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ERRATA

p.49 In column two, line 13, "(p. < .01)" should read "(p < .01)" in line 26, "(p. < .01)" should read "(p < .01)" line 35 was unclearly printed and should read "> 7 > 450"

p.51 In line 8, % fingers infested of Ripe Fingers Only for Variety Tui was unclearly printed and should read "39.59"

p.54 *Table 4.* in the title "... Banana Infestation Using 0.5% Concentrations" should read "... Banana Infestation using .05% Concentrations"

p.59 Under Results and Analysis, second paragraph, line 15, the first two words were unclearly printed and should read *"(Amaranthus tricolor)"*

p.78 *Table 6.* Saleable tuber yields for trial 4 with treatment P^1 was unclearly printed and should read "10,100"

p.82 *Table 11.* Weight top growth at harvest for the 31st planting with treatment N^2 was unclearly printed and should read "5,600"

p.91 First column, paragraph 3, line 9, "N Conditions" should read "N conditions"

p.100 *Table 1,* under Application Costs, ("Petrol, oil, lubricants @ 4.5 l/20 ha dusted)" should read "Petrol, oil, lubricants (@ 4.5 l/20 ha dusted)"

under Total Costs the cost per ha was unclearly printed and should read "K25.80 to K36.25 per year"

Changes of Address

E.S.C. Smith is now Senior Entomologist, Lowlands Agricultural Experiment Station, Keravat, East New Britain Province.

R. Michael Bourke is now Senior Horticulturist, Highlands Agricultural Experiment Station, Aiyura, Eastern Highlands Province.

ABSTRACTS

EFFECT OF ARTIFICIAL DEFOLIATION ON COCONUT YIELDS IN PAPUA NEW GUINEA

Peter Bailey, Dermot O'Sullivan and Christopher Perry
Papua New Guin. agric., J., 28 (2, 3 & 4) : 39 - 45

Damage caused by defoliating insects to coconut palms was simulated by removal of 0, 10, 20, 30, 40, 50, 60 and 70 per cent of the frond area; each treatment was replicated 10 times. This level of defoliation was maintained for 12 months by removal of leaf area of new fronds to the predetermined level.

Yields of nuts produced after 9 months defoliation decreased linearly with increasing defoliation. The causes of the reduction in total nuts were an accelerated shedding of nuts already on the tree at the commencement of defoliation, and premature nut fall during growth of a new crop.

After 9 months' defoliation, the number of fronds produced by the 70% treatment palms was significantly reduced. There was no evidence of compensatory frond growth in any treatment.

Significant yield differences were detected in the 50% and 60% treatment palms until 5 months after defoliation ceased, and in the 70% treatment palms 17 months after cessation of defoliation.

It is concluded that defoliation above 40% has long term effects on the health of the tree.

STUDIES ON THE BIOLOGY AND COMMODITY CONTROL OF THE BANANA FRUIT FLY, *DACUS MUSAE* (TRYON), IN PAPUA NEW GUINEA

E.S.C. Smith, *Papua New Guin. agric., J.*, 28 (2, 3 & 4) : 47 - 56

Work on the distribution, oviposition behaviour, life stage durations and seasonal population fluctuations of *Dacus musae* (Tryon), a serious pest of cultivated bananas in Papua New Guinea, is reported and discussed. Female flies oviposited into full-sized green bananas, and the incubation period ranged from 3 to 11 days. If, after 11 days, the pulp had not softened, eggs failed to hatch. The larval and pupal durations were 7 to 11 and 7 to 10 days respectively. In a 2 ha banana block, male flies were trapped throughout the year, but peak populations occurred during the dry season (July to September) and in December during the wet season.

In other studies, it was shown that the banana variety Giant Cavendish was less infested by larvae than the shorter varieties Tui and Dwarf Cavendish, and that this may have been due to a preferred flight height, or to the differing hardness of the fruit skins. *D. musae* was also found to infest chillies, tomatoes and guavas. An earwig, *Chelisoches morio* F., which may exert a small predatory influence on larvae and pupae in the field, was the only natural enemy detected.

Based on the biological data reported, and on results of insecticide dipping trials, recommendations for commodity treatment of export bananas are given.

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ABSTRACTS — *continued*

A SURVEY OF FOOD GARDENS IN THE HOSKINS OIL PALM SCHEME

C. Benjamin, *Papua New Guin. agric. J.*, 28 (2, 3 & 4) : 57 - 71

During the period August to October, 1975, a survey of food gardens attached to settler blocks on the Hoskins Oil Palm Scheme (see *Figure 1*) was conducted. Block ownership was stratified by ethnic origin and 140 food gardens randomly selected for survey. Principal enquiries included total and average garden area by strata, principal crops grown and available fallow periods.

The survey indicated a total planted garden area of 605 hectares on the total of 1,439 blocks or .420 hectares per block. Of this average planted garden area, .402 hectares were traditionally located in the "back blocks" and .018 hectares in "roadside" or ancillary blocks (see *Figure 2*). Areas planted to food gardens suggest the possibility of 6 to 9 year rotation periods for larger blocks and 4 to 6 years for smaller blocks.

Food production is for both home consumption and market, and some correlation is discernible between garden size and family size and between garden size and marketable surplus. It is concluded that this trend toward marketed produce will continue and that further cash cropping can occur on the larger garden blocks but not on the smaller blocks without adversely affecting yields. The lower estimate of average fallow period suggested that taro (*Colocasia esculenta*) will decline in importance because the fallow is too short to maintain high yields. The areas of the various staples grown by the different ethnic groups reflect their traditional preferences.

SWEET POTATO (*IPOMOEA BATATAS*) FERTILIZER TRIALS ON THE GAZELLE PENINSULA OF NEW BRITAIN: 1954 - 1976

R. Michael Bourke, *Papua New Guin. agric. J.*, 28 (2, 3 & 4) : 73 - 95

The influence of fertilizer on sweet potato yields was examined in 17 field and 6 pot trials on a young volcanic soil. Nitrogen (N) had the greatest effect on yield and it gave large yield increases, especially at grassland sites. In three fertilized plantings of a block cropped continuously with sweet potato (Soil Exhaustion Trial), however, nitrogen depressed tuber yield. It is suggested that different responses to N were due to varietal differences. Nitrogen increased top growth in all trials where this was assessed.

Phosphate (P) improved top growth and yield in only a few trials. Negative responses to residual P occurred in most plantings of the Soil Exhaustion Trial. Large yield responses to applied and residual potash (K) fertilizer were recorded in the Soil Exhaustion Trial. Potassium did not affect top growth in any trial but it increased tuber number. No responses to other nutrients were recorded in field trials except a response to residual magnesium (Mg) in two plantings. In the pot trials there were top growth responses to N, P, K, Mg and maganese. Fertilizer (N-P-K or N-K) gave large yield increases in a rotation trial, especially in narrow rotations. A significant negative relationship was found between the magnitude of fertilizer responses and control yields.

Soil analyses, fertilizer placement and the economics of fertilization are discussed. Recommendations for fertilizers for sweet potato are made for both grassland and former forest areas.

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ABSTRACTS — *continued*

THE CARDAMOM MIRID *RAGWELELLUS HORVATHI* POPPIUS (HETEROPTERA : MIRIDAE) IN PAPUA NEW GUINEA

E.S.C. Smith, *Papua New Guin. agric. J.*, 28 (2, 3 & 4) : 97 - 101

The mirid *Ragwelellus horvathi* Poppius is potentially a serious pest of cultivated cardamoms in Papua New Guinea. In this paper information on the distribution, life-history and biology, native hosts and nature of damage is presented.

Control of *R. horvathi* by chemical and cultural methods is also briefly discussed.

EFFECT OF ARTIFICIAL DEFOLIATION ON COCONUT YIELDS IN PAPUA NEW GUINEA

Peter Bailey*, Dermot O'Sullivan†, and Christopher Perry‡

ABSTRACT

Damage caused by defoliating insects to coconut palms was simulated by removal of 0, 10, 20, 30, 40, 50, 60 and 70 per cent of the frond area; each treatment was replicated 10 times. This level of defoliation was maintained for 12 months by removal of leaf area of new fronds to the predetermined level.

Yields of nuts produced after 9 months defoliation decreased linearly with increasing defoliation. The causes of the reduction in total nuts were an accelerated shedding of nuts already on the tree at the commencement of defoliation, and premature nut fall during growth of a new crop.

After 9 months defoliation, the number of fronds produced by the 70% treatment palms was significantly reduced. There was no evidence of compensatory frond growth in any treatment.

Significant yield differences were detected in the 50% and 60% treatment palms until 5 months after defoliation ceased, and in the 70% treatment palms 17 months after cessation of defoliation.

It is concluded that defoliation above 40% has long term effects on the health of the tree.

INTRODUCTION

Coconut palms in most of Papua New Guinea are subjected to periodic attack from insects which reduce their photosynthetic area. The most important of these are coconut treehoppers, *Segestidea* spp., which chew the fronds. Although these insects are thought to reduce coconut yield, a damage versus yield relationship suitable for use in pest population studies is wanting.

In a study of similated defoliation, Krishna Marar and Padmanabhan (1970) found that regular cutting of old fronds from trees during a four year trial did not affect yield. However, "drastic" pruning of fronds throughout a three year trial reduced yield; the palms recovered when the treatment was discontinued.

The aim of the present study was to relate loss of frond area to yield. This study is preliminary to a later study of populations of *Segestidea* spp. in Papua New Guinea in which pest density will be related to loss of frond area.

The method used in this study was to remove part of the frond area by cutting. There are two main problems in extrapolating from an experiment in which part of the frond area is removed artificially, to a field pest situation: first, severity of defoliation in the field may change from month to month, reflecting the dynamic nature of the pest population and second, the damage simulated by cutting may not have the same physiological effect on the palm as the chewing of insects. However, until a pest density-damage-yield relationship is painstakingly established under conditions of field attack, it is hoped that the data presented below will enable the establishment of an economic threshold (in the sense of Stern, 1973) which will be useful in estimating crop damage.

* Formerly Entomologist, Department of Primary Industry. Present address: South Australian Department of Agriculture and Fisheries, Research Centre, Loxton, South Australia, Australia, 5333.

† Formerly Entomologist, Department of Primary Industry. Present address: P.O. Box 965, Bundaberg, Queensland 4670.

‡ Entomologist, Lowlands Agricultural Experiment Station, Keravat.

METHODS

The experiment was done on Pellavarua plantation, near Rabaul (4°21'S. 152°2'E.) on New Britain. At the start of the experiment, the palms were 6 years old, and bearing well. The crowns of the palms were low enough to enable the fronds to be cut from the ground, using curved knives mounted on bamboo poles. The spadices and nuts could be easily counted with the aid of binoculars.

Eight treatments, each replicated 10 times, were allocated at random to a block of 80 palms. The treatments were 0, 10, 20, 30, 40, 50, 60 and 70% removal of the total frond area. At the beginning of the experiment, the total number of fronds on each tree were counted, and the pinnae from the number of fronds corresponding to the predetermined treatment level were removed, starting from the youngest opened frond. The rachis was not cut off. Where a fraction of a frond was to be removed, the fraction was estimated by dividing the frond area on each side of the rachis into equal fifths. Thus, for example, on a palm which had initially 27 opened fronds, from which 40% of the frond area was to be removed, the pinnae were completely cut from 10 fronds. From the eleventh, the pinnae were completely cut from one side, and then from three fifths of the length of the other side, starting from the axillary end.

For each of twelve months following this initial defoliation all newly-opened fronds were subjected to the predetermined level of defoliation. Thus, for example, if a 50% treatment palm produced one new frond during a month, the pinnae were cut from one side of this frond.

Prior to defoliation, pre-treatment counts of total nuts, spadices and fronds were made. Then, the youngest spadix on each tree was marked so that counts could be made of the number of nuts which were on the tree at the start of the experiment. In addition, the number of nuts on the marked spadices were counted. After twelve months, all the marked spadices were either lowermost, or had fallen off. Total numbers of fronds and spadices were counted.

Defoliation was stopped after 12 months but counts of "large " nuts were continued for a further 22 months. "Large" nuts were those defined as being the size of a cricket ball (about 7cm diameter) or larger.

RESULTS

All the results are presented as treatment means (10 replicates per treatment) adjusted for covariation with pre-treatment counts. Analyses of variance were performed on adjusted data, and differences between adjusted treatment means were detected by the least significant difference (L.S.D.) test.

The fate of the cohort of nuts, of a known age, produced on the youngest opened spadix of each palm and marked at the start of defoliation, is shown in *Table 1*. The normal, physiological shedding of a proportion of small nuts was almost completed at the first count, three months after defoliation commenced. Already, the accelerated nutfall is apparent in the 70% treatment. After five months, significant accelerated nutfall is apparent in the 50 to 70% treatments.

Table 1.— Mean number of nuts on marked spadices. Adjustment has been made for covariation with pre-treatment nut count. Means have been rounded to the nearest whole number.

Level of Defoliation %	Pre-treatment Count	Mean No. of Nuts Months since start of treatment				
		3	5	6	8	9
0	35	8	7	6	6	5
10	47	6	5	5	3	3
20	52	6	5	4	4	4
30	24	5	4	4	4	4
40	36	5	5	4	4	3
50	28	4	3	3	1	1
60	33	5	4	4	3	2
70	37	3	1	1	0	0
L.S.D. = 0.05		2.7	2.2	2.2	2.0	2.1

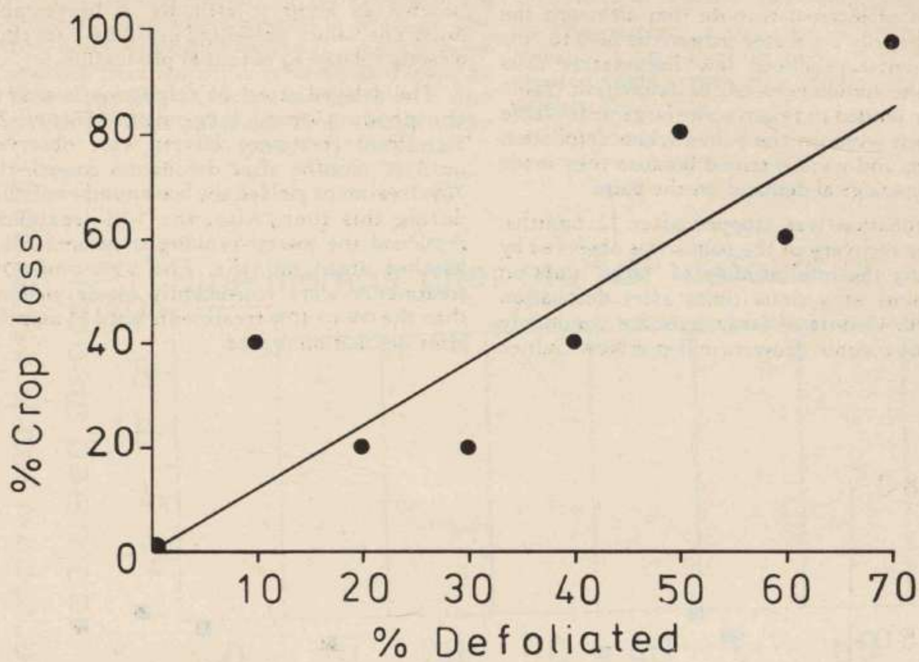

Figure 1.— Relationship between level of defoliation and crop loss after 9 months defoliation. Each point represents the adjusted mean number of mature nuts on the spadix which was youngest on each tree when the experiment started, expressed as a percentage of the control palms.

The reduction in yield is estimated as the difference between the numbers of nuts on the control palms and on the treated palms after nine months (from *Table 1*); these data expressed as percentages are presented as a linear regression of percent defoliation in *Figure 1.* The nut count after nine months is an estimate of the harvestable crop.

Because spadices are produced more or less continuously throughout the year, the nuts on each palm were of different ages when defoliation started. The rates of retention of these nuts are shown in *Table 2.* The trends are similar to those shown in *Table 1;* fewer nuts were retained by the defoliated palms, and fewer nuts were retained as defoliation increased. After nine months, the 40% to 70% palms retained significantly fewer nuts than the control palms.

Table 2.— Mean number of nuts on palms at beginning of defoliation which were subsequently retained. Adjustment has been made for pre-treatment nut count. Means have been rounded to the nearest whole number.

Level of Defoliation %	Pre-treatment Count	Mean No. of Nuts Months since start of treatment				
		3	5	6	8	9
0	131	71	59	45	40	34
10	181	65	59	41	31	22
20	186	70	51	39	32	24
30	119	66	41	33	28	26
40	152	65	38	30	23	17
50	124	61	30	21	14	9
60	194	67	37	28	19	14
70	149	41	16	5	2	1
L.S.D. = 0.05		N.S.	17	15	12	12

It is of interest to note that although the more heavily defoliated palms (the 50% to 70% treatments) produced few harvestable nuts after the commencement of defoliation (*Table 1*) they tended to retain some large nuts (*Table 2*) which were on the palms when defoliation started, and were retained because they made no physiological demand on the palm.

Defoliation was stopped after 12 months, and the recovery of the palms was observed by counting the total number of "large" nuts on the palms at various times after defoliation stopped. Counts of large nuts are commonly made by coconut growers in Papua New Guinea to give an accurate estimate of harvestable nuts. The values presented in *Figure 2* are thus directly related to potential production.

The delayed effect of defoliation is seen in the production of large nuts (*Figure 2*). Significant treatment effects were observed until 17 months after defoliation ceased; the 70% treatment yielded the least number of nuts during this time. Also, the 70% treatment remained the lowest-ranking treatment for a further eight months. The 50% and 60% treatments were consistently lower yielding than the 0% to 40% treatments until 11 months after defoliation ceased.

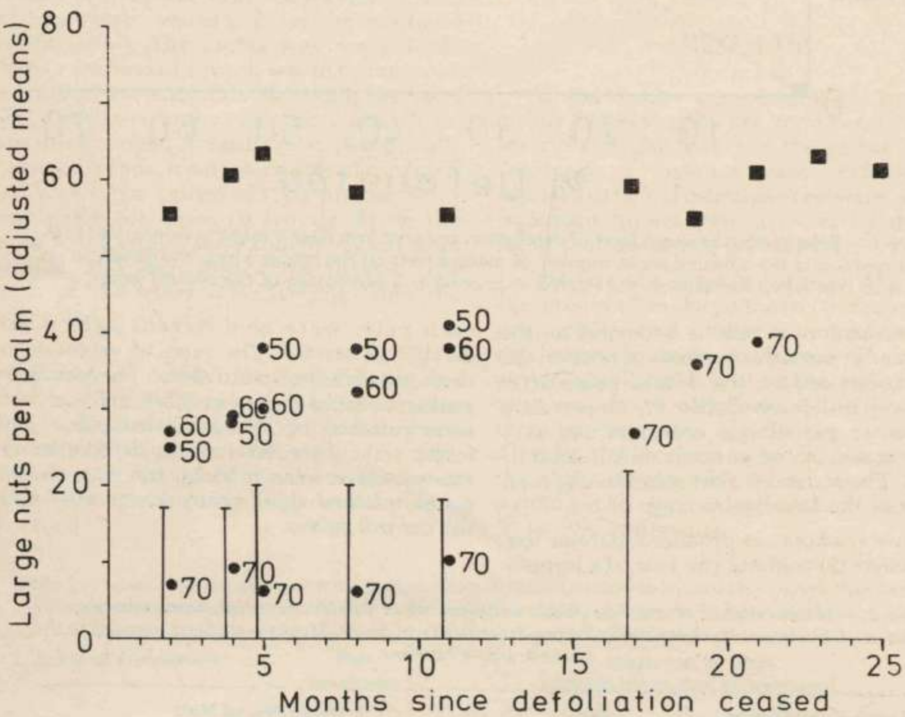

Figure 2.— Recovery of nut production after cessation of defoliation. Solid squares are the means of treatments which do not differ significantly from controls. Solid circles represent treatment means which differ significantly from controls: numbers indicate percent defoliation. At 19 and 21 months after defoliation, the 70% treatment did not differ significantly from controls, but the means are included separately to show the tendency for these palms to produce low yields.

Vertical bars span 5% L.S.D. probability levels.

There were no significant differences in the numbers of spadices produced although the 70% defoliated palms tended to produce fewer spadices than the other treatments (*Figure 3*). Thus the significant reduction in nut production during this experiment could not be attributed to reduced production of spadices.

The number of new fronds produced per palm was significantly reduced in the 70% treated palms, compared with other treatments (*Figure 4*).

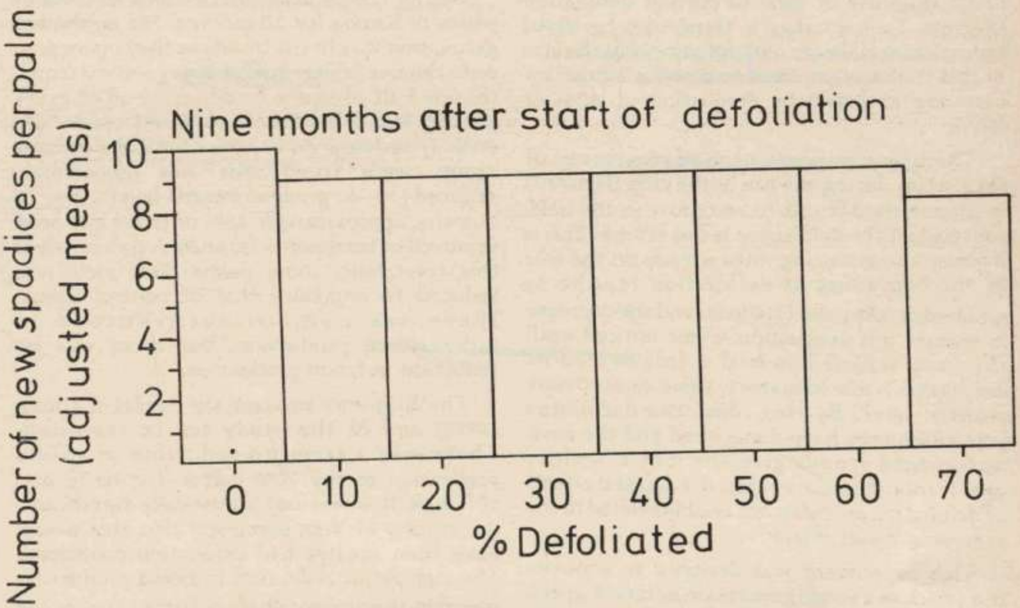

Figure 3.— Mean number of new spadices produced since the start of defoliation.

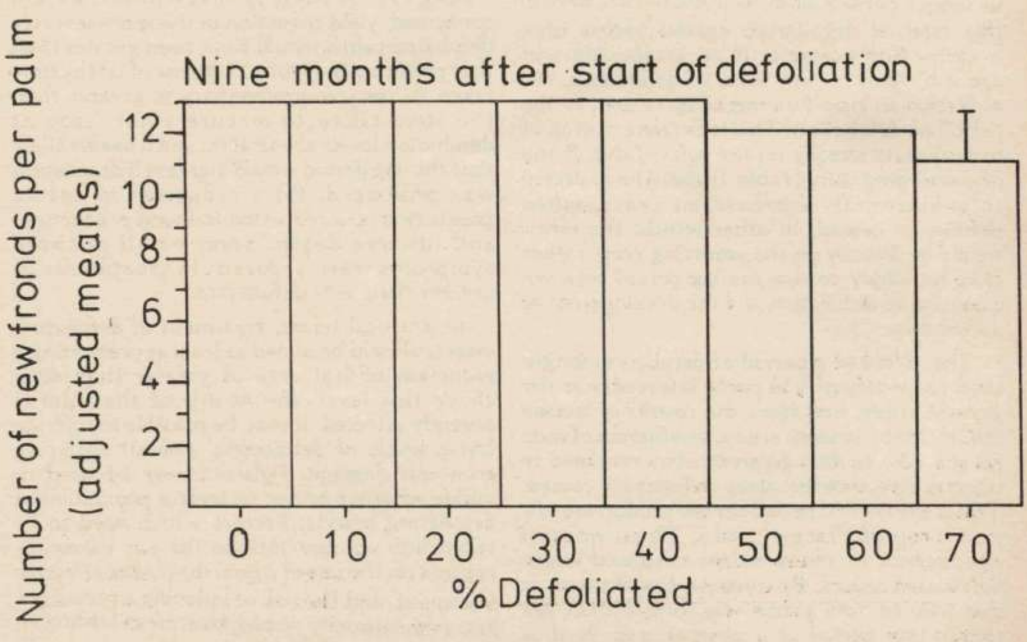

Figure 4.— Mean number of new fronds produced since the start of defoliation. Vertical bar spans the 0.05 L.S.D. value.

DISCUSSION

In terms of the design of this experiment, statistically significant treatment effects could only be demonstrated above the 40% level of defoliation (*Table 1* and *Figure 2*). However, the linear response of yield to percent defoliation (*Figure 1*) indicates a tendency to yield reduction at all levels of defoliation, but the size of this trial was too small to detect a significant response at levels of defoliation of 40% or lower.

The linear response of yield to severity of defoliation during the life of the crop (*Figure 1*) is sometimes difficult to recognise in the field, especially if the defoliation is not severe. This is because the maturing nuts already on the tree at the beginning of defoliation tend to be retained on the palm (*Table 2*), and the decrease in mature nut production is not noticed until the crop which has had a full period of defoliation is due to mature, some eight to nine months later. By this time, the defoliator population may have diminished and the new, undamaged fronds give the tree a healthy appearance. Because of this, the delayed effects of defoliation are often not readily related to the preceding insect attack.

This experiment was designed to simulate the attack of a single generation of treehoppers, which may be of nine to 12 months' duration (Froggatt and O'Connor, 1940). The question arises as to the likely effect on yield for shorter or longer periods of defoliation to that used in this trial. If defoliation ceased before nine months (for example, if an insecticide was applied), then for any level of defoliation, the reduction in crop loss might be related to the period of defoliation. This is because nutfall of mature nuts already on the palm (*Table 2*) and of developing nuts (*Table 1*) could be expected to substantially decrease, or cease, when defoliation ceased. In other words, the effect would be directly on the maturing crop, rather than to simply reduce the lag period between cessation of defoliation and the development of a new crop.

The effect of a period of defoliation longer than 12 months may be partly inferred from the present study, and from the results of Young (1975). In the present study, production of nuts on the 10% to 40% treated palms returned to normal five months after defoliation ceased. This is the normal period for the production of a new crop of "large" nuts. Thus, normal production in these palms resumed when defoliation ceased. By contrast, the recovery of the 50% to 70% palms was longer than the maturation period of a normal crop. It thus appears that the 50% to 70% treatments affected the health of the palms much more severely than the other treatments, and it is possible that if defoliation were prolonged, the lag in recovery might be proportionately longer.

Young (1975) defoliated a block of coconut palms in Samoa for 20 months. His method of defoliation was to cut fronds as they opened, so as to remove (a) one half of every second frond, (b) one half of every frond, or (c) all of every second frond. In this way frond cover was steadily reduced (in contrast with the present study, were frond area was immediately reduced to a predetermined level). By 20 months, approximately 45% of cover had been removed in treatments (b) and (c). As a result of this treatment, some palms died, yield was reduced to one-third that of control palms, there was a significant reduction in inflorescence production, but there was no reduction in frond production.

The difference between the results of Young (1975) and of this study can be reconciled. There was a trend to reduction in spadix production in the 70% palms (*Figure 3*), and although this was not statistically significant, the results of Young suggest that this would have been greater had defoliation continued. The significant reduction in frond production found in the present study occurred at a higher level of defoliation than those used by Young.

Thus, the present results, and those of Young (1975) suggest that had defoliation continued, yield reduction in the more severely defoliated palms would have been greater than that predicted in *Figure 1* because of (a) the time taken to recover productivity is greater than the time taken to mature a new crop at defoliation levels above 40%, and it seems likely that this lag period would increase if defoliation was prolonged, (b) a reduction in spadix production (c) a reduction in frond production, and (d) tree death. Some or all of these symptoms were apparent in treatments of greater than 40% defoliation.

In practical terms, treatment of defoliating insects should be aimed at least at preventing a reduction of leaf area of greater than 40%; above this level, the health of the palm is severely affected. It may be possible to tolerate lower levels of defoliation without suffering economic damage. *Figure 1* may be used to decide whether or not to treat a population of defoliating insects. Factors which need to be taken into account include the net monetary returns on the sale of copra, the cost of effective treatment, and the risk of inducing a resurgent pest population by wrong treatment leading to damage of greater intensity.

ACKNOWLEDGEMENTS

We are grateful to Mr Josephat Guguna, Mr August Tameta and Mr Mesulam Warainu, (DPI) for their technical assistance. Mr T.V. Bourke (DPI) advised on the design of the experiment, Mrs Pam Woods (South Australian Department of Agriculture) analysed the results. Mr J. Sumbak (DPI) and Dr D.A. Maelzer (University of Adelaide) commented on the manuscript.

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STUDIES ON THE BIOLOGY AND COMMODITY CONTROL OF THE BANANA FRUIT FLY, *DACUS MUSAE* (TRYON), IN PAPUA NEW GUINEA

E.S.C. Smith*

ABSTRACT

Work on the distribution, oviposition behaviour, life stage durations and seasonal population fluctuations of Dacus musae *(Tryon), a serious pest of cultivated bananas in Papua New Guinea, is reported and discussed. Female flies oviposited into full-sized green bananas, and the incubation period ranged from 3 to 11 days. If, after 11 days, the pulp had not softened, eggs failed to hatch. The larval and pupal durations were 7 to 11 and 7 to 10 days respectively. In a 2 ha banana block, male flies were trapped throughout the year, but peak populations occurred during the dry season (July to September) and in December during the wet season.*

In other studies, it was shown that the banana variety Giant Cavendish was less infested by larvae than the shorter varieties Tui and Dwarf Cavendish, and that this may have been due to a preferred flight height, or to the differing hardness of the fruit skins. D. musae *was also found to infest chillies, tomatoes and guavas. An earwig,* Chelisoches morio F., *which may exert a small predatory influence on larvae and pupae in the field, was the only natural enemy detected.*

Based on the biological data reported, and on results of insecticide dipping trials, recommendations for commodity treatment of export bananas are given.

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are distributed virtually world-wide, and the genus *Dacus* contains a very large number of species which inhabit the warmer areas of the world. Drew (1972 a, b) has recently reviewed the classification of the Dacini from the South Pacific area.

The banana fruit fly *D. musae* (Tryon) appears to be confined to areas in North Queensland, Papua New Guinea and the Solomon Islands (Drew 1975) but it is very probable that its range extends into Irian Jaya, Indonesia, the western half of the main island of New Guinea. In Papua New Guinea, the species is widely distributed throughout the mainland, where it has been recorded at elevations up to 1,600 m, and is found on some of the off-shore islands. Although found on New Britain, the fly has not been detected on either New Ireland or Bougainville, despite trapping programmes on these islands (Drew 1972 b, 1975).

D. musae has long been considered an economic pest of bananas (*Musa* spp.) in Papua New Guinea (Szent-Ivany and Barrett 1956), but detailed studies were not conducted until 1972, when the species was found to cause substantial damage to trial plots of commercial banana varieties in the Northern Province.

In this paper, work on the life history, ecology and commodity control of *D. musae* infesting bananas is reported.

MATERIALS AND METHODS

Initially, attempts were made to breed banana fruit fly in the laboratory. No successful method of maintaining *D. musae* cultures was found, although adults were offered honey and water solutions, sugar and water solutions, freshly cut bananas or guavas and a high protein (casein) powder as food sources. Since laboratory oviposition could not be induced, all life history studies were conducted on fruit "stung" in the field.

* Senior Entomologist, Highlands Agricultural Experiment Station, Aiyura, Eastern Highlands Province.

Unstung fruits at different stages of ripeness were exposed to field populations of *D. musae*. As each individual fruit was stung, it was then removed to the laboratory, checked twice daily to record the time of hatching and the larvae reared to the adult stage. During the period of investigation, laboratory temperatures ranged from 25°C to 31°C.

To record field population changes, cylindrical, plastic fruit fly traps (Steiner 1957), containing methyl eugenol attractant (Drew 1974) were placed for a 24 hour duration each week at four separate stations in a 2 ha banana block at Lejo DPI Experimental Station, North Sangara, Northern Province, and the number of trapped flies was counted and recorded over a 3-year period from October, 1972 to September, 1975.

In laboratory and field investigations, other factors which may have affected oviposition and fruit infestation rates were examined. These included the variety of banana, height of the bunch above the ground, hardness of fruit skin, presence of alternate host fruit and the effect of an earwig predator. Heenan (1973 a, b) has described the growth characteristics of the three banana varieties tested for fruit fly infestation rate, height of bunch above ground and hardness of skin.

In order to determine the preferred flight height of *D. musae* males, a long pole was erected in an area of the banana block which contained all three varieties, and lure traps were hung at heights of 0, 150, 300 and 450 cm above the ground. These heights corresponded to those of the developing bunches in Dwarf Cavendish, Tui and Giant Cavendish bunches respectively. Trapping was carried out over a 24-hour period each week, for a total of nine samplings, between April and June 1973, and the results analysed statistically.

Differences in skin hardness between varieties were determined by using a "tensiometer" (Heenan 1973 b), which measured the pressure needed to penetrate the skin of each variety.

Finally, commodity treatments which could be used to guarantee banana fruit free from *D. musae* larval infestation were tested. In a preliminary experiment, five separate trials were conducted, using freshly prepared emulsions of commercially available insecticides at the following concentrations, into which individual fingers of bananas were dipped:

Dimethoate - 30% w/v a.i. - 0.01, 0.03, 0.05 and 0.10%

Fenthion - 55% w/v a.i. - 0.01, 0.03, 0.05, 0.075 and 0.10%

Trials I and II used fingers from bunches of Tui or Dwarf Cavendish bananas (Heenan 1973 a) which had been harvested from the 2 ha block previously mentioned and held in a fly-proof, well ventilated room for 5 to 7 days before selecting for "stung" fruit.

The three later trials used fingers selected for fullness, hard green skin and fruit fly stinging, within one day of harvest. Each trial comprised at least three replicates of 10 fingers each for the insecticide concentrations previously mentioned, and a similar number to act as controls. These latter fruit were dipped in rain water. Fingers were divided at random into replicates, and fingers of each replicate were dipped individually, using tongs, into the appropriate treatment emulsion for 5 seconds. Detergent, at the rate of 0.25 ml per litre of emulsion, was added to each of the treatments to act as a wetting agent.

After dipping, the fingers in each replicate were placed on sawdust in flat aluminium or plastic trays, and held in the fly-proof room until ripe, when each fruit was dissected and the number of live or dead *D. musae* larvae counted. The few larvae which escaped from the fruit into the sawdust were also counted.

Several 10-second dipping experiments showed no difference in infestation rate when compared to a 5-second treatment.

After the results of the preliminary trial had been analysed, it was apparent that dipping fruit into a 0.05% fenthion emulsion for a 5-second period should prevent *D. musae* larvae from developing, and the main experiment of seven trials was conducted.

This main experiment differed from the previous trials in that hands of bananas, rather than individual fingers, were dipped for a 5-second period. In trials I and II, Giant Cavendish and Tui bunches were used since no Dwarf Cavendish bunches were available, but in the remaining five trials, Tui and Dwarf Cavendish fruit were treated. For each trial, 5 to 10 bunches of each variety were harvested at the normal, hard-green stage and held for up to three days before treatment. Just prior to treatment, all hands from the bunches of one variety were detached and piled into one heap from where they were picked at random for each treatment. A similar procedure was followed for the other variety.

Three treatments were applied: dimethoate 0.05%, fenthion 0.05% and rain water (as control). From the concentrated insecticides mentioned previously, 8 litres of each emulsion was freshly prepared in clean buckets and 5 ml of detergent added to each bucket as a wetting agent. Each hand of fruit was totally immersed in the appropriate treatment emulsion for 5 seconds before being placed on a sawdust tray and held in the fly-proof room until ripe. Heavy duty gloves wêre worn by the operator during the dipping. Individual fruits were dissected when ripe, and live and dead *D. musae* larvae counted.

RESULTS

Life history of D. musae

Gravid females preferred to oviposit into green bananas at the "full" stage (Heenan 1973 a), when fruits were hard and totally green but would begin to colour in about 3 days. Some fruit was stung at the hard green stage before complete "filling out", but very few fingers were stung after the fruit had actually begun to colour or the pulp had begun to soften.

Ovipositing females made several exploratory stings of several seconds duration before depositing eggs in batches of 7 to 12 (mean 9.0) just below the skin and into the hard pulp. Incubation time ranged from 3 to 11 days, provided the pulp had softened within this period. If after 11 days, the pulp had not softened, eggs failed to hatch.

Larvae developed over a 7 to 11 day period (mean 8.6 days) before the mature larvae left the rotting fruit and sought suitable pupation sites. In the laboratory, larvae readily pupated in moist soil, and the pupation period lasted 7 to 10 days. The sex ratio of several hundred *D. musae* reared was very close to unity.

Under normal tropical lowland conditions, the total generation time was 3 to 4 weeks.

Field Population Fluctuations

During the 3 year study period, it was found that *D. musae* males were trapped throughout the year, and that peak catches tended to occur in August - September and December. A summary of banana fruit fly catches over the entire period is presented in *Figure 1*.

Factors affecting Fruit Infestation Rates

(1) Variety of banana

Field collected bunches of the three varieties of bananas grown in the block were inspected for fruit fly infestation. A summary of these data is shown in *Table 1*.

The information collected was statistically analysed, using the angular transformation, and showed that ripe fingers from Giant Cavendish bunches were much less infested ($p < .01$) than those of the two shorter varieties. However, a similar analysis comparing infestation rates of the total number of fingers was less sensitive, and the only significant difference to emerge showed Giant Cavendish bunches to be less infested with *D. musae* larvae than Dwarf Cavendish ($p < .01$).

For these reasons, either Tui or Dwarf Cavendish bunches were used whenever possible in the subsequent dipping trials.

(2) Height of bunch above ground

In the traps hung at different heights in the banana block, *D. musae* males were collected much more frequently ($p. < .01$) at heights around 300 cm than at the other heights, and this level corresponds to the normal height of Tui bunches above ground level. It is not known if the females of this species show similar height preferences. A summary of the number of male flies trapped at each of the heights is presented in *Table 2*.

(3) Hardness of the fruit skin

Skin hardness varied with the variety of banana and the stage of ripeness. Some results have been published by Heenan (1973 b), who concluded that the fruit skin of Giant Cavendish was significantly harder ($p. < .01$) to penetrate than that of the variety Dwarf Cavendish. Data was also collected on the changes in skin hardness as the fruit ripened, and these are shown below:

Tui variety - Days to ripen	Skin hardness (arbitrary measurements in g)
1 - 3	*225 - 350*
4 - 7	*350 - 450*
> *7*	– *450*

(4) Alternate hosts

During 1972, larvae of *D. musae* were found infesting 5% to 10% of the maturing pods of birds-eye chillies (*Capsicum annuum*) in a 0.5 ha block in the Northern Province. No subsequent infestation in the area has been reported.

D. musae has also been reared from the fruits of tomato (*Lycopersicum esculentum*) and guava (*Psidium guajava*). In the latter fruit, larvae and emerging pupae developed over very similar time periods to those recorded in bananas.

(5) Natural enemies

The only natural enemy of *D. musae* detected was the earwig *Chelisoches morio* F. (Dermaptera : Chelisochidae), which is widely found infesting banana bunches in the field. In the laboratory, adult *C. morio* readily attacked and consumed two or three half grown *D. musae* larvae per day.

Figure 1 — Mean monthly numbers of male Dacus musae flies captured in methyl-eugenol lure traps over a 3 year period.

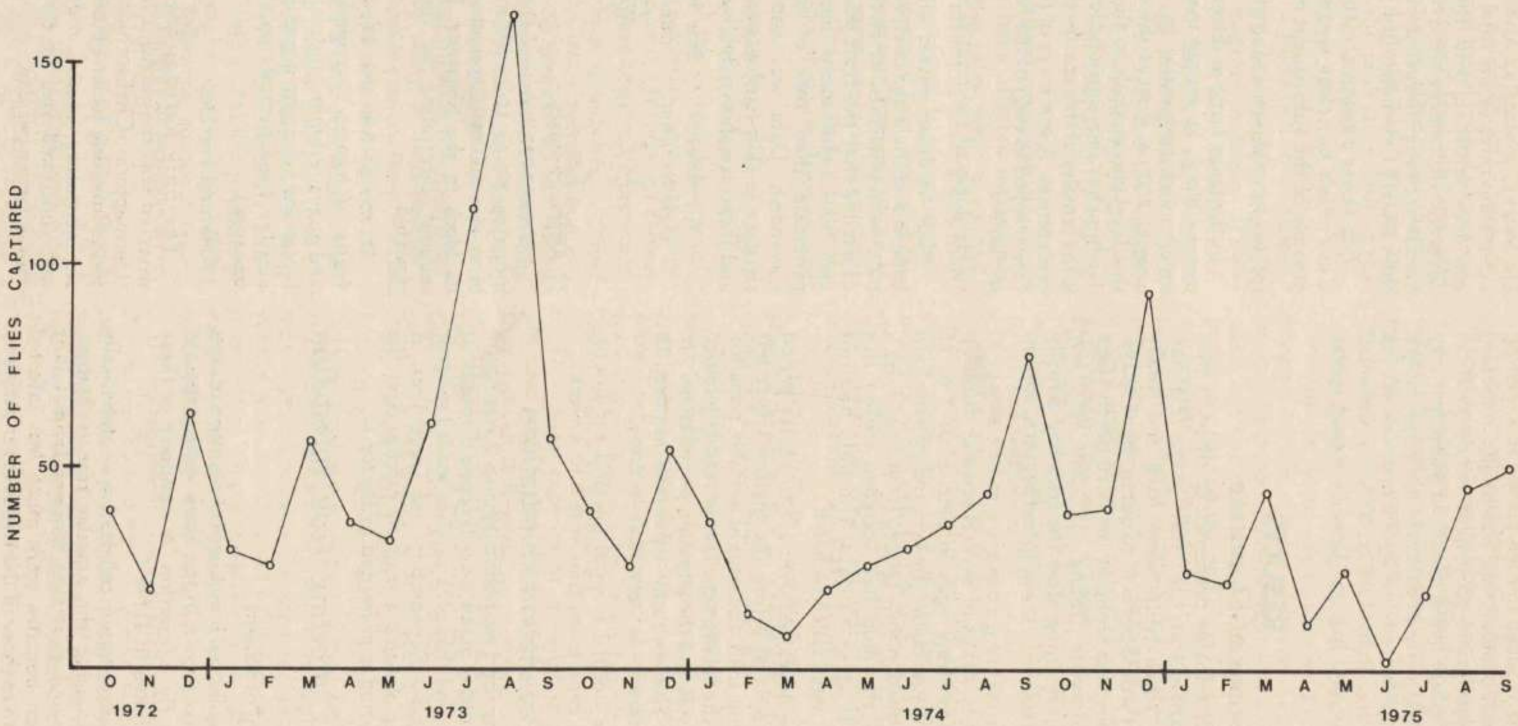

TABLE 1. — **(a)** *D. MUSAE* **INFESTATION RATES IN THREE VARIETIES OF BANANAS**

	TOTAL FINGERS				RIPE FINGERS ONLY			
Variety of banana	Dwarf	Tui	Giant	Total	Dwarf	Tui	Giant	Total
Number of bunches examined	18	26	19	63	18	26	19	63
Total fingers examined	3,018	4,433	2,840	10,291	1,627	1,028	1,575	4,230
No. of fingers infested by *D. musae*	642	407	155	1,204	642	407	155	1,204
No. Unripe fingers	1,391	3,405	1,265	6,061	—	—	—	—
% fingers infested	21.27	9.18	5.46	11.70	39.46	39.59	9.84	28.46

(b) LEAST SIGNIFICANT DIFFERENCES - TRANSFORMED DATA

Between Types	Difference between Means and Significance levels			
	Total fingers infested		Ripe fingers infested	
Dwarf - Tui	5.64	N.S.	7.66	N.S.
Dwarf - Giant	11.55	**	19.61	**
Tui - Giant	5.91	N.S.	27.27	***

* = p<.05 ** = p<.01 *** = p<.001

N.S. = Not significant

TABLE 2. — **NUMBERS OF *D. MUSAE* MALES COLLECTED AT METHYL EUGENOL BAITED TRAPS PLACED AT VARIOUS HEIGHTS IN A 2 ha BANANA BLOCK.**

(Total numbers collected after 9 exposures for a 24 hour period each week)

Trap Height	No. males	Mean No.
Ground level	85	9.4
150 cm	56	6.2
300 cm	252	28.0
450 cm	109	12.1
Combined catch	502	—

LEAST SIGNIFICANT DIFFERENCES

Between treatments	Difference between means and significance levels	
Ground level — 150 cm	3.2	N.S.
Ground level — 300 cm	18.6	**
Ground level — 450 cm	2.7	N.S.
150 — 300 cm	21.8	***
150 — 450 cm	5.9	N.S.
300 — 450 cm	15.9	**

* $p < .05$ ** $p < .01$ *** $p < .001$

N.S. = not significant

Commodity Treatment Trials

In the preliminary trials, several concentrations of both dimethoate and fenthion were tested against *D. musae* larvae. The results indicated that a 0.05% fenthion dipping emulsion should prevent fruit fly larvae from developing, although some larvae survived this and higher concentrations of fenthion, possibly due to the insecticide being from old stock held at the laboratory for 3 to 4 years before use. The results of these dipping trials are tabulated in *Table 3*.

Although no bunch dipping was carried out, a 5-second dipping period was selected with large scale bunch dipping in mind. Several experiments comparing 5-second and 10-second dipping periods showed that no difference in infestation rate could be expected by using the longer dipping time.

The main trials, which used hands of bananas, compared the sterilisation of fruit fly infested bananas dipped in 0.05% dimethoate, 0.05% fenthion or a control rain water treatment for a period of 5 seconds. These trials confirmed that 0.05% fenthion emulsion was a suitable concentration at which dipped banana fruit could be assured to be free of fruit fly infestation. A summary of the seven trials is presented in *Table 4*.

In addition, the very low infestation rates in the control treatments during these trials, indicated that by harvesting bunches at the hard green stage, one or two days before ovipositing normally occurred, the numbers of larvae subsequently hatching was greatly reduced.

DISCUSSION

In 1966, Saunders and Elder attempted to breed *D. musae* in the laboratory but, as in this study, no successful method was found. In the field *D. musae* preferred to oviposit into immature fruit, as also occurs in North Queensland (May 1963), but if after 11 days, the pulp had not softened, the eggs failed to hatch. A similar finding was reported by Umeya and Yamamoto (1971) who studied banana infestation by the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann).

Oviposition into fruit at the preferred stage had a distinct advantage since larvae emerged as the fruit softened and completed development before the fruit pulp had completely rotted. Gravid females selected those fruits which would provide softened pulp within three to four days, although it is possible that the enzymes which soften the pulp may have influenced the development of the eggs.

TABLE 3. — **PRELIMINARY STERILISATION DIPPING TRIALS AGAINST *D. MUSAE* BANANA INFESTATION USING VARIOUS CONCENTRATIONS OF DIMETHOATE AND FENTHION INSECTICIDES**

Mortality as a percentage of Water control treatment *

Trial No.	No. Reps. +	Water Control	DIMETHOATE				FENTHION				
			.01	.03	.05	.10	.01	.03	.05	.075	.10
I	3	2.4	76.5	96.1	—	—	95.6	97.5	—	—	—
II	3	10.4	—	87.3	96.0	95.4	—	97.9	99.8	—	100.0
III	5	2.5	—	—	99.2	98.6	—	—	100.0	98.9	99.4
IV	6	21.3	97.8	99.4	—	—	99.0	100.0	—	—	—
V	6	19.4	—	—	99.1	—	—	100.0	100.0	—	—
Mean		11.2	87.2	94.3	98.1	97.0	97.3	98.9	99.9	98.9	99.7

* Calculated from the number of fruit fly larvae found alive in each treatment, divided by the total number of larvae found in control treatment.

+ Each replicate consisted of 10 fingers dipped for 5 to 10 seconds in insecticide solution.

TABLE 4. — **STERILISATION DIPPING TRIALS AGAINST *D. MUSAE* BANANA INFESTATION USING 0.5% CONCENTRATIONS OF DIMETHOATE AND FENTHION INSECTICIDES**

Numbers of banana fingers infested

Trial No.	Banana Variety	CONTROL (WATER)			DIMETHOATE .05%			FENTHION .05%		
		Uninfested	Infested	Total	Uninfested	Infested	Total	Uninfested	Infested	Total
I	Tui	303	4	307	283	1	284	294	0	294
II	Tui	214	0	214	270	1	271	273	0	273
III	Tui	234	10	244	207	1	208	194	0	194
IV	Tui	302	0	302	282	0	282	297	0	297
V	Tui	239	2	241	280	1	281	268	0	268
VI	Tui	578	13	591	542	2	544	549	0	549
VII	Tui	530	1	531	529	0	529	579	0	579
TOTAL		2,400	30	2,430	2,393	6	2,399	2,454	0	2,454
%		98.77	1.23	—	99.75	0.25	—	100.0	0	—
I	Giant	194	0	194	179	0	179	178	0	178
II	Giant	209	0	209	205	1	206	229	0	229
III	Dwarf	260	0	260	324	2	326	215	0	215
IV	Dwarf	270	3	273	269	1	270	297	0	297
V	Dwarf	275	11	286	269	2	271	305	0	305
VI	Dwarf	688	52	737	665	8	673	610	0	610
VII	Dwarf	536	2	538	492	0	492	544	0	544
TOTAL		2,432	68	2,500	2,403	14	2,417	2,378	0	2,378
%		97.28	2.72	—	99.42	0.58	—	100.0	0	—
GRAND TOTAL		4,832	98	4,930	4,796	20	4,816	4,832	0	4,832
%		98.01	1.99	—	99.58	0.42	—	100.0	0	—

It was found that the variety Giant Cavendish was less liable to *D. musae* infestation than either Tui or Dwarf Cavendish bananas, and that only when ripe, were Tui fruit as heavily infested as Dwarf Cavendish (*Table 1*). These differences in infestation rates may possibly be explained by the variations in hardness of the fruit skins, and by the finding that male flies showed a strong tendency to fly at about 300 cm above ground level (*Table 2*), the height at which most Tui bunches were produced but below the height of the developing Giant Cavendish bunches. The skin of Giant Cavendish fingers was harder than that of the other two varieties (Heenan 1973 b; Anon. 1974), and it appears that the stimuli to oviposit mav be triggered by a "skin hardness" measure of 300 to 400 g, a figure generally exceeded in Giant Cavendish fingers, but not by the other varieties. Since the skin of Tui fruit softens during the ripening process (Wardlaw 1961) to a hardness measure less than 400 g within seven days of ripening (Anon. 1974), these fruit would become increasingly acceptable as oviposition sites by *D. musae* females, and if the female flight preference followed that of the males, the fruit would readily become infested.

During the studies, the fly was bred from four economic plant species, but in Queensland, it has also been reared from native bananas (*Musa banksii*), pawpaw (*Carica papaya*) and a bush shrub (*Capparis lucida*) (May 1953). It is likely that the species infests similar hosts in Papua New Guinea.

Marucci (1955) reported that two species of Hawaiian earwigs were predatory on fruit fly larvae from guavas and other rotten fruit and in the soil. It is thought that in this country the earwig *C. morio* may exert a small predatory influence on numbers of *D. musae* larvae and perhaps pupae which are exposed in the field.

If banana fruit is to be exported from Papua New Guinea, assurances must be made to the importing countries that the fruit is free from fruit fly infestation. In Queensland, "sound plantation hygiene practices and early harvesting" have been recommended for control of *D. musae* in bananas (Saunders 1961).

Braithwaite (1963) and Saunders and Elder (1966) showed that larvae of *D. tryoni* (Froggatt) (Queensland fruit fly) and *D. musae* respectively, were killed by dipping infested bananas into emulsions of dimethoate or fenthion insecticides. Braithwaite also presented data showing that the dipping of banana fruit into emulsions of fenthion 0.05% for as long as three minutes did not impart an undesirable flavour to the fruit, nor was any toxicity hazard to humans likely to have been encountered from the insecticide residues.

In the present study, the preliminary sterilisation dipping trials had been conducted with the view to determining an insecticide treatment which would prevent development of fruit fly larvae infesting bananas, and the results indicated that fenthion at 0.05% concentration would achieve this aim. The intention in the main trials was the development of a relatively simple commodity treatment, which would be applied during normal harvesting and shipping practices to bunches of fruit destined for export markets. In these trials, control by insecticides was considered inadequate if any flies could be reared out of dipped fruit.

On the basis of the *D. musae* life history studies and the dipping trials reported in this paper, a guarantee for banana fruit free from banana fruit fly infestation can be made as follows:

> Banana fruit, harvested at the hard green stage, held in a cool room for 11 to 12 days to prevent ripening, and then dipped in a freshly prepared 0.05% fenthion emulsion for a five-second period, before being shipped to the customer country in a refrigerated ship, can be guaranteed to be free from *D. musae* infestation.

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A SURVEY OF FOOD GARDENS IN THE HOSKINS OIL PALM SCHEME

C. Benjamin *

ABSTRACT

During the period August to October, 1975 a survey of food gardens attached to settler blocks on the Hoskins Oil Palm Scheme (see Figure 1*) was conducted. Block ownership was stratified by ethnic origin and 140 food gardens randomly selected for survey. Principal enquiries included total and average garden area by strata, principal crops grown and available fallow periods.*

The survey indicated a total planted garden area of 605 hectares on the total of 1,439 blocks or .420 hectares per block. Of this average planted garden area, .402 hectares were traditionally located in the "back blocks" and .018 hectares in "roadside" ancillary blocks (see Figure 2*). Areas planted to food gardens suggest the possibility of 6 to 9 year rotation periods for larger blocks and 4 to 6 years for smaller blocks.*

Food production is for both home consumption and market, and some correlation is discernible between garden size and family size and between garden size and marketable surplus. It is concluded that this trend toward marketed produce will continue and that further cash cropping can occur on the larger garden blocks but not on the smaller blocks without adversely affecting yields. The lower estimate of average fallow period suggested that taro (Colocasia esculenta) will decline in importance because the fallow is too short to maintain high yields. The areas of the various staples grown by the different ethnic groups reflect their traditional preferences.

INTRODUCTION

The first commercially grown oil palm in Papua New Guinea (*Elaeis guineensis*) was sown on the fertile volcanic soils of the Hoskins area of West New Britain in 1966. The rainfall in the area is approximatelv 3,750 mm/annum of which two thirds falls in January, February and March. Based on a nucleus estate arrangement there were at the time of the survey some 10,000 settlers on 1,439 smallholder blocks in 7 subdivisions around the nucleus estate of 2,497 hectares and processing facility at Mosa (see *Figure 1*).

Several ethnic groups are represented among the smallholders; the major groups being Chimbu, Tolai and Sepik peoples. Minor groups are Morobe, Papuan, West New Britain, New Ireland, North Solomon and Irian Jaya people. Each settler has approximately 6.07 ha of land in his block. In the earlier planted subdivisions, Kapore, Tamba, Sarakolok, Buvussi and Galai, each settler has 3.24 ha (8 acres) of oil palm and approximately 2.83 ha of arable land available for subsistence or market gardens. In the later subdivisions, Kavui and Kavugara, these "back blocks" are only 2.02 ha as the area planted to oil palm has been increased to 4.05 ha (10 acres) (see *Figure 2*). Roadside gardens have been established from the earliest inception of the scheme and are still used because the land has been previously cleared and is close to the home.

* Rural Development Officer, Department of Primary Industry, P.O. Box 351, Kimbe, West New Britain Province.

JUSTIFICATION FOR SURVEY

Despite the generation of regular income from a perennial cash crop, scheme settlers continue to place a high degree of importance on the provision of subsistence foods from their own blocks. Unlike the normal village situation where land for subsistence cropping is generally available and fallow periods are extended, scheme settlers must garden in a fixed area of land of 2 to 2.8 ha. Not only has this meant a change in some traditional cropping patterns but it could mean future food production will be limited by soil and plant fertility and the length of crop rotation available.

As a result, concern has been expressed at the lack of definitive knowledge on cropping patterns, food garden areas and rotations on

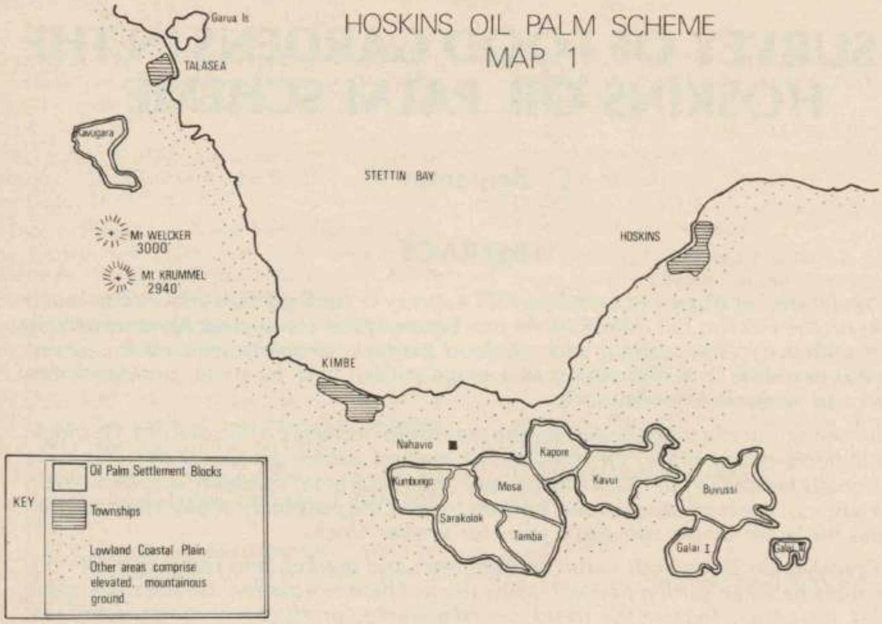

Figure 1.— Hoskins Oil Palm Scheme

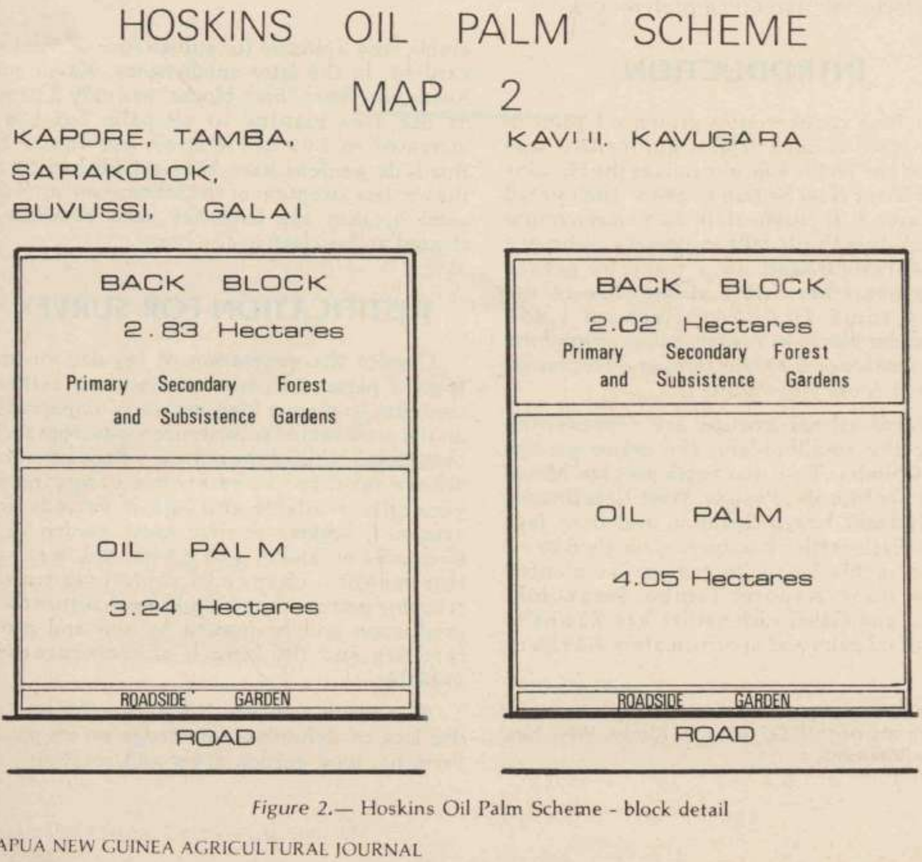

Figure 2.— Hoskins Oil Palm Scheme - block detail

the back blocks. This survey was designed to assist the formulation of recommendations for future land use policies for the back blocks and, in association with a proposed market survey in the area, to assess long-term trends in food production, disposal and consumption patterns.

In 1972 Mr R.M. Bourke conducted a food garden survey in the Hoskins - Talasea area including gardens on the oil palm scheme (Bourke, 1972). The author conducted a survey of gardens on the oil palm scheme in 1974 (Kemp, 1974).

SAMPLING PROCEDURE AND ENQUIRY

The survey was confined to the 1,439 smallholder settler blocks included in the oil palm scheme in January 1975. A further 180 village blocks were excluded from the sample frame as the villagers' gardens were not subjected to the same area restriction as the settlers' gardens. The sampling procedure chosen was a proportional stratified cluster sample resulting in 140 blocks being included in the survey. The distribution of food gardens included in the sample can be seen in *Table 1*. Approximately 10 percent of all blocks in each subdivision were randomly selected and those sub-samples stratified by ethnic origin of the settlers. Again, the results appear in *Table 1*. The primary sampling units were generated by a randon selection of blocks in each subdivision and a second-stage cluster sampling of randomly selected adjacent blocks. These were then visited and surveyed and stratified into ethnic groups. The group entitled "Others" is a mixture of West New Britain, Papuan, North Solomon and New Ireland people.

The number of people resident on the surveyed blocks is recorded and reflects the blockholder, his immediate family and any others, usually relatives or clansmen, who had been living on the block for longer than 3 months and thus could be considered semi-permanent or permanent residents. As *Table 1* indicates, the average number of residents per block was approximately 7.

The prime aim of the survey was to establish the garden area in production at that time and the area planted but not in production in both back block and roadside plots. Physical measurements were taken of garden areas. In addition, several major crops were individually measured for planted area. Plantings of sweet potato (*Ipomoea batatas*) and peanuts (*Arachis hypogea*) were measured accurately, and reliable estimates were obtained. Approximate areas were determined by pacing, for taro (*Colocasia* Spp.), Chinese taro, (*Xanthosoma* Spp.) and yams and mami (*Dioscorea* Spp.). Although these later results are reproduced in *Table 9* and *Figure 6* it is felt that they should be accepted as indicative guides only.

All data presented in *Tables 2* to *9* and *Figures 3* to *6* are total estimates for the Hoskins Oil Palm Scheme. As additional blocks have been occupied since January, 1975 (1,566 blocks were occupied in November 1976) these results now underestimate total food garden areas on the scheme.

RESULTS AND ANALYSIS

Of the 140 blocks surveyed only 2 settlers had completely abandoned food gardening. All other settlers were engaged to varying degrees of activity, but average garden life from planting to abandonment was consistently recorded as from 1 to 1½ years.

Cropping patterns varied between ethnic groups. Most gardens followed a primary bush fallow rotation. Sweet potato was commonly alternated with peanuts on the same piece of ground before the land was fallowed. Interplanting of crops in gardens of all ethnic groups was common practice. For example, in Chimbu gardens, sweet potato and corn were commonly interplanted as were peanuts and corn; in Sepik gardens, yams and mami were commonly interplanted with taro and/or Chinese taro. Other vegetables commonly recorded in gardens included aibika (*Hibiscus manihot*), tomatoes (*Lycopersicum* spp.), aupa (*Amaranthus tricolor*), karakap (*Solanum nigrum*), pit pit (*Saccharum edule*), pumpkin (*Cucurbita maxima*) and varieties of cabbage (*Brassica* spp.). Some roadside gardens were planted on a grassland fallow or on old abandoned gardens, and the planting of peanuts was common.

For purposes of comparison, total garden area in the back blocks alone has been separated out in *Table 2* and is presented by sub-divisions and ethnic origin of settlers. Of the total back block area of 3,813 ha available for food gardens, 580 ha or 15.2 percent of that area was under crop at the time of the survey. Total roadside garden area available was not measured but actual roadside plantings amounted to 26 ha, an average of 181 sq. metres per block. Total garden areas are given in *Table 3*. *Figure 1* shows total areas under food gardens for back block garden area and roadside garden area. Average garden area sown per year in back blocks and in total, and average garden area sown per person (resident) per block per year are given in *Tables 4* to *6* and Figures 4 and 5. In *Tables 7* to *9* and *Figure 6* measured areas of

TABLE 1. — **SETTLEMENT BLOCKS SURVEYED**

Sub-Division	Date of establish-ment	Total No. of blocks occupied Jan. '75	Total No. of blocks in survey	% Blocks survey	Total No. of people in survey	Total No. of Chimbu blocks	Total No. of Sepik blocks	Total No. of Tolai blocks	Total No. of Morobe blocks	Total No. of "other" blocks
KAPORE	1968	133	14	10.5	114	3	5	5	NIL	1
TAMBA	1968	200	20	10	133	2	7	6	1	4
SARAKOLOK	1969	250	24	9.6	157	4	8	4	5	3
BUVUSSI	1970	366	35	9.6	279	9	20	4	1	1
GALAI	1971	170	15	8.8	105	NIL	7	2	5	1
KAVUI	1972	210	21	10	147	9	4	4	1	3
KAVUGARA	1972	110	11	10	74	6	2	1	1	1
TOTALS		1,439	140	9.7	1,009	33	53	26	14	14

TABLE 2. — **TOTAL GARDEN AREA IN BACK BLOCKS (HECTARES)**

SUB-DIVISION	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	TOTALS
KAPORE	9.38	21.7	20.2	NIL	14.8	66.1
TAMBA	10.5	30.3	26.1	6.3	7.9	81.1
SARAKOLOK	26.1	39.8	10.4	12.8	12.9	102
BUVUSSI	43.7	76.6	7.1	.8	3	131.2
GALAI	NIL	21.1	7.4	30	3.2	61.7
KAVUI	46.9	17.7	12.6	4.5	8.4	90.1
KAVUGARA	22.3	12.4	1.0	8.4	3.3	47.4
TOTALS	158.9	219.6	84.8	62.8	53.5	579.6

TABLE 3. — **TOTAL GARDEN AREA OF BACK BLOCK & ROADSIDE GARDENS (HECTARES)**

SUB-DIVISIONS	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	TOTALS
KAPORE	12.1	22.3	20.2	NIL	14.8	69.4
TAMBA	10.5	30.3	26	6.3	7.9	81
SARAKOLOK	26.1	40	10.6	12.8	15.2	104.7
BUVUSSI	45.6	77.2	7.1	.8	3	133.7
GALAI	NIL	22.6	7.4	32	3.2	65.2
KAVUI	48.1	17.9	14	5.8	10.2	96
KAVUGARA	28.1	12.4	2.6	9	3.3	55.4
TOTALS	170.5	222.7	87.9	66.7	57.6	605.4

TABLE 4. — **AVERAGE GARDEN AREA IN BACK BLOCKS (HECTARES)**

SUB-DIVISION	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	AVERAGE
KAPORE	.304	.421	.392	NIL	1.436	.458
TAMBA	.509	.420	.422	.611	.192	.393
SARAKOLOK	.633	.483	.252	.248	.417	.412
BUVUSSI	.471	.372	.172	.078	.291	.364
GALAI	NIL	.292	.359	.582	.310	.399
KAVUI	.505	.429	.306	.437	.272	.416
KAVUGARA	.361	.601	.097	.815	.320	.418
AVERAGE	.467	.402	.316	.435	.371	.402

TABLE 5. — **AVERAGE OF TOTAL GARDEN AREAS (HECTARES)**

SUB-DIVISION	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	AVERAGE
KAPORE	.391	.433	.392	NIL	1.436	.481
TAMBA	.509	.420	.420	.611	.192	.393
SARAKOLOK	.633	.485	.257	.248	.491	.423
BUVUSSI	.491	.374	.172	.078	.291	.371
GALAI	NIL	.313	.359	.621	.310	.422
KAVUI	.518	.435	.340	.563	.330	.443
KAVUGARA	.454	.602	.252	.873	.320	.489
AVERAGE	.501	.408	.328	.462	.399	.420

TABLE 6. — **AVERAGE GARDEN AREA/PERSON (HECTARES)**

SUB-DIVISION	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	AVERAGE
KAPORE	.058	.045	.052	NIL	.180	.059
TAMBA	.102	.067	.066	.076	.023	.059
SARAKOLOK	.105	.073	.040	.037	.074	.065
BUVUSSI	.054	.049	.029	.026	.017	.047
GALAI	NIL	.047	.038	.094	.039	.060
KAVUI	.081	.072	.045	.043	.052	.063
KAVUGARA	.065	.109	.036	.146	.040	.073
AVERAGE	.070	.056	.047	.069	.050	.058

TABLE 7. — **AREA OF PEANUTS (HECTARES)**

SUB-DIVISION	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	TOTAL
KAPORE	6.3	.1	9.5	NIL	.3	16.2
TAMBA	2.8	.8	.8	NIL	.1	4.5
SARAKOLOK	7.2	.4	2	.1	1.8	11.5
BUVUSSI	13.5	.9	1.1	NIL	NIL	15.5
GALAI	NIL	.9	1.2	.1	NIL	2.2
KAVUI	16.9	.1	.2	1.2	.1	18.5
KAVUGARA	11.2	NIL	.1	NIL	.1	11.4
TOTALS	57.9	3.2	14.9	1.4	2.4	79.8
Average Area (hectares/block)	.17	.006	.056	.010	.016	.055

TABLE 8. — **AREA OF SWEET POTATO (HECTARES)**

SUB-DIVISION	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	TOTAL
KAPORE	2.8	4.7	3.4	NIL	1.1	12
TAMBA	7.2	1.3	.6	1.8	.7	11.6
SARAKOLOK	4.3	2	.7	6.1	9	22.1
BUVUSSI	31.3	12.3	1.8	.4	1.1	46.9
GALAI	NIL	3.2	.7	14.7	.7	19.3
KAVUI	22.2	2	8.1	NIL	5.4	37.7
KAVUGARA	18.0	2.3	NIL	6.2	1.2	27.7
TOTAL	85.8	27.8	15.3	29.2	19.2	177.3
Average Area (hectares/block)	.252	.051	.057	.202	.133	.123

TABLE 9. — **APPROXIMATE AREAS OF CHINESE TARO, TARO AND YAMS/MAMI (HECTARES)**

TYPE OF CROP	ETHNIC		GROUP			SUB-DIVISION
	CHIMBU	SEPIK	TOLAI	MOROBE	OTHERS	TOTAL
CHINESE TARO	10.6	58	28.9	12.5	14	124
TARO	4.0	49	11	12.8	10.2	87
YAMS AND MAMI	.15	57	NIL	8.8	3.6	69.6
APPROXIMATE AVERAGE AREAS OF CHINESE TARO, TARO AND YAMS/MAMI (HECTARES/BLOCK)						
CHINESE TARO	.031	.106	.108	.087	.097	.086
TARO	.012	.090	.004	.089	.071	.060
YAMS AND MAMI	.0004	.104	NIL	.061	.025	.048

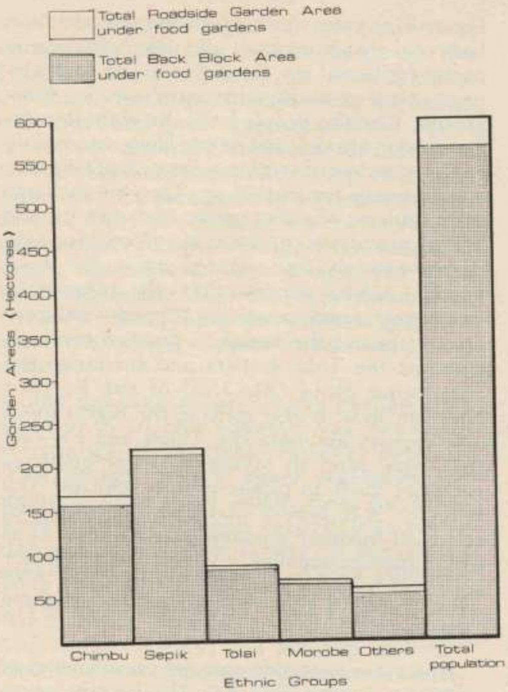

Figure 3.— Total areas under food gardens

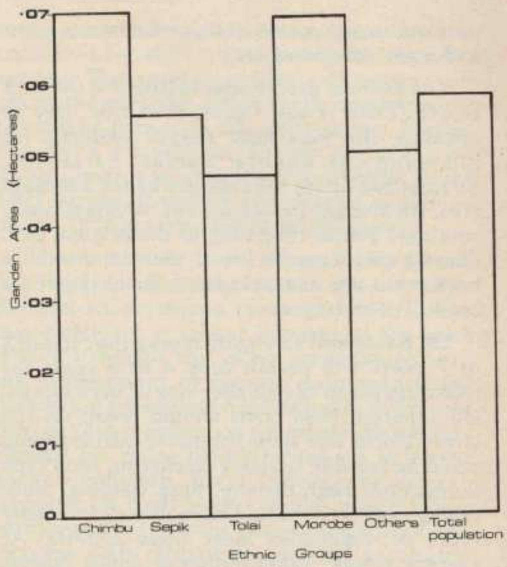

Figure 5.— Average garden area/person

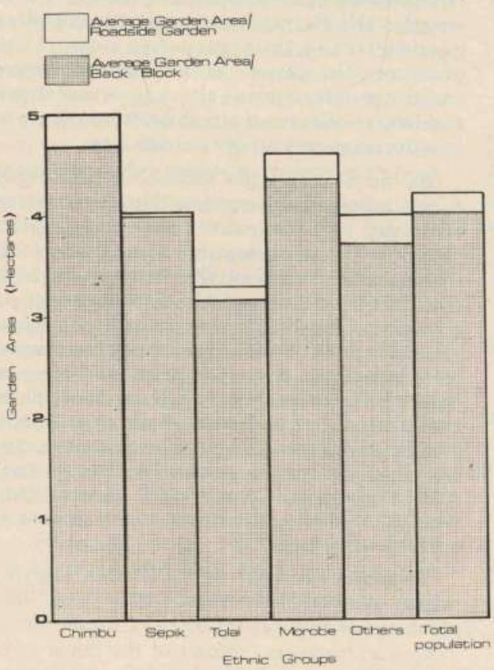

Figure 4.— Average garden area/block (hectares)

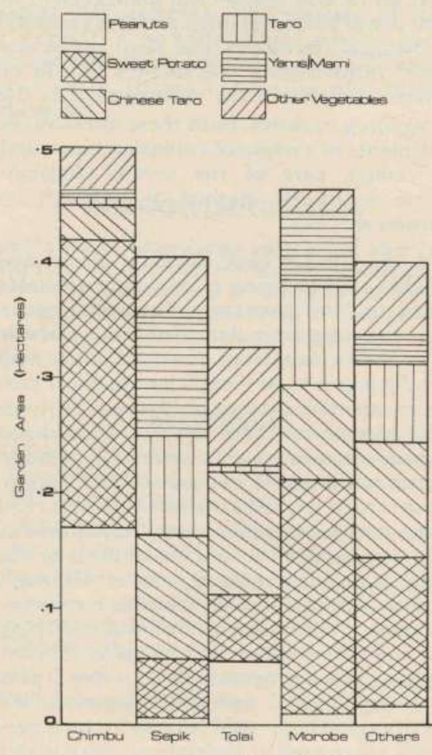

Figure 6.— Cumulative average total garden area by crop type and ethnic group

peanuts, sweet potato, taro, chinese taro, yams and mami are presented.

The average garden areas planted in the back blocks (*Table 4* and *Figure 4*) can be used to calculate the maximum period available for fallowing. At Kapore, Tamba, Sarakolok, Buvussi and Galai, the back blocks are 3.83 ha in area. An average garden area of .402 ha allows 7 rotations before returning to the original plot. Given a useful garden life of 12 to 18 months, 6 to 9 years are available for fallowing given a cycle of 7 to 10 years.

On Kavui and Kavugara blocks the cycle of 5 to 7 years will permit only 4 to 6 years for fallowing given the smaller size of back blocks. No apparent food crisis should result on the larger blocks and some intensive cash cropping could be feasible without disrupting food crop production. High density, high yielding, land-saving cash crops would be required, and many types of vegetables meet these criteria. At current prices, 1,000 birds-eye chillie bushes (*Capiscum frutescens*) occupying only about .10 ha would return a minimum of K120/annum. On the other hand, yields may suffer without either: (a) careful fallow-field management or (b) the use of biological (high yielding varieties) and chemical (fertilizers and plant protection sprays) innovations. Fertilizers would be required to maintain the performance of the high yielding varieties. Both these alternatives are elements of a required extension input, and they remain part of the overall decision-problem as to the method of approach by extension services.

On the smaller back blocks at Kavui and Kavugara cash cropping of any nature is liable to lead to land shortages for subsistence gardening. A particular problem of these smaller blocks is that 4 to 6 years of fallow may generally prove to be insufficient to allow taro crops to maintain current yield levels. Without careful husbandry there appears a likelihood that crops requiring a shorter fallow period to maintain yield levels such as sweet potato, chinese taro or triploid bananas (*Musa* spp.) will become more prominent in cropping patterns as has become evident in land deficit areas of the Gazelle Peninsula (see Bourke, 1976). Although over time it seems remote that this trend may be reversed, controlled use of soil enriching cover and fallow crops such as winged beans (*Psophocarpus tetragonolobus*), cow peas (*Vigna unguiculata*) and other legumes will serve to extend high-yield periods for taro, particularly when used in association with suitable fertilizers.

The average total garden area per block per year is .420 ha including roadside plots. As *Figure 6* indicates there is considerable variation between ethnic groups, and this variation is partly explained by "family" size and partly by production of marketable surpluses by some groups. Chimbu people have the highest average garden area of .501 ha per block due mainly to the growing of food in excess of subsistence requirements for marketing. They are the largest producers of sweet potato and peanuts, and a large proportion of these are offered for sale. The seemingly low planted areas for Tolai people (.328 ha) partly reflects the difficulty in measuring areas sown to triploid bananas grown around the house, a practice common amongst the Tolai settlers and similar to the compound plots (Ala Ulo) of the Eastern Nigerian Ibos. It also reflects the high rate of absenteeism amongst the Tolais and the fact that they tend to invest in other business activities such as public motor vehicles. The tendency is to believe that Tolais are prepared to invest in other business activities and thus utilise market supplies of vegetables as a major source of food supply. Despite this, some Tolai gardens were very large, and they were obviously cropping for a market.

The average garden area per person per year is .058 ha (*Table 6, Figure 5*). This is at the lower end of the range of garden area of .06 to .12 ha per person suggested by Barrau (1954) for this environment. The comparison, however, is not strictly valid. Barrau was concerned with village garden areas, but growing population pressures, the growth of fixed market centres and the proliferation of alternative investment and labour-allocation possibilities has likely led to a decrease in average garden size.

As can be seen from *Tables 7* to *9* and *Figure 6*, the areas of crops grown by ethnic groups strongly reflect individual consumption patterns. The total area of peanuts grown in the scheme at the time of the survey was 80 ha (*Table 7*). Of this area 58 ha or 73 per cent was grown by Chimbu people primarily for market sales. The bulk of Chimbu carbohydrates result from sweet potato consumption, and of a total of 177 ha of sweet potato grown (*Table 8*) this group produced 86 ha or 49 per cent of total plantings. A large proportion of this production remains as internal scheme consumption and is sold to others as is true for the Morobe group who planted over .2 ha of sweet potato on average per block.

Taro and yams are not traditional highland staples and this is reflected in the small plantings of these crops by the Chimbu group. They are, however, staples of the Sepik group as is reflected by *Table 9* and *Figure 6* where average values of .104 ha/block of yams and mami were recorded. Most yams and mami were grown by the Sepiks though a surprising amount was grown by the Morobe group. The Tolai and Sepik settlers grew more Chinese taro than other ethnic groups while the Sepiks and Morobes grew approximately equal amounts of taro and Chinese taro. Chinese taro has been observed to have become an important staple over the past years of settlement in the Hoskins Oil Palm Scheme due to its ease of maintenance, higher yields than taro and disease resistance to virus attack. The Tolai "other vegetables" (*Figure 6*) are predominantly triploid bananas. The crops traditionally grown in the area by local villagers are taro and diploid bananas.

One positive result of the garden area allotments to the scheme has been the interchange of vegetable varieties between ethnic groups. Several lesser vegetables and kumus (a generalised pidgin term for green vegetables) have been recorded as being interchanged. A wide variety of kumu was noted in all ethnic groups. Aibika (*Hibiscus manihot*) was common to most blocks as was pumpkin (*Cucurbita maxima*), aupa (*Amaranthus tricolor*) and karakap (*Solanum nigrum*). Pit pit (*Saccharum edule*) was widely grown and groups did not differentiate by ethnic group between Chimbu pit pit and the larger lowland varieties. Other integrating patterns existed; all groups grew edible ferns of *Alsophila* Spp., and a traditional Tolai yellow leafed kumu, locally named valagur (*Polyscias grandifolia*), is now widely grown by all ethnic groups for house garden decoration and consumption. The main varieties of beans grown are snake beans (*Vigna unguiculata*) and winged beans (*Psophocarpus tetragonolobus*).

In January, 1976 a cross-check of the data collected above was completed as part of practical field-work requirements by women students of the Vudal Agricultural College, one of Papua New Guinea's tertiary agricultural training institutions. A similar approach was employed and 306 blocks of the oil palm scheme surveyed. The results gained were slightly higher than those of the 1975 survey. The total back block area planted to gardens on the 1,566 blocks in the scheme at that time amounted to 725 ha as compared to 580 ha for 1,439 blocks in the 1975 survey. The total garden area for the 1976 survey for 1,566 blocks was 764 ha as compared to 604 for the 1975 survey for 1,439 blocks. The average back block area used for gardening and the average total garden area came to .468 ha and .489 ha respectively as compared to .402 ha and .420 ha for the 1975 survey. The average garden area/person was calculated out to be .066 ha/person as compared to .058 ha/person in the 1975 survey. During the 1976 survey, 21 people were taking measurements as compared to 2 people in the 1975 survey; therefore enumerator variability of the 1976 survey cannot be overlooked.

The immediate implications of the survey for "back block management" are not clear. Subsistence gardening currently constitutes a major element in labour demand on the block holdings though this is not inconsistent with the achievement of regular maintenance and harvesting schedules on the oil palm. At present further cash cropping on a limited scale appears feasible for those blocks facing a 6 to 9 year garden rotation. Over indulgence in cash cropping on back blocks would reduce fallow periods and necessarily food garden output, but increase cash returns for market purchases. The efficiency of the marketing system will largely determine these trends particularly as local village production is mainly of taros and diploid bananas which do not fully satisfy all market requirements. The efficacy of these alternative approaches to back block management should become a major element in local agricultural extension and farmer education.

ACKNOWLEDGEMENTS

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SWEET POTATO (*IPOMOEA BATATAS*) FERTILIZER TRIALS ON THE GAZELLE PENINSULA OF NEW BRITAIN: 1954 - 1976

R. Michael Bourke*

ABSTRACT

The influence of fertilizer on sweet potato yields was examined in 17 field and 6 pot trials on a young volcanic soil. Nitrogen (N) had the greatest effect on yield and it gave large yield increases, especially at grassland sites. In three fertilized plantings of a block cropped continuously with sweet potato (Soil Exhaustion Trial), however, nitrogen depressed tuber yield. It is suggested that different responses to N were due to varietal differences. Nitrogen increased top growth in all trials where this was assessed.

Phosphate (P) improved top growth and yield in only a few trials. Negative responses to residual P occurred in most plantings of the Soil Exhaustion Trial. Large yield responses to applied and residual potash (K) fertilizer were recorded in the Soil Exhaustion Trial. Potassium did not affect top growth in any trial but it increased tuber number. No responses to other nutrients were recorded in field trials except a response to residual magnesium (Mg) in two plantings. In the pot trials there were top growth responses to N, P, K, Mg and manganese. Fertilizer (N-P-K or N-K) gave large yield increases in a rotation trial, especially in narrow rotations. A significant negative relationship was found between the magnitude of fertilizer responses and control yields.

Soil analyses, fertilizer placement and the economics of fertilization are discussed. Recommendations for fertilizers for sweet potato are made for both grassland and former forest areas.

INTRODUCTION

As well as being the most important subsistence crop in Papua New Guinea, sweet potato (*Ipomoea batatas* (L.) Lam.) is a significant cash crop. Large quantities are grown in both the highlands and lowlands for sale in the markets and to institutions. Because of its cash crop status, information on fertilizer requirements is needed.

Many sweet potato fertilizer trials have been conducted overseas and there is an extensive literature on the subject, much of it from the U.S.A. A precis of de Geus' (1973) review of the literature is as follows: Potash is generally considered a key factor in the fertilizer programme of sweet potato. A number of experiments have indicated that sweet potato does not require very large quantities of phosphate for root development, although yield increases due to phosphate application have been obtained. Many experiments have shown an appreciable yield increase resulting from nitrogen application. An excess of nitrogen should be avoided however because this may cause excessive top growth but a reduction in tuber yield. Yield responses to magnesium (Hester *et al.* 1951), to boron (Nusbaum 1947; Landrau and Samuels 1951), and to manganese (Anderson *et al.* 1962) have also been recorded.

The trials reported here were conducted on highly fertile, young, volcanic ash derived soils on the Gazelle Peninsula of New Britain. The soils vary somewhat from location to location. Nitrogen (N) is the main nutrient to which responses have been recorded on this soil type. Responses to N have occurred for a wide range of annual and perennial crops (Sumbak 1970; Byrne 1971; unpubl. data L.A.E.S.). Yield responses or deficiency symptoms have been recorded from a number of crops for sulphur (S), manganese (Mn) and magnesium (Mg). Sorghum has responded to phosphorus (P),

* Formerly Agronomist, Lowlands Agricultural Experiment Station, Keravat, E.N.B. Present Address: 16 Blackstone Street, Indooroopilly, Queensland, 4068, Australia.

Plate 1. — Fertilizer is applied to the soil surface in a band before ridging and planting

Plate 2. — Ridges are made over the fertilizer

potash (K) and copper (Cu) application and foliar deficiency symptoms in citrus have been alleviated by zinc (Zn) application.

This paper reviews 17 field and 6 pot trials most of which have not previously been reported in published form The present author conducted 13 of the field trials. The other 4 field trials and the pot trials were conducted by previous staff L.A.E.S. (Lowlands Agricultural Experiment Station, Keravat, East New Britain) (see Acknowledgements). The trials are considered as three groups. These are general trials, the Keravat Soil Exhaustion Trial and the Keravat Rotation Trial.

I GENERAL TRIALS

Seven trials were conducted in various locations on the Gazelle Peninsula, three in grassland areas and four in former forest areas. Five of the trials were NPK factorials.

MATERIALS AND METHODS

Trial Sites

The Trial 1 site had been cropped with sweet potato for many years and soil fertility was considered very low. The Trial 2 area had also been gardened for many years. Part of the area was covered in *Sorghum propinquum* and part with *Pueraria phaseoloides* and *Mimosa invisa*. Two sorghum crops preceded the trial. Trials 3 and 4 were situated in nearby areas which had been under gardens and fallows for many years. Kunai grass (*Imperata cylindrica*) and *Sorghum propinquum* were the dominant species at the two sites respectively. Trial 5 was also in a kunai grassland area which had been used for gardens occasionally.

Trials 6 and 7 were in former forest areas. The Trial 6 site had been under various root crops for five years prior to the trial. The Trial 7 site had been used for gardens and fallows for many years. A short term fallow of volunteer sweet potato with some cassava and *Sorghum propinquum* preceded the trial. The area had been gardened continuously for at least three years prior to this.

Trial details

Trial design, fertilizer application (*Table 1*) and treatment of vegetation varied from trial to trial. For Trial 2, the sorghum was slashed and turned under. At the grassland sites (Trials 3, 4, 5) the grass was slashed and burnt. For Trials 6 and 7 previous crop residues were removed prior to cultivation.

Ridges were used for all trials except Trial 7 where mounds were used. Ridges and mounds were formed with hand hoes and were some 25 cm in height. Ridges were triangular in cross section. Mounds were about 50 cm across at the base. A single row of cuttings was planted in the ridges with one, two or three cuttings per planting position. For Trials 2 to 7, fertilizer was applied to the soil in a band before planting and the ridge or mound built over it (*Plates 1* and *2*). Urea or ammonium sulphate provided nitrogen, and superphosphate and muriate of potash provided phosphate and potash respectively. Guard rows were used for Trials 1 and 2.

Soil samples were collected for chemical analysis from Trials 4, 5 and 6. One sample was collected per plot between soil cultivation and planting and the samples were bulked to give a composite sample per trial.

RECORDINGS

Top growth vigour and colour were assessed visually for Trials 2 to 7. Scores for vigour and colour were allocated to each plot on a 0 to 10 scale, higher scores indicating greater vigour or colour. Results for vigour and colour for all trials, including the Soil Exhaustion and Rotation Trials, were analysed using the X^2 test for independence. For Trials 2 to 7 tubers were classified as saleable on the basis of size, and saleable yield recorded as well as total yield. Tubers longer than 10 cm and with a diameter of over 5 cm were classed as saleable in Trials 2 and 3. For Trials 4 to 7 the critical size was reduced, and tubers more than 140 g in weight were considered saleable. This classification approximates to that used by local farmers.

Table 2.— **Soil Analysis, 0 - 30 cm. Trials 4, 5, 6**

Parameter	Trial 4	Trial 5	Trial 6
Nitrogen %	.47	.26	.40
Carbon %	5.6	3.2	3.8
C/N ratio	11.9	12.1	9.6
Olsen P p.p.m.	6.3	35.2	34.5
Exch. Ca m.e.%	13.1	18.5	32.5
Exch. Mg m.e.%	3.1	3.8	4.0
Exch. K m.e.%	1.7	>3.0	>3.0
Exch. Na m.e.%	1.2	1.1	1.0
Cation exchange capacity m.e.%	22.2	24.6	35.4
pH	5.9	6.4	7.0
Specific conduc. mhos x 10^3	.069	.068	.120
Total soluble salts	.021	.020	.036
K/N ratio	3.5	>11.5	>7.6

Table 1. — **Details of general trials**

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Location	L.A.E.S., Keravat	L.A.E.S., Keravat	Vunadidir Village	Vunadidir Village	Palnakiau Village	Sonoma College	George Brown High School
Original vegetation	Forest	Forest	Grassland	Grassland	Grassland	Forest	Forest
Experimental design	2^4 factorial in an 8 x 8 quasi-latin square design	3 x 3 x 5 factorial with 2 replicates	3 x 3 x 4 factorial	½ replicate of 4^3 factorial with 2 blocks	½ replicate of 4^3 factorial with 2 blocks	½ replicate of 4^3 factorial with 2 blocks	Randomized blocks. 3 treatments, 5 replicates
Treatments	2N x 2P x 2Ca x 2 minors	3N x 3P x 5K	3N x 3P x 4K	4N x 4P x 4K	4N x 4P x 4K	4N x 4P x 4K	1. $N^0P^0K^0$ 2. $N^1P^1K^1$ 3. $N^2P^2K^2$
Levels (kg N/ha) and form of N	0, 25 A/S (1)	0, 45, 90 Urea	0, 45, 90 Urea	0, 45, 90, 135 A/S	0, 45, 90, 135 A/S	0, 45, 90, 135 A/S	0, 50, 100 A/S
Levels of P (kg P/ha)	0, 10	0, 25, 50	0, 25, 50	0, 25, 50, 100	0, 25, 50, 100	0, 25, 50, 100	0, 15, 30
Levels of K (kg K/ha)	(2)	0, 93, 186, 372, 744	0, 93, 186, 372	0, 90, 180, 360	0, 90, 180, 360	0, 90, 180, 360	0, 85, 170
Plot size (m)	4.8 x 4.8	9.1 x 4.3	9.1 x 4.3	9 x 4	9 x 4	9 x 4	5.5 x 4.5
Variety	K1	V23	V23	V23	V23	V23	V2
Between row and within row spacing	1.2 m, 30 cm	1.1 m, 30 cm	1.1 m, 30 cm	1 m, 30 cm	1 m, 30 cm	1 m, 30 cm	(3)
Planting density (cuttings/ha)	81,000	62,000	62,000	67,000	67,000	67,000	30,000
Planting date	9/11/1954	16/9/1971	17/11/1971	8/5/1973	3/4/1973	9/4/1973	16/4/1974

(1) A/S = Ammonium sulphate

(2) No K treatment. Other treatments were Ca and Mg applied as dolomite at 0, 63 kg/ha and minor elements (Fe, Mn, Zn, Cu, B, Mo) at 0, 63 kg/ha.

(3) Mounds not ridges used

TABLE 3. — **Visual top growth vigour assessments. Main effect means. Trials 2 - 6. On a 0 - 10 scale, higher scores indicate greater vigour.**

Treatment	Trial 2 12 weeks	Trial 3 12 weeks	Trial 4 8 weeks	Trial 5 8 weeks	Trial 6 8 weeks
N^0	8	8	4	4	7
N^1	9	8	5	5	8
N^2	9	9	5	7	9
N^3			5	8	8
P^0	9	8	5	6	8
P^1	8	8	5	6	8
P^2	9	9	5	7	8
P^4			5	6	8
K^0	8	8	5	6	8
K^1	9	9	5	6	8
K^2	9	8	5	6	8
K^3	9	8	5	6	8
K^4	9				
Significant effects	N (0.001) P (0.05)	N (0.01)	N (0.01)	N (0.001)	—

TABLE 4. — **Visual top growth colour assessments. Main effect means. Trials 2 - 6. On a 0 - 10 scale, higher scores indicate greater colour.**

Treatment	Trial 2 12 weeks	Trial 3 12 weeks	Trial 4 8 weeks	Trial 5 8 weeks	Trial 6 8 weeks
N^0	7	8	7	7	8
N^1	8	8	8	7	8
N^2	9	9	8	8	9
N^3			9	9	9
P^0	8	8	8	8	9
P^1	8	9	8	7	8
P^2	8	9	8	8	9
P^4			8	8	8
K^0	8	8	8	8	9
K^1	8	8	8	7	8
K^2	7	9	8	8	8
K^3	8	8	8	8	8
K^4	8				
Significant effects	N (0.01)	N (0.05)	N (0.01)	N (0.01)	—

TABLE 5.— **Total tuber yield (kg/ha). Main effect means. Trial 1**

Treatment	Yield
N^0	25,200
N^1	25,200
P^0	25,100
P^1	25,200
Ca^0/Mg^0	24,500
Ca^1/Mg^1	25,900
$Minors^0$	25,300
$Minors^1$	25,100
Significant effect	—
L.S.D. (0.05)	2,100

TABLE 7. — **Saleable tuber yield, visual top growth vigour and colour assessments. Trial 7**

Treatment	Saleable tuber yield (kg/ha)	Visual top growth assessment 8 weeks on a 0 - 10 scale	
		vigour	colour
Control	4,100 a	9	9
$N^1P^1K^1$	5,200 ab	9	9
$N^2P^2K^2$	5,900 b	10	9
Level of significance	0.05	0.001	N.S.
L.S.D. (0.05)	1,200	—	—

Yield values followed by the same letter are not significantly different at p = 0.05.

TABLE 6.— **Saleable tuber yields (kg/ha). Main effect means. Trials 2, 3, 4, 5, 6**

Treatment	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
N^0	18,100	6,900 a	6,900 a	4,900 a	18,000
N^1	18,400	10,100 b	9,900 ab	7,200 ab	20,200
N^2	18,200	11,700 b	11,300 bc	7,200 ab	20,500
N^3			14,200 c	10,100 b	20,500
P^0	16,500 a	9,500 ab	10,500	6,000	19,100
P^1	19,900 b	8,000 a	0,100	8,200	19,000
P^2	18,300 ab	11,300 b	10,600	8,000	20,500
P^4			11,200	7,000	20,700
K^0	18,700	9,900	9,300	8,400	19,600
K^1	18,200	10,700	8,700	6,400	20,200
K^2	17,700	9,800	12,100	7,800	21,800
K^3	19,500	8,000	12,300	6,500	17,700
K^4	17,100				
Significant effects	P (0.01)	N (0.001) P (0.05)	N (0.01)	N (0.05)	—
L.S.D. (0.05) N or P	2,000	2,300	3,400	3,400	3,400
L.S.D. (0.05) K	2,600	2,700	3,400	3,400	3,400

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at P = 0.05.

RESULTS

Soil analysis from the Trial 4, 5 and 6 sites showed that all three soils were well supplied with nutrients although N was low at the Trial 5 site (*Table 2*). The carbon/nitrogen (C/N) ratio was moderately high for Trials 4 and 5, indicating that nitrogen unavailability was possible for the Trial 4 site and likely for the Trial 5 site (D.W.P. Murty, pers. comm.).

Top growth vigour and colour were significantly improved by nitrogen for Trials 2 to 5 (*Tables 3, 4*). Phosphate fertilizer significantly improved top growth vigour early in Trial 2 and colour early in Trial 3. Potassium had no significant effect on top growth. Fertilizer significantly improved vigour in Trial 7 (*Table 7*). It was observed that weeds were more vigorous in high N plots for Trials 4 and 5.

In Trial 1, yield levels were high and fertilizer did not significantly influence total tuber yield (*Table 5*). Large significant responses to N occurred for the three grassland sites (Trials 3, 4 and 5). An apparent N response in Trial 6 was not statistically significant. Significant responses to P were recorded for Trials 2 and 3, although in Trial 3 the result was not clear, as the P^1 yield was less that P^0, and the significance lay in the difference between P^1 and P^2. Potassium had no effect on yield except for a possible but non-significant response in Trial 4 (*Table 6*). A significant response to $N^2P^2K^2$ occurred for Trial 7 (*Table 7*).

Cracking of tubers was observed to be more severe than normally experienced in Trials 3, 5 and 6. Cracked tubers were weighed for Trials 4 and 5 and assessed for Trial 6. The percentage of cracking was not related to fertilizer treatments except for Trial 5 where potassium significantly reduced the percentage of cracked tubers from 30% at K^0 to 20% at K^4 ($p = 0.05$).

II SOIL EXHAUSTION TRIAL

In 1954 a soil exhaustion trial was laid down at Keravat on an area formerly under forest. The aim was to exhaust the soil with continuous cropping of sweet potato and then investigate the fertilizer requirements for sweet potato yield restoration to the original levels (Newton and Jamieson 1968). Eight fertilizer trials have been conducted on the trial site, six with sweet potato and two with sorghum. The sweet potato fertilizer trials are reported here. No fertilizer was used at any planting other than those plantings involving fertilizer trials.

There were 10 sweet potato plantings in the first 6 years of the trial. The 11th and 12th plantings were used for fertilizer trials and these were followed by another 4 plantings without fertilizer. The 17th planting was used for another fertilizer trial. Sorghum fertilizer trials were conducted on the site after the 19th and 25th plantings. The 26th, 30th and 31st plantings were also used for sweet potato fertilizer trials.

MATERIALS AND METHODS

The Soil Exhaustion Trial contained 64 plots each 4.6 m square. Plot size varied slightly for certain plantings. In the 30th and 31st plantings a growth analysis study was performed. Data presented here for these two plantings is from the final sampling at 22 weeks. Plot size for this sampling was 3.6 m x 2.7 m. Trial design, treatments, and variety varied for the different fertilized plantings (*Table 8*). Ridges were used for all plantings and guard rows were used in the latter three fertilized plantings. The method of fertilizer application varied from planting to planting. In the 11th planting the ridges were formed to a height of 10 cm, the fertilizer applied to the top of the ridges and then ridging was completed. For the 12th planting fertilizer was applied in three applications, 4, 9 and 23 weeks after planting. For the 17th planting all fertilizer except superphosphate was split into four applications and was applied at 5, 10, 15 and 20 weeks after planting. Phosphorus was applied at 5 weeks only. Fertilizer was applied to the soil surface and ridges built over it for the 26th, 30th and 31st plantings.

Treatments in the fertilizer trial at the 12th planting were the same as in the 11th planting and were applied to the same plots. For the 17th planting phosphate treatments were applied to the same plots as for the 11th and 12th plantings while other treatments were re-randomized. Treatments were completely re-randomized for the 26th planting and again for the 30th planting. Treatments and plots for the 31st planting were identical to those for the 30th. Gypsum was applied to P^0, P^1 and P^2 plots in the 17th planting to bring calcium and sulphur levels to a uniform rate on all plots. A basal dressing of elemental sulphur was applied to all plots at 60 kg/ha in the 26th planting.

Soil samples were collected from each plot for 0 to 30 cm depth, mixed to give a plot sample and analysed at various times during the trial. Top growth vigour and colour were assessed visually during the 12th, 17th and 26th plantings by allocating a score to each plot. Scores have been converted to a 0 to 10 scale. The weight of top growth at harvest was recorded for the 17th, 26th, 30th and 31st plantings and number of tubers for the 17th, 30th and 31st plantings.

A fertilizer pot trial was conducted on soil collected prior to the 11th planting. Between the 12th and 17th plantings, five fertilizer pot trials were conducted in a shadehouse (D.A.S.F. 1965).

RESULTS

Soil analyses

Values of most parameters have declined with time, particularly between the 17th and 20th samplings. Exchangeable K has shown the greatest decrease (*Table 9*).

TABLE 8. — **Soil Exhaustion Trial. Details of fertilized plantings**

	11th planting	12th planting	17th planting	26th planting	30th planting	31st planting
Experimental design	½ replicate of $4^2 \times 2^3$ factorial in four blocks	½ replicate of $4^2 \times 2^3$ factorial in four blocks	¼ replicate of 4×2^6 factorial in four blocks	¼ replicate of $4^2 \times 2^4$ factorial in two blocks	4 x 4 factorial with four replicates	4 x 4 factorial with four replicates
Treatments	4N x 4P x 2Fe x 2Zn x 2Minors (Mn,Cu,B,Mo,Co)	4N x 4P x 2Fe x 2Zn x 2Minors (Mn,Cu,B,Mo,Co)	2N x 4P x 2K x 2Mg x 2Mn x 2Cu x 2Minors (Fe,Zn,B,Mo)	4N x 2P x 4K x 2Mg x 2Cu x 2Mn	4N x 4K	4N x 4K
Nutrient levels (kg element/ha) and form						
N	0,55,110,220 Urea	0,55,110,220 Urea	55,220 Urea	0,20,40,80 Urea	0,75,150,225 Urea	0,75,150,225 Urea
P	0,50,100,200 Superphosphate	0,50,100,200 Superphosphate	0,12,25,50 Superphosphate	0,20 Monosodium phosphate	—	—
K	—	—	0,90 Muriate of potash	0,41,83,166 Muriate of potash	0,125,250,375 Muriate of potash	0,125,250,375 Muriate of potash
Mg	—	—	0,22 Magnesium sulphate	0,30 Magnesium chloride	—	—
Fe	0,6 Ferrous sulphate	0,6 Ferrous sulphate	0,6 Ferrous sulphate	—	—	—
Zn	0,7 Zinc sulphate	0,7 Zinc sulphate	0,11 Zinc sulphate	—	—	—
Mn	0,6 Manganese sulphate	0,6 Manganese sulphate	0,6 Manganese sulphate	0,10 Manganese chloride	—	—
Cu	0,4 Cupric sulphate	0,4 Cupric sulphate	0,6 Cupric sulphate	0,10 Copper oxychloride	—	—
B	0,3 Boric acid	0.3 Boric acid	0,1 Boric acid	—	—	—
Mo	0,0.6 Ammonium molybdate	0,0.6 Ammonium molybdate	0,0.03 Sodium molybdate	—	—	—
Co	0,3 Cobalt sulphate	0,3 Cobalt sulphate	—	—	—	—
Variety	K1	K1	K1	K9	K9	K9
Between and within row spacing	1.2 m, 30 cm	1.2 m, 30 cm	1.2 m, 30 cm	90 cm, 30 cm	90 cm, 30 cm	90 cm, 30 cm
Planting density	81,000	81,000	81,000	72,000	37,000	37,000
Planting date	26/4/1960	24/11/1960	16/5/1964	22/11/1972	28/8/1974	10/2/1975

TABLE 9. — **Soil Exhaustion Trial. Soil analysis, 0 - 30 cm**

Parameter	1st sampling	13th sampling	17th sampling	20th sampling
Sampling date	early 1954	June, 1961	June, 1964	January, 1971
Planting	Prior to 1st planting	After 12th planting	Prior to fertilizer application, 17th planting	After 25th planting
Nitrogen %	.47	.47	.46	.21
Carbon %	4.9	4.4	4.3	1.9
C/N ratio	10.6	9.5	9.1	8.7
Olsen P p.p.m.	8.0	10.8	27.2	12.7
Exch. Ca m.e.%	17.5	16.8	15.7	8.9
Exch. Mg m.e.%	1.8	2.3	1.6	.8
Exch. K m.e.%	1.2	.6	.7	.3
Exch. Na m.e.%	—	.91	.46	.23
Cation Exchange Capac. m.e.%	19.9	20.3	21.5	12.1
pH	6.8	6.3	6.6	5.7
Specific conduct. mhos x 10^3	.083	.170	.239	.020
Total soluble salts %	—	—	—	.006
K/N ratio	2.5	1.4	1.6	1.4

TABLE 10. — **Soil Exhaustion Trial. Visual top growth vigour and colour assessments. Main effect means. Using a 0 - 10 scale with higher scores indicating greater vigour and colour. 12th, 17th, 26th plantings**

	Top growth vigour			Top growth colour	
Treatment	12th planting 10 weeks	17th planting 20 weeks	26th planting 7 weeks	17th planting 20 weeks	26th planting 7 weeks
N^0	1	6	6	8	5
N^1	5		7		6
N^2	6		8		8
N^4	10	9	9	10	9
P^0	6	8	7	9	7
P^1	6	8	8	8	7
P^2	5	8		9	
P^4	5	8		8	
K^0		8	7	9	7
K^1		8	8	9	8
K^2			8		7
K^4			7		7
Mg^0		8	8	9	7
Mg^1		8	7	9	7
Mn^0		8	8	9	7
Mn^1		8	7	9	7
Cu^0		8	7	8	7
Cu^1		8	8	9	7
$Minors^0$		7		9	
$Minors^1$		8		9	
Significant effects	N (0.001)	N (0.001)	N (0.001)	N (0.001)	N (0.001)

TABLE 11. — **Soil Exhaustion Trial. Weight top growth at harvest (kg/ha). Main effect means. 17th, 26th, 30th, 31st plantings**

Treatment	17th planting	26th planting	30th planting	31st planting
N^0		5,700 a	3,400 a	3,900
N^1	16,000 a	6,600 ab	5,100 b	6,000
N^2		7,500 b	5,200 b	5,600
$N^{3/4}$	24,000 b	9,900 c	7,200 c	6,700
P^0	21,100	7,300		
P^1	19,200	7,600		
P^2	20,400			
P^4	19,100			
K^0	19,300	7,600	5,400	6,100
K^1	20,600	8,100	5,300	5,300
K^2		7,500	5,200	5,800
$K^{3/4}$		6,500	5,000	5,100
Mg^0	20,500	7,200		
Mg^1	19,400	7,700		
Mn^0	19,700	7,500		
Mn^1	20,300	7,400		
Cu^0	19,300	7,400		
Cu^1	20,700	7,500		
$Minors^0$	18,900			
$Minors^1$	21,100			
Significant effects	N (0.001) NP (0.01) PK (0.05)	N (0.001)	N (0.001)	—
L.S.D. (0.05) 2 levels	2,900	1,000		
L.S.D. (0.05) 4 levels	4,100	1,400	1,200	2,000

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at $p = 0.05$.

TABLE 12.— **Number of tubers/ha. Main effect means. 17th, 30th, 31st plantings**

Treatment	17th planting	30th planting	31st planting
N^0		79,900	73,100
N^1	69,500 a	75,500	88,900
N^2		73,400	85,900
$N^{3/4}$	53,500 b	75,500	91,000
P^0	56,000 b		
P^1	68,300 a		
P^2	65,300 ab		
P^4	56,300 b		
K^0	56,300 a	60,600 a	75,700
K^1	66,600 b	78,500 b	82,400
K^2		76,400 b	86,300
K^3		88,700 b	94,400
Mg^0	63,400		
Mg^1	59,500		
Mn^0	62,000		
Mn^1	60,900		
Cu^0	62,000		
Cu^1	60,900		
$Minors^0$	59,500		
$Minors^1$	63,400		
Significant effects	N (0.001) P (0.05) K (0.01)	K (0.01)	—
L.S.D. (0.05) 2 levels	6,900		
L.S.D. (0.05) 4 levels	9,700	15,500	16,700

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at $p = 0.05$.

TABLE 13. — **Soil Exhaustion Trial. Total tuber yields (kg/ha). Main effect means for fertilized and subsequent plantings. Fertilizer applied at 11th and 12th plantings.**

Treatment	11th planting	12th planting	13th planting	14th planting	15th planting	16th planting
N^0	5,300 a	8,500 a	10,800	3,200	4700	1,500
N^1	4.900 a	7,100 b	9,300	3,000	4,400	1,600
N^2	4.600 a	6,500 b	9,400	3,300	4,200	1,600
N^4	3,300 b	5,300 c	9,500	3,300	4,900	1,700
P^0	4,300	7,200	10,400	3,700	5,600	1,800
P^1	4,400	6,500	9,300.	2,900	4,500	1,700
P^2	4,700	7,000	9,800	3,100	4,200	1,300
P^4	4,600	6,700	9,700	3,100	4,000	1,700
Fe^0	4,700	7,100	10,100	3,200	4,800	1,600
Fe^1	4,300	6,600	9,400	3,200	4,300	1,600
Zn^0	4,700	7,000	10,000	3,100	4,600	1,500
Zn^1	4,400	6,700	9,500	3,300	4,500	1,800
Minors^0	4,400	6,700	9,700	3,000	4,500	1,400
Minors^1	4,600	7,100	9,900	3,400	4,600	1,800
Significant effects	N (0.001)	N (0.001)	—	—	—	—
L.S.D. (0.05) N or P	900	1,200	1,300	800	1,200	700
L.S.D. (0.05) Fe, Zn or Minors	600	800	900	600	800	500

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at p = 0.05.

TABLE 14. — **Soil Exhaustion Trial. Total tuber yield (kg/ha). Main effect means for fertilized and subsequent plantings. Fertilizer applied at 17th planting.**

Treatment	17th planting	18th planting	19th planting	20th planting	21st planting
N^1	6,300 a	7,200	8,600	20,500	12,800 a
N^4	4,500 b	6,500	8,200	22,800	11,500 b
P^0	5,500	7800 a	10,200 a	23,500	13,200
P^1	5,900	7,300 a	8,400 b	20,800	11,600
P^2	5,500	6,600 ab	7,700 b	21,700	12,400
P^4	4,700	5,700 b	7,400 b	20,400	11,400
K^0	4,600 a	5,700 a	8,500	22,900	12,200
K^1	6,100 b	8,000 b	8,400	20,300	12,100
Mg^0	5,600	6,300 a	8,100	19,300 a	11,900
Mg^1	5,200	7,400 b	8,800	23,900 b	12,300
Mn^0	5,100	7,000	8,400	21,800	12,000
Mn^1	5,600	6,700	8,500	21,400	12,200
Cu^0	5,400	6,900	8,200	22,800	11,800
Cu^1	5,300	6,800	8,600	20,400	12,500
Minors^0	5,000	7300 a	8,600	22,700	12,400
Minors^1	5,700	6,300 b	8,300	20,500	11,800
Significant effects	N (0.001) K (0.001)	P (0.01) K (0.001) Mg (0.05) Minors (0.05)	P (0.01)	Mg (0.05)	N (0.05)
L.S.D. (0.05) N, K, Mg, Mn, Cu, Minors	700	800	1,100	4,500	1,200
L.S.D. (0.05) P	1,000	1,200	1,500	6,400	1,700

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at p = 0.05.

TABLE 15. — **Soil Exhaustion Trial. Total tuber yield (kg/ha). Main effect means for fertilized and subsequent plantings. Fertilizer applied at 26th planting.**

Treatment	26th planting	27th planting	28th planting	29th planting
N^0	8,300 a	4,800	5,500	2,200
N^1	9,900 b	4,400	5,300	2,200
N^2	11,500 c	4,300	4,900	2,200
N^4	14,900 d	4,700	4,900	2,100
P^0	11,000	4,600	5,500 a	2,300
P^1	11,300	4,500	4,800 b	2,100
K^0	8,700 a	4,000 a	4,400 a	2,000 a
K^1	11,500 b	4,200 a	5,100 ab	2,100 a
K^2	11,900 b	4,600 a	5,500 b	2,100 a
K^4	12,500 b	5,400 b	5,700 b	2,600 b
Mg^0	11,100	4,600	5,100	2,200
Mg^1	11,200	4,500	5,300	2,100
Mn^0	11,500	4,600	5,100	2,200
Mn^1	10,800	4,500	5,200	2,100
Cu^0	11,000	4,500	5,200	2,200
Cu^1	11,300	4,600	5,200	2,100
Significant effects	N (0.001) K (0.001)	K (0.01)	P (0.05) K (0.01)	K (0.05)
L.S.D. (0.05) N or K	1,600	700	800	400
L.S.D. (0.05) P, Mg, Mn or Cu	1,100	500	600	300

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at p = 0.05.

TABLE 16. — **Soil Exhaustion Trial. Total tuber yield (kg/ha). Main effect means for fertilized and subsequent plantings. Fertilizer applied at 30th and 31st plantings.**

Treatment	30th planting	31st planting	32nd planting	33rd planting
N^0	5,900 a	4,400 a	6,600	2,100 a
N^1	7,900 b	7,000 bc	6,500	2,000 a
N^2	8,200 b	5,500 ab	6,700	2,200 a
N^3	10,300 c	7,700 c	7,900	2,700 b
K^0	6,200 a	5,100 a	4,700 a	1,700 a
K^1	7,700 a	5,200 a	6,600 b	2,200 b
K^2	8,100 a	7,000 b	8,000 c	2,400 bc
K^3	10,300 b	7,400 b	8,400 c	2,700 c
Significant effects	N (0.001) K (0.01)	N (0.001) K(0.05)	K (0.001)	N (0.01) K (0.001) NK (0.05)
L.S.D. (0.05)	2,000	1,700	1,300	400

For significant treatments, values in columns for each nutrient followed by the same letter are not significantly different at p = 0.05.

Values of a number of parameters were influenced by previous fertilizer application. The most significant was soil P which increased as a result of phosphate fertilizer applications applied prior to the 13th, 17th and 20th samplings. Soil pH was significantly lower in high N plots in the 13th and 20th samplings; Mg was significantly higher in Mg^1 plots and the C/N ratio was significantly lower in the Cu^1 plots in the 20th sampling.

Pot trials

The only significant effect in the pot trial conducted before the 11th planting was a response to P (Newton and Jamieson 1968). In the five pot trials conducted between the 12th and 17th plantings, top growth responded to N, P, K, Mg and Mn. Doubtful responses to copper and calcium also occurred (D.A.S.F. 1965).

Top growth

Nitrogen improved top growth vigour and colour in all six fertilized plantings (*Table 10*) and increased the weight of top growth at harvest in the four plantings where this was measured (*Table 11*) (see *Plate 3*). In the 12th and 17th plantings large responses to N were recorded in the visual assessments just prior to harvest.

Phosphorus improved top growth vigour to some degree early in the crop in the 11th planting. In the 17th planting it decreased the weight of top growth at N^1, but increased it at N^4.

Number of tubers

Nitrogen significantly depressed tuber number in the 17th planting. However, at the 31st planting there was a trend towards tuber number increasing with increasing N. Potassium increased tuber number at all plantings. The effect of P on tuber number was tested only in the 17th planting where it caused a significant increase at the P^1 and P^2 levels but not at P^4 (*Table 12*).

Total tuber yield

Nitrogen significantly depressed tuber yield in the 11th, 12th and 17th plantings, but increased it in the 26th, 30th and 31st plantings (*Tables 13, 14, 15, 16*). Potassium increased the total tuber yield in all four plantings where it was tested (*Tables 14, 15, 16*). A positive NK interaction occurred in the 26th and 30th plantings, responses to both N and K being greater when both were supplied together than when one was supplied without the other.

Total tuber yields for all plantings were plotted against time (*Figure 1*). Where significant responses to applied or residual fertilizer occurred, the yield plotted is that of the control plots (for example N^0K^0 for the 26th planting). Yields declined rapidly from an initial level of 27 t/ha to 4 t/ha by the 10th planting. Following fertilization applied after the 10th,

Plate 3. — A large top growth response to nitrogen in the 30th planting of the Soil Exhaustion Trial. Growth is poor in the N^0 plot in the foreground, the soil surface is exposed and leaves are yellow-green in colour. In the N^3 plot behind the figure, growth is lush and leaves are dark green

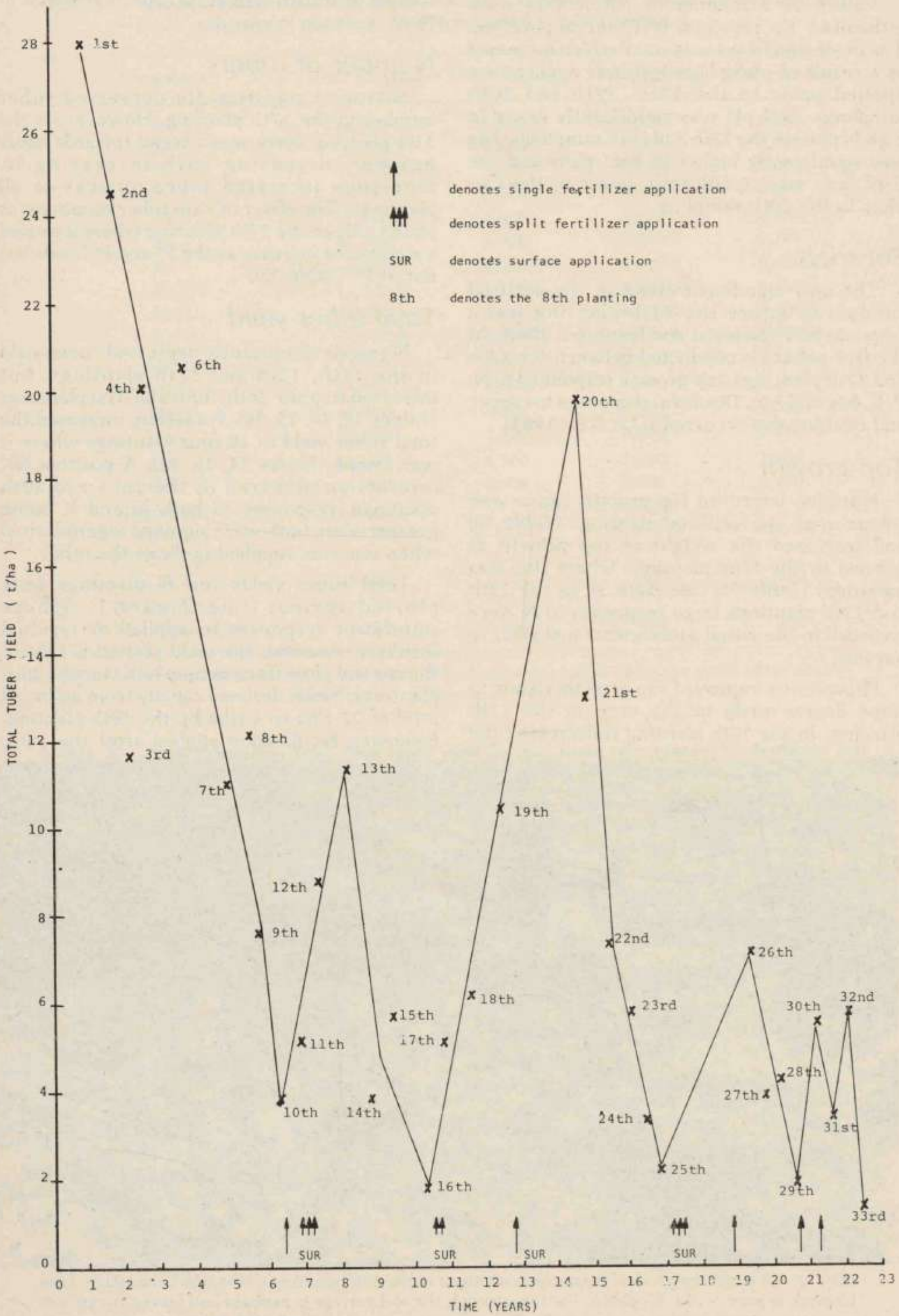

Figure 1. — Soil Exhaustion Trial Total tuber yield (or control yield) v. time

11th, 16th, 19th, 25th and 29th plantings, yields rose initially and then declined until the next fertilizer application.

Residual effects

Yields of plantings following fertilized ones indicated residual effects of applied fertilizer. A small but significant yield depression from residual N occurred in the 21st planting (*Table 14*) and there was a significant yield increase in the 33rd planting (*Table 16*). Yield depressions from residual P occurred in most plantings and the effect attained significance in the 18th, 19th and 28th plantings (*Tables 14, 15*).

Residual K significantly increased yields in the 18th, 27th, 28th, 29th, 32nd and 33rd plantings (*Tables 14, 15, 16*). Residual Mg significantly improved yields in the 18th and 20th plantings; and minors (Fe, Zn, B, Mo) apparently depressed yields in the 18th planting (*Table 14*).

III ROTATION TRIAL

The Keravat Rotation Trial was laid down in 1954 adjacent to the Soil Exhaustion Trial to study the effects of rotational cropping on crop yields and soil fertility (Newton and Jamieson 1968). Basically the trial consists of seven rotations which compare continuous cropping of food crops with a rotation of food crops and leguminous cover crops. In 1973 the trial was modified and fertilizers were used in certain rotations. Here the results of four fertilized plantings of sweet potato are presented. A full description of the trial up to 1973 is given by Bourke (in press).

MATERIALS AND METHODS

The trial includes seven rotational treatments, each with a different sequence of six plantings (*Table 17*). Each complete sequence of six plantings is termed a cycle and takes 3-3½ years to complete. There are 63 plots in the trial consisting of 7 treatments x 3 replicates in space x 3 replicates in time.

Rotations that include a leguminous fallow are termed wide rotations (rotations 1, 2, 6, 7) and those with no fallow or a short fallow are termed narrow rotations (rotations 3, 4, 5). Plot size is 9 m square. Sweet potato ridges are 1.2 m apart; there is one row per ridge; and within row spacing is 30 cm. Two cuttings of variety K9 are planted per position giving a planting density of 56,000 plants/ha. Guard rows are employed.

Sweet potato is fertilized in rotations 1, 4 and 6. Corresponding unfertilized rotations are 2, 5 and 7 respectively (*Table 17*). Thus rotation 1 should be compared with rotation 2; rotation 4 with rotation 5; and rotation 6 with rotation 7. Fertilizer rates varied from planting to planting (*Table 18*). Ammonium sulphate provided N in the first two plantings. Urea was used in the second two. Superphosphate and muriate of potash were the other fertilizers used. The fertilizer was applied to the soil surface in rows and the ridges built over it.

Vigour and colour of top growth were assessed visually in three of the plantings. At harvest tubers were classified as saleable or unsaleable on the basis of size. Those over 140 g were considered saleable. Soil samples were collected before and during the trial to a depth of 30 cm. The first sampling was done prior to 1st planting, 1st cycle (January, 1954) and the 11th was taken prior to 3rd planting, 6th cycle (March, 1973), prior to fertilizer being used in the trial.

RESULTS

Soil analyses indicate that the levels of most nutrients declined greatly between the 1st and 11th samplings (*Table 19*). The decline was greatest for K and Mg. The C/N ratio altered little with cropping, but the K/N ratio dropped considerably. Fertility was reduced more in the narrow rotations than in the wide rotations.

In the 3rd planting 6th cycle, where the N level was only 20 kg/ha, fertilizer had little effect on top growth vigour and colour (*Table 20*). By contrast, fertilizer significantly improved both top growth vigour and colour for all comparisons for the other two plantings where this was assessed (*Table 20*).

Significant differences in saleable tuber yield occurred between rotations for all four plantings (*Table 21*). For 9 of the 12 comparisons, significant responses to fertilizer occurred and for a further 2 comparisons, large, but not significant, responses were recorded. Yield responses in the narrow rotations were particularly large. In the 5th planting 6th cycle, fertilizer increased yield in the narrow rotations from 2.8 to 12.5 t/ha.

DISCUSSION

Large, significant responses to fertilizer occurred in most trials or plantings reported here. Small, negative or no responses occurred in others. The most important plant nutrients will be discussed individually.

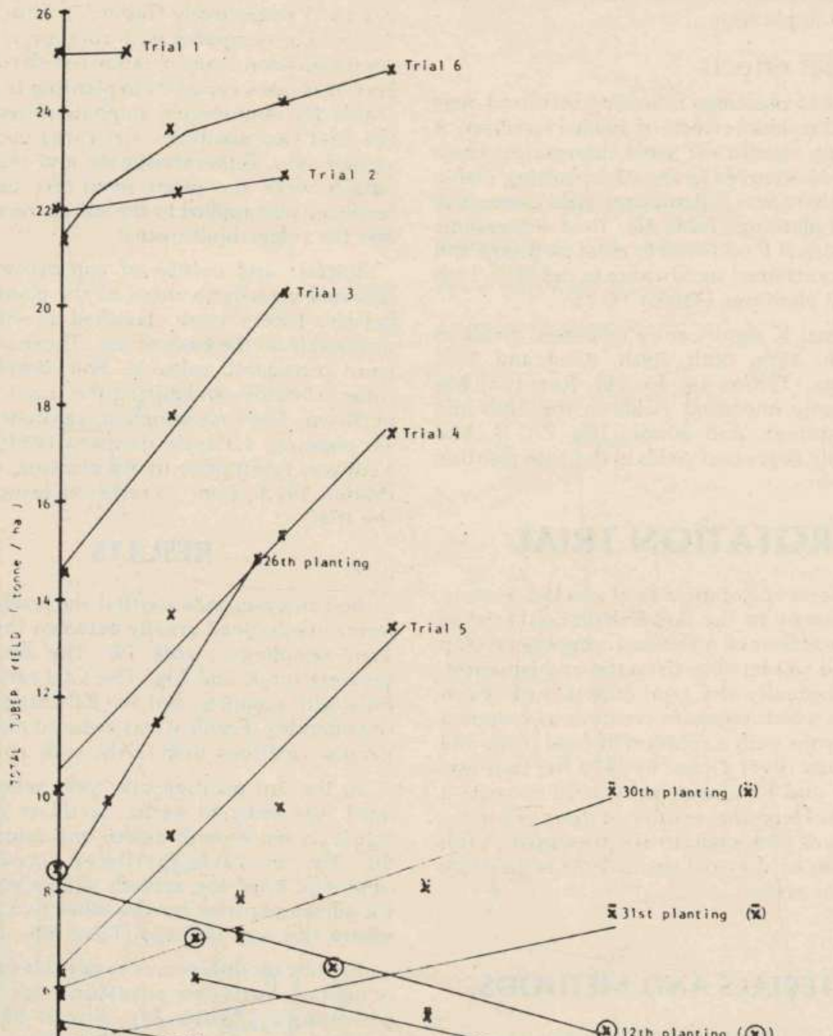

Figure 2. — General Trials and Soil Exhaustion Trial. Total tuber yield (kg/ha) v. nitrogen level

TABLE 17. — **Rotation Trial. Plan of rotations**

Planting	Rotation number and type						
	1 Wide	2 Wide	3 Narrow	4 Narrow	5 Narrow	6 Wide	7 Wide
1	SP*	SP	SP	SP*	SP	SP*	SP
2	So*	So	So	So*	So	So*	So
3	Pe*	Pe	CP	Pe*	Pe	Pe*	Pe
4	M	M	To	To*	To	Pu	Pu
5	M	M	To	To*	To	Pu	Pu
6	M	M	CP	Ma*	Ma	Pu	Pu

SP	Sweet potato	*Ipomoea batatas*	* Fertilized crop
So	Sorghum	*Sorghum vulgare*	
Pe	Peanuts	*Arachis hypogaea*	
M	Mimosa	*Mimosa invisa*	
CP	Cowpea	*Vigna unguiculata*	
To	Taro	*Colocasia esculenta*	
Ma	Maize	*Zea mays*	
Pu	Pueraria	*Pueraria phaseoloides*	

TABLE 18. — **Rotation Trial. Details of fertilized plantings**

Planting	Cycle	Rotation type	Nutrient level (kg/ha) N	P	K	Planting date
3	6	Wide	20	13	65	23/3/1973
3	6	Narrow	20	13	65	23/3/1973
5	6	Wide	90	50	240	26/2/1974
5	6	Narrow	130	60	260	26/2/1974
1	7	Wide	90	0	180	21/1/1975
1	7	Narrow	130	0	260	21/1/1975
3	7	Wide	130	0	260	9/10/1975
3	7	Narrow	130	0	260	9/10/1975

Nitrogen

The effect of N on top growth is very clear. In almost every trial or planting where top growth vigour or colour was assessed or the weight recorded at harvest, N gave increased top growth. The effect of N on tuber number is not clear.

Nitrogen gave the greatest yield increases in both the general trials and the Soil Exhaustion Trial. A plot of total tuber yield against N level for the 12 trials or plantings where N was tested shows good agreement between the various groups of trials or plantings (*Figure 2*).

Where the control yields are high (Trials 1, 2, 6), responses are negligible or small. Yield responses at the grassland sites (Trials 3, 4, 5) are especially pronounced and the slope of the response line is similar for the three sites. In the three plantings of the Soil Exhaustion Trial where variety K1 was used (11th, 12th, 17th plantings), the negative response is similar. Only for the three plantings where variety K9 was used (26th, 30th, 31st plantings) are the slopes of the response lines markedly different.

Nitrogen is clearly required in both grassland sites and also in former forested areas where soil fertility has been reduced by cropping. For both grassland areas and the Soil Exhaustion Trial site, N levels could go higher than those used (*Figure 2*). In grassland areas the requirement for N fertilizer could be reduced by either a fallow between burning and planting to allow mineralization of soil N or opening the rotation with another crop such as peanuts. The results from grassland sites are similar to those obtained in grasslands on

TABLE 19. — **Rotation Trial. Soil Analysis, 0 - 30 cm**

Parameter	Rotations 1, 2		Rotations 3, 4, 5		Rotations 6, 7	
	1st sampling	11th sampling	1st sampling	11th sampling	1st sampling	11th sampling
Nitrogen %	.57	.31	.58	.23	.59	.29
Carbon %	6.0	3.0	6.2	2.4	5.9	3.0
C/N ratio	10.6	9.9	10.7	10.7	9.8	10.2
Olsen P p.p.m.	3	9	4	9	5	8
Exch. Ca m.e.%	18.3	9.0	16.0	7.0	21.2	8.7
Exch. Mg m.e.%	2.3	.87	2.5	.65	2.7	.93
Exch. K m.e.%	1.2	.4	1.1	.2	1.4	.4
Exch. Na m.e.%	—	.56	—	.53	—	.54
Cation exch. cap. m.e.%	24.8	12.1	24.4	9.4	26.9	11.6
pH	6.5	5.7	6.4	5.7	6.6	5.7
Spec. conduc. mhos x 10^3	.121	—	.115	—	.128	—
Total soluble salts %	—	.017	—	.011	—	.018
K/N ratio	2.2	1.3	2.0	1.0	2.4	1.3

TABLE 20. — **Rotation Trial. Visual top growth vigour and colour assessments on a 0 - 10 scale with higher scores indicating greater vigour and colour.**

Rotation number and type	Top growth vigour			Top growth colour		
	3rd planting 6th cycle 17 weeks	5th planting 6th cycle 7 weeks	3rd planting 7th cycle 16 weeks	3rd planting 6th cycle 17 weeks	5th planting 6th cycle 7 weeks	3rd planting 7th cycle 16 weeks
1 Wide, fertilized	8	9	8	7	9	8
2 Wide	8	7	6	8	7	6
4 Narrow, fertilized	6	9	6	5	9	6
5 Narrow	4	4	4	6	5	4
6 Wide, fertilized	9	10	9	9	9	8
7 Wide	8	8	7	8	8	7
Level of significance (fertilized v. unfertilized rotations)	N.S.	0.001	0.05	N.S.	0.001	0.01

TABLE 21. — **Rotation Trial. Yield saleable tubers (kg/ha)**

Rotation	Rotation type	3rd planting 6th cycle	5th planting 6th cycle	1st planting 7th cycle	3rd planting 7th cycle
1	Wide fertilized	9,000 b	14,900 ab	9,300 a	9,100 b
2	Wide	5,000 cd	10,500 c	5,200 b	6,600 bc
4	Narrow fertilized	6,100 c	12,500 bc	3,400 b	9,100 b
5	Narrow	2,800 d	2,800 d	3,000 b	2,000 c
6	Wide fertilized	12,600 a	16,900 a	9,200 a	14,700 a
7	Wide	9,200 b	13,600 abc	5,300 b	8,900 b
Level of significance		0.001	0.001	0.001	0.01
L.S.D. (0.05)		2,700	3,400	2,700	4,800

Values in columns followed by the same letter are not significantly different at $p = 0.05$.

Guadalcanal Island in the Solomon Islands (L.D.C. Chase pers. comm.). There 50 kg N/ha applied as urea gave 4 t/ha yield increase in the first two plantings of sweet potato in a soil exhaustion trial.

In the Soil Exhaustion Trial, all significant responses to applied or residual N were negative up to the 21st planting, but after this planting all significant responses were positive, irrespective of potassium levels. The change from variety K1 to K9 was made about the 22nd planting. K1 has a greater leaf area under low N conditions than K9. It is suggested that the different variety used accounts for the reversal of the N response.

Tsunoda (1959) designated varieties of sweet potato as adapted to high, low or medium optimum levels of fertilization. He reported that varieties adapted to light fertilization tend to have a larger leaf area per plant than those adapted to heavy fertilization, at least during earlier growth. In Trinidad a variety with low leaf area and one with high leaf area were compared under low and high N Conditions (Haynes *et al.* 1969). The low leaf area variety produced low yield without nitrogen, and high yield with nitrogen fertilizer. By contrast the high leaf area variety under high N conditions produced excessive leaf area and a low tuber yield when harvested at four months. Haynes *et al.* (1969) suggest the possibility of higher ultimate yield from the high leaf area variety under high N fertilization provided harvest is delayed beyond four months.

Reports of yield reductions in fertilized sweet potato crops have been received from local farmers from time to time. It is likely that varieties adapted to low N conditions were used in these cases.

Newton and Jamieson (1968) suggested that the negative response to N in the 11th and 12th plantings of the Soil Exhaustion Trial may have been associated with omission of potassium and magnesium from the treatments. This hypothesis is not supported by later plantings where variety K9 was used and responses to N were always positive, even in the absence of potassium or magnesium. However, in the 17th planting the deleterious effects of N on yield were greater at K^0 then at K^1, suggesting that potash can reduce the negative effect of N to some degree.

In the 12th and 17th plantings nitrogen was applied as late as 7 and 8 weeks before harvest respectively. The large top growth responses to N recorded just prior to harvest suggest that nitrogen continued to promote top growth at the expense of tuber development right up to harvest.

The lack of any significant relationship between N levels and tuber cracking in Trials 4, 5 and 6 contrasts with the results of Lutz *et al.* (1949) who found that high nitrogen levels and lime increased tuber cracking. It also differs from Nusbaum (1947) who reported that growth cracking was most severe with low P and high N fertilizer mixes and increased in proportion to the rate of applied borax. De Geus (1973) states that an excess of N may result in cracking of tubers.

Phosphorus

Phosphate had little effect on top growth, although it did improve vigour and colour in a number of crops. The significant interaction of nitrogen and phosphorus on top growth weight at harvest in the 17th planting is puzzling. Phosphate fertilizer has had little effect on yield and a significant yield increase over the control occurred in Trial 2 only.

The apparent yield depression from residual superphosphate that occurred in most plantings of the Soil Exhaustion Trial appears to be a real effect. It may be that Ca applied in superphosphate and sodium in monosodium phosphate was antagonistic to K or Mg.

Potassium

Soil potassium levels in this soil are initially high but they decline rapidly with intensive cropping with root crops. Potash fertilizer did not significantly affect top growth in any trial. It increased tuber number in all three plantings of the Soil Exhausion Trial where this variable was measured. At two of the former forest sites where yield levels were high (Trials 2 and 6), no yield response to K occurred. However, in the Soil Exhaustion Trial, K increased tuber yield in the four plantings where it was included. It is obviously required in former forest sites where soil fertility has been reduced. Results from the Soil Exhaustion Trial indicate that, where K deficiency has developed, applied K may carry over a residual effect into succeeding crops.

No clear indication of a requirement for potash was shown at the grassland sites. In Africa, responses to K occur after the first or second year of cropping following a forest fallow, particularly with root crops, but responses to K in the savanna have been disappointing (Nye 1966). A similar situation appears to exist on the Gazelle Peninsula.

Other nutrients

No responses to nutrients other than N, P or K were recorded in field trials except to residual Mg in the 18th and 20th plantings. The indications from the pot trials that magnesium and manganese are required on intensively cropped soil should be borne in mind. No indication of a sulphur requirement was obtained and S free fertilizers such as urea should be satisfactory.

Non-factorial trials

The small response in Trial 7 was unexpected and disappointing. The saleable yield on the control treatment was a fraction of the yield that could have been expected under fertile soil conditions for this variety. The variety used, V2, may not respond to fertilizer. For the wide rotations in the Rotation Trial, responses were about 4 t/ha for all four plantings. This suggests that there has not been a further response to the higher N and K levels used in some of the plantings. It is likely that one or more other nutrients are limiting the response, most likely Mg.

Relationship between responses and control yields

The total tuber yield increase from fertilizer was plotted against the control yield for each general trial, planting of the Soil Exhaustion Trial or comparison in the Rotation Trial (*Figure 3*). The two were found to be related by the following equation:

$$Y = 7.975 - .28x \qquad r = .54^{**}$$

where Y = yield increase from fertilizer (t/ha); x = yield of control treatment (no fertilizer) (t/ha); and r = correlation coefficient, significant at $p = 0.01$.

It can be seen that yield increases from fertilizer tend to decrease as the control yields (soil fertility) increase. Because this equation is derived from trials using different nutrients and rates of those nutrients, no further deductions can be made from it.

Proportion of saleable tubers

Fertilizer increased the proportion of saleable tubers in all general trials and comparisons in the Rotation Trial where a yield response occurred. It is thus important to record the yield of saleable tubers as well as total tuber yield, so as not to underestimate the magnitude of the fertilizer response.

Fertilizer placement

No comparisons were made within trials to evaluate fertilizer placement but the different methods used in various trials have given some indications of the effect of this.

Despite the fact that the site for Trial 1 was considered "exhausted", the average yield for the trial of 25.2 t/ha was one of the best yields ever recorded for this variety. It is suggested that a small quantity of N was washed over all plots and caused an overall yield increase. Further evidence for the movement of fertilizer between plots comes from the Soil Exhaustion Trial where average control yields rose following fertilizer application (*Figure 1*). Following heavy showers of rain, a lot of water moves between plots in this trial and it appears that fertilizer is moved between plots, even when placed under the ridges.

Mixing fertilizer and soil during ridging or mounding may result in more efficient fertilizer use. Fertilizer may have been inadequately mixed in the 30th and 31st planting as responses were less than in the 26th planting (*Figure 2*).

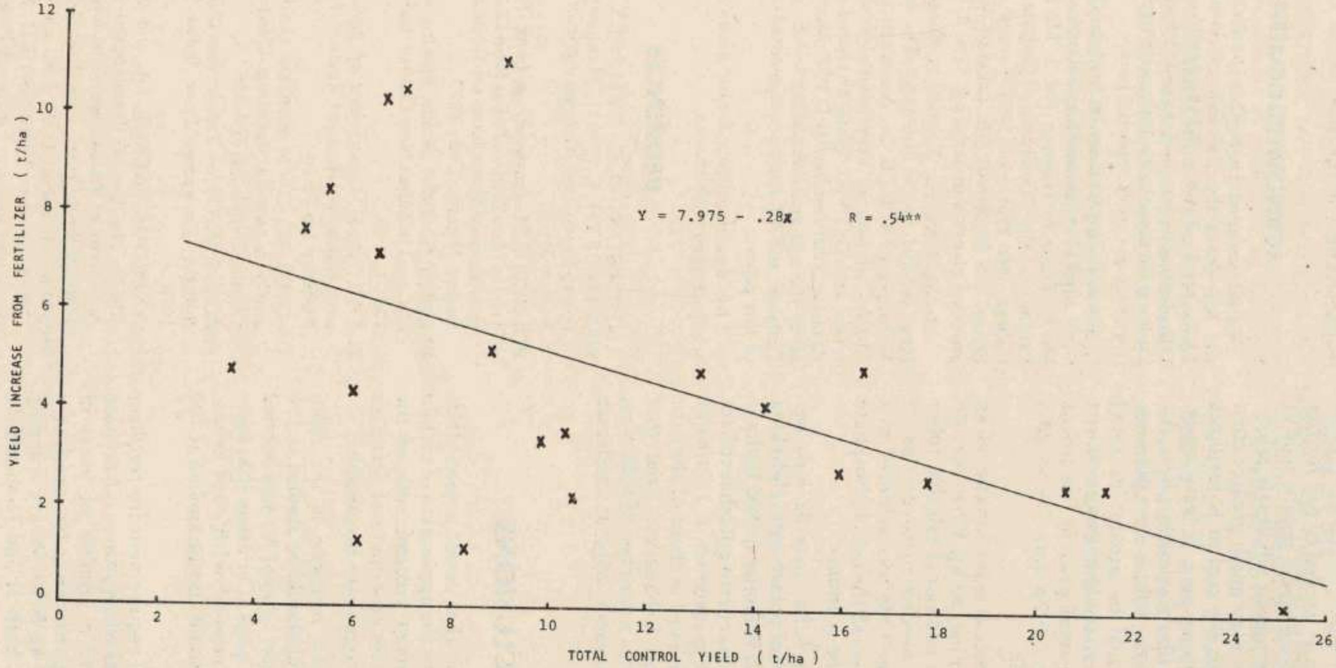

Figure 3 — All trials. Total tuber yield increase from fertilizer v. total control yield

Economics of fertilizer use

With urea at nine kina per 50 kg bag, fertilizer containing 100 kg of nitrogen per hectare costs 40 kina per hectare. A yield response of 600 kg/ha is needed to pay for the cost of N fertilizer when sweet potato sells at 6.5 toea/kg (the government wholesale price). Responses to N were very much greater than this and in most trials the cost of N fertilizer was returned many times over. If fertilization resulted in an extra 4 t/ha of saleable tubers, the value/cost ratio on 100 kg N/ha is 6.5:1. Returns from retail sales would be greater as retail prices are higher than the government wholesale price. The retail price in five towns for the June quarter, 1976 was 7.3 to 23.4 toea/kg (Fergie, 1976).

With superphosphate at seven kina per 50 kg bag, fertilizer containing 50 kg P/ha costs 80 kina per hectare. An additional saleable tuber yield of 1.2 t/ha is needed to cover this. A response of this magnitude was achieved in a few trials only, and overall the use of phosphate fertilizer would not be economic.

Potash at 100 kg K/ha costs 32 kina per hectare when muriate of potash costs eight kina per 50 kg bag. A yield response of 500 kg/ha is sufficient to recover the cost of potash fertilizer at 100 kg K/ha. A yield response of 1.5 t/ha or greater to K^1 was achieved in three of the four plantings of the Soil Exhaustion Trial that evaluated K, as well as a number of following crops. Potash is economic only at moderate rates.

CONCLUSIONS

It has been shown that sweet potato yields are very responsive to the application of certain nutrients on the recent volcanic soils of the Gazelle Peninsula. The economics of fertilizer use, particularly nitrogen, are favourable.

In grassland areas, nitrogen is the main nutrient required and should be applied at 150 kg N/ha as urea. Higher rates of N could be tried on an experimental basis. On areas that have been intensively cropped with root crops, muriate of potash should also be applied at 100 kg K/ha.

There is no initial requirement for fertilizer in former forest areas when an area is first used after a fallow. After a number of years of cropping, N can profitably be used at a moderate rate of 50 kg N/ha. Where cropping has been intensive, both N and K should be applied at a rate of 100 kg/ha.

Fertilizer should be incorporated into the soil prior to planting. Nitrogen should not be applied late in the life of a crop. Fertilizer should be applied cautiously to varieties whose responsiveness to fertilizer is not known.

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THE CARDAMOM MIRID (*RAGWELELLUS HORVATHI*) POPPIUS (HETEROPTERA : MIRIDAE) IN PAPUA NEW GUINEA

E.S.C. Smith *

ABSTRACT

The mirid Ragwelellus horvathi *Poppius is potentially a serious pest of cultivated cardamoms in Papua New Guinea. In this paper information on the distribution, life-history and biology, native hosts and nature of damage is presented.*

Control of R. horvathi *by chemical and cultural methods is also briefly discussed.*

INTRODUCTION

The mirid *Ragwelellus horvathi* was first described from specimens collected early this century in the Morobe and Madang Provinces (Poppius 1912), but further specimens were not collected in Papua New Guinea until 1969, when cultivated cardamoms (*Elettaria cardamomum* (L.) Maton: Fam. Zingiberaceae) at Karimui, Chimbu Province were attacked. Several years later, adults and immature stages of this insect were observed feeding on cardamoms at Trauna Valley Farm, and on wild gingers (Fam. Zingiberaceae) at Baiyer River, both in the Western Highlands Province. More recently, *R. horvathi* has been collected from cardamoms or wild gingers growing at Kokoda, Northern Province, Brown River, Central Province and Bubia, Morobe Province. The insect is therefore widely distributed on the mainland of Papua New Guinea, at elevations from sea-level to at least 1,100 m.

At Afore, Northern Province, mirid damage to young cardamom leaves was first noticed in late 1971, but not until the dry season in mid 1973 did the damage levels cause concern. Attack occurred both on village small holder blocks and to plants on the one expatriate-owned plantation in the Sila-Afore area.

Cardamom is a new crop to Papua New Guinea and is not grown extensively at present, but conditions in certain areas appear to be ideal for the cultivation of this labour-intensive, high value crop (Brown 1968). Further notes on the cultivation and production of cardamoms by growers under Papua New Guinea village conditions have been published by Breay (1972) and Grant (1976).

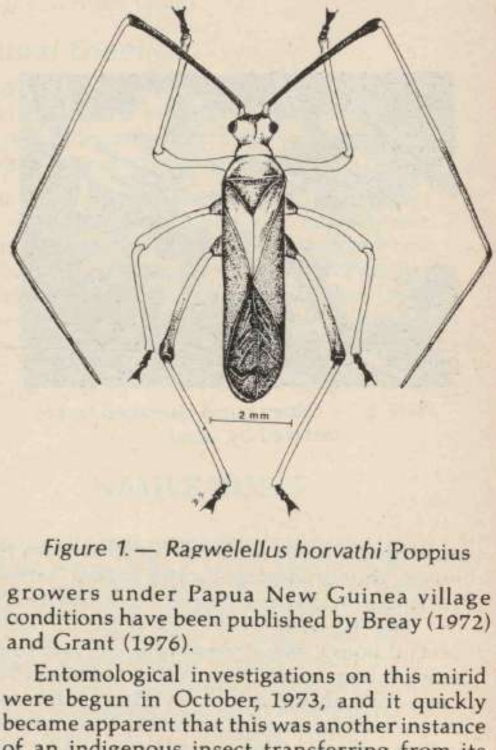

Figure 1. — Ragwelellus horvathi Poppius

Entomological investigations on this mirid were begun in October, 1973, and it quickly became apparent that this was another instance of an indigenous insect transferring from its native hosts to an introduced crop plant.

PLANT DAMAGE

On cardamoms, all life history stages of *R. horvathi* feed on young leaf blade tissue between the lateral veins, on leaves at the fully furled to the fully expanded stages. Leaf tissue unfolded for more than about three weeks is rarely attacked. The insects insert their stylet

* Senior Entomologist, Highlands Agricultural Experiment Station, Aiyura, Eastern Highlands Province.

Plate 1. — *R. horvathi* feeding damage on young cardamom leaves

Plate 2. — Older mirid damaged leaves tattered by wind.

mouthparts to draw up cell contents from the leaves, thus producing a water soaked "streak" varying in width and length, from two to five cm long between the veins (*Plate 1*). After several hours, the affected cells die, and some one or two weeks later, clear "windows" or holes form in the leaf blade (*Plate 2*). In some cases, feeding on the unfurled shoot causes leaves which subsequently expand to be malformed and reduced in area. Older leaves which have been severely attacked are often badly tattered by wind and have little photosynthetic area remaining.

Some newly planted cardamom splits can be very badly damaged, with up to an estimated 70% of the leaf area damaged or destroyed. This reduction in leaf area could severely retard growth and reduce subsequent crop yield, especially on young cardamoms.

BIONOMICS OF *R. HORVATHI*

The following data were compiled from insects caged over potted cardamom plants placed outside, in the shade, at Popondetta, Northern Province, and from field studies at Afore.

Life History

Female insects inserted eggs singly into the proximal half of the mid rib on a recently expanded or almost expanded new leaf. Generally only two to three eggs were laid in each leaf, with the egg being inserted between the epiderm and mesoderm layers, and lying roughly parallel to the surfaces. Two very fine chorionic processes which protruded from the epidermal tissue were probably used in gaseous exchange.

The first instars began feeding on the soft leaf blades, usually on a more recently expanded leaf than that in which the egg was laid, within a few hours of hatching from the egg. Five nymphal stadia were passed before the immature nymphs moulted to the adult insect. During this nymphal period, the insects migrated upwards to feed on newer, softer leaf tissue. The durations in days of the various stages at Popondetta were as follows:

Stage	Mean Duration (days)	Range (days)
Egg	20.9	18-24
1st instar	4.5	3-6
2nd instar	3.5	2-4
3rd instar	4.7	4-6
4th instar	3.8	3-5
5th instar	6.4	6-7
Total Nymphal	20.3	19-22

These durations may be increased in other areas at higher elevations where cardamoms are normally grown, and which experience generally cooler temperatures.

The total generation time at Popondetta was about 50 days, of which the egg stage lasted 21, nymphal stages about 21 and the pre-oviposition period was from 6 to 8 days (3 to 5 days for females to attain sexual maturity and 3 days between mating and oviposition).

Adults (*Figure 1*) survived at least eight weeks, and females probably laid 60 to 70 eggs during their life span, at a rate of 12 to 14 per week, decreasing with age. Mating occured at most times of the day with copulation lasting up to four hours. Female *R. horvathi* probably produce a pheromone which attracts males for mating, since most pairs observed copulating in the field were accompanied by one or more other males of the species.

In the field the insects were quite mobile, and readily took to flight (adults) or moved to escape detection, either by movement around a leaf, escape down the plant stem or by adoption of a cryptic attitude, usually in the slightly hollowed mid rib of the upper surface of the leaf.

Plant Infestation Rate

Insect infestation rates were determined by counting nymphs and adults present on the unfurled shoot and the five youngest expanded leaves of each stem on a series of plant clumps. Recording was carried out in seven different blocks at six to seven weekly intervals between October, 1973 and December, 1975.

In the Sila-Afore area, infestation of cardamom blocks was widespread, and in contiguous blocks the number of insects per plant stem was extremely uniform. This phenomenon explained why the younger clumps, although with fewer stems and consequently lower absolute numbers of mirids, suffered greater damage than the older clumps. In the latter plants, stems may have been three times the length of those in young clumps, and supported five to ten times the leaf area. Thus, the percentage of "susceptible" leaf tissue (i.e. leaves unfolded for less than three weeks) was much less in these clumps than in the large, vigorously growing clumps which had been planted out for more than 18 months.

In the field, it appeared that of the two varieties grown in the area, Mysore was less infested by the mirid than the Malabar variety. However, when the data was statistically analysed (N = 26), no difference in infestation rate was evident.

Population Levels

Data collected from the various blocks mentioned above, have indicated that insect populations fluctuated seasonally, with maximum numbers occuring in the dry season and lower numbers during the wetter periods of the year. These fluctuations were most probably caused by the growth habit of the host plants which were affected by weather conditions, and in particular by rainfall. Flush growth in cardamoms was greatest during dry spells after a period of wet weather.

Absolute numbers found during the year on mature, producing cardamom plants ranged from about 2,000 to about 30,000 mirids per hectare.

Other Factors Affecting Population Levels

From observations at Afore, it has been concluded that where the crop is grown under ideal conditions (thinned primary bush, deep leaf litter, well drained soil, etc.), the intensity of shade probably has little effect on mirid population levels. Similarly, the type of shade would appear to have no effect on populations. No differences in insect attack could be detected in cardamoms growing under thinned primary bush or thinned secondary bush shade, and some feeding damage to wild ginger was noted in very exposed areas at the edge of secondary bush. In addition, the observations revealed no differences in the susceptibility to attack between the two varieties grown in the area or between plants of different ages (several months to three years).

Natural Enemies

Mirids as a group are relatively free from attack by specific predators or parasites. Thus the possibilities for effective biocontrol of *R. horvathi* appear to be remote.

As yet, no parasites have been discovered and the level of predation also appears low, probably exerting little influence on population levels. Only two predators, a reduviid, *Euagorus* sp., and an unidentified salticid spider have been observed actually preying on the mirid, but it is likely that other general predators collected from cardamom foliage do, in fact, prey on *R. horvathi*.

NATIVE HOSTS

The insect pest would appear to have a range of host plants which occur widely in both primary and secondary bush. In primary forest surrounding badly damaged village cardamom plantings, four species of wild ginger were found on which feeding damage similar to that on cardamoms was noted. Nymphs, adult mirids and fresh feeding damage were found on two of these species. Similarly, fresh feeding damage and mirids were observed on two species of plants belonging to the family Commelinaceae and probable feeding damage was noticed on leaves of *Heliconia indica*, a commonly occurring bush species. It is likely (Henty and Womersley, pers. comm.) that *R. horvathi* feeds on *Heliconia indica* and other as yet unidentified plant species.

The host plants which have so far been identified are:

Alpinia purpurata (Vieilla) K. Shun.	(Fam. Zingiberaceae)
Alpinia sp.	(Fam. Zingiberaceae)
Elettaria cardamomum (L.) Maton	(Fam. Zingiberaceae)
Hedychium coronarium Koen.	(Fam. Zingiberaceae)
Aneilema humile Warb.	(Fam. Commelinaceae)
Pollia thyrsifolia (Bl.) Stewd.	(Fam. Commelinaceae)
Heliconia indica Lamk.	(Fam. Musaceae)

. INSECT CONTROL

Large, vigorously growing clumps planted in the field for more than 18 months generally appear to absorb insect attack to the leaves without serious setback. Insect control should therefore be mainly directed to protect younger plants. Mirid control is relatively easy and effective if the procedures outlined below are followed.

Village Blocks

All alternate host plants growing in the immediate vicinity of the cardamom block should be removed.

Growers should inspect the three or four youngest leaves and the unfurled shoot on each cardamom stem at about six-weekly intervals throughout the year, and especially from April to October or during the dry season. All adult and immature insects can be easily hand-picked and killed.

At Afore, these measures have greatly reduced insect populations in village blocks, but the importance of a six-weekly follow up kill must be stressed if effective control is to be maintained.

Large Scale Plantings

It is recommended that insects be controlled by the use of γ-BHC dust at 150 to 160 g a.i./ha (2.2 oz. a.i./ac.) applied to the whole area of young plants in April and followed by a second dusting six to seven weeks later. This treatment was very effective at Boikik Plantation, Afore during 1974. Dusting was carried out in the early morning during a gentle breeze by walking down every 10th row and using a motorised mist blower.

Further applications of insecticide at six to seven weekly intervals during the dry season may be necessary.

Costs of insecticidal control, kindly supplied by Mr G.N. Breay, Boikik Plantation, Afore and based on 1976 values are presented in *Table 1*.

TABLE 1

Cost of insecticide application to 40 ha of cardamom at Afore [1]

(Based on three applications per year, using a Solo Port 423 Misting Machine)

Application Costs	K
Machine Depreciation[2] (20% p.a. of landed cost price)	40.00
Petrol, oil, lubricants @ 4.5 l/20 ha dusted) 27 l 2 stroke fuel @ 40t/l.	10.80
Maintainence and repairs (10% p.a. of cost price)	20.00
Labour (10 man days/application)[3] 30 man days @ K10.00 p.w.	60.00
	130.80
Insecticide Costs	
12.5 - 18.3 Kg Gammexane No. 10 Dust/ha[4] @ 60t/kg and 3 applications/year	900-1,318
Total Costs	1031-1449

Cost per ha K25 80 to K36.25 per year

Notes:

1 Based on estimated 1976 prices.

2 When dusting larger areas, this figure of 20% could be reduced.

3 Under ideal conditions, this figure of 10 man days can be reduced by half.

4 Extremely good kills were obtained using the lower (12.5 kg/ha) application rate.

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BOOK REVIEW
PEST CONTROL IN RICE

PANS Manual No. 3, Centre for Overseas Pest Research, London. Second edition, fully revised, 1976.

"Pest Control in Rice", PANS Manual No. 3, second edition is a completely revised and expanded version of the standby for rice workers since 1970.

Illustrations have been increased and the addition of colour plates to assist the worker in identifying common diseases and pest problems is welcome. More colour plates would have been desirable particularly as it is often the symptom that the field worker first has contact with.

Following an introductory section, it covers weeds, diseases, nematodes, molluscs, crustaceans, insects, mites, birds and rodents. Also included is a valuable section on storage methods and problems and another on pesticide application. The storage methods are generally applicable to other Papua New Guinea commodities.

Quite recent information on suitable chemicals for insect and disease control is presented both with articles on each pest or disease and also in table form. It would have been useful if the appendix had also listed manufacturers of the chemicals. Such information would have been readily available to the editors of the manual in the latest issue of the Farm Chemicals Handbook *, which lists world-wide manufacturers and brand names.

Certain errors are also noticeable. For example the colour plate of brown spot describes it as Helminthosporium leaf spot, although the text describes the disease by its now correct name of *Drechslera oryzae* for the asexual state; the valid name for the sexual state is still *Cochliobolus miyabeanus* as mentioned in the text. There are also dropped words which may be misleading; the introduction's first line missed the word "thousand" when stating that the 1974 world rice production was "323,201 metric tons".

A final criticism which is the most important is the excessive use of complex English phrasing and the use of highly technical words where simpler words are possible. Since many people throughout the world who will use this book do not speak English as a first language, it would have been more appropriate for the editors to make special efforts to use controlled English where possible.

Nevertheless the new edition is a welcome improvement on the contents of the first edition. Particularly for field officers, agriculturalists and mill managers who must make the right decisions without benefit of other resources the book is a must. The price with postage is K2.51, but it is free to government, educational and research establishments when addressed to individuals under their official title.

Peter R. Hale
National Rice Co-ordinator.

* An annual publication from Meister Publishing Company, Willoughby, Ohio, U.S.A.