Glochidion and Evodia) which occurred in all vegetation types for the 3 tree samples and three root slides per tree.**

Assessment of infection

Root pieces, each approximately 1 cm long, were selected at random from a stained sample and mounted on glass microscope slides in groups of 10. The roots were then observed under lower power microscope. Length of cortex infected was assessed in millimetres for each root piece, averaged for the ten pieces and expressed as means for the replicates. Each tree species replicate comprised of 3 slides each with 10 root pieces per slide. In situations where observations of the root samples could not be carried out immediately the stained roots were stored in tightly capped McCartney bottles at 4°C for periods not exceeding 10 days. The mean percentage of infection and standard deviation of each three replicate was calculated. An analysis of variance to determine the least significant difference between the vegetation types was also determined.

RESULTS

The initial study showed that most trees at the Park were infected. Although generally, secondary species showed a higher VAM infection levels than primary species (Table 3). The VAM infection levels on the roots of different tree species from the three

Table 6. **Soil characteristics of the sampled sites vegetation**

Vegetation	Soil pH H_2O	0.01M $CaCl_2$	Organic C (%)	Textural class
Rain forest	4.6	4.0	7.62	Clay
Savanna	4.7	4.6	7.23	Clay
Savanna/Rain forest	4.6	4.25	11.91	Clay

vegetation types found in the national park indicates that basically all trees sampled had some infections (Table 4). These infection levels ranged from very high (59.90%) in *Leea indica* in the savanna to very low (0.13%) in *Macaranga* species in the savanna-rain forest. Although the infection levels may be high, the standard deviations were also high, indicating high variations between the trees sampled within the same species.

Among the three vegetation types the VAM infection levels also showed some variations ranging from 10.64% in the rain forest to 15.09% in the savanna-rain forest transitional zone (Table 5). However, because of the very high standard deviations in the infection levels among the different tree species within the vegetation type, there was no significant statistical difference between the sample infection levels among the different secondary trees. In most cases, there was also no significant difference between the species. However, there was a significant difference in the infection levels between primary and secondary tree species (Table 3).

The soils are generally acidic with pH ranging from 4.6 to 4.7 in water and 4.0 to 4.6 in $CaCl_2$ (Table 6). The soils however, have high organic carbon levels ranging from 7.23 to 11.91 percent.

DISCUSSION

All the trees sampled at the Varirata National Park showed some infection with VA mycorrhizae. Infection levels ranged from the highest observed in *Leea indica* (Leeaceae) in the savanna to the lowest infection in *Macaranga* spp. in the savanna-rain forest site. The species in the savanna seemed to exhibit two levels of infection; the high levels observed among *Leea indica* and *Rhus taitensis* (i.e. 59.9% and 37.4% respectively); the second group which showed low infection were *Glochidion* sp., *Evodia* sp. and *Breynia cemua* with low infection levels of 10%, 16% and 8% respectively (Table 4).

The species *Rhus taitensis* and *Leea indica* are the dominant species in the eroded zones which are located in the Savanna-Rain forest. These species are also much heavier infected than the other species in these eroded zones. That is why we made the conclusion that their heavy infection may be the reason for their heavy dominance in the area. *Breynia cemua* is also very heavily infected with VA mycorrhizae, but it is not a dominant species in the eroded sites.

There were significant differences in infection levels among the different species within the same vegetation (Table 4). However, there were no significant differences within the same species across the three vegetation types (Table 4). This may indicate that vegetation variations may not be the main factor influencing infection level but rather by species variation.

Differences in infection levels among species in the same vegetation may be attributed to host physiology and perhaps age related changes in photosynthate allocation (Visser and Danielson 1989). This may be the case in this study as the there were differences in ages and sizes of the trees sampled. The *Leea indica* sampled in the savanna which showed higher infection levels were older than those sampled in the Savanna-Rain forest and the Rainforest. Species infection levels may also vary due to some species producing phenolic compounds which inhibits the growth of many fungi (Allen 1992).

High levels of phenolic compounds are mostly found in the seeds and leaves of plants. Under seed germination and/or leaf degradation (decomposition) such compounds could be released, thus preventing fungi from attacking the plant, especially the plant with high litter mass around its base.

In these studies, members of Euphorbiaceae have shown significantly lower infection levels when compared to the Anacardiaceae and Leeaceae families (Table 4). Similarly, Alexander and Hogberg (1986) reported low levels of infection among members of Euphorbiaceae under natural vegetation in comparison to Anacardiaceae and Leeaceae. While Molina *et al.* (1992) reported high mycorrhizae infection levels among members of the Rubiaceae and Anacardiaceae. The low level VAM infections observed in Euphorbiaceae could be attributed to high content of alkaloids found among members of family, which are used for protection.

In Variarata National Park *Leea indica* (Leeaceae) and *Rhus taitensis* (Anacardiaceae) sampled were found to have high VAM infections and also observed to be the dominant species on the partially eroded sites, i.e. savanna-rain forest. These high levels of infection with VA mycorrhizae may indicate the role mycorrhizae play in aiding plants to obtain the necessary nutrients in the eroded ecotones when part of the A1 horizon has been washed away.

Although soil physical and chemical characteristics may influence VA infection levels due to the decrease in nutrient availability with stand age (Visser and Danielson 1988), this may not have been the case here since all the soils had the same texture indicating a similar inherent cation exchange capacity due to their clay content (Table 6). These soils however, indicated high organic carbon content of up to 11.91% among the rainforest soils. These soils are part of the Kokoda Trail which have previously been documented to be very high in organic carbon (Bleeker 1983).

Although not always significant, generally, tree species in the savanna-rainforest had higher levels of VA infections in comparison to the established rainforest species (Table 5). The infection levels in the savanna-rainforest areas were also higher than the level among the savanna tree species, although they were non significant. This confirms the results observed by Reevese *et al.* (1979) and Janos (1980) which have indicated that the development of mycorrhizal association in disturbed tropical forests is based on the host's need for the fungus. The younger trees in the savanna-rainforest undergoing rapid growth require more nutrients and minerals, thus would be expected to have a higher demand for phosphorous and other cations. This may be the factor which has led to the higher infection levels among the species in the savanna-rainforest when compared to the other vegetation types.

When the levels of VA infection among primary and secondary tree species were compared, the secondary trees showed significantly higher levels of infections (Table 3). The secondary trees -VAM association increase the mycorrhizal spore population in soil. Secondary trees, due to their ability to grow on eroded sites are generally pioneers of bare lands. Thus, their mycorrhizal infection may be creating conducive growing conditions for the primary species that come in at later stages of succession (Kimminis 1987; Whitmore 1988). Similar studies in tropical Africa (Whitmore 1988) which compared the colonisation rate of pioneer trees of *Leea* spp., *Macaranga* spp. and *Trema* spp. to other tree species have shown high mycorrhizal association among these pioneers. These studies indicate that the secondary trees may have unique adaptive features conducive to high mycorrhizal infection which the primary species do not possess.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Papua New Guinea Research and Publications Committee for funding this project.

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ASSESSMENT OF THE PRAWN RESOURCES OF ORANGERIE BAY, MILNE BAY PROVINCE

Christopher Evans[1] and Christopher Tumi[2]

ABSTRACT

The maximum sustainable average yield (MSY) for the multi-species prawn resources at Orangerie Bay was estimated at 28.6 +/- s.e. 1.2 t per year by correlation/regression of catch per unit of fishing effort (CPUE) on fishing effort for the period 1981-1994 (p = 0.0007). The optimum effort was similarly estimated to be 1329 +/- s.e. 165 trawl-hours per year, and the year (C_f) for a given effort (f) was as follows: $C_f = 43.5f - 0.01681^2$. A total allowable catch (TAC) in the region of 30-35 t per year (multi-species, whole weight) is recommended, with in-season revision should unfavourable environmental conditions become established.

Keywords: *Assessment, multi-species, surplus-production, penaeid prawns, TAC, management plan, Orangerie Bay*

INTRODUCTION

The Orangerie Bay prawn fishery is located in Milne Bay Province, south-west of Alotau. It is a relatively small fishery compared to the Gulf of Papua prawn fishery, and has operated with only one or two smaller vessels since 1981. The bottom comprises rocky ground, reefs and sand compared to the soft substrate which forms the sea bed of the Gulf of Papua; the principal industrial trawling grounds are located between Baibara Island and Saubina, from 2 to 10 m (approximately 1 to 5 fathoms) depth, but chiefly between Laimodo and Saubina (figure 1). The seaward limit of the trawl grounds is the 5 fathom (10 m) depth contour (shown on Figure 1).

Based upon the reported annual catches and associated fishing effort (there may have been some under-reporting), the fishery had a 16.2 t average annual yield during 1981-1994, n = 13 years (Table 1).

There is only one company, *Nako Fisheries*, operating. They company has two vessels, the Streaker, of approximately 13 m length and the much smaller Trekka, of approximately 8 m length. they each have two main nets and no try nets.

Vessels have traditionally spent the months of March to October trawling in Orangerie Bay chiefly between Saubina and Laimodo (Figure 1).

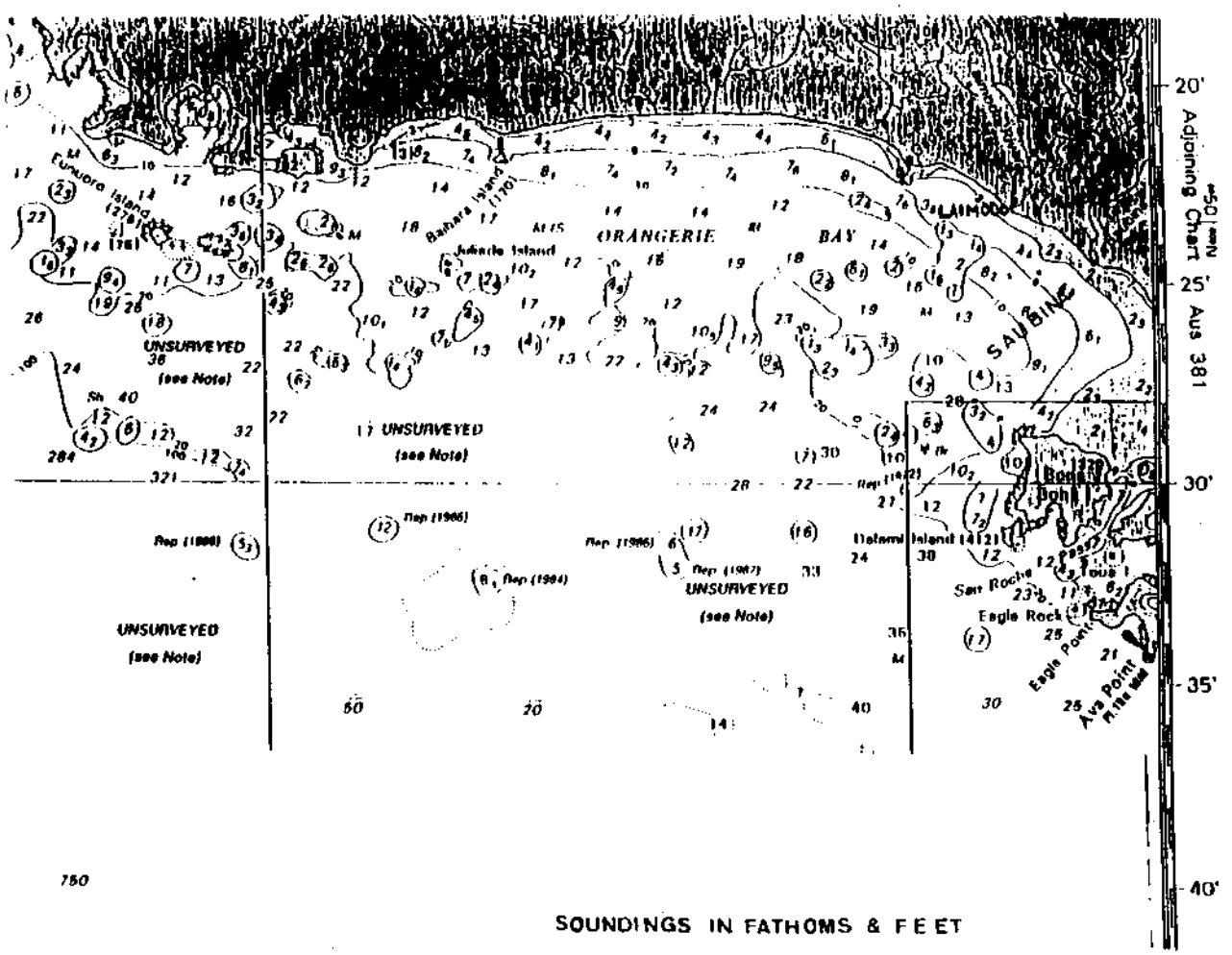
The principal catch is the white banana prawn *Penaeus merguiensis*, with a smaller proportion of black tiger prawn *(P. monodon)* and the Indian banana prawn *(P. indicus)* and even smaller catches of endeavour prawns (*Metapenaeus* sps.). Trawling only occurs in the day time as fewer prawns are caught at night. Prawns are sorted on the boat and are weighed head-on. After weighting, they are deheaded, cleaned with cold fresh seawater and placed in a chilled brine holding tank.

The catch was traditionally transported by sea to Alotau, but from 1994 the two licensed fishing trawlers have unloaded their catch at Bona Bona Island, near the entrance to Mullins Harbour (Figure 1). This has increased the efficiency of operation and therefore potential fishing effort. From there the catch is transported by a dory for 4 hours along the southern shore of Mullins Harbour and up the Sagarai River to the landing stage at Tamanai, where it is offloaded and taken to *Nako Fisheries* Alotau processing plant.

[1,2]National Fisheries Authority, Research and Management Branch, P O Box 2016, Port Moresby, NCD, Papua New Guinea.

[1] Current address: Pg. Dip. student in coastal zone management, Department of Conservation Sciences, Boumemouth University, Fern Barrow, Poole, Dorset, England.

Figure 1: **Showing the Orangerie Bay Prawn Trawl Grounds (Chiefly Saubina to Laimoda).**



An interim management plan for the Orangerie Bay prawn fishery was gazetted in April 1995 and set out the agreed management measures based upon the results and recommendations of the Evans and Opnai (1994) study, and upon earlier consultations with *Nako Fisheries*.

The sustainable yield was initially estimated to be approximately 35-45 t from historical data on catch in the developing phase of the fishery. The research of Evans and Opnai (1994, 1995) indicated a somewhat lower maximum sustainable average yield in the region of 30 t.

A survey of the Orangerie Bay prawn resource was requested by the Milne Bay Provincial Fisheries Department during consultations in October 1995, and was already targeted by the National Fisheries Authority. This was with a view to the development of a more comprehensive management plan for the small, but valuable, resource. The purpose of the present study was to refine the earlier stock assessment of Evans and Opnai (1994, 1995) and to give accurate estimates with standard error, of the maximum sustainable average yield (MSY) and the optimum effort, also the equation of yield for a given effort.

In 1997, a TAC of 35 t was introduced based upon the stock assessment of the present study, together with a closed fishing season from 1st December to 30th April, to allow young prawns recruiting to the fishery in the first quarter of the year to grow and realise their growth potential. These management measures, and related measures limiting the number of vessels to 2 and their size to 14 m overall

Table 1: **Orangerie Bay Multi-species Prawn Fishery Catch and Effort Data.**

Year	Total Effort (trawl-hours)	Total Catch (metric tonnes)	Mean CPUE (kg/trawl-hour)
1981	169	4.9	29.0
1982	151	5.3	35
1983	1393	39	28.1
1984	195	10.3	53
1985	1793	25.8	14
1986	no records available		
1987	214*	1.8*	8.4*
1988	2134	9.6	4.5
1989	279	9.4	34
1990	439	16.7	38.1
1991	1252	16.2	12.9
1992	825	25.4	31
1993	600	21.5	35.8
1994	587.9	24.3	41.3
1995	records unprocessed		

*Suspected aberrant data: 1) 1.8 t catch is unusually low and may have resulted from incomplete reporting or incomplete records (personal communication, Mr Neil Stanton, *Nako Fisheries*, 1996) and 2) 1987 was a year with a pronounced El Nino effect. The availability of prawns for capture may have been excessively reduced as a result of insufficient rainfall for offshore emigration and/or reduced extent of suitable mangrove nursery habitat (at intermediate salinity levels).

Sources:
(1) Fisheries Annual Report 1985-91;
(2) Prawn Database Management System 1990-93;
The data in this table was sourced primarily from logbook data sheets and secondarily from data in Doulman and Kolkolo (1985).

length, and restricting fishing to the day-time, were formalised under a new management plan agreed with the prawn operators *Nako Fisheires* in September 1996 and approved by the National Fisheries Authority Board on 21st October 1996.

MATERIALS AND METHODS

Data

Catch and effort data from the log-book sheets were the primary source of the data. Information reported in Doulman and Kolkolo (1985) was a secondary source, as was the DFMR Annual Report for the years 1985-1991.

The fishery is a multi-species fishery and the catch data used in the analyses (Table 1) is for all species combined, in aggregated biomass (the total weight of whole prawns caught).

Data for the year 1987 have been left out of the analyses of the present study. There was exceptionally low catch (1.8 t) and CPUE during this year, which may have arisen due to incomplete reporting (personal communication, Neil Stanton, *Nako Fisheries*, 1996). 1987 was also one of exceptionally high temperatures in the eastern Pacific and Caribbean with a pronounced El Nino effect and concomitant reduced rainfall in the Western Pacific which could have caused very low annual catch in Orangerie Bay. The availability of prawns for capture may have been excessively reduced as a result of insufficient rainfall for offshore emigration and/or reduced extent of suitable mangrove nursery habitat (at intermediate salinity levels).

Quadratic regression

Annual yield (in metric tonnes, t) was plotted on annual fishing effort (in trawl-hours), since there were plots on the right hand side of the parabola (at the higher levels of fishing effort) which could help to identify where the curve peaked, thereby giving estimates of maximum sustainable average yield (MSY) and optimum effort (f_{msy}).

Correlation/Regression

Catch per unit of fishing effort (CPUE) was plotted on the total effort by linear regression. The maximum sustainable average yield (MSY) in the multi-species fishery was estimated from the Schaeffer (1954) model, using aggregated biomass, by the equations outlined in Pauly (1983):

$[MSY] = a^2/4b$ (1)

where a = the y-intercept and b = the slope (with the sign of the slope changed from negative to positive). Optimum effort (f_{msy}) was estimated from the Schaeffer (1954) model using Equation 2 (Pauly 1983):

$f_{msy} = a/2b$ (2)

The yield for a given effort C_f is similarly given by the Schaeffer (1954) model using Equation 3 (Pauly 1983):

$C_f = a.f - b.f^2$ (3)

The correlation/regression analysis and estimation of the standard error of a and b were carried out using the 'C-Stat for Windows' programme, and the estimates of s.e. generated were used in the estimation of the MSY +/- s.e. The method of estimation of MSY and f_{msy} consists of (a) substituting the sets of maximum slope and intercept values (i.e. slope+s.e., intercept +s.e.) in equations 1 and 2, to obtain minimum estimates of MSY and fmsy; and (b) substituting the sets of minimum slope and intercept values (i.e. slope-s.e., intercept-s.e.) in equations 1 and 2, to obtain maximum estimates of MSY and f_{msy}. The estimates are then taken as the median of the minimum and maximum.

RESULTS

The curve of catch on effort (Figure 2) indicated a maximum sustainable average yield (MSY) of approximately 29 t and an f_{msy} of approximately 1 250 trawl-hours. Linear regression of CPUE on effort (Fig. 3), and the related correlation/regression analyses (Table 2), resulted in an estimate of MSY at 28.6 +/-s.e. 1.2 t per year. The optimum effort was similarly estimated at 1329 t /-s.e. 165 trawl-hours per year. The yield (C_f) for a given effort (f) was as follows:

$C_f = 43.5f - 0.0168f^2$

Table 2: **Correlation-regression analysis for Orangerie Bay multi-species prawn resources: regression of CPUE on effort (data from Table 1, excluding 1987).**

	Value	s.e.	95% CI
Slope	- 1.68E-02	3.45E-03	-245E-02 to -9.10E-03
Intercept	43.5	3.6	35.4 to 51.5

Correlation coefficient = -0.8384
Degrees of freedom = 10
p = 0.0007

Figure 2: **Curve of catch on effort for Orangerie Bay prawn, all species.**

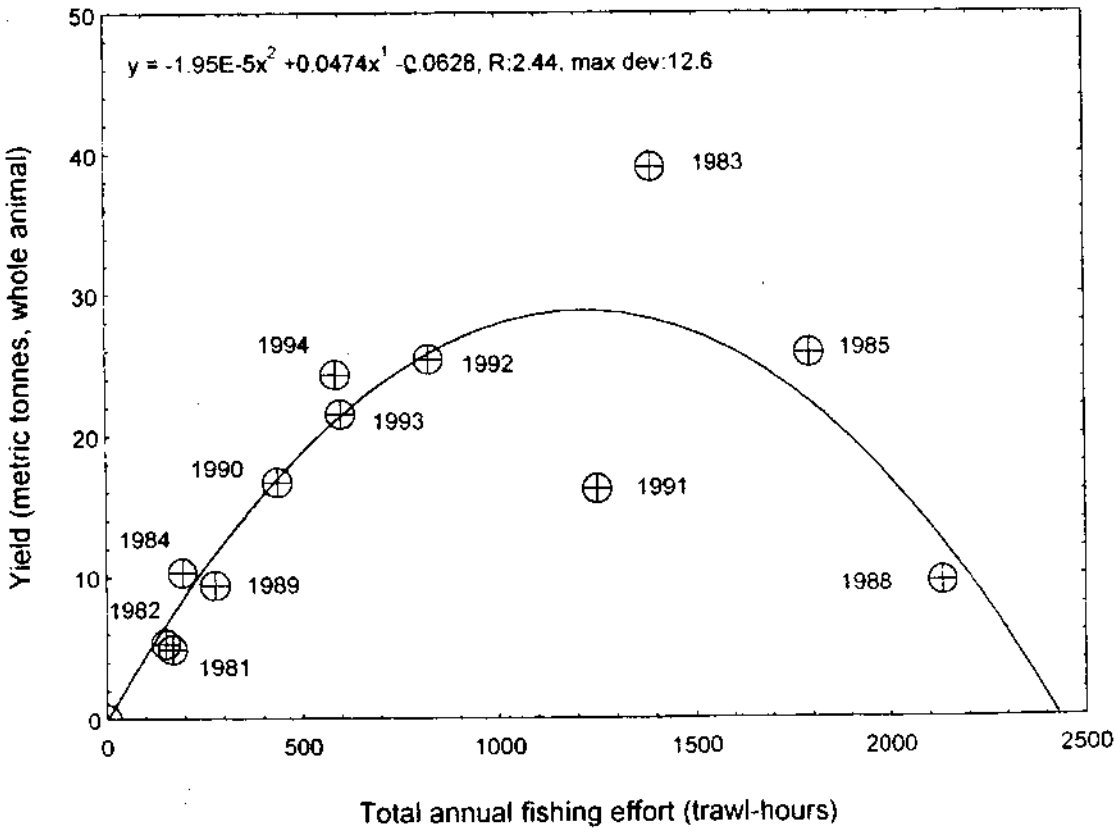
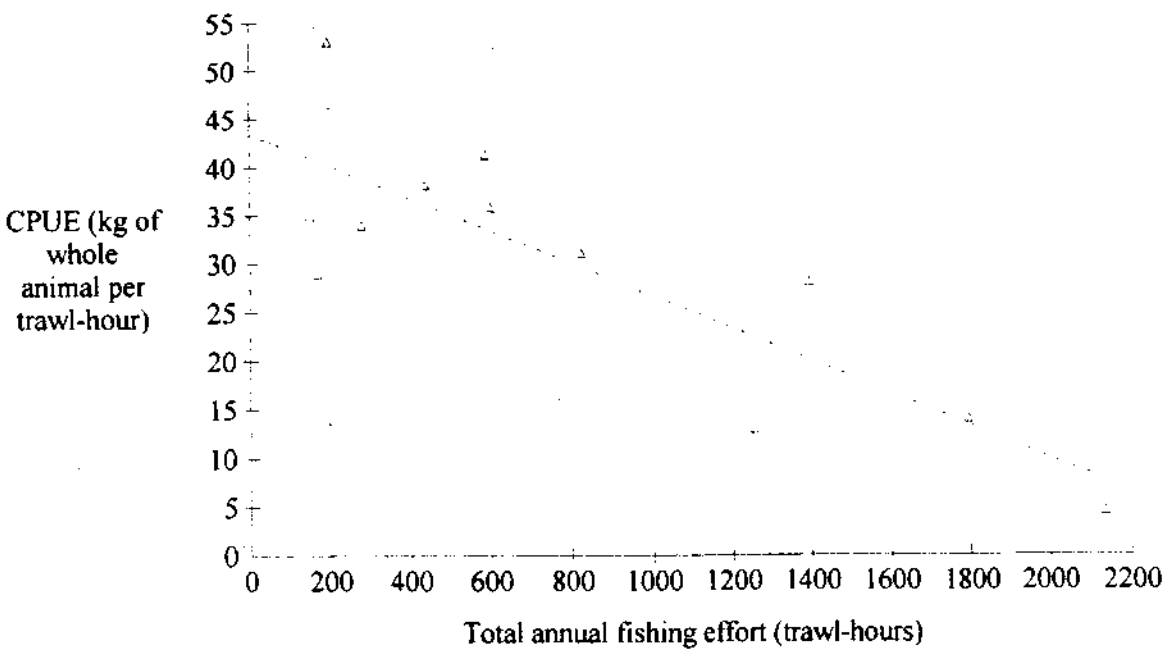


Figure 3: **Linear regression of CPUE on effort, Orangerie Bay prawn.**



DISCUSSION

Multi-species analysis using aggregated biomass is an acceptable method of stock assessment of species groups. Ralston and Polovina (1982) carried out multi-species analysis of the commercial deep-sea hand-line fishery of Hawaii, and were able thereby to determine the fishery dynamics when single species analysis revealed little of what was happening in that fishery.

Linear regression of CPUE on fishing effort is one of the most accurate ways of estimating maximum sustainable average yield (MSY) and f_{msy} with s.e. when data are available from both the developing phase and over-exploited phases of a fishery (Hillborn and Walters, 1992). This method has been used by Evans and Evans (1995), Evans *et al* (1996) and Evans *et al* (1997).

In the present study, estimates of MSY and f_{msy} by quadratic regression offer a comparison because there are data in the far right, on the decreasing leg of the curve (in the over-exploited phase), and estimates are likely to be accurate. The estimates from quadratic regression fall within the standard error margins of the estimates from linear regression.

The omission of the 1987 data from the analyses slightly increased the MSY estimates resulting from the Evans and Opnai (1994 and 1995) studies (which were 27.5 t from quadratic regression and 26.6 t from linear regression).

The sustainable yield was initially estimated to be around 35-45 t (personal communication, Mr. Joel Opnai, National Fisheries Authority, 1995) from data on catch and effort in the developing phase of the fishery. During the developing phase of a fishery, catches and CPUE can frequently be higher than can be sustained in the long-term, since most fisheries have an inherent lagged response towards the equilibrium state (Hillborn and Walters, 1992). Thus the present study, including additional data from the over-exploited phase), provides a more reliable estimate of the maximum sustainable average yield (MSY) than the earlier approximation.

CONCLUSIONS

The maximum sustainable average yield for the multi-species prawn resources at Orangerie Bay is 28.6 +/- s.e. 1.2 t per year ($p = 0.0007$). The Optimum effort was similarly estimated to be 1 329 +/- s.e. 165 trawl-hours per year, and the yield (C_f) for a given effort (f) was as follows: $C_f = 43.5f - 0.0168f^2$.

The maximum sustainable average yield is therefore relatively small at 26 to 31t (95% confidence limits) and will be lower if unfavourable environmental conditions occur, such as exceptionally low levels of rainfall.

RECOMMENDATIONS

1. Because of the relatively small maximum sustainable average yield of 26-31 t (95% confidence limits), only two trawlers of less than 14 m overall length should be allowed to operate in the fishery, based on the number and size of vessels operated by *Nako Fisheries* since 1992 (during 1992 to 1994): annual catches of 21.5 to 25.4 t were caught by this fleet (of 2 vessels) during 1992-94.

2. A total allowable catch (TAC) in the region of 30-35 t per year (multi-species, whole weight) is recommended, based upon the upper limit of the 95% confidence limits of the estimate of maximum sustainable average yield. The TAC should be set at lower levels if unfavourable environmental circumstances occur, such as exceptionally low levels of rainfall in the wet season: should unfavourable environmental conditions become established, there should be in-season revision of the TAC.

ACKNOWLEDGEMENTS

We would like to thank *Nako Fisheries* staff, the Director Mr Neil Stanton, the Manager Mr. Reuben Ngu, and the skipper and crew of the Trekka, and the skipper of the Streaker for all their kind help during the survey, the same to Mr. Peter (who participated in the parallel field studies of size and spatial distribution patterns) and Mr Kelo Kelo of the Provincial Fisheries Office (who approved and facilitated the survey), also many thanks to Mr Chris Able of Masuarina who assisted with transport. Grateful thanks also to our NFA colleagues Mr Barre Kare, Mr Lester Baule and Mr Mishak Tatamasi, for their laborious and fine work on the parallel field

studies, and NFA Divisional Executive Manager Mr Joel Opinai, for approving and facilitating the programme of stock asssessment and parallel studies, despite a lack of funding at the provincial level.

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BOOK REVIEW

Grasshopper Country, the Abundant Othopteroid Insects of Australia. D.C.F. Rentz 1996. Pp 284. University of New South Wales Press: ISBN 0868400637

To a non-specialist reader the title grasshopper country may appear somewhat misleading as the book also covers cockroaches, mantids and stick insects. Although the term Orthopteroid includes all such creatures of orthopteran stock nowhere the author tells us the common features that link all such apparently diverse animals even though a chapter is devoted to basic characteristics of the group.

This 284 page book runs into 16 chapters illustrated with 425 colour plates, 150 black - and - white photographs and many drawings. In reviewing a book of this kind on Australian insects one cannot but make comparison with CSIRO'S revised (1991) book on "Insects of Australia". There is no doubt that the grasshopper country with its keys to Australian Orthopterioid genera and related technical notes would interest specialist readers. But general readers and even entomology graduates may find the book a heavy reading. The insects of Australia with its large line drawings, excellent lay out and easy to read style immediately catches and sustains the interests of non-specialist readers. The large number of colour plates and black and white photographes while adding considerably to the cost of the book perhaps add much less to the usefulness of grasshopper country.

Even for specialists readers the book is poorly referenced. While this may reflect the poor state of knowledge of the Australian insect fauna, the author could have included at least some well known publications on the biology and ecology of these beasts from other parts of the world. For example the outstanding works of Roy and associates on mantids of Africa has been ingored altogether. Similarly the author could have done better than merely stating that "several species of grasshoppers and locusts are of economic importance and their biology and ecology is well known and documented". At least some publications on Orthopteroids from Pacific Island countries such as Papua New Guinea would have increased the usefulness of the book beyond Australian borders. No harm would have been done by the inclusion of Blattodea Study Group under the "Special Interest Groups" (p. 266-267).

Grasshopper country would certainly be prized by the few Orthopteroid enthusiasts in Australia and perhaps elsewhere. But I am not certain if amateur naturalists, beginners in entomology and teachers of entomology would be fired by it. Certainly pest control and agriculture workers would require far more information for their routine work than given in the book. The high cost of the book (about A$90.00) may also turn away the most ardent admirers of the grasshopper country.

R. Kumar
Biology Department
University of Papua New Guinea.

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BOWET, C.M. and SMITH, L.N. (1950). Measurement of phosphorus. *Methods of Soil Analysis.* Ed. C.A. Lack. Department of Primary Industry, Port Moresby.

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

Levels of significance

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

Either kg/ha or $kg.ha^{-1}$ is acceptable, but large combinations of units should be in the form kg.ha to avoid possible mathematical ambiguity.

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