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## CONTENTS

# VARIATION IN NUTRIENT CONTENTS BETWEEN UPPER AND LOWER RANK LEAFLETS OF OIL PALM (*ELAEIS GUINEENSIS*)

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## ABSTRACT

*Chemical analysis of upper and lower rank oil palm leaflets has shown that, while differences in composition are generally small, they could occasionally affect the interpretation of results. Samples should therefore contain equal numbers of upper and lower rank leaflets.*

## INTRODUCTION

The leaflets of an oil palm frond are inserted at varying angles to the plane of the rachis. Generally the leaflets conform to two distinct ranks, with consecutive leaflets alternating between upper and lower ranks. There is, however, no set regularity and often two or more consecutive leaflets occur in the same rank. As lower rank leaflets are shaded by upper rank leaflets to varying degrees their physiological responses may be somewhat different to those of the upper rank. For example, magnesium deficiency symptoms are observed first in upper rank leaflets (Bull 1954).

If leaflet nutrient contents were to vary significantly with rank, samples taken for chemical analysis would need to contain the same numbers of upper and lower rank leaflets. The literature records some differences between ranks in nutrient composition but the reports are somewhat contradictory and cover only the elements Mg, K, Ca and P. Thus Bull (1954) found that upper rank leaflets had a higher magnesium concentration than lower rank leaflets and attributed this to shading. Further work in West Africa (WAIFOR 1960) showed that lower rank leaflets contained more potassium than upper rank leaflets while the opposite held for calcium. There were no consistent differences for phosphorus. The magnesium contents were lower in upper rank leaflets in young fronds (Nos. 1 to 9) but higher in upper rank leaflets of older fronds (Nos. 17 to 33). These conclusions were based on the analysis of leaflets from only one palm and therefore can hardly be considered applicable to all situations.

Because of the paucity of published data and the importance of chemical analysis in assessing the nutrient requirements of the oil palm, a number of upper and lower rank leaflet samples were collected from pilot blocks and plantations in Papua New Guinea and analysed for all essential elements except molybdenum.

## EXPERIMENTAL METHODS

Leaflets were sampled from 5-year-old palms from pilot blocks at Keravat, Dami, Mosa, Bubia, Saiho, Murua, Epo and Kapogere and from Mosa Plantation. As the 17th frond is internationally accepted as the reference frond for assessment of the nutrient status of oil palms (Ollagnier *et al.* 1970), only these fronds were sampled. Three upper and three lower rank leaflets were taken from each side of the rachis midway along its length. Only the "middle thirds" of each leaflet were retained for analysis. Ten palms were sampled in each block.

The leaflet segments were oven-dried at 70 degrees C as soon as possible after collection, usually on the same day. The midribs were discarded before the laminae were ground in a Wiley mill fitted with a 1 mm stainless steel sieve. Before analysis the ground samples were dried overnight at 100 degrees C. Nitrogen was determined by the Kjeldahl method, sulphate-sulphur by the method of Johnson and Nishita (1952) and boron colorimetrically with curcumin. All other elements were determined on a single nitric-perchloric acid digest, phosphorus

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colorimetrically after reaction with ammonium vanadate/molybdate, potassium by flame photometry and the remainder by atomic absorption spectrophotometry on a Varian-Techtron AA-5 spectrophotometer.

## RESULTS AND DISCUSSION

A quick perusal of the analytical results (*Table* 1) shows that upper rank leaflets often had higher concentrations of most elements than those of the lower rank. In most cases the differences were small and would have made no difference to the interpretation of the data. An analysis of variance showed that differences between upper and lower rank leaflets were significant at the 1 per cent level for N and Ca.

In a normal random sample of oil palm leaflets it would be unlikely that they would be predominantly from one or other rank. There could be a bias one way or the other, but the magnitude of any effect on elemental composition of the composite sample would generally be much smaller than the maximum differences indicated in the present series of samples. Even in these samples the interpretation of the data would have been changed in only seven instances if all upper or all lower rank leaflets had been collected. However, these few instances suggest that personnel who collect oil palm leaflets should take some care during sampling.

There could be a considerable bias towards one rank or the other if only two or three leaflets are taken from each side of the rachis. Taking a larger number would probably give more nearly equal numbers from upper and lower ranks and would be quicker than asking collectors to actually count equal numbers from the two ranks. Further investigations are indicated to determine the optimum number of leaflets which should be taken.

### ACKNOWLEDGEMENTS

My thanks are due to Mr N. Mendham, formerly Oil Palm Agronomist, Dami; Mr E. K. Best, Soil Chemist, and especially Mr J. Horne, Saiho, for their interest and help in collecting samples and to Mrs K. Hietbrink for statistical analysis.

*Table* 1.—Concentrations of nutrient elements in upper and lower rank leaflets from oil palm 17th fronds

| Sample Source | Rank | % on Dry Basis | | | | | p.p.m. on Dry Basis | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | $SO_4$-S | Mn | Fe | Zn | Cu | B |
| Dami .... .... | U | 2.39 | 0.15 | 0.82 | 0.95 | 0.16 | 85 | 14 | 39 | 13 | 5.6 | 12.3 |
| | L | 2.32 | 0.15 | 0.80 | 0.93 | 0.17 | 105 | 13 | 35 | 13 | 4.5 | 12.8 |
| Mosa, pilot .... | U | 2.42 | 0.16 | 0.90 | 1.01 | 0.15 | 103 | 23 | 42 | 14 | 4.3 | 16.5 |
| | L | 2.47 | 0.15 | 0.86 | 0.96 | 0.15 | 101 | 26 | 43 | 14 | 4.5 | 16.5 |
| Mosa, block B .... | U | 2.56 | 0.14 | 0.92 | 0.90 | 0.21 | 87 | 52 | 36 | 12 | 4.8 | 14.5 |
| | L | 2.34 | 0.13 | 0.85 | 0.83 | 0.20 | 100 | 57 | 43 | 10 | 5.4 | 12.5 |
| Keravat .... | U | 2.53 | 0.17 | 1.10 | 0.71 | 0.17 | 76 | 60 | 44 | 15 | 5.4 | 15.0 |
| | L | 2.35 | 0.16 | 1.15 | 0.65 | 0.17 | 72 | 47 | 35 | 15 | 4.4 | 13.0 |
| Murua .... | U | 2.47 | 0.17 | 0.80 | 1.10 | 0.26 | 130 | 300 | 56 | 13 | 5.0 | 12.0 |
| | L | 2.16 | 0.14 | 0.75 | 0.93 | 0.26 | 120 | 220 | 49 | 12 | 4.5 | 12.3 |
| Epo .... .... | U | 2.36 | 0.10 | 0.52 | 0.95 | 0.15 | 105 | 320 | 48 | 11 | 5.7 | 8.5 |
| | L | 2.19 | 0.09 | 0.50 | 0.73 | 0.14 | 120 | 140 | 40 | 9 | 4.9 | 9.5 |
| Saiho, H palms | U | 2.80 | 0.15 | 1.00 | 0.88 | 0.27 | 118 | 85 | — | 18 | 5.8 | 16.0 |
| | L | 2.42 | 0.13 | 0.98 | 0.73 | 0.25 | 110 | 66 | — | 15 | 5.3 | 12.0 |
| Saiho, C palms | U | 2.28 | 0.13 | 0.90 | 0.75 | 0.15 | 87 | 68 | 59 | 13 | 4.5 | 13.0 |
| | L | 2.19 | 0.13 | 0.98 | 0.73 | 0.15 | 72 | 64 | 45 | 11 | 4.3 | 12.5 |
| Saiho, H palms | U | 2.30 | 0.15 | 0.95 | 0.83 | 0.21 | 72 | 62 | 37 | 13 | 5.0 | 13.0 |
| with white stripe | L | 2.15 | 0.13 | 0.90 | 0.78 | 0.23 | 75 | 62 | 45 | 11 | 5.0 | 13.0 |
| Saiho, C palms | U | 2.40 | 0.15 | 0.98 | 0.85 | 0.16 | 86 | 77 | 40 | 11 | 4.4 | 16.0 |
| with white stripe | L | 2.47 | 0.14 | 0.98 | 0.90 | 0.18 | 83 | 72 | 44 | 11 | 4.4 | 13.5 |
| Kapogere .... | U | 2.69 | 0.18 | 0.85 | 1.00 | 0.28 | 114 | 16 | 78 | 17 | 6.7 | 16.0 |
| | L | 2.65 | 0.19 | 0.87 | 0.98 | 0.28 | 107 | 14 | 63 | 13 | 6.7 | 15.3 |
| Bubia .... .... | U | 2.08 | 0.13 | 0.75 | 0.77 | 0.14 | 100 | 30 | 145 | 13 | 5.2 | 16.5 |
| | L | 1.91 | 0.12 | 0.90 | 0.70 | 0.16 | 104 | 30 | 200 | 14 | 5.2 | 15.5 |
| Mean .... .... | U | 2.44 | 0.15 | 0.87 | 0.89 | 0.19 | 97 | 92 | 57 | 14 | 5.2 | 14.1 |
| | L | 2.30 | 0.14 | 0.88 | 0.82 | 0.20 | 97 | 76 | 59 | 12 | 4.9 | 13.2 |

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# METHODS OF INCREASING GRAIN SORGHUM PRODUCTION IN THE MARKHAM VALLEY

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## ABSTRACT

*Fertilizers are not in current general use for production of grain sorghum in the Markham Valley. On former native grassland yield of grain sorghum (cv. Texas 626) was increased from 1,237 lb per acre to 3,046 lb per acre by the application of 71 lb of nitrogen as ammonium sulphate ($P<0.001$). Responses to phosphorus and potassium were not significant.*

*Doubling the seeding rate of the same cultivar from 7 to 14 lb per acre sown in rows 2 ft apart increased yield 16 per cent from 2,671 lb per acre to 3,092 lb per acre. This yield response was equivalent to that obtained from the application of an extra 23.5 lb of nitrogen per acre.*

*At the maximum level of fertilizer applied, yield was still increasing. Economic increases in yield of grain could be expected from the application of nitrogenous fertilizers. The effect of seeding rate change requires further study to determine possible effects of changes of sowing geometry.*


## INTRODUCTION

Growing of grain sorghum in Papua New Guinea as a cash crop could be of considerable importance in the development of increased local production of pork and poultry products. Springhall (1969) obtained good weight gains from pigs from rations compounded from sorghum and soy beans. Hill (1969a) has shown that good yields of soy beans are possible in the lowlands provided precautions are taken to maintain seed viability prior to sowing.

The lowlands of the Markham Valley have attractions for growing both of these crops, firstly because the generally flat terrain would allow use of large agricultural machines for broadacre sowings, and secondly because alternatives to the cultivation of peanuts are required.

At the time this trial was laid down, little sorghum was grown in the Markham Valley. Fertilizer was not generally used and farm yields from hybrid seed were not impressive (Hill 1969b).

Although soils of the Markham Valley are thought to be adequate with regard to phosphorus and potassium requirement, it is almost certain that under native grasslands nitrogen would be limiting for plant growth.

Sowing rates used in Papua New Guinea have generally followed Australian recommendations and no information is available as to suitable sowing rates for the New Guinea lowland environment. Also in accordance with the observations of Downes (1968), hybrids derived from American parents do not tiller in the lowlands. It was therefore thought possible that an increase in sowing rate might give increased yields of grain because of the presence of a greater number of heads.

Two experiments were conducted to determine response to major elements and the effect of sowing rate on yield at Wawin, about 40 miles north-west of Lae in the Markham Valley.

## MATERIALS AND METHODS

Both experiments were sown on a commercial property. The soil was a silty brown to black clay loam with a well-defined crumb structure. Prior to sowing the experiments, the land had not been cropped and was under native grasses dominated by *Imperata cylindrica*.

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*Experiment* 1

A confounded $3^3$ factorial design was used with nitrogen, phosphorus and potassium at three levels. There were three blocks of nine plots (total 27).

The application rates of the fertilizers used were:

Ammonium sulphate
$N_0$=0 cwt per acre
$N_1$=1 cwt per acre
$N_2$=3 cwt per acre

Superphosphate
$P_0$=0 cwt per acre
$P_1$=1 cwt per acre
$P_2$=2 cwt per acre

Potassium sulphate
$K_0$=0 cwt per acre
$K_1$=0.5 cwt per acre
$K_2$=2 cwt per acre

Plots within blocks were 10 ft x 43.5 ft. There were no spaces between plots within blocks. Spaces of 10 ft were left around all blocks. The experiment occupied an area of 90 ft x 157.5 ft.

Each plot comprised five rows 2 ft apart of Texas 626 sown at 7 lb per acre.

Fertilizers were broadcast onto the plots following sowing and precautions were taken to ensure that no fertilizer was walked from plot to plot.

The control plot received a dressing of gypsum equal in sulphur content to that applied to the $N_1P_1K_1$ plot to ensure that sulphur was not limiting yield. Sulphur had previously been reported deficient in several areas in the Markham Valley (Southern 1967) and yield responses to sulphur have been obtained from peanuts lower down the valley (Hill 1970).

The experiment was sown on 9th January, 1969. At harvest the central 40 ft of the three inside rows of each plot were harvested by cutting off the heads below the panicle, and they were weighed green in the field and bagged. Individual bags were then dried for 48 hours in a forced-draught oven at 50 degrees C to facilitate threshing and for determination of dry grain yields.

The experiment was harvested on 10th April, 1969.

*Experiment* 2

A randomized blocks design was used with four replicates. Plot size was as in Experiment 1. Spaces of 10 ft were left between blocks and the area occupied by the trial was 90 ft x 97 ft.

To obtain differences in sowing rate, distance between rows was held constant at 2 ft and distance between seeds within the row varied. Distance between seeds within the row and the equivalent sowing rate are shown in *Table* 1.

*Table* 1.—Distance between seeds and sowing rate cv. Texas 626

| Distance Between Seeds (in) | Sowing Rate (lb/acre) |
|---|---|
| 1.5 | 14.0 |
| 3.0 | 7.0 |
| 6.0 | 3.5 |
| 9.0 | 2.3 |

The variety used was Texas 626. All plots received a basal fertilizer dressing of 6 cwt per acre of a mixture of equal parts by weight of ammonium sulphate, potassium chloride and superphosphate. Harvesting procedures were the same as those used in Experiment 1. The experiment was sown on 10th January, 1969 and harvested on 10th April, 1969.

## RESULTS AND DISCUSSION

*Progress of Trials*

Both experiments were remarkably free of attack by insects and plant pathogens. This was probably due to good separation from other sorghum growing on the property.

Although the growing period of the experiments coincided with the wet season in the Markham Valley (November to April), rainfall was erratic. Reasonable rain fell in January followed by a relatively dry February and good rain fell again in March. An adjacent dryland rice trial made very poor growth. The sorghum, presumably because of its greater drought resistance, grew well.

Response to nitrogen could be seen from early in the experiment. Plots treated with nitrogen were greener, flowered earlier, and produced bigger grain heads.

In the sowing rate trial, plants at 6 in and 9 in spacings were larger and produced bigger grain heads than those spaced at 1.5 in and 3 in. Tillering was not observed in any treatment of either experiment.

*Experiment* 1

Analysis of variance on the yield of green heads showed that there were no significant interactions and only nitrogen gave a significant fertilizer response ($P<0.001$).

During drying some of the bags from individual plots were bulked by accident. Actual grain yields from all plots are therefore not available. Yield of dry grain for the bulked bags was estimated by a regression based on the available values. The equation was:—

$$Y = -0.650 + 0.559X$$
$$(t = 7.894^{**})$$

where Y = yield of dry grain in kg per plot
X = yield of wet heads in kg per plot

The very highly significant relationship ($P<0.001$) indicates that estimated yields can be accepted with reasonable confidence. Means for the various fertilizer levels are shown in *Table* 2.

*Table* 2.—Response of hybrid sorghum to major elements—yield of grain in lb per acre

| Element | Level | | | Significance |
|---|---|---|---|---|
| | 0 | 1 | 2 | |
| Nitrogen | 1237 | 2065 | 3046 | *** |
| Phosphorus | 2209 | 2113 | 2025 | N.S. |
| Potassium | 2265 | 1881 | 2201 | N.S. |

On the soil type concerned the only major element to increase yield was nitrogen, an extra 828 lb of grain per acre being obtained from the application of 1 cwt of ammonium sulphate (23.7 lb nitrogen) and an extra 1,809 lb from 3 cwt (71 lb nitrogen).

*Experiment* 2

As in Experiment 1, some dried bags were mixed prior to final weighing. A regression was again used to estimate yield of dry grain. The equation was:—

$$Y = -9.799 + 1.166X$$
$$(t = 4.528^{**})$$

where Y = yield of dry grain in kg per plot
X = yield of heads in kg per plot

The highly significant linear relationship ($P<0.01$) again indicates that the estimated results can be accepted with reasonable confidence.

Grain yields were subjected to analysis of variance and overall treatment effect were not significant. Partitioning of the treatment sum of squares by fitting of polynomials indicated that a significant linear treatment effect existed ($P<0.05$).

The regression was of the form:—

$$Y = 3085.101 - 90.559X$$
$$(t = 2.646^{*})$$

where Y = yield of dry grain in lb per acre
X = distance apart in inches of seeds within the row

Mean treatment yields and those estimated from the regression are shown in *Table* 3.

*Table* 3.—Effect of sowing rate on yield of grain in lb per acre

| Sowing Rate (lb/acre) | Mean Yield (lb/acre) | Estimated Yield (lb/acre) |
|---|---|---|
| 2.33 | 2341 | 2270 |
| 3.50 | 2471 | 2542 |
| 7.00 | 2671 | 2813 |
| 14.00 | 3092 | 2949 |

Within the range of sowing rates, tested yield of grain decreased by 91 lb per acre per inch increase in the distance between seeds. It is of interest to note that the yield in Experiment 2 for the 14 lb per acre sowing rate which received 2 cwt of ammonium sulphate was slightly higher than that obtained in Experiment 1 where 3 cwt of ammonium sulphate had been applied with a sowing rate of 7 lb per acre.

It should be remembered that in this experiment the distance between rows was held constant while within-row distance was varied. Further work of interest would be to investigate the effect of decreasing between-row distances, as it has been shown in maize that competition is decreased as equidistant distribution is approached and that denser spacings give higher yields (Downey 1971).

*The Production Function*

By combining mean yields of nitrogen treatments in Experiment 1 with mean yield at the

same sowing rate (7 lb per acre) in Experiment 2, results are available for four nitrogen levels. By fitting polynomials it is possible to determine the shape of the production function. The data were found to be best fitted by a quadratic equation of the form:—

$$Y = 1235.792 + 941.296\,X - 112.569X^2$$

where Y=yield of sorghum grain in lb per acre
X=ammonium sulphate applied in cwt per acre

From the equation it is possible to estimate the change in grain production per cwt of fertilizer or per lb of nitrogen added (*Table* 4).

*Table* 4.—Effect of ammonium sulphate on yield of sorghum grain in lb per acre

| Fertilizer Application Rate | | | Increment in Yield for Each Extra cwt of Fertilizer | |
|---|---|---|---|---|
| $(NH_4)_2SO_4$ cwt/acre | N lb/acre | Yield lb/acre | lb/cwt $(NH_4)_2SO_4$ | lb/lb N |
| 0 | 0 | 1240 | | |
| 1 | 23.7 | 2060 | 820 | 34.5 |
| 2 | 47.4 | 2670 | 610 | 25.7 |
| 3 | 71.1 | 3040 | 370 | 15.6 |

In this experiment the point of maximum response to applied nitrogen was not reached at the levels tested. Further work is therefore required to determine this level. It is also of note that at the prices prevailing when the trial was conducted, the maximum rate of application was not at the point required to maximize profit. On economic grounds, profit is maximized when the cost of the last factor added equals the extra return. In 1969 sorghum grain was worth $52 a ton at the farm gate, while ammonium sulphate cost $98 per ton. The last cwt of ammonium sulphate therefore cost $4.90 while the extra 370 lb of grain it produced would have been worth $8.59. Comparison with the current price of ammonium sulphate and sorghum grain should allow a farmer to make some estimate of his required optimum rate of fertilizer application for profit maximization.

*Further Work*

These experiments raise almost as many questions as they answer. Doubling the seeding rate at a constant between-row distance increased yield 16 per cent. However, sorghums of tropical origin should be sought for comparison with imported American hybrids to determine the importance for sorghum yield of ability to tiller in a New Guinea lowland environment.

The response to nitrogen was obtained from ammonium sulphate. Other forms of nitrogenous fertilizer require testing. Repeated use of sulphur-free forms of nitrogen could lead to induction of sulphur deficiency.

In this experiment fertilizers were broadcast onto the soil surface after sowing. Soils of the Markham Valley are generally basic, a condition that can lead to the loss of up to 25 per cent of ammonia added as fertilizer, a process which is probably accelerated by high temperatures and non-incorporation (Martin and Skyring 1962). Work is therefore also required on the mode and timing of nitrogen application to maximize yield.

## CONCLUSIONS

The experiments showed that significant yield increases in grain sorghum can be expected from the application of nitrogenous fertilizers on former native grasslands in the Markham Valley. On the other hand, responses to phosphorus and potassium were not evident. Yield increased from 1,237 lb of grain per acre with no nitrogen to 3,046 lb of grain with an application of 71 lb of nitrogen (as ammonium sulphate). Considerable increase in grain sorghum production could be expected from commercial use of nitrogenous fertilizers by sorghum growers in the Markham Valley.

Doubling the seeding rate from 7 lb to 14 lb per acre increased yield of grain 16 per cent from 2,671 lb per acre to 3,092 lb which was approximately the same response as could be expected from the addition of an extra cwt of ammonium sulphate. Further work is required on this aspect to determine if at a constant sowing rate yield can be altered by changes in the geometry of seeding.

### ACKNOWLEDGEMENTS

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# NOTE ON THE WATER CHARACTERISTICS AND MINERALOGY OF A SOIL CONTAINING DIAGNOSTIC PUMICE

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## ABSTRACT

*Soil samples from Hoskins, New Britain, containing diagnostic pumice were analysed. While allophane was found in the samples, its high silicon content suggests it would not adsorb phosphate strongly. The amount of water held by the soil that would be readily available to plants is unusually large. It is suggested this will buffer the effect of uneven rainfall distribution throughout the year.*


## INTRODUCTION

SIGNIFICANT amounts of particulate pumice are found in some volcanic ash soils. In the Hoskins area of New Britain such soils occur, and in some instances are being used to grow oil palm. The effect of this pumice on the basic physical and chemical properties of the soil is not well understood and is a matter of some interest. While pumice soils are thought to hold large amounts of water, how much is held and whether this water is readily available to plants appears not to be known. Furthermore, soils developed on pumice or volcanic ash often contain the amorphous clay mineral allophane. This mineral has a large specific surface and is very reactive; it stabilizes soil organic matter and can strongly adsorb phosphate. The water characteristics and mineralogy of pumice soil from Mosa, Hoskins (New Britain) are reported here.

## MATERIALS AND METHODS

Soil samples were collected at the Mosa block from depths of 0 to 5 cm and 50 to 55 cm and stored in sealed polythene bags. The soil profile is described in the *Table*. The rainfall at the site is 400 cm per annum.

For the mineralogical analysis the clay fraction (less than 2$\mu$) was separated by centrifugation after ultrasonic dispersion at pH 10 with sodium hydroxide. The clay was treated to remove free iron with dithionite-citrate, then with 2 per cent $Na_2CO_3$ and 0.5M NaOH according to Wada and Greenland (1970).

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*Table* 1.—Profile description of the Mosa soil

| Depth (cm) | Description |
|---|---|
| 0—7 | Moist very dark brown (5 YR 2/2) friable loam with fine sub-angular blocky structure, pH 7 |
| 7—35 | Moist yellowish brown (10 YR 5/4) structureless sandy loam, pH 6.5 |
| 35—50 | Intermediate ash and pumice layers relatively unweathered |
| 50—55 | Moist brown (7 YR 4/4) structureless gravelly loam, pH 6 |

The amount of clay dissolved at each extraction was determined. The clay minerals were determined with a Perkin Elmer 257 infrared spectrometer and by X-ray powder photography using a Phillips PW1120 generator.

The relation between matric potential and gravimetric water content for the two samples was determined for potentials ranging from —0.1 bar to —27.3 bar. To cover this wide potential range a hanging column and fritted glass funnel were used from —0.1 to —0.2 bar; pressure plate and pressure membrane apparatus were used from —0.5 bar to —15 bar; and a vacuum desiccator containing a saturated copper sulphate solution was used at —27.3 bar. All determinations were made in duplicate. Unsieved material was used for the analyses, the lack of structure in the samples precluding the use of natural aggregates. The amount of pumice in the soil was estimated by hand-picking and floating off the pumice particles in water or dibromoethane. The two fractions were then oven-dried and weighed.

## RESULTS AND DISCUSSION

The 0-5 cm sample contained 15 per cent clay and the 50-55 cm depth subsoil yielded 9 per cent by repeated extraction. Both clay fractions contained the clay minerals allophane and hydrated holloysite with minor amounts of cristobalite. Selective dissolution analysis caused large amounts of clay to be removed. Dithionite-citrate and $Na_2CO_3$ treatment dissolved 70 per cent of the clay from the topsoil and 40 per cent of the clay from the subsoil. Examination of the clay by infrared spectroscopy before and after treatment showed that silicon-rich, amorphous, aluminium silicate gel (an allophane) was removed by the treatment. Amorphous compounds usually adsorb phosphate strongly and cause it to be unavailable to plants. However, allophanes with a high silicon content fix phosphate less strongly (Cloos *et al.* 1968). The Mosa soil is unlikely to adsorb phosphate strongly and this prediction has been confirmed (J. Brigatti 1970, personal communication).

The 0-5 cm horizon was found to contain 13 per cent pumice by weight, and the 50-55 cm horizon 30 per cent. The pumice particles ranged in size from a fraction of a millimetre to approximately a centimetre in diameter.

The soil water characteristic release curves are shown in the *Figure*. The gravimetric water contents at —0.1 bar water potential, the value often assumed to approximate field capacity in well-drained soil profiles, were 1.20 and 1.05 for the surface and subsoil horizons respectively. Both these values are unusually large, even when compared with values for heavy clay or humus soils (see Stace 1968). The samples lost much of their water at quite low suctions. At a matric potential of -1 bar (equivalent to a suction of 1 bar) the water contents of the samples were 0.8 and 0.55, which indicates that a large fraction of the water held in the profile would be readily available for plant use. The gravimetric water contents at —15 bars potential, which can be taken as approximating the wilting point or lower level of available water, were 0.36 and 0.33 for the 0-5 cm and 50-55 cm depth samples respectively. These values are not unusual (Stace *op. cit.*).

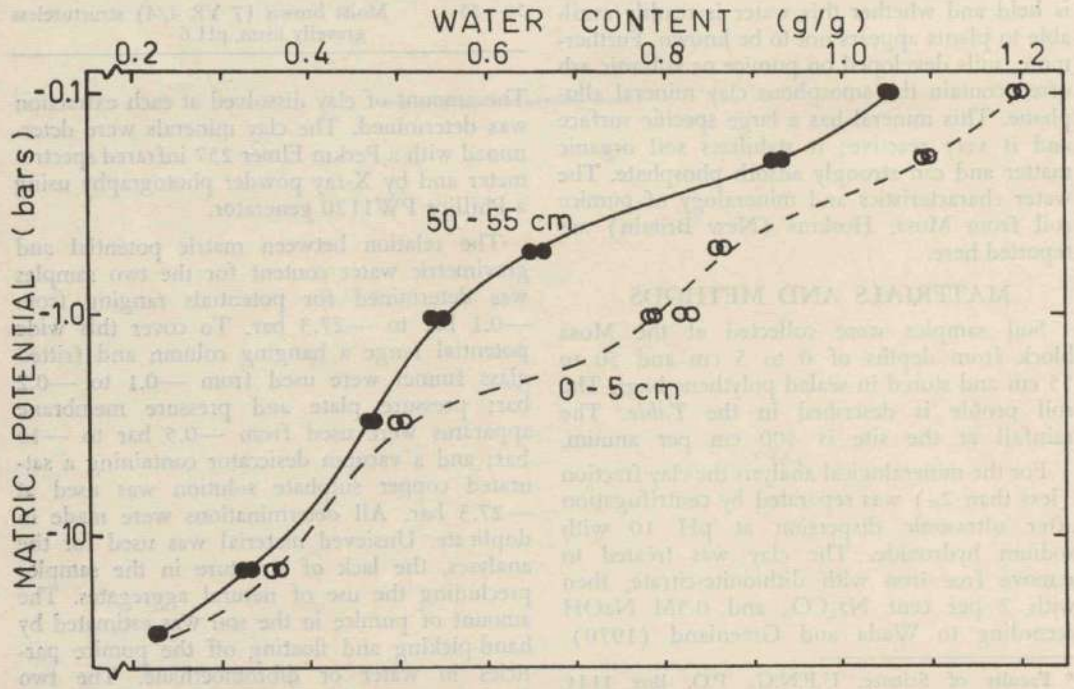


*Figure.*—Water release curves for 0-5 cm and 50-55 cm soil samples

The differences between the water contents at —0.1 and —15 bars show the available water held by the soil to be unusually large, and approximately two thirds of this water is available at suctions of less than 1 bar. Qualitative observation of outflow rates from soil samples coming to potential equilibrium indicated the saturated and unsaturated hydraulic conductivity of the soil to be high, which would suggest it has excellent infiltration and drainage characteristics. The net result of these factors would be that during rainfall the profile would wet up readily and retain in it a very large amount of water which would effectively tide the oil palm over even quite extended rainless periods without the plants experiencing any deleterious water stress. Tensiometer readings under oil palms at Mosa (Mendham 1971, personal communication) have confirmed this. Mendham found that even during a two-month dry period with less than 10 cm of rainfall the water potential in the root zone did not fall below —0.56 bars.

## CONCLUSION

The physical characteristics of the Mosa soil are such that plant water stress caused by uneven distribution of the high rainfall is unlikely, due to the unusually large amount of water held by the soil. The high hydraulic conductivity should preclude waterlogging, even after heavy rain. The mineralogy of the soil suggests phosphate fixation will not be a serious problem, as the allophane present has a high silicon content.

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# THE RHIZOBIUM SUPPLY SERVICE IN PAPUA NEW GUINEA

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## ABSTRACT

*This report of the Rhizobium Supply Service in Papua New Guinea since its inception in* 1956 *includes an account of the history of the service, the strains used and their origins. Up till June,* 1971 *nearly* 18,000 *bottles of inoculum were supplied to local growers and to some overseas countries, mainly for legumes of economic importance. The results of field sowings of inoculated and uninoculated seed are given; these showed, among other things, that in* 36.9 *per cent of the cases recorded uninoculated plants had nodulation as effective as occurred on the inoculated plants and that in* 36.8 *per cent of the cases plants derived from inoculated seed performed better than the uninoculated controls. The details of performances in field sowings are also given for some selected legumes.*

## INTRODUCTION

FIXATION of atmospheric nitrogen (N) has been recorded as occurring in non-leguminous plants (members in nine families including the Casuarinaceae with root nodules and six families with leaf-glands) including lichens. Nitrogen is also fixed by free-living bacteria (*Azotobacter*, *Beijerinckia*, *Clostridium* and others) and by some algae (the blue-greens), but claims for fixation by fungi are at present mainly unconfirmed (Henzell and Norris 1962; Norris 1962).

However, according to Henzell and Norris (1962), the cultivation of leguminous plants is probably the most important method of adding N to the soil/plant system.

Only a small percentage of the described species in the Leguminosae have yet been examined for nodulation by Rhizobium bacteria. In 1956 only 1200 or about 10 per cent of the then described 11,000 species had been checked in varying degrees[4] (Norris 1956), and of these 133 (9 per cent) apparently never bear nodules at all, the figures for the three subfamilies being 64 without nodules of the 97 species examined in the Caesalpinioideae, 12 without nodules of the 134 examined in the Mimosoideae, and 57 without nodules of the 969 examined in the Papilionoideae.

Absence of nodules at one particular time, however, is no guarantee that the species is a non-nodulating type, as the occurrence of nodules may be cyclic at least in perennial shrub and tree legumes (Hannon 1949, cited by Norris 1956) or absent because of drought or other reasons (Beadle 1964).

The presence and number of nodules is no guide to their effectiveness; if they are ineffective the bacteria may be parasitic on the host for nitrogen and the legumes must obtain their nitrogen from the soil, in which case they deplete the nitrogen reserves quicker than cereals and grasses. Effective nodules contain red leghaemaglobin which can be seen on cutting them across. Ineffective nodules are usually small, hard, spherical and a greenish colour inside. Norris (1956) has stated that in species that can nodulate, the absence or ineffectiveness of nodulation results in a much lower protein content.

The Rhizobium bacteria are not obligate symbionts; they spend much of their existence as free-living saprophytic soil inhabitants. As

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4. Grobbelaar *et al.* (1964) stated that no more than about 15 per cent of the family had been investigated for the capacity to form root nodules.

such they possess the ability to survive and multiply in the soil for long periods between chance sojourns within legume root nodules (Norris 1956).

Norris (1965) considers that there are two great groups of Rhizobium nodule bacteria associated with legumes, viz., the ancestral, alkali- ~~alcohol~~-producing "cowpea" type, largely tropical, tolerant of acid soils and promiscuous on a wide range of hosts; and the recent, largely temperate, fast-growing, acid-producing type, intolerant of acid soils with very specific host ranges, such as those on species of *Trifolium* (clovers) and *Medicago* (medics).

Investigations into the nodulation of legumes in Papua New Guinea started, as far as is known, in 1954 and proceeded in conjunction with the development of the free Inoculum Supply Service inaugurated in 1956 by the Department of Agriculture, Stock and Fisheries.

## HISTORY OF THE INOCULUM SUPPLY SERVICE

As far as can be traced, at least one importation of a Rhizobium culture was made into Papua New Guinea about 1955, that is, just prior to the establishment of the Papua New Guinea Rhizobium Service. Details are given later in the section on Rhizobium strains.

The initial work with Rhizobium in Papua New Guinea was done by Mr L. B. Thrower in the period 1954-57. This work consisted mainly of the isolation of Rhizobium from *Leucaena leucocephala* and the initiation of some field trials. Further isolations were undertaken by Shaw, who began work in 1955. The regular supply to growers of cultures of Leucaena Rhizobium isolated in this country commenced in August, 1956.

In 1956 importation from Australia of isolates of proved efficiency for other hosts was begun. The first two cultures were for *Medicago sativa* (lucerne) and *Trifolium pratense* (red clover), both from the Queensland Department of Primary Industries, followed by cultures for peanut and soybean.

Since that date various officers have been involved with the maintenance of the service but any comments or opinions in this paper are the responsibility of the senior author.

## ORIGIN OF STRAINS

### *Leucaena leucocephala*

The culture of Rhizobium introduced about 1955, prior to the establishment of the Rhizobium Service, was culture CB81 for *Leucaena leucocephala*, originally isolated by Norris from nodules on a specimen plant in the Botanic Gardens, Brisbane, in June, 1954. In July, 1955 Norris isolated culture CB415 from nodules from well-nodulated introduced *L. leucocephala* growing at Keravat in New Britain. It is not known where in Papua New Guinea if at all CB81 was used, or whether any Rhizobium was accidentally introduced with the early Leucaena[5] seed introductions.[6] In 1956 Norris reported to Shaw (in correspondence) that in tests at the Cunningham Laboratory CB415 performed nearly as well as CB262 and just a little better than CB430 and four other isolations, all from sources outside Papua New Guinea.

The first isolations from Leucaena made in Papua New Guinea were those of Thrower from nodules found on plants growing at Keravat and in the Lower Markham Valley and designated K1, K2, K3, etc., and M1, M2, M3, etc., and by Shaw from plants growing in areas around Port Moresby.

Up to January, 1961, the cultures for Leucaena regularly supplied in the service were of the K and M series, particularly K3, K5, K6 and M1. From January, 1961 the main culture supplied was RM1 this being a reisolate by Trinick from M1; in October 1961 RM1 was renamed NGR8 and since then has retained this designation. In 1963-64 NGR8 replaced CB81 as the Rhizobium strain recommended in Australia for Leucaena by U-DALS (the University-Department of Agriculture Laboratory Service), Department of Microbiology, University of Sydney, and has continued to be supplied both in Papua New Guinea and in

5. The common name for *Leucaena leucocephala* in Papua New Guinea is "Leucaena" and throughout this paper Leucaena refers to *L. leucocephala* (Lam.) de Wit, syn. *L. glauca* (L.) Benth., in the subfamily Mimosoideae.

6. Norris (1956) pointed out that the Leguminosae failed to evolve a system for ensuring that the appropriate bacterium was automatically transferred with the seed, except in such genera as *Arachis* and *Trifolium* which bury their seed pods.

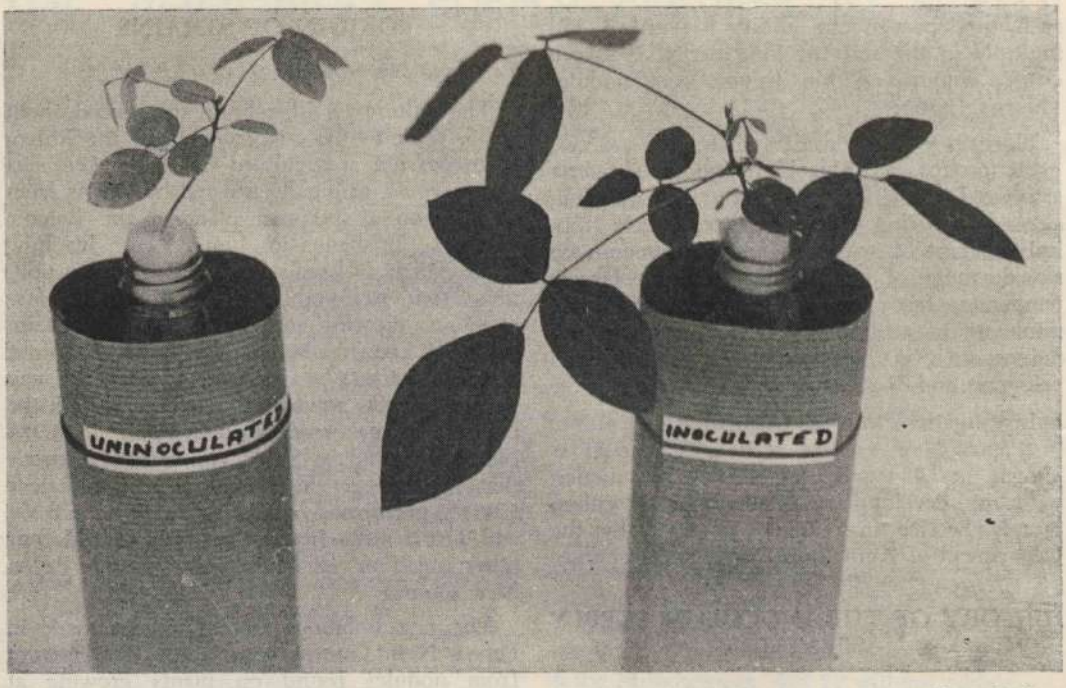


Photo D Shaw

*Plate* I.—Laboratory check on effectiveness of nodulation. Young inoculated and uninoculated plants of *Pueraria phaseoloides* growing in agar culture. The uninoculated are yellowish with fewer leaves than the inoculated and these differences will become more pronounced as the plants age

Australia as the recommended strain. The culture has also been forwarded to some overseas countries as described in a later section. However, widespread nodulation failures of Leucaena on acid soils in Queensland have now been traced to inability of NGR8 to multiply under acid conditions, and a return is to be made to strain CB81 which is adapted to acid soils (Norris, personal communication). Both strains are now being used in Papua New Guinea.

*Other Hosts*

As mentioned previously, Rhizobium cultures for other hosts were imported from Australia by Shaw, later by Trinick and after 1966 again by Shaw, as new recommendations became available. Centres supplying cultures were the Cunningham Laboratory (CSIRO), Queensland; the Department of Primary Industries, Brisbane; the Department of Agriculture, Sydney; U-DALS, University of Sydney;[7] and the University of Western Australia, Perth. Cultures originating elsewhere were usually obtained through the above centres.

The cultures used for the main groups of economically important legumes are shown in *Table* 1.

Some growers in Papua New Guinea have occasionally imported peat cultures from Australia.

## CULTURES

Since the service was initiated in 1956, cultures on agar medium have been sent to most areas in Papua New Guinea and to some overseas consignees. An agar medium suitable for the growth of Rhizobium was used initially on the advice of the Acting Chief Biologist of the Department of Agriculture in N.S.W., and continued in use for the following reasons:

(1) It was easier to handle with the laboratory facilities available than the preparation of peat cultures.

7. Replaced in July, 1970 by the Australian Inoculants Research and Control Service (AIRCS), housed since February, 1971 at the Biological and Chemical Research Institute, Rydalmere, N.S.W.

*Table* 1.—Strains[1] of Rhizobium and number of bottles distributed for the economically important legumes during 1956-1971

| Host | Standard Strain Distributed[2] | No. of Other Strains Occasionally Distributed (All Purposes)[3] | No. of Bottles Supplied |
|---|---|---|---|
| *Arachis hypogaea* (Peanut) .... | CB756 | 2 | 94 |
| *Cajanus cajan* (Pigeon pea) .... | CB756 | | 14 |
| *Calopogonium caeruleum* .... .... | CB756 | | 26 |
| *Calopogonium mucunoides* (*Calopo*) | CB756 | | 28 |
| *Calopogonium* sp. .... .... .... | CB756 | | 18 |
| *Centrosema pubescens* (Centro) .... | *NGR*118[2], *NGR*26, CB1103 | 10 | 1,023 |
| *Crotalaria* spp. .... .... .... | CB756 | 1 | 45 |
| *Desmodium intortum* .... .... | CB627 | 1 | 90 |
| *Desmodium uncinatum* .... .... | CB627 | | 102 |
| *Desmodium* spp. .... .... .... | CB627 | 3 | 74 |
| *Dolichos axillaris* .... .... .... | CB756 | | 46 |
| *Dolichos lablab* .... .... .... | CB159 | 5 | 114 |
| *Dolichos* spp. .... .... .... | CB756 | 3 | 26 |
| *Glycine max* (Soybean) .... .... | *NGR*27R, *NGR*38, *NGR*47, *NGR*147, CB1809 | 6 | 175 |
| *Glycine wightii* (*javanica*) .... | *QA*922, *CB*450, CB756 | 4 | 198 |
| *Leucaena leucocephala* .... .... | *K*1, *K*2, *K*5, *K*6, *M*1, *M*2, *M*3, *M*5, *RM*1 (reisolate of M1), NGR8 (redesignate of RM1) | | 13,684 |
| *Lotononis bainesii* .... .... | *CB*360, CB376 | | 37 |
| *Lupinus* spp. .... .... .... | W72 | 2 | 10 |
| *Medicago* spp. .... .... .... | *SU*277, U45, SU47 | 2 | 44 |
| *Phaseolus atropurpureus* (Siratro) | CB756 | | 207 |
| *Phaseolus vulgaris* (Bean) .... .... | CC511 | | 5 |
| *Phaseolus* spp. .... .... .... | CB756 | | 47 |
| *Pueraria phaseoloides* .... .... | CB756 | 6 | 981 |
| *Stizolobium deeringianum* .... .... | CB756 | | 18 |
| *Stylosanthes guianensis* (*Stylo*) .... | CB756 | | 157 |
| *Stylosanthes* spp. .... .... .... | CB756 | | 41 |
| *Trifolium pratense* (Red Clover) .... | *UNZ*29, TA1 | 3 | 76 |
| *Trifolium repens* (White Clover) | *UNZ*29, TA1 | 1 | 77 |
| *Trifolium* spp. (Clovers) .... .... | *CB*772, *UNZ*29, TA1 | 4 | 94 |
| *Vigna sinensis* (Cowpea) .... .... | CB756 | 3 | 93 |
| *Vigna* spp. .... .... .... .... | CB756 | | 53 |
| Other legumes .... .... .... | Various | | 44 |
| | | Total | 17,741 |

1. Imported cultures distributed from June, 1965 to March, 1968 had been redesignated by Trinick NGR (e.g., CB756 designated NGR241, CB627 as NGR224, etc.). However, after March 1968 and herein, cultures are designated by their original numbers.

2. Strain numbers shown in italics not now distributed; all strains being distributed at present are those recommended by U-DALS (now AIRCS).

3. Including cultures isolated from the host specified and other hosts and used in sowings to check ability or inability to nodulate and efficiency in the field. As much of this work was part of Trinick's research studies, it is not given here in detail.

(2) It was more striking to indigenous growers than peat cultures.

(3) No peat cultures were or are yet produced commercially in Papua New Guinea, and indigenous growers are unlikely to carry out importation involving correspondence and money with an overseas country such as Australia.

Close touch has been kept with Rhizobium workers in Australia, particularly with Professor J. M. Vincent and the U-DALS (now AIRCS) organization in Sydney, and with Dr D. O. Norris at CSIRO, Cunningham Laboratory, Brisbane, who with the Department of Primary Industries in Brisbane, has supplied many of the cultures. The officers in charge of

the Papua New Guinea Rhizobium Service have attended Australian Rhizobium Conferences. The recommendations of the AIRCS organization are closely studied to ascertain the strains of Rhizobium shown to be the most efficient nodulators of crops common to both Australia and Papua New Guinea. When necessary new cultures are imported to maintain the Papua New Guinea Rhizobium Supply Service at maximum efficiency; some cultures were isolated from local nodules.

Cultures are supplied in bottles of three sizes, depending firstly on the quantity of seed to be inoculated, and secondly, on the size of the seed (either large, medium, or small); sheets on inoculation technique are supplied with each consignment. With most consignments Record Sheets were also forwarded, requesting that some uninoculated seed be sown as well as the main sowing of inoculated seed, so that the grower could see the difference himself, and so that the officers in charge of the service could determine the necessity for inoculation in that area, or perhaps detect abnormalities in results for further investigation.

Cultures are maintained on nutrient agar, under oil and with freeze drying.

## NODULATION OF ECONOMICALLY IMPORTANT LEGUMES

Leucaena (Hawaii strain) is the most important legume used as shade for plantation crops in Papua New Guinea. In some areas, for example, parts of the Gazelle Peninsula around Keravat and in the lower Markham Valley around Lae, introduced Leucaena was found by Thrower (1954-57) and by Shaw from 1955 to be well nodulated without, as far as is known, artifical inoculation.

Because of the proved suitability of Leucaena in those areas where it grew well with good nodulation, and the undoubted difficulty of establishment in many areas where no suitable strain of Rhizobium was present in the soil, cultures were established of Rhizobium isolated from Leucaena nodules in those areas

Photo: D. Shaw

**Plate II.—Inoculated Leucaena leucocephala as shade for Robusta coffee at Popondetta, an area where it had been practically impossible to establish uninoculated Leucaena**

where they occurred abundantly and with apparent efficiency. The supply of these cultures, made available free of charge to any planter or grower who required them, initiated the Rhizobium Supply Service.

Almost 14,000 bottles of Leucaena inoculum were sent out by the Department from August, 1956 to June, 1971, as shown in *Table* 1. Nearly 75 per cent of the cultures were used on the Papuan lowlands, mainly in the Popondetta area.

Because of the importance of Leucaena, one officer undertook research on the Leucaena-Rhizobium complex as his main problem. Published work arising from these studies (Trinick 1965) showed that Leucaena failed to nodulate with slow-growing root nodule bacteria isolated from 41 different tropical legumes, but successful nodulation was obtained with Rhizobia from tropical legumes which were fast-growing and had cultural characteristics similar to those of the Leucaena root-nodule bacteria. Three cultures isolated from Leucaena were successful in nodulating a wide range of tropical legumes including *Vigna sinensis*, *Phaseolus lathyroides*, *P. atropurpureus*, *Centrosema plumieri* and *Calopogonium mucunoides*; two of the three cultures nodulated *Medicago sativa*.

Later Trinick (1968) showed that Leucaena failed to nodulate with 94 of the 99 strains of Rhizobium tested, representing the seven recognized cross-inoculation groups. A group of legumes including *L. leucocephala*, *Mimosa invisa*, *M. pudica*, *Acacia farnesiana* and *Sesbania* spp. showed the properties of a cross-inoculation group of plants. Rhizobia isolated from these legumes were all fast-growers and nodulated Leucaena, often effectively, and also many other tropical legumes, including *Vigna sinensis*, which are usually nodulated effectively with slow-growing root nodule bacteria.

The results of field sowings of Leucaena with inoculated and uninoculated seed are given in a later section.

Other leguminous species used mainly for temporary shade include *Crotalaria anagyroides* which has been used mainly as the initial and temporary cover for Arabica coffee in the Highlands, and to a much less extent, *Tephrosia candida*. Both species nodulate without artificial inoculation in those areas where checks have been made, but Rhizobium cultures are available for those growers who wish to test the performance of plants from inoculated seed against uninoculated.

*Albizia fulva*, an indigenous species, was used initially on some Arabica coffee plantations as the permanent shade tree, but as it is very susceptible to the twig-deforming rust caused by *Uromycladium tepperianum* (Shaw 1963) it has been replaced by the introduced species, *A. stipulata*, which appears to be immune. *A. stipulata* has been noted as nodulated naturally in the field, and both species grow well without artificial inoculation.

The most important ground covers are *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium mucunoides*, although the latter is not now recommended. *P. phaseoloides* has also been used as a ground cover in the New Britain oil palm plantings, now over ten thousand acres in extent, all with inoculated seed. Usually all these legumes are nodulated in the field, but cultures are available for those growers who wish to inoculate. The total quantity of inoculum for *C. pubescens* and *P. phaseoloides* for all purposes (i.e., for ground cover and pasture) during 1956-71 was over 2000 bottles, as given in *Table* 1. The results of field sowings with inoculated and uninoculated seeds of these ground covers are given in a later section.

A variety of legumes has been under trial for use in pastures in both the lowlands and the highlands, and some species have been in use in commercial pastures for some time (Hill 1970b). Many of these species nodulate naturally in the field, but inoculum is available for growers who wish to inoculate, and it is recommended for those species which are new to any area. The amount of inoculum supplied for these species is shown in *Table* 1, and includes figures for *Centrosema pubescens* (1023 bottles), *Pueraria phaseoloides* (981 bottles, all purposes, i.e., ground covers and pastures) and


Photos: N. Mendham

*Plate* III.—Inoculated Pueraria phasedoides as ground cover in oil palm plantation, West New Britain. *A.* Young Pueraria growing from inoculated seed sown directly after burn with young transplanted oil palms in background. *B.* Established Pueraria cover over 2ft 6in high (about 80cm) between oil palms

other species just becoming popular, viz., *Desmodium* spp. (266 bottles), *Trifolium* spp. (247), *Phaseolus atropurpureus*[8] (207), *Glycine wightii*[9] (198), *Stylosanthes* spp.[10] (198) and *Dolichos* spp. (186). The results of inoculated and uninoculated field sowings are given in a later section.

From trials carried out mainly in the Markham Valley (unpublished reports and Hill 1970a) and by spot checks on the nodulation in village plantings, it has been found that inoculation is usually not necessary with peanuts, although cultures are available if required. It is recommended that soybeans be inoculated, especially in new areas.

The average indigenous food garden contains a wide variety of leguminous vegetables, such as *Psophocarpus tetragonolobus*, *Phaseolus lunatus; Dolichos lablab*[11] *and Vigna sesquipedalis*[12] although species such as *Phaseolus mungo, Phaseolus calcaratus, Vigna sinensis,*[12] *Canavalia ensiformis* and *Cajanus cajan* have not as yet been widely accepted into gardening practices and diet. All these village sowings have so far been made without inoculation, although inoculum is available if required.

Although as far as is known to the senior author, little or no use is made medically of species of *Cassia* such as *C. alata* and *C. fistula* or of *Tamarindus indicus* but those plants which are grown do so without artificial inoculation.

Some species of *Derris* are indigenous while others have been introduced, and to date none has been artificially inoculated. Trinick (1968) isolated from a nodule on *D. elliptica* and found the culture effective on *Vigna sinensis* and *Phaseolus lathyroides* but no nodulation occurred on Leucaena.

Many foreign legumes, especially introduced horticultural species and weeds, as well as long-established and indigenous species, grow well in Papua New Guinea without artificial inoculation. These include *Acacia farnesiana*, and species of *Aeschynomene*, *Alysicarpus*, *Bauhinia*, *Calopogonium*, *Cassia*, *Caesalpinia*, *Centrosema*, *Clitoria*, *Crotalaria*, *Delonix* (*D. regia*, Poinciana), *Desmodium*, *Erythrina*, *Mimosa* (especially *M. invisa* and *M. pudica*), *Peltophorum* (especially *P. pterocarpum*, syn. *P. ferrugineum*), *Prosopsis*, *Pueraria triloba* (syn *P. lobata* and *P. thunbergiana*), *Samanea saman* (rain tree), *Sesbania aculeata* and *Uraria lagopodioides*, as well as the indigenous leguminous forest components in the genera *Adenanthera*, *Albizia*, *Cathormion*, *Erythrina*, *Inga*, *Inocarpus*, *Cassia*, *Kingiodendron*, *Maniltoa*, *Pahudia* (=*Afzelia*), *Pericopsis*, *Piptadenia*, *Pithecellobium* (*sensu lato*) and *Pongamia*. The roots of the above, and of other indigenous legumes are being checked for presence or absence of nodules, and effectiveness if present, whenever possible.

## SUPPLY OF CULTURES TO OVERSEAS COUNTRIES

During the 15 years since the inception of the Rhizobium Supply Service cultures have been supplied for several overseas countries.

The countries receiving cultures have been Australia, the British Solomon Islands Protectorate, Cocos Island, Costa Rica (Central America), French Polynesia, Gilbert Islands, Indonesia, Malaysia, South Africa, Trinidad, U.S.A., West Irian (Indonesia), Western Samoa. The cultures forwarded have been for the following hosts: *Centrosema pubescens*, *Flemingia congesta*, *Glycine max*, *G. wightii*, *Leucaena leucocephala*, *Phaseolus atropurpureus*, *Pisum-Vicia* group, *Stylosanthes guianensis*, *Trifolium* spp., *Vigna sinensis*. Cultures for *L. leucocephala* were particularly in demand.

8. The Director, Royal Botanic Gardens, Kew, has recently stated (letter H0005/71) that one of their specialists thinks that there is a good case for maintaining *Macroptilium* separate from *Phaseolus* —thus this species would be *Macroptilium atropurpureum* (DC.) Urb.

9. Syn. *G. javanica.*

10. Including *Stylosanthes guianensis*, which is sometimes designated *S. guyanensis* or *S. gracilis*. The Director, Royal Botanic Gardens, Kew, has recently (letter H4481/70) advised the senior author that "*Stylosanthes gracilis* Kunth is a synonym of *S. guianensis* (Aubl.) Sw. according to the latest revision of Mohlenbrock in *Ann. Missouri Bot. Gard.* 44 (1957). We prefer the spelling '*guianensis*' to '*guyanensis*', because Aublet used this rendering for the original description, though the plate was labelled '*guyanensis*' ".

11. Given by some authors as *Lablab niger* Medik.

12. Usually given now as *Vigna unguiculata* subsp. *sesquipedalis* and *Vigna unguiculata* subsp. *unguiculata* respectively.

*Figure.*—Copy of record sheet sent to growers for inoculated legume sowings

DEPARTMENT OF AGRICULTURE, STOCK AND FISHERIES

LEGUME RHIZOBIUM TRIAL

Sheet 1

Host _____

Culture No _____

Owner _____

Address _____

Locality _____

Date despatched _____

Date sown _____

Acreage or amount sown _____

_____

2 months after sowing:

| INOCULATED | | | UNINOCULATED | | |
|---|---|---|---|---|---|
| Height or spread* | Colour* | Nodules* | Height or spread* | Colour* | Nodules* |
| | | | | | |

Other observations

Signed.....

*Height or spread: Give average in inches and feet; mark H or S.

*Colour: State whether green, yellow-green, etc., or state whether inoculated plants are greener than (or the same as) the uninoculated plants.

*Nodules: Nodules on the roots are very easily detached. Carefully remove or rinse soil from the roots of about six plants and state whether nodules are present or not, abundant or sparse. Cut a few big ones in half and state whether the inside is pink-red-brown or white-grey-green.

## RESULTS OF FIELD SOWINGS BY GROWERS

*General*

Since 1956 Record Sheets have been forwarded with most batches of cultures to both private growers and agricultural officers, the latter being responsible for distribution to indigenous growers and for trial plantings in new areas. The present sheet for readings two months after sowing is reproduced in the *Fig*; a similar sheet is also sent for recordings

at four months after sowing. Previously, readings were sometimes obtained for two, four and six months and even for longer periods, with a maximum of six readings.

With each sheet went a request that the grower sow a little uninoculated seed when the main inoculated sowings were made, so that he could see for himself the result of inoculation. In the 15-year period from 1956 to 1971, 731 Record Sheets were returned, while some other growers sent qualitative comments. The readings were studied and the grower advised whether he should or should not continue to artifically inoculate seed of that plant species in his area.

In the case of no response to inoculation, the grower was advised to check his technique of inoculation and sowing and to note carefully the results of his next sowing with new cultures. On occasion lack of response to nodulation was perhaps due to time taken by cultures to reach their destination.

In *Table* 2 the results are summarized as to the various degrees of effective nodulation, or ineffective nodulation, or no nodulation, of both inoculated and uninoculated seed for 615 Record Sheets returned for inoculations with the main strains of Rhizobium in the Supply Service.

It will be noted that:—

(1) In 36.9 per cent of the Records uninoculated plants showed nodulation as effective as occurred on the inoculated plants indicating either

($a$) the presence of a naturally occurring effective strain in the soil of that area, or

($b$) build-up of an introduced effective strain previously artificially inoculated on seed sown in the area.

(2) In 21.8 per cent of the Records, uninoculated plants were either sparsely nodulated, nodulated with a strain not as effective as the supplied strain, or nodulated ineffectively, the latter as determined in some cases by inspection of the interior of the nodules by the agricultural officer or grower. Some of these results are given in detail in a later section.

(3) In 15.0 per cent of the Records no nodulation occurred on the uninoculated controls at all. Some of these results are given in a later section.

Inoculation of the seed can be seen to have been well worthwhile in cases (2) and (3).

(4) In 5.7 per cent of the Records, inoculation produced plants which were not well nodulated, not a good green colour or which had some or many ineffective nodules, while the controls were ineffectively nodulated. In 1.3 per cent of the cases nodulation was effective at the next reading.

(5) In 4.7 per cent of the records inoculated plants were as in (4) above while the controls were without nodules. At a later reading 0.5 per cent of the inoculated plants were effectively nodulated.

(6) In 0.7 per cent of the Records, no nodulation was obtained with inoculation and controls showed sparse or ineffective nodulation.

(7) In 12.4 per cent of the cases no nodulation was obtained in either inoculated or control sowings. In some cases a further reading was taken later and then 2.8 per cent had effective and 0.3 per cent ineffective nodulation of inoculated plants.

In the cases of (4), (5), (6) and (7) above, strains were checked for purity in the laboratory, and growers were advised to watch age of cultures in the future, to check techniques of inoculation and sowing, or to take extra care in lifting plants from the soil for checks on the presence or absence of nodules in the future; soil nutritional aspects were also considered and in some cases further sowings with selected fertilizing treatments were carried out. Some experiments are also under way with pelletting in order to determine whether this is desirable for some species on certain soils.

(8) In 2.9 per cent of the Returns, records were incomplete in some way, either because of death of controls or no controls were sown, or the area was flooded or waterlogged.

*Table* 2.—Analysis of nodulation reports for field sowings for standard strains[1] of Rhizobium on various hosts for 1956-1971

| Host | Sites | Plantings | Record Sheets Returned | Record Sheets for Standard Strains | Nodulation of Inoculated v. Uninoculated plants in the following classes: Effective v. Effective | Effective v. Ineffect.[2] | Effective v. No nods. | Ineffect. v. Ineffect. | Ineffect. v. No nods. | No nods. v. Ineffect. | No nods. v. No nods. | Information Incomplete |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arachis hypogaea | 3 | 5 | 7 | 7 | 7 | | | | | | | |
| Cajanus cajan | 3 | 3 | 5 | 2 | 2 | | | | | | | |
| Calopogonium caeruleum | 2 | 2 | 3 | 3 | 2 | | | | 1 | | | |
| C. mucunoides | 4 | 5 | 7 | 4 | 4 | | | | | | | |
| Centrosema pubescens | 21 | 27 | 59 | 33 | 16 | 5 | 1 | 4 | 5 | | 1 | 1 |
| Crotalaria laburnifolia | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| C. striata | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| Crotalaria sp. | 1 | 1 | 5 | 0 | | | | | | | | |
| Desmodium intortum | 15 | 16 | 26 | 22 | 8 | 8 | 3 | | | | 2 | 1 |
| D. uncinatum | 12 | 14 | 19 | 18 | 5 | 3 | 6 | 1 | 1 | | 1 | 1 |
| Desmodium sp. | 2 | 3 | 5 | 5 | 1 | | 4 | | | | | |
| Dolichos axillaris | 7 | 8 | 13 | 13 | 7 | | 2 | 2 | 1 | | 1 | |
| D. biflorus | 3 | 4 | 6 | 6 | 6 | | | | | | | |
| D. lablab | 11 | 13 | 18 | 17 | 6 | 3 | 2 | 2 | 2 | | 1 | 1 |
| Flemingia congesta | 6 | 7 | 8 | 5 | 4 | | | | | | 1 | |
| Glycine max | 31 | 46 | 70 | 70 | 25 | 13 | 10 | 5 | 6 | | 8 | 3 |
| G. wightii | 21 | 39 | 75 | 68 | 39 | 10 | 2 | 6 | 3 | | 6 | 2 |
| Leucaena leucocephala | 41 | 76 | 192 | 191 | 35 | 71 | 43 | 4 | 2 | 2 | 33 | 1 |
| Lotononis bainesii | 2 | 2 | 3 | 2 | | | | | | | 1 | 1 |
| Lupinus angustifolia | 1 | 1 | 3 | 3 | | | | | | | 2 | 1 |
| L. digitatus | 1 | 1 | 3 | 3 | | | | 1 | | 1 | | 1 |
| L. luteus | 1 | 1 | 3 | 3 | | | | | | | 3 | |
| Lupinus sp. | 2 | 2 | 4 | 4 | 2 | 1 | | 1 | | | | |
| Medicago sativa | 3 | 3 | 4 | 4 | | 1 | | 1 | | | 2 | |
| Mimosa sp. | 1 | 1 | 1 | 0 | | | | | | | | |
| Mundulea sericea | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| Ornithopus compressus | 1 | 1 | 3 | 3 | | | | | 2 | | 1 | |
| Phaseolus atropurpureus | 24 | 29 | 55 | 34 | 22 | 2 | 2 | 3 | 1 | | 2 | 2 |
| P. calcaratus | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| P. lathyroides | 4 | 4 | 6 | 3 | 3 | | | | | | | |
| P. vulgaris | 3 | 7 | 8 | 0 | | | | | | | | |
| Phaseolus sp. | 2 | 2 | 4 | 4 | 1 | | | | 2 | | 1 | |
| Pisum sativum | 2 | 2 | 4 | 0 | | | | | | | | |
| Psophocarpus palustris | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| Psophocarpus tetragonobolus | 1 | 1 | 1 | 1 | | 1 | | | | | | |
| Pueraria phaseoloides | 6 | 6 | 9 | 8 | 2 | 5 | | | | | | 1 |
| Stizolobium deeringianum | 2 | 2 | 3 | 3 | 2 | | | | | | 1 | |
| Stylosanthes guianensis | 10 | 13 | 18 | 11 | 5 | 2 | 1 | 1 | 1 | | 1 | |
| S. humilis | 3 | 4 | 5 | 2 | | | | | | | | 2 |
| Stylosanthes sp. | 1 | 1 | 3 | 0 | | | | | | | | |
| Tephrosia noctiflora | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| T. vogelii | 1 | 1 | 1 | 0 | | | | | | | | |
| Trifolium pratense | 10 | 15 | 21 | 20 | 4 | 2 | 6 | 2 | 1 | | 5 | |
| T. repens | 8 | 14 | 20 | 16 | 1 | 3 | 6 | 2 | 1 | 1 | 2 | |
| T. subterraneum | 1 | 1 | 2 | 2 | 1 | 1 | | | | | | |
| Trifolium sp. | 2 | 2 | 3 | 3 | | | 2 | | | | 1 | |
| Vicia atropurpurea | 1 | 1 | 1 | 0 | | | | | | | | |
| Vicia sativa | 1 | 1 | 1 | 0 | | | | | | | | |
| Vigna luteola | 6 | 6 | 9 | 7 | 4 | 1 | 2 | | | | | |
| Vigna sesquipedalis | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| Vigna sinensis | 5 | 6 | 8 | 8 | 6 | 2 | | | | | | |
| Totals | 295 | 406 | 731 | 615 | 227 | 134 | 92 | 35 | 29 | 4 | 76 | 18 |
| | | | | | % 36.9 | 21.8 | 15.0 | 5.7* | 4.7* | 0.7 | 12.4* | 2.9 |

1 Standard strains as designated in Table 1

2 "Ineffective" in this case includes ineffective, sparse effective and not as effective

* In some cases later readings showed improved nodulation in inoculated plants

Even so, some of these Returns were of interest. For example, a report on the performance of *Lotononis bainesii* at Mendi stated that inoculated plants were 4½ inches high with abundant nodules, with the further remark, "it has taken a good hold and has come away well. Uninoculated seed showed but was weak and spindly and after the very cold night of 16th June, petered away to nothing."

*Details of some sowings*

In this section details are given of the results of some of the sowings where nodulation of inoculated plants was effective and where nodulation of the controls was either:—

(1) effective but sparse, or not as effective as the inoculated, or ineffective, or

(2) lacking.

In many cases the records were substantiated by qualitative statements as to appearance and vigour of the inoculated and uninoculated controls, amount of leafage and onset of flowering, and occasionally yield where applicable. The information given in the Tables is, therefore, a selected summary of only the main points.

A reading given in the Tables may be only one of a series taken for one particular sowing, the others being omitted. Some of the readings are for different periods after sowing, so that the only figures which can be compared directly in the Tables are the uninoculated with its own inoculated. Also, the sowings are at different altitudes and rainfalls, and for some species especially (for example, as shown in *Table* 3 for Leucaena), altitude affects the height of the plants.

Details of some of the results for sowings with effective nodulation of inoculated plants, and with effective but sparse, or less effective or ineffective nodulation of uninoculated controls are given in *Table* 4, and the results of sowing with effectively nodulated inoculated plants but with uninoculated controls lacking nodulation altogether are given in *Table* 5.

It will be seen that inoculation in these cases was well worthwhile.

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*Table* 3.—Height of inoculated *Leucaena leucocephala* at sites differing in rainfall and altitude at 6 months after sowing[1]

| Site | Region | Average Annual Rainfall (in)[2] | Altitude (ft)[3] | Height (ft)[3] |
|---|---|---|---|---|
| Madang .... .... | ....NGL | 139 | 25 | 12 |
| Popondetta .... | ....PL | 95 | 400 | 10-12 |
| Pakia Village nr Kieta | ....B | 119+[4] | 500[5] | 10 |
| Erap .... .... | ....NGL | 49 | 856 | 8- 9 |
| Dumpu .... .... | ....NGL | | 870 | 6 |
| Goroka .... .... | ....EH | 76 | 5200 | 3.5 |
| Mt Hagen .... | ....WH | 103 | 5500 | 3 |
| Aiyura .... .... | ....EH | 85 | 6000 | 2 |

1 Sowings made at different times and read by different observers

2 1 inch = 100 points = 25.4 mm

3 1 foot = 0.305 m

4 Rainfall estimated to be higher than 119 inches, the average recorded for Kieta, the nearest recording centre

5 Altitude estimated only

*Table* 4.—Comparison of size, colour and nodulation of some inoculated hosts at different sites with poorer performance of controls[1]

| Host | Site | Region[2] | Inoculated | | | Uninoculated | | |
|---|---|---|---|---|---|---|---|---|
| | | | Height (or spread) (in) | Colour of Plant[3] | Nodules | Height (or spread) (in) | Colour of Plant | Nodules |
| Centrosema pubescens | Popondetta | PL | 5-20 | G | med.-large, av. 5.7 per plant | 14 | G | very small, white, av. 6.8 per plant |
| C. pubescens | Leron Plains Markham V. | NGL | av. 72 | YG | present | 48-60 | YG | present |
| Desmodium intortum | Kagua | SH | 12 | G | fair | 6-9 | LG | few |
| D. intortum | Mendi | SH | 6-18 | BG | abundant | 2-6 | lighter | sparse |
| D. intortum | Bundi | FT | 30 | G | abundant | 20 | G | less than inoculated |
| Desmodium uncinatum | Mendi | SH | 6-18 | PG | abundant | 2-6 | PG | sparse |
| Dolichos lablab | Popondetta | PL | 24-41 | G | large, red inside, 9.7 per plant | 20-32 | G | large, green-brown, 8 per plant |
| Glycine wightii | Passam, Sepik | NGL | 15-28½ | G | very abundant | 12-18 | PG | sparse |
| G. wightii | Mendi | SH | 7 | PG | abundant | 4½ | PG | sparse |
| G. wightii | Bundi | FT | 12 | G | sparse | 5 | G | very sparse |
| G. wightii | Kurakakaul | NB | 30-45 | G | present | 20-30 | G | present |
| G. max | Mendi | SH | 24 | PG | present | 18 | PG | sparse |
| G. max | Ialibu | SH | 10 | Y | abundant | 9 | Y | on 5% of plants, sparse |
| G. max | Bula nr Salamaua | NGL | 30 | DG | abundant | 25 | PG | very few |
| G. max | Goroka | EH | 24 | G | abundant | 18 | G | sparse |
| G. max | Korn Farm | WH | 13 | G | plentiful | 10 | G | few, small |
| G. max | Wabag | WH | 13-16 | G | abundant | 11-16 | G | sparse |
| Leucaena leucocephala | Kusi Village | B | 9 | G | abundant | 5 | YG | abundant to sparse |
| L. leucocephala | Ou Ou Creek | PL | 36 | G | present | 12 | G | sparse |
| L. leucocephala | Aropa Plantation | B | 76 | G | present | 54 | G | sparse |
| L. leucocephala | Kurakakaul | NB | 54 | DG | abundant | 28 | YG | sparse |
| L. leucocephala | Tapini | FT | 8-10 | DG | abundant | 5-6 | G-Y | sparse |
| L. leucocephala | Kubuna Estate | FT | 66 | DG | plentiful | 30 | LG | sparse |
| L. leucocephala | Popondetta | PL | 72 | DG | abundant | 60 | DG | abundant |
| L. leucocephala | Wasangabang Vill. nr Bogia | NGL | 30 | G | present | 24 | YG | on some plants |
| L. leucocephala | Goroka | EH | 72 | DG | present | 42 | MG | present |
| L. leucocephala | Bainyik | NGL | 12 | DG | large, plentiful | 5 | | almost nil |
| L. leucocephala | Arawa Plantation (Site 1) | B | 60 | G | present | 25 | G | present |
| L. leucocephala | Arawa Plantation (Site 2) | B | 65 | G | present | 50 | G | present |
| L. leucocephala | Dumpu | NGL | 60-72 | DG | heavy | 12 | Y or dying | light |
| L. leucocephala | Ukua Estate via Kairuku | PL | 60 | G | present | 48 (uneven) | G | present |
| Lupinus sp. | Ogelbeng | WH | 26 | BG | 4-7 nods on 4 plants in 6 | 18 | G | 1-4 nods on 3 plants in 6 |
| Phaseolus atropurpureus | Passam | NGL | 3-9 | PG | fairly abundant | 2-4 | PYG | sparse |
| P. atropurpureus | Bundi | FT | 18x60 | G | abundant | 8x18 | G&Y | sparse |
| Phaseolus vulgaris | Rabaul | NB | 22 | DG | abundant, pinkish | 18 | G | sparse, small greyish |
| Pueraria phaseoloides | Parusi Village | NI | 60 | G | plentiful, pink | 24 | G | some present, green |
| P. phaseoloides | Kwolakessi | N3 | 52 | G | 31 per plant | 42 | PG | 7 per plant |
| Stylosanthes gracilis | Bisianumu | FT | up to 10½ | G | 10 per plant | up to 8 | G | few small nods on larger plants |
| Vigna sinensis | Passam | NGL | 22-35 | DG | abundant | 18-27 | G | sparse |

1 Readings taken at various periods after sowing; descriptive terms used are as given by the growers

2 Regions of Papua New Guinea: PL Papuan Lowlands; NGL New Guinea lowlands; SH Southern Highlands; WH Western Highlands; EH Eastern Highlands; FT Foothills; NB New Britain; NI New Ireland; B Bougainville

3 G = green; Y = yellow; B = blue; D = dark; L = light; P = pale

*Table* 5.—Comparison of size, colour and nodulation of some inoculated hosts at different sites with performance of non-nodulated controls[1]

| Host | Site | Region[2] | Inoculated | | | Uninoculated | | |
|---|---|---|---|---|---|---|---|---|
| | | | Height (or spread) (in) | Colour of Plants[3] | Nodules | Height (or spread) (in) | Colour of Plants | Nodules |
| Desmodium intortum | Tari | SH | 15 | G | abundant | 6-8 | G | - |
| Desmodium sp. | Komplam | WH | 36 | G | sparse | 24 | G | - |
| Dolichos lablab | Banz | WH | 14 | G | abundant | 8 | LG | - |
| Glycine wightii | Kokoda | FT | 18 | G | present | 14 | GY | - |
| G. max | Henganofi | EH | 15 | VDG | abundant | 12 | PG | - |
| G. max | Tente via Mendi | WH | 10-26 | G&Y | large on large plants | 6-8 | GY | - |
| G. max | Baiyer R. | WH | 18-24 | | sparse large nods on 1 in 3 plants, pink inside | 10 | | - |
| G. max | Wapenamanda | WH | 13-22 | BG | sparse to abundant | 9 | LG | - |
| G. max | Bula | NGL | 15 | DG | present | 11½ | G | - |
| Leucaena leucocephala | Ou Ou Creek (Site 1) | PL | 36-48 | G | abundant | 12-24 | YG | - |
| L. leucocephala | Ou Ou Creek (Site 2) | PL | 12 | G | sparse | 4 | YG | - |
| L. leucocephala | Kusi Vill. | B | 29 | G | fairly abundant | 10 | Y | - |
| L. leucocephala | Bakankani Vill. | B | 37 | G | many | 11 | Y | - |
| L. leucocephala | Kubuna Estate | PL | 14 | G | abundant | 8 | LG | - |
| L. leucocephala | Pakia Vill. | B | 120 | G | plentiful | 48 | LG | - |
| L. leucocephala | Boregaina | PL | 2-18 | G-BY | plentiful | 2-12 | DG-Y | - |
| L. leucocephala | Aiyura | EH | 24 | DG | 35 nods per plant | 24 | DG | - |
| L. leucocephala | Aitape | NGL | 15 | G | present | 5 | G | - |
| L. leucocephala | Madang | NGL | 4-6 | DG | present | 4-6 | YG | - |
| L. leucocephala | Bainyik, Sepik | NGL | 84 | | heavy | 42 | | - |
| L. leucocephala | Goroka | EH | 42 | G | not very apparent (possibly left behind in soil) | 18 | G | - |
| L. leucocephala | Madang | NGL | 180 | G | numerous | 108 | MG | - |
| L. leucocephala | Ukua Estate nr Kairuku | PL | 10 | G | present | 10 | PG | - |
| L. leucocephala | Karimui | EH | 8 | G | large, pink | 6 | G | - |
| Phaseolus atropurpureus | Kagua | SH | 6 | G | med. to good | virtually nil | | - |
| P. atropurpureus | Tarawa, Gilbert Islands (coral atoll) | - | 3-4 | G | present, pink inside, up to 3/16 inch diameter | 1 | LG-Y | - |
| Pisum sativum | Minj | WH | 21 | G | sparse | 15 | YG | - |
| Stylosanthes guianensis | Baiyer R. | WH | 12 | DG | sparse | 12 | LG | - |
| Trifolium pratense | Yamonti via Laiagam | SH | 5 | DG | abundant | 1 | Y | - |
| T. pratense | Laiagam | SH | 6-8 | DG | fairly big, v. plentiful | 4-6 | YG | - |
| T. pratense | Minj | WH | 10 | G | abundant | 8 | Y | - |
| T. repens | Banz | WH | 18 | LG | abundant | 15 | LG | - |
| T. repens | Yamara via Laiagam | SH | 12 | DG | abundant | 1 | YG | - |
| Vigna marina | Tari | SH | 8-10 | G | small, sparse | 4 | PG | - |

1 Readings taken at various periods after sowings; descriptive terms used are as given by the growers
2 See Table 4
3 G = green; Y = yellow; B = blue; D = dark; L = light; P = pale; V = very; M = medium

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## CORRIGENDA

p.22, *Table* 2: *Psophocarpus tetragonobolus* should be *Psophocarpus tetragonolobus.*

p.24, *Table* 4: *L. leucocephala,* Goroka, given as MG should be G.

p.25, *Table* 5. *L. leucocephala,* Boregaina, given as G-BY should be G-Y.

Some name changes have occurred with some of the species listed in *Tables* 2 and 4, and for these see text.

# REVIEW OF THE COCONUT LEAF MINER AND TREE HOPPER PROBLEMS IN PAPUA NEW GUINEA, WITH A REPORT ON THEIR INCIDENCE ON SOUTHERN NEW BRITAIN

G. M. Baloch*


## ABSTRACT

*A brief review is given of the coconut hispid leaf miner* Promecotheca papuana *Csiki and coconut tree hoppers* (Segestidea *spp.*, Eumossula gracilis *Will. and* Pseudonicraza szentia *Will.*) *in Papua New Guinea.* P. papuana *is distributed throughout New Britain, Manus Island, Duke of York Islands, New Ireland District and the north-east of mainland New Guinea. However, serious outbreaks have occurred only on New Britain and the Duke of York and Manus Islands. It has never been of any importance on New Ireland and in the north-east of New Guinea. Tree hoppers are widely distributed in Papua New Guinea and their status as a pest varies from place to place.*

*Although a number of indigenous natural enemies have been responsible for a considerable degree of control of these two coconut pests in Papua New Guinea, the periodic occurrence of serious outbreaks necessitated the introduction of exotic parasites from the Indonesian area in the late* 1930*s. These introductions consisted of* Pediobius parvulus *Ferriere* (*Eulophidae*) *against the larvae and pupae of* P. papuana *and* Leefmansia bicolor *Waterst.* (*Encyrtidae*), Doirania leefmansi *Waterst.* (*Trichogrammatidae*), *and* Stethynium *sp.* (*Mymaridae*) *against the eggs of the various species of tree hoppers. In spite of successful establishment of and good control exerted by these parasites in most of the affected areas, periodic outbreaks of both* P. papuana *and tree hoppers still occur.*

*The recurrence of* Promecotheca *outbreaks could possibly arise through*:

1. *Population crashes of the beetle as a result of either unfavourable environmental conditions or disease followed by drastic reductions in parasite populations;*
2. *The lack of alternate hosts for the parasites; and*
3. *The existence of some host plants of* P. papuana *in which the larval and pupal parasites may not be able to successfully attack the host.*

*More detailed investigations on the ecology of tree hoppers and their natural enemies are necessary before an understanding of the tree hopper problem can be attained.*

*A survey of southern New Britain in April to May,* 1969 *revealed that the important parasites of* P. papuana, *with the exception of* Eurytoma promecothecae, *were fairly well distributed throughout the areas visited, but that those of* Eumossula gracilis *were mostly absent. Almost all the localities infested with* P. papuana *appeared to be those where the insect was accidentally brought in and the parasites became effective only after one and a half to two years after the pests' introduction.*


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## INTRODUCTION

COCONUT palm (*Cocos nucifera*) in Papua New Guinea is subject to attacks, to varying degrees, of about 80 species of insects belonging to 64 genera (Dumbleton 1954; Dun 1954; Froggatt 1940; Froggatt and O'Connor 1940; Lever 1969). Tree hoppers (*Eumossula gracilis* Willemse, *Segestidea* spp., and *Pseudonicraza szentia* Willemse) and the hispid leaf miner (*Promecotheca papuana* Csiki) are among the dozen or so more important insects which cause economic damage at high population densities (Froggatt and O'Connor 1940).

A brief review of both these problems and a report on the incidence of the tree hopper *Eumossula gracilis* and the leaf miner *P. papuana* in southern New Britain is given below.

## PROMECOTHECA PAPUANA

The genus *Promecotheca* and its geographical distribution have been well discussed by Gressitt (1959). Of about 35 species with a Philippine—Papuan distribution, *P. papuana* Csiki is the only one which is a pest of coconut in Papua New Guinea.

*P. papuana* has been recorded from New Britain, Manus Island, Duke of York Islands, New Ireland and the north-east coast of mainland New Guinea (*Figure* 1). It has not been of any importance in the last two localities (Gressitt 1959), but the first three localities have suffered heavy damage from time to time. Outbreaks have been particularly severe both in intensity and frequency on New Britain, especially at Lindenhafen and Linga Linga Plantations on the south and north coasts, respectively.

Life-history studies on *P. papuana* have been reported by O'Connor (1940), Froggatt and O'Connor (1941) and Gressitt (1959). Eggs are mostly laid on the underside of leaflets in straw-coloured egg cases. The number of eggs per case varies from 1 to 6. On Manus Island and the Gazelle Peninsula the majority of

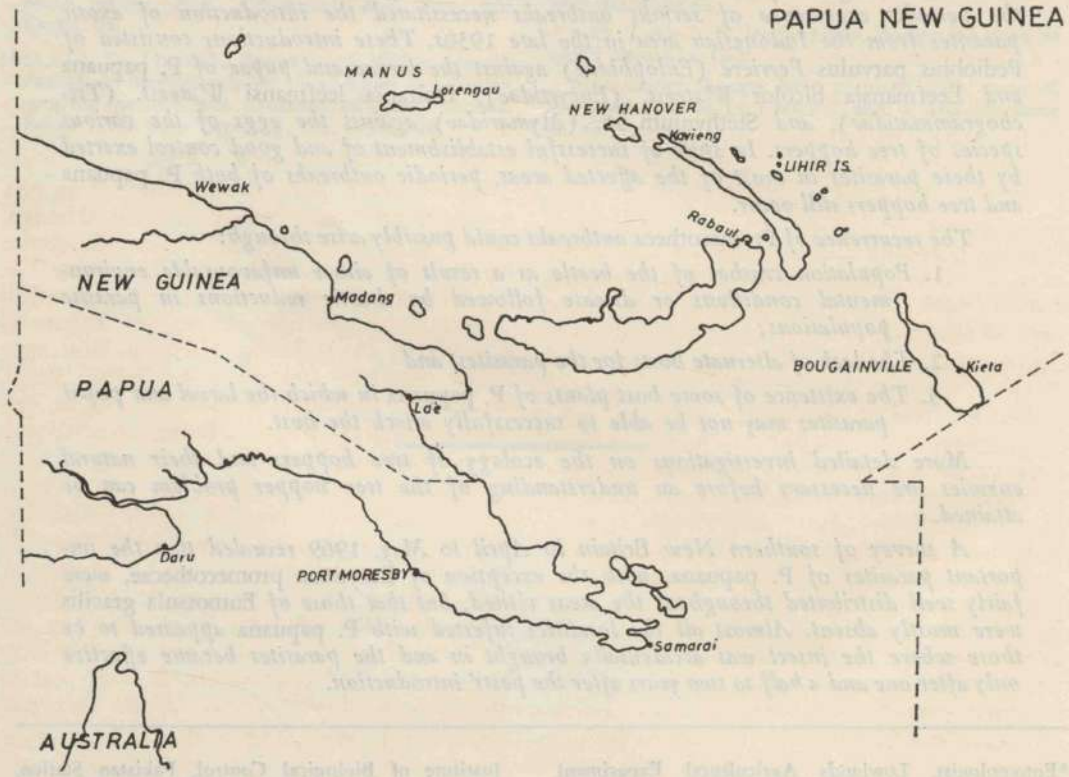


*Figure* 1.—Papua New Guinea

egg cases have 3 eggs, whilst 5 is the usual number in the Lindenhafen area. The egg stage lasts from 11 to 17 days.

The female of *P. papuana* chews a slit on the leaf surface before ovipositing. Thus, the young larvae, on hatching, enter directly into the inner leaf tissue and feed as leaf miners. The larvae arising from one egg case feed side by side in the same mine and also stop feeding at the same time to moult. There are three larval instars and the entire larval period varies from 17 to 30 days. On the completion of feeding, the fully grown larvae retreat from the end of the mine and pupate anywhere in the dry portion of it, as they do at each moult.

The pupae are to be found in the mines with their dorsal surface facing the underside of the leaf. The prepupal and pupal periods last for 13 days and the imagoes remain in the mines for another two days before emerging.

According to Froggatt and O'Connor (1941), copulation takes place two to three weeks after emergence and oviposition commences six to ten days later. Gressitt (1959), however, reports a pre-mating period of one week and a pre-oviposition period (excluding pre-mating) of two weeks. Both observations therefore agree that there is a period of three to four weeks from the emergence of adults to oviposition.

O'Connor (1940) has reported adult longevity to be as long as five months or more under cage conditions, but Gressitt (1959) suggested that longevity could be much shorter under natural conditions because of unfavourable environmental conditions and the incidence of disease.

On the Gazelle Peninsula, until the great volcanic eruption of 1937, the pest had been kept under control by the indigenous hymenopterous egg parasite *Closterocerus splendens* Kowalski (Eulophidae), and larval parasites *Eurytoma promecothecae* Ferriere (Eurytomidae) and *Apleurotropis lalori* Girault (Eulophidae). The eruption caused a serious upset in the natural balance through the destruction of parasites and was followed by a major outbreak of *P. papuana*. The parasites, however, regained control within three to four months (Froggatt and O'Connor 1941) and the position has since remained mostly unchanged except for periodic outbreaks in small pockets.

In Fiji, a related species, *Promecotheca coeruleipennis* Blanchard, became a serious pest in 1929 when dry weather encouraged the build-up of the predatory harvest mite *Pyemotes ventricosus* Newport which destroyed young stages of both *P. coeruleipennis* and its parasites. This caused a 'one-stage' condition to develop (one-stage condition according to Gressitt (1959) is the occurrence of a single cycle or generation at one time, i.e. when a population in a given area consists entirely of one stage or two successive stages such as adults and eggs, eggs and young larvae, mature larvae and pupae, or pupae and adults). Introduction of the pupal parasite *Pediobius parvulus* Ferriere (Eulophidae) from Java solved the Fijian leaf miner problem and no further outbreaks have been reported (Taylor 1937).

In view of the recurrence of outbreaks and the absence of pupal parasites of *P. papuana* in Papua New Guinea *P. parvulus* was introduced into New Britain, Manus Island and New Ireland in 1938 and soon became established (Froggatt and O'Connor 1941). Further outbreaks have continued to occur, however, especially at Linga Linga and Lindenhafen Plantations, sometimes simultaneously, although they are on opposite coasts of New Britain and have their seasons reversed.

Parasites of *P. papuana* apparently afford very good control over a period of time although, according to Gressitt (1959), outbreaks appear to develop once every 10 to 15 years. The egg parasite *C. splendens* has been reputed to cause a one-stage condition in New Britain as a result of its ability to parasitize host eggs to the extent of 100 per cent (DASF 1968). Because of the total destruction of eggs, the larval and pupal parasites starve to death and the one-stage condition develops.

The leaf miner problem in Papua New Guinea thus still remains partly unsolved. Population build-up cannot definitely be associated with either the effects of weather or the action of the harvest mite *P. ventricosus*. Very often the problem only comes to the attention of entomologists when a serious outbreak occurs, and consequently it is too late to study the factors responsible for the outbreak.

Gressitt (1958) studied the ecology of *P. papuana* and concluded that parasites are capable of keeping the insect under control,

but that from time to time unknown factors make them ineffective. By this he perhaps meant that the unknown factors caused an increased death rate for the natural enemies.

It is possible that environmental factors (high humidity?) at Linga Linga, and perhaps also at Lindenhafen, make the adults of *P. papuana* susceptible to disease which causes a rapid decline in their numbers. This would entail even faster reduction in the parasite populations, possibly to the point of near extinction. The pest populations, under favourable conditions, would increase faster than those of the parasites and an outbreak would result.

Although coconut palm is the preferred food plant of *P. papuana*, nipa palm (*Nipa fruticans*), is also fed on. Under outbreak conditions adults can also feed and deposit eggs on oil palm (*Elaeis guineensis*), but the larvae are unable to complete their development on it (Gressitt 1959). Recently all stages of this hispid have been found on a cluster palm (? *Ptychosperma* sp.) at the Lowlands Agricultural Experiment Station, Keravat, at a time when the populations in the area were low.

No signs of parasitism of any stage could be found on ? *Ptychosperma* sp., but it is not known whether this was due to the scarcity of eggs and larval mines or the unsuitability of this host plant for the parasites. However, it could well be that *P. papuana* parasites behave differently when the host insect develops in different host plants, as has been reported by Smee (1965) for the braconid larval parasite *Apanteles tirathabae* Wilkinson parasitizing *Tirathaba rufivena* Walker on nipa and coconut palms. Thus, it is possible that the host plant range of *P. papuana* is wider than that known at present, and some of these plants might have unfavourable morphological characteristics that prevent successful parasitism. Such plants could serve as potential foci for the development of outbreaks.

Under low population and multiple-stage conditions high adult numbers have almost always been observed on young palms (Gressitt 1959). Personal observations for over a year at Baliora Plantation on the Gazelle Peninsula support this. Mortality of eggs from natural enemies on this plantation remained comparatively higher on the older palms. To date, this behaviour pattern has not been considered to be of great significance in the population ecology *P. papuana* (Gressitt 1959) but it would appear that outbreaks could eventually arise from such situations.

Thus, factors responsible for *P. papuana* outbreaks in Papua New Guinea are still not definitely known. A long term study of population fluctuations and factors causing these fluctuations should be carried out in order to arrive at an understanding of the problem. However, population crashes of the pest resulting from unfavourable environmental conditions or diseases which lead to a drastic reduction in parasite populations, the possibility of the existence of some host plants of *P. papuana* in which the various stages of the pest may not be easily accessible to the parasites, and the possible lack of alternate hosts for the parasites (especially of *P. parvulus*), are suggested as possible reasons for the recurrence of *Promecotheca* outbreaks in Papua New Guinea.

Until the factors responsible are fully known, chemical control measures can only be recommended when the insect is in the one-stage condition and parasite activity is very low. DDT/BHC dust applied from the ground at the rate of ½ lb per palm has given good results under such conditions.

## COCONUT TREE HOPPERS

Coconut tree hoppers were previously known under the generic name of *Sexava* and two species, *nubila* and *novae-guineae*, were recorded from Papua New Guinea, the former from New Britain, New Ireland, New Hanover and Madang and the latter from Manus Island and New Hanover (Froggatt 1935; Froggatt and O'Connor 1940). A revision of Papua New Guinea material by Dr Willemse in 1953 and 1958 revealed that Papua New Guinea coconut tree hoppers comprised species belonging to the genera *Segestidea*, *Pseudonicraza* and *Eumossula*.

The species of tree hoppers in Papua New Guinea and their distribution are now known to be as follows:—

1. *Eumossula gracilis* Willemse—Morobe, New Britain and New Ireland Districts, Lihir Island, Masahat Island and Mahur Island;

2. *Segestidea hanoverana* Willemse—New Hanover and Tatau Island;
3. *S. insulana* Willemse—Pak Island, Lou Island, Manus Island, New Ireland, Masahat Island and Lihir Island;
4. *Pseudonicraza szentia* Willemse—Kerema (Gulf District).

As can be seen, tree hoppers are widely distributed throughout Papua New Guinea but their status as a pest varies from place to place. 'Outbreaks' have almost always occurred at irregular intervals and usually in areas lacking regular dry periods (Froggatt and O'Connor 1940).

Life-history studies have been reported by Froggatt (1935) and Froggatt and O'Connor (1940). According to these authors *Segestidea* spp. eggs are deposited singly in the soil to a depth of half an inch. Eggs are also laid in the fibre in the crowns of palms, in the epiphytic growths on the trunks, and, in severe infestations, in rotting bases of fronds, coconut husks and logs and amongst palm roots growing above the ground. However, moist, loosely compacted sandy soils are preferred oviposition sites.

The incubation period varies from 45 to 100 days, but under favourable conditions most of the eggs hatch within 60 days. Climatic conditions appear to exert a pronounced effect on the successful hatching of oothecae. Under dry conditions a considerable proportion of eggs may die. Many, however, enter diapause or aestivation and yield normal nymphs when moist conditions return. For example eggs kept in very dry soil for 110 days under laboratory conditions produced 40 per cent of nymphs after 10 days following application of water to the soil.

Table 1 from Froggatt and O'Connor (1940) gives the average duration of the various nymphal instars of *Segestidea insulana.*

The total nymphal period therefore lasts from 78 to 117 days for males and from 90 to 124 days for females.

Copulation takes place 10 to 12 days after emergence, usually at dusk but often at night. Oviposition commences 21 to 31 days after mating and continues almost throughout the life of a female *S. insulana.* The females volplane or glide down during the night to oviposit in the soil, and after ovipositing walk back up the trunk. Females can lay up to a maximum of 52 eggs during a lifetime but the average is usually 40. Eggs laid on the same night hatch at the same time, but a lot of variation occurs even in those laid on consecutive nights (Froggatt and O'Connor 1940).

Adult longevity under captivity was found to vary from 35 to 110 days (average 72.3) for males and from 28 to 91 days (average 67.1) for females.

A number of indigenous egg parasites have been recorded from tree hopper eggs collected from various localities in Papua New Guinea, viz. *Leefmansia bicolor* Waterst. var. ? (Encyrtidae), *Doirania leefmansi* Waterst. (Trichogrammatidae), *Scelio* sp. (Scelionidae) and *Anaphes* sp. (Mymaridae) from Manus Island and New Hanover; *Prosapegus atrellus* Dodd. (Scelionidae) from Manus Island, New Hanover, New Britain, New Ireland and Lihir Island; *Ootetrastichus dubius* Waterst. (Eulophidae) from Manus Island, New Hanover and New Britain; an unidentified mymarid from Lihir Island; an unidentified eulophid from New Britain and Lihir Island (Froggatt 1937; Froggatt and O'Connor 1940); and *Tetrastichus* sp. (Eulophidae) from New Britain (Baloch, unpublished data). The status of the last species as a primary or secondary parasite has not yet been confirmed, although it would appear to be a primary parasite.

*Table* 1.—Mean duration in days for the various nymphal instars of *Segestidea* sp.

| | Nymphal Instar | | | | | | | Total Duration | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | Range | Average |
| Macropterous male .... | 13.8 | 13.3 | 11.5 | 13.0 | 14.2 | 17.7 | — | 78- 91 | 83.5 |
| Micropterous male .... | 13.8 | 13.3 | 11.5 | 13.0 | 13.1 | 14.1 | 18.1 | 91-117 | 96.0 |
| Female .... .... | 13.8 | 13.3 | 11.5 | 13.0 | 14.5 | 15.4 | 19.4 | 90-124 | 100.9 |

A strepsipteron, *Stichotrema delatoreanum* Hofender, has been bred from the adults in the Madang, Manus and Sepik Districts. Attempts to introduce it to other areas have met with failure as the male is known only as a parasite of an unidentified species of ant. Simmonds (1960) has mentioned the presence of tachinid eggs on museum specimens but no tachinids have ever been bred from field-collected material.

Prior to 1933, although appearing in appreciable numbers at times, the indigenous parasites did not appear to control the pest and it was therefore decided to introduce the Indonesian races of the egg parasites *L. bicolor*, *D. leefmansi* and *Stethynium* sp. (Mymaridae) from Amboina. All three became established at many areas throughout Papua New Guinea, but especially on New Hanover. However, in spite of this, outbreaks are often reported from New Hanover, though tree hopper numbers obviously fluctuate from year to year. Apparently the same position applies to New Ireland and Lihir Island where *L. bicolor* is also well established.

New Hanover has served and continues to serve as a source of supply for both *L. bicolor* and *D. leefmansi*. From here both parasites have been periodically sent to almost all tree hopper affected areas in Papua New Guinea, and in a majority of cases very good establishment and subsequent control have been reported. However, there are many areas where the parasites appear to be ineffective.

In contrast to New Hanover, New Ireland and Lihir Island, no recurrence of outbreaks has ever been reported from Ablingi and Arawe Plantations in the Gasmata area of New Britain after parasite releases in 1935. Similarly, tree hoppers have been almost non-existent on the Gazelle Peninsula since the releases of *L. bicolor* in 1948.

Environmental conditions would appear to play a significant part in the regulation of populations of both tree hoppers and their natural enemies. However, in view of the findings of Froggatt and O'Connor (1940) that highest parasitism of eggs by *L. bicolor* and *D. leefmansi* occurs in those eggs which are laid in epiphytes, followed by those in the fibre in the head of the palms, followed by those in the soil, a closer study of the parasitism rates for the various oviposition sites in different localities throughout Papua New Guinea should be made. Simmonds (1960) has also commented on this point. It could be that in less affected areas the oviposition sites are such that the oothecae are easily accessible to parasites.

Thus, a great deal of work on the ecology of both the pest and its parasites remains to be carried out before a clear understanding of the problem can be gained. No adequate chemical control measures have yet been devised although good kills of adults and nymphs have been obtained with malathion and monocrotophos sprays and DDT/BHC dust. In areas where parasites have not yet been released, it would seem desirable to introduce them before attempting other methods of control. General observations have indicated that perhaps *L. bicolor* does not have good dispersal powers and therefore separate releases might be necessary for different areas located at a distance from one another.

## REPORT ON THE SURVEY OF SOUTHERN NEW BRITAIN, 24th APRIL TO 4th MAY, 1969

The survey was undertaken in response to reports that *Eumossula gracilis* and *Promecotheca papuana* were causing damage to the coconut palms on the south and north coasts, West New Britain (*Figure* 2—localities not to scale). The primary purpose of the survey was to assess the severity of the damage, to investigate the role of parasites and predators as biocontrol agents, and in the case of *Promecotheca*, to see what stages were present.

With *Promecotheca*, old egg cases and larval mines were examined in the field for the presence of parasite emergence holes and samples of these stages of the present generation, wherever possible, were also collected for laboratory examination. With *Eumossula*, oothecae were collected for laboratory examination, usually from the soil around the bases of palms and occasionally from the fibre on the palm trunks.

Detailed observations for each locality visited are listed separately, although there are some general points which can be stated at the outset. Almost without exception the Local Government Councillors of *Promecotheca* affected areas stated that the initial infestation commenced


*Figure* 2.—New Britain

on a couple of shore-side palms at the anchorage point near the village. This would possibly mean that the primary infestation had arisen from infested sago, nipa or coconut leaves transported to the site by the natives themselves for the construction of houses or baskets, or both. Work boats calling at places where an outbreak was in progress could be another source of adult spread to new areas. It has been suggested that the source of new infestations of *P. opacicollis* Gestro (a related species) on the island of Tikopia was infested coconut leaves brought ashore by strong waves (Greenslade 1965). This could also be true for *P. papuana* in Papua New Guinea.

During the survey it was observed that although *Promecotheca* and *Eumossula* may occur together, only one reaches pest proportions at any one time at a locality. Furthermore, it appeared that both insects apparently had distinct domains of dominance, especially along the south coast. *Promecotheca* being a pest from Amio Village to Malenglo Island and *Eumossula* from Sep Sep Island to Cape Gloucester. However, in the Emeline Bay area on the north coast, *Promecotheca* occurred on the Poi mainland whereas on the island *Eumossula* was the main pest.

Whilst *Eumossula* and *Promecotheca* were the two main pests surveyed, opportunity was taken to observe the incidence and severity of other coconut insects. Comments on these are also included in the detailed survey report.

## DETAILED REPORT OF LOCALITIES SURVEYED

### *Pomio*

This was the first place to be visited. No infestation of *Eumossula* and *Promecotheca* was seen while moderate damage by the New Guinea rhinoceros beetle (*Scapanes* sp.) and palm weevil (*Rhynchophorus* sp.) was quite evident.

### *Amio Village*

According to the villagers *Promecotheca* first appeared on nipa palms growing on the Ania River to the east of Amio village. On coconuts, the pest was observed for the first time on a shore-side palm near the village during the wet season of 1968, approximately one year later. From that palm it spread to the rest of the grove.

At the time of the visit the palms, especially those growing near the shore, appeared to be badly hit although undamaged new fronds were unfolding. Both eggs and adults were present with as many as 110 adults occurring on a frond of a one-year-old palm. Palms growing in comparatively open places carried a heavier population of adults than those under shade, as did palms growing near the shore.

Many of the previous as well as present generation egg-cases showed parasite emergence holes and the action of predators. From the size of the emergent holes it would appear

that the egg parasite was probably *C. splendens*. A few dead larvae of the previous generation showing parasite emergence holes were found in the old mines in the leaves and, although it is difficult to say with certainty, the pupal skins of the larval parasites suggested that they were *P. parvulus* and *A. lalori*. *A. lalori* is already known to occur on the south coast and since *P. parvulus* had been bred and released at Fulleborn and Lindenhafen Plantations, it is little wonder that this parasite, which has good powers of dispersal, should have spread to Amio.

With regard to other plants attacked by *P. papuana*, none of the *Pandanus* inspected were infested, but old broken egg-cases and old larval mines were found on one or two leaves of betel-nut palms growing under coconuts. Neither emergence holes nor pupal skins of parasites were found in these eggs and mines.

The presence of egg and adult stages only appeared to be suggestive of the 'one-stage' condition. However, O'Connor (1940) observed that there was very little overlapping of generations in *Promecotheca* and that this was due either to destruction of eggs by parasites and predators or to a shorter life span in the field than that observed in the laboratory. This last suggestion appeared to fit in well with the Amio situation, as the parasitism and predation rates were still low. During an outbreak period, two to three thousand adults are usually present on fronds. As the numbers present at Amio were much lower than this and as the palms were putting out new undamaged fronds, it appeared that the outbreak was already over.

Since the palms were recovering and parasites were also in evidence, the application of chemical control measures did not appear to be warranted. However, a careful watch on the situation for some time seemed to be necessary.

*Eumossula* damage was not in evidence at the time of the visit, but the villagers reported that the insect had almost defoliated a few shore-side palms near the village before the *Promecotheca* outbreak but that it disappeared shortly afterwards.

*Fulleborn Plantation*

The manager reported appreciable damage by *Promecotheca* on a shore-side palm in November, 1968. After some time many adults of the parasite *P. parvulus* were noted and apparently checked the spread of the pest. At the time of the visit, isolated mines were present on a few young palms near the site of the original infestation and quite a few larvae on these were parasitized.

No *Eumossula* damage was observed but the manager said that *Scapanes* sp. was responsible for considerable damage to palms.

*Penlolo Village*

*Promecotheca* damage was more pronounced at this village than at Amio. Many of the shore-side palms near the village had a burnt appearance and only the midribs of the leaflets were left. According to the villagers, the pest appeared about the end of the 1968 wet season on a couple of palms near houses at the anchorage point.

At the time of this visit the severity of damage seemed to have slackened and new undamaged fronds were unfolding. Palms for a distance of about a mile and a half along the coastal fringe appeared to be in the same condition, except that the shore-side palms (mostly old) had suffered more damage than the inland ones (mostly young).

Both eggs and adults were present but were less abundant than at Amio. As at Amio, parasite emergence holes and cast pupal skins were present in the egg cases and larval mines of the previous generations, but no parasites were seen.

A number of dead adults were found sticking to the underside of fronds. Whitish fungal mycelium protruded from underneath the beetles and from the head and thorax and from between the pleurites. A maximum of 14 dead adults was counted on a frond whilst an average of two dead adults was common. The fungus appeared to be *Synnematium jonesii*, as described by O'Connor (1940). Although O'Connor discounts this fungus as being of any importance in the control of *Promecotheca*, at Penlolo it certainly seemed to be one of the factors responsible for reduced adult populations.

No *Eumossula* damage was observed but there was a mild attack of *Scapanes* sp. evident.

*Atui Island*

The *Promecotheca* attack on Atui Island was probably recent as the damage was negligible and mainly concentrated on the shore-side palms. However the villagers reported a severe outbreak on palms on the mainland side of the island a year or so ago.

The shore-side palms at the original infestation site carried heavy populations of all stages of the pest. In the inland areas, whilst numbers were much lower, all stages were also present. The larval parasites *P. parvulus* and *A. lalori* and the egg parasite *C. splendens* were recovered from field-collected samples.

On the mainland side of the island there had previously been some damage by *Promecotheca*, but at the time of the inspection new undamaged fronds were appearing and the pest was in the multiple-stage condition. Both egg and larval parasites were abundant and quite a few adults killed by the fungus (? *Synnematium jonesii*) were in evidence.

No *Eumossula* damage was observed.

*Lindenhafen Plantation*

When inspected, *Promecotheca* were very rare and the ones present were in the multiple-stage condition. Some palms supporting kurukum ants (*Oecophylla smaragdina* F.) were entirely free of the pest while a few others nearby without kurukums were infested. Frond samples from randomly selected palms from different parts of the plantation were examined and most were found free of the pest, whilst a few had old larval mines showing parasite emergence holes. On almost all the infested palms cast pupal skins, pupae and dead adults of *P. parvulus* were to be found inside the *Promecotheca* larval mines.

A very mild attack of *Eumossula* was present in scattered, localized pockets.

Starting from Lindenhafen, palms on four small islands (Lue, Walanguo, Sivot and Kiwok) were scanned with field-glasses, but no evidence of attack by *Promecotheca* and *Eumossula* was observed.

*Avrin Island*

This island appeared to be free from both *Promecotheca* and *Eumossula*. There were, however, a few old *Promecotheca* mines, but most showed parasite emergence holes. From the cast pupal skins it appeared that both *P. parvulus* and *A. lalori* may have been present.

*Ring Ring, Akam and Avhan Villages*

Although these villages are situated in close proximity to each other *Promecotheca* attained outbreak proportions at Ring Ring and Akam some two to three years previously. At Avhan it reached pest proportions in 1953, and since then apparently appeared in small numbers every wet season. It usually declined soon after the wet season finished. Transportation of a small number of older larvae or pupae from Avhan, possibly through the agency of local inhabitants carrying sago or nipa palm leaves or baskets made from coconut leaves, apparently spread it to the other two villages. However, it would appear that *Promecotheca* has been kept under check by natural enemies at Avhan following the initial 1953 outbreak.

At the time of the visit, the insect was in the multiple-stage condition at all three villages, the only difference being that the populations at the newly infested villages were greater than at Avhan. *P. parvulus* was the main larval parasite present, although *A. lalori* was also present in small numbers.

Nipa palm was quite common in the area and appeared to be as attractive as coconut as a host for *Promecotheca*, as were the pest larvae in them as hosts for egg and larval parasites. Appreciable numbers of the present generation mines were dry and small in size, indicating that the *Promecotheca* larvae in them had either been attacked in the early stages by parasites or had been killed by a disease.

On the whole, the *Promecotheca* situation at these villages appeared to be good, with natural control of the pest species occurring.

No *Eumossula* damage was evident.

*Agur Island*

As at the preceding three villages, *Promecotheca* was in a multiple-stage condition and under good natural control. *P. parvulus* was the main larval parasite present while the few specimens of egg parasites reared out appeared to be different from *C. splendens*. They could possibly be *Anastatus* sp.

No *Eumossula* damage was observed. *Scapanes* sp. and palm weevil (*Rhyncophorus* sp.) had been causing light damage since August, 1968.

*Ablingi Plantation*

The owner of the plantation stated that there had been no *Promecotheca* or *Eumossula* problem on the mainland plantation, but that a mild infestation of the latter had been in evidence on the island for quite some time. On inspection, the mainland plantation was found to be free from both insects except for one third-stage larva of *Promecotheca* which was obtained from a young palm.

The island palms showed a mild attack of *Eumossula* but this was restricted to a few shore-side palms. *Eumossula* oothecae were hard to find. *Leefmansia bicolor* was released on Ablingi in 1935, and since then no outbreak has been reported. However, it is not known whether the low numbers since 1935 are due to the activities of the parasite or to some other factors.

Coconut palms on Aivet Island were scanned with field-glasses. Most of the palms appeared to be healthy except for a patch of young palms at the end of the island. They looked as though they may have been infested by *Promecotheca* but it was not possible to have a close look to substantiate this.

*Malenglo Island*

According to the statements of the islanders, a *Promecotheca* infestation on Malenglo Island started about two years ago on a few shore-side palms near the school. When inspected, most of the palms were showing new, undamaged fronds. *Promecotheca* was present mainly as adults and eggs, although isolated first instar larval mines were also found.

Parasitism in the previous generation eggs appeared to be in the vicinity of 60 to 70 per cent and an appreciable number of old larval mines also showed evidence of parasite attack. The parasites reared out from the collected material were *P. parvulus* from larvae, and *C. splendens* from eggs.

No *Eumossula* damage was observed.

*Sep Sep Island and Mainland*

Although *Promecotheca* was present in adult, egg and larval stages, numbers have apparently been so low that it has never been noticed by the people of the island. Some of the old mines showed evidence of parasite emergence holes.

*Eumossula* was said to have been quite serious both on the island and the mainland palms some two years ago. Present damage was moderate. On the mainland side of the island there were quite a few eggs present in the soil, of which about 80 per cent had already hatched. There was no evidence of parasite emergence from the eggs and intact oothecae obtained from the island failed to produce any parasites in the laboratory. Thus it would appear that egg parasites are absent from this area. Should the pest break out again, introduction of *L. bicolor* would be desirable.

*Aliwa Plantation*

This plantation appeared to be free from *Promecotheca* and *Eumossula*, but there was a mild attack of the leaf-eating hispid *Brontispa* sp.

From Aliwa Plantation to Kandrian, native coconut groves along the shore were scanned with field-glasses, but none appeared to have been affected by either *Promecotheca* or *Eumossula.*

*Kandrian*

As at Sep Sep, it was reported that *Eumossula* had been serious some time ago. At the time of inspection, little damage was evident. Oothecae samples received at Keravat from this area a month later only yielded one specimen of the scelionid egg parasite *Prosapegus atrellus.*

*Demgalu Village*

At Demgalu Village *Eumossula* damage was mild but was reported to have been serious some time ago. Most of the oothecae collected were intact and seemed to have developing nymphs inside. No parasites were obtained from the material collected.

Very few scattered adults, egg cases and larvae of *Promecotheca* were in evidence and the main larval parasite operating at this time was *A. lalori.*

Another village nearby, Messelia, was not actually visited but people at Demgalu described the *Eumossula* situation there as being similar to that at Demgalu.

*Pelilo Island*

The first *Eumossula* outbreak on Pelilo Island is reported to have occurred some time in 1934-35. This was approximately the same time that tree hopper damage was bad at Arawe Plantation, and the egg parasites *L. bicolor*, *D. leefmansi*, an unidentified encyrtid and an unidentified mymarid were introduced to Arawe, of which only *L. bicolor* established (Department of Agriculture, New Guinea 1937).

The present outbreak at Pelilo Island started in 1968 when most of the palms were stripped bare of leaflets and many deaths followed.

During 1968, *L. bicolor* was introduced and *Eumossula* disappeared almost completely soon after. When inspected on this visit, most of the palms had already recovered from the attack and only isolated *Eumossula* adults could be found. Where hundreds of oothecae had been collected just by scraping the top soil around the base of the palms during the outbreak period, seven trained persons searching for eggs for about an hour obtained only nine eggs. Most of these were flattened, with a dead, hard, brittle embryo inside, indicating possible death by disease. Eggs so affected were also obtained from most of the *Eumossula* infested areas visited.

It is not known whether the immediate disappearance of *Eumossula* from Pelilo Island was due to the action of *L. bicolor* or to a population crash resulting from lack of food. The much improved condition of palms at this island compared to palms at other *Eumossula* outbreak areas visited earlier would seem to suggest that the introduction of *L. bicolor* has been successful.

*Promecotheca* was present but in very small numbers.

*Arawe Plantation*

A very short visit was paid to this plantation. The manager was not aware of any serious damage by *Eumossula* or *Promecotheca* and inspection of some of the coastal palms revealed only a mild attack of *Eumossula*. As already mentioned, *L. bicolor* was introduced and established in 1935.

*Kumbun Island*

No detailed observations could be made at Kumbun Island as we arrived there late in the evening and had to leave early in the morning. However, a brief inspection of the palms showed a moderate attack by *Eumossula*. The islanders stated that the pest appeared by the end of every wet season on the shore-side palms on one side of the village. It always disappeared of its own accord after three to four months but during this period the palms suffered considerably.

Only scattered mines and adults of *Promecotheca* were present.

*Sag Sag Village*

Except for a completely stripped frond or two on a few scattered palms, *Eumossula* damage was only moderate at Sag Sag Village. The soil was a heavy, wet soil, and no oothecae were obtained, even from under those palms which had the few completely stripped fronds.

From Sag Sag we travelled to Kilengi Mission. All along the road moderate *Eumossula* damage could be seen on coconut palms, whilst damage to banana leaves was also observed.

No *Promecotheca* damage was noticed.

*Kilengi Mission*

The *Eumossula* position at Kilengi Mission appeared to be the same as that at Pelilo, the insect having reached plague proportions some time in 1967. *L. bicolor* was liberated at the Mission in the same year. During the present inspection it was obvious that the situation was even better than that at Pelilo. Palms looked very healthy and hardly any trace of *Eumossula* could be found.

Efforts were made to collect oothecae to see if *L. bicolor* had established, but intensive search by nine people at sites where eggs had been plentiful before liberation of the parasite yielded two eggs only. It is possible that the lack of oothecae at most of the places visited could be due to the fact that this was not the proper breeding period for *Eumossula*. However, it is thought that the very low number of *Eumossula* at Pelilo Island and Kilengi Mission was due to the activities of *L. bicolor*. At least the villagers appeared to be very much impressed by the role of *Leefmansia* in reducing the pest population.

No *Promecotheca* was found.

*Cape Gloucester*

A mild attack of *Eumossula* was evident on the coastal palms at Cape Gloucester, and a few eggs were collected, mostly from the fibre around the trunks. Some of the oothecae showed parasite emergence holes but no parasites were obtained from the eggs collected. Quite a few of the oothecae appeared to be diseased.

No *Promecotheca* damage was in evidence.

*Tavelei Village*

*Eumossula* had been very serious at this village a year or so ago, so serious that some of the palms had been killed. However, when inspected on this visit, the palms had recovered, although some damage was still present. Comparatively more unhatched oothecae were collected than at any of the other localities visited so far. No parasites were bred from the oothecae collected.

Very few *Promecotheca* were present but a mild attack of *Brontispa* sp. was evident.

*Iboki Plantation*

*Eumossula* is known to have been present at Iboki Plantation for more than 20 years and appeared to be responsible for a considerable amount of foliage damage during a certain period of each year (possibly the wet season). When inspected, damage was moderate and in fact was the heaviest observed at any locality visited, as were the number of oothecae present in the soil. Some of the eggs had obviously been parasitized by the scelionid *P. atrellus* while many appeared depressed and flat possibly indicating that they were diseased.

Of the 180 eggs collected and taken back to the laboratory, 120 appeared to be diseased. Of the remaining 60, 12 yielded 340 individuals of *Tetrastichus* sp. and 6 produced one individual each of *P. atrellus*. As mentioned earlier, it is not certain whether *Tetrastichus* sp. is a primary or secondary parasite, although it is considered likely to be primary.

*Promecotheca* was not present, but the coconut spathe bug, *Axiagastus cambelli* Dist., was found for the first time during the survey. It occurred in numbers on flowers but did not appear to be of economic importance.

*Poi Island and Mainland*

*Promecotheca* was present on the mainland in small numbers as adults, eggs and larvae. Whilst parasite emergence holes were observed both in eggs and third-stage larvae of the previous generation, no specimens were obtained. The third-stage larvae of the present generation collected all turned into pupae from which adults successfully emerged.

The councillor for Poi Island, when questioned, said he had never seen *Promecotheca* damage on any palm on the island although its presence on the mainland was known. *Eumossula*, on the other hand, was well known as it had been responsible for damage to palms on the island over an extended period. It was not known to be present on the mainland. At the time of the visit, a moderate infestation of *Eumossula* was present on the island, while on the mainland it was rare. The few oothecae obtained from under island palms did not yield any parasites.

*Linga Linga Plantation*

As at Lindenhafen, Linga Linga appeared to be free of both *Promecotheca* and *Eumossula*. Examination of old, tall palms with field-glasses failed to reveal the presence of any stages of *Promecotheca*. However, isolated third-stage larvae and pupae (very rarely first- and second-stage larvae also) were observed on scattered young palms. Pupae and larvae of *P. parvulus* were also recovered from larval mines on these palms.

Since the majority of the third-stage larvae and pupae collected from Linga Linga grew into adults in the laboratory, it would appear that there could well be a population increase in the near future, and *Promecotheca* could assume a one-stage condition. However, under normal circumstances and in the presence of *P. parvulus*, this should not occur unless unfavourable environmental conditions favour the build-up of the pest and hinder the parasites. At the time of the visit the position appeared to be normal with a balance existing between host and parasites.

## CONCLUSIONS

Generally speaking it can be said that in the area surveyed *Promecotheca* and *Eumossula* had been serious, mostly on native groves, about a year or two before the present visit. In April, 1969, the situation appeared to have improved considerably. It is not known whether this was just a seasonal phase (especially with *Eumossula*) or termination of the outbreak. Most of the plantations—Fulleborn, Lindenhafen, Ring Ring, Arawe, Ablingi and Linga Linga—were free from *Promecotheca* and *Eumossula*. However, Iboki Plantation was still affected to a moderate extent by *Eumossula*.

Most of the natural enemies of *Promecotheca*, with the exception of *Eurytoma promecothecae*, appeared to be fairly well distributed throughout the areas visited, while the egg parasites of *Eumossula* (as determined from the very small samples of eggs available) appeared to be absent. At Iboki Plantation a eulophid, *Tetrastichus* sp., was obtained from about 20 per cent of eggs collected whereas the scelionid *Prosapegus atrellus* was only rarely obtained.

The healthy-looking condition of palms and the almost complete absence of both oothecae and adults at a couple of groves where the egg parasite *Leefmansia bicolor* had been liberated against *Eumossula* a couple of years ago could possibly be taken as a guide to the successful role of this parasite under similar ecological conditions. However, it would appear that because of its apparently poor dispersal rate, separate liberations for each of the affected localities may be necessary, should the need for introductions arise.

The most likely mode of *Promecotheca* spread to new areas in Papua New Guinea is through the agency of the local inhabitants themselves through transportation of infested sago or nipa palm leaves for use in house-making and other purposes. Even coconut leaves used for basket-making would serve the same purpose. Work boats coming from infested areas also appeared to have been partly responsible for transporting adults from one place to another.

Whilst the factors responsible for the recurrence of outbreaks of *Promecotheca papuana* in Papua New Guinea, even where the parasites are well established, are partly unknown, it would appear that sudden population crashes possibly resulting from unfavourable environmental conditions and diseases (thus causing drastic reductions in parasite populations) may be one of the reasons. Perhaps there are no alternate hosts for the parasites to maintain reasonable populations when sudden crashes in *P. papuana* populations occur. It could well be that the host plant range of *P. papuana* in Papua New Guinea is not fully known and that some of these unknown host plants may be unsuitable for the successful parasitization of the larvae and pupae within the mines on these plants.

The causes of the periodic outbreaks of tree hoppers are also not fully known, but environmental conditions appear to play a significant role in the regulation of populations. Outbreaks are more frequent in areas where no regular dry periods occur. It would also seem that the oviposition behaviour of the tree hopper, in different localities of Papua New Guinea, may be important. Highest parasitism rate of eggs by *Leefmansia bicolor* and *Doirania leefmansi* is to be found in those oothecae which were laid in epiphytes, followed by those in the fibre in the crown of palms. It could be that in the seriously affected areas oviposition by tree hoppers occurs in sites where the eggs are not easily accessible to the egg parasites.

As the *Promecotheca* outbreaks at all the infested localities, except for Atui Island where the outbreak was only recent, had greatly declined and the parasites were present at the time of the visit, it was considered that the destructive phase of the insect attack was over and no other control measures were deemed necessary. Because of the apparent absence of tree hopper egg parasites from most of the affected areas, introduction of *L. bicolor* into these localities was considered worthwhile.

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# SPECIES OF *PHYTOPHTHORA* AND *PYTHIUM* IN PAPUA NEW GUINEA

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## ABSTRACT

*The paper records the species of* Phytophthora *and* Pythium *isolated from diseased plants of various genera between* 1963 *and* 1971 *and the species isolated from* 52 *of* 82 *mixed soil and root samples from various sites in Papua New Guinea using the lupin bait technique in a survey conducted in* 1970-71.


## INTRODUCTION

THE species of *Phytophthora* recorded in Papua New Guinea were listed by Shaw (1963) and included *P. colocasiae* causing leaf blight of taro (*Colocasia* sp.), *P. palmivora* causing pod rot, canker and chupon wilt of cacao (*Theobroma cacao* L.), and *Phytophthora* sp. causing collar rot of *Saintpaulia* sp. A listing of *P. infestans* on potato by Dumbleton (1954), records of *P. palmivora* (Dwyer 1940a, 1940b, 1953) and a possible record (Bryce 1924) on coconut, a possible record of *P. palmivora* on rubber (Mann 1963), a possible record of *Phytophthora* sp. on oil palm (Dwyer 1953) and *P. parasitica* and *Phytophthora* sp. on *Citrus* sp. (Dumbleton 1954) had not been confirmed. A listing of *Pythium debaryanum* on tobacco (*Nicotiana tabacum* L.) by Dumbleton (1954) had also not been confirmed.

## ISOLATIONS BETWEEN 1963 AND 1971

Since 1963 other species of *Phytophthora* and *Pythium* have been obtained as isolates from diseased specimens, mainly with damping-off, collar rot or root rot, sent in for identification from various parts of Papua New Guinea. The isolates, made by Shaw and Messrs W. A. Layton, A. Williams and R. M. Burnett, were identified at the Commonwealth Mycological Institute. They were as follows:—

*Phytophthora* sp. probably *P. nicotianae* str., from *Hibiscus* sp. (IMI 118060);

*Pythium butleri* from *Citrus* sp. (IMI 140039); from *Nicotiana tabacum* (IMI 142124); from *Phaseolus vulgaris* (IMI 133993); from *Zea mays* (IMI 145235);

*Pythium butleri* (nearest) from *Nicotiana tabacum* (IMI 134848);

*Pythium irregulare* from *Citrullus vulgaris* (IMI 145234);

*Pythium myriotylum* from *Nicotiana tabacum* (IMI 135527);

*Pythium vexans* from *Cocos nucifera* (IMI 150165); from *Theobroma cacao* (IMI 133526);

*Pythium deliense* (nearest) from *Nicotiana tabacum* (IMI 116988).

## SAMPLING AND LOCALITIES

In the present study 82 soil samples with fibrous roots were taken from the 0-4 inch layer (less litter) from various localities. The plants from all sites were reported as healthy with the following exceptions: three nurseries where damping-off had occurred; one site at which introduced *Pinus* sp. had been reported as slow-growing; three samples from the same general area where introduced *Pinus* sp. was said to be unthrifty, and two samples from a site where death of planted *Eucalyptus deglupta* had been reported. The positions of the sites are shown in the *Figure* and the number of samples from primary forest, secondary bush, drain or creek banks and roadside areas, nurseries or home and village gardens, plantation areas and afforested areas is given in *Table* 1. It is not known what, if any, contamination may have been accidentally introduced at the primary forest sites.


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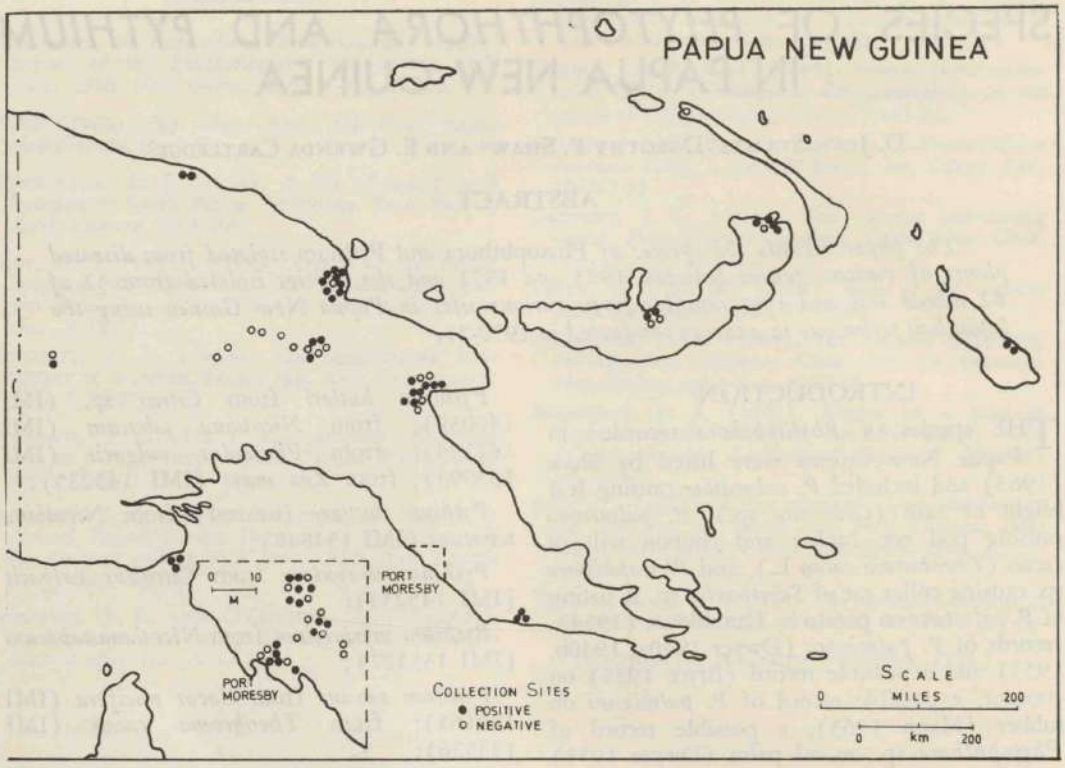


*Figure.*—Location of soil/root samples

## METHODS

The soil/root samples were baited for *Phytophthora cinnamomi* and other species of *Phytophthora* and *Pythium,* using the method which Pratt (personal communication) adapted from the lupin-baiting technique of Chee and Newhook (1965), with slight modifications to suit local conditions. Three lots of 50 cc of each soil/root sample were placed in three plastic cups with 150 cc of de-ionized water (with maximum total dissolved salts less than 1 ppm). Onto this water were floated $\frac{1}{4}$ inch deep corks with three holes through which radicles of pregerminated New Zealand blue lupin seed (*Lupinus angustifolius* L.) penetrated to the water below. The radicles were allowed to reach $\frac{1}{2}$ inch in length before being placed in position: on Dr Pratt's advice, 24-hour fluorescent lighting was arranged to within three inches of the tops of the corks.

Each radicle was removed after three days to a microscope slide, a few drops of water and a cover slip were added, and it was examined under the low power of the microscope and checked for lesions or sporangia. Radicles showing either, and some radicles chosen at random not showing lesions or sporangia, were cut from the seed, cut lengthwise in half, then each half was cut in four. The four pieces of one half were plated on to potato dextrose agar (later PDA with pimaricin and penicillin for bacterial control), and the four from the other half on to lima bean extract agar. The isolates were established in pure culture on PDA. Any apparently different types, and a representative selection taken at random from the remainder of the isolates derived from each sample, were inoculated on to boiled pieces of grass (*Dicanthium aristatum* (Poir.) C. E. Hubbard) in water, as described by Waterhouse (1963, 1967, 1970) and many

*Table* 1.—Species of *Phytophthora* and *Pythium* isolated from various habitats

| Sites and species | Primary forest | Secondary bush, roadside, drain, etc. | Nursery | Home or village garden plantation or afforested area | Total |
|---|---|---|---|---|---|
| *Sites* | | | | | |
| Total | 10 | 11 | 8 | 53 | 82 |
| Negative | 3 | 5 | 1 | 21 | 30 |
| Positive | 7 | 6 | 7 | 32 | 52 |
| With 1 species | 7 | 5 | 3 | 23 | 38 |
| With 2 species | | 1 | 1 | 7 | 9 |
| With 3 species | | | 2 | 2 | 4 |
| With 4 species | | | 1 | | 1 |
| *Species* | | | | | |
| *Phytophthora drechsleri* (IMI 154105 and 3 other IMI Nos.) | | | 3 | 1 | 4 |
| *Phytophthora nicotianae* var. *nicotianae* (nearest) (IMI 154098) | | 1 | | | 1 |
| *Phytophthora* sp., probably *P. nicotianae* str. (no sex organs) | 2 | 1 | 2 | 7 | 12 |
| *Pythium aphanidermatum* (IMI 154100) | | 1 | 3 | 13 | 17 |
| *Pythium butleri* (IMI 154101, IMI 154110) | | | | 5 | 5 |
| *Pythium carolinianum* (nearest) (IMI 157218) | | | | 1 | 1 |
| *Pythium debaryanum* Hesse (IMI 158771) | | 1 | | | 1 |
| *Pythium debaryanum* Hesse (nearest) (IMI 157216) | | | | 1 | 1 |
| *Pythium debaryanum* auct. non Hesse (IMI 154104) | | | 1 | 1 | 2 |
| *Pythium irregulare* (nearest) (IMI 157211 and 7 other IMI Nos.) | 2 | | 3 | 3 | 8 |
| *Pythium middletonii* (IMI 154103 and 3 other IMI Nos.) | | 2 | 2 | 4 | 8 |
| *Pythium* sp. (lobulate sporangia, no sex organs; not identifiable) (IMI 154102, IMI 154107) | | | 1 | 1 | 2 |
| *Pythium* sp. (discrete sporangia, no sex organs; not identifiable) (IMI 154111 and 9 other IMI Nos.) | 3 | 2 | | 5 | 10 |

were also inoculated on to maize meal agar, lima bean agar and on to sterile bean pods (*Phaseolus vulgaris*) in order to induce sporangial and oospore production, and to study germination.

Isolates not sporulating on any media at Port Moresby were forwarded to the Commonwealth Mycological Institute, where crossings with other strains were carried out by Stamps. Representative isolates of the various types were also forwarded to Stamps for confirmation or identification of the species.

## RESULTS

Lupin radicles from 50 of the 82 soil/root samples developed faint lesions or sporangia, and isolates of *Phytophthora* and/or *Pythium* were established from them. Isolates were also obtained from two other samples chosen at random whose radicles showed neither lesions nor sporangia. From radicles of the 52 samples 476 isolates were made and 225 of these were studied on boiled grass in water and on some of the other media, as mentioned under "Methods", for sporangia and oospore production, type of germination and method of fertilization.

One of the 52 samples yielded four species of *Phytophthora* and *Pythium*, four samples yielded three species of *Phytophthora* and/or *Pythium*, nine samples yielded two species of *Phytophthora* and/or *Pythium*, while the remaining 38 yielded one species only (*Table* 1).

Two species of *Phytophthora* and seven species of *Pythium* as well as several unidentifiable species of *Pythium* and *Phytophthora* (because no sex organs were produced on any medium) were obtained from the various habitats, as shown in *Table* 1.

## DISCUSSION

Relatively few species of *Phytophthora* and *Pythium* were isolated from soil/root samples from a range of habitats over a wide area in Papua New Guinea. The isolates were derived

***Table* 2.—List of species of *phytophthora* and *Pythium* recorded in Papua New Guinea**

| Species | Host | Reference |
|---|---|---|
| ***Records herein or confirmed*:—** | | |
| *Phytophthora colocasiae* Rac. | *Colocasia* sp. | Shaw 1963* |
| | | Hicks 1967a |
| *Phytophthora drechsleri* Tucker | Soil/root | Herein |
| *Phytophthora nicotianae* B. de Haan var. *nicotianae* | Soil/root | Herein |
| *Phytophthora palmivora* (Butl.) Butl. | *Theobroma cacao* | Shaw 1963* |
| | | Hicks 1967b |
| *Phytophthora* sp. probably *P. nicotianae* str. | *Hibiscus* sp. | Herein |
| | Soil/root | Herein |
| *Phytophthora* sp. | *Saintpaulia* sp. | Herein |
| *Pythium aphanidermatum* (Edson) Fitzp. | Soil/root | Herein |
| *Pythium butleri* Subramaniam | *Citrus* sp. | Herein |
| | *Nicotiana tabacum* | Herein |
| | *Phaseolus vulgaris* | Herein |
| | *Zea mays* | Herein |
| | Soil/root | Herein |
| *Pythium butleri* Subramaniam (nearest) | *Nicotiana tabacum* | Herein |
| *Pythium carolinianum* Matthews (nearest) | Soil/root | Herein |
| *Pythium debaryanum* Hesse | Soil/root | Herein |
| *Pythium debaryanum* Hesse (nearest) | Soil/root | Herein |
| *Pythium debaryanum* auct. non Hesse | Soil/root | Herein |
| *Pythium deliense* Meurs (nearest) | *Nicotiana tabacum* | Herein |
| *Pythium irregulare* Buisam | *Citrullus vulgaris* | Herein |
| *Pythium irregulare* Buisman (nearest) | Soil/root | Herein |
| *Pythium middletonii* Sparrow | Soil/root | Herein |
| *Pythium myriotylum* Drechsler | *Nicotiana tabacum* | Herein |
| *Pythium vexans* de Bary | *Cocos nucifera* | Herein |
| | *Theobroma cacao* | Herein |
| *Pythium* sp. (lobulate sporangia, no sex organs) | Soil/root | Herein |
| *Pythium* sp. (discrete sporangia, no sex organs) | Soil/root | Herein |
| ***Records unconfirmed at present*:—** | | |
| *Phytophthora infestans* | *Solanum tuberosum* | Dumbleton 1954 |
| *Phytophthora palmivora* | *Cocos nucifera* | Bryce 1924 (possible record) |
| | | Dwyer 1940a, b; 1953 |
| | *Hevea brasiliensis* | Mann 1953 (possible record) |
| *Phytophthora parasitica* | *Citrus* sp. | Dumbleton 1954 |
| *Phytophthora* sp. | *Citrus* sp. | Dumbleton 1954 |
| | *Elaeis guineensis* | Dwyer 1953 |
| *Pythium debaryanum* | *Nicotiana tabacum* | Dumbleton 1954 |

* Summary of all previous records.

from 63.4 per cent of the samples, but as these included isolates from two samples chosen at random whose radicles showed neither faint lesions nor sporangia, it is possible that more samples would have yielded isolates if other "negative" radicles had been plated in nutrient agar.

The area yielding the most species was one of the nurseries where damping-off had previously been reported. No isolates were obtained from the site with introduced *Pinus* sp. said to be "slow-growing"; *Pythium aphanidermatum* was obtained from only one of the two sites previously reported to have had dead *Eucalyptus deglupta*; *Phytophthora drechsleri* was obtained from one and unidentifiable *Pythium* sp. from another of the three samples from the area with unthrifty introduced *Pinus* sp. Pathogenicity tests would be needed to determine whether any or all of the above pythiaceous isolates were associated with the conditions reported to the authors.

At all the other sites, the plants growing at the time of collection were reported by the collectors to be healthy, and roots taken at random from each sample also appeared healthy when examined in the laboratory. The pythiaceous isolates obtained from many of these were apparently not pathogenic at the time of collection on these plants, which ranged from indigenous forest trees to horticultural species, ferns, weeds and grasses.

None of the isolates was *Phytophthora cinnamomi*, which has been commonly isolated in recent years by the use of the lupin bait technique (Chee and Newhook 1965; Pratt pers. comm.; Jehne 1970).

All the species of *Phytophthora* and *Pythium* listed in *Table* 1 have been recorded in the literature as causing damping-off of seedlings or other diseases of a variety of plants.

The complete list of species of *Phytophthora* and *Pythium* recorded in Papua New Guinea is now as given in *Table* 2.

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# FIRST RECORDS OF *PHYTOPHTHORA CINNAMOMI* IN PAPUA NEW GUINEA

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## ABSTRACT

Phytophthora cinnamomi *Rands was isolated from soil from three sites from two localities under dead indigenous Nothofagus and at the margin of a dead patch on Mt Giluwe, these being the first records of this fungus in Papua New Guinea. No claim is made that the fungus is the cause of the dead and dying Nothofagus, as the problem needs further investigation.*


## INTRODUCTION

DURING 1970 and 1971 reports of dead indigenous Nothofagus occurring in patches in various stands throughout the Western Highlands of Papua New Guinea were received by the senior author from Mr R. A. Hynes (pers. comm.). Because of the relative inaccessibility of the sites, soil/root samples were not obtained until March, 1972, when collections were made by Mr B. Zaneky of the Department of Forests.

## MATERIALS AND METHODS

The samples were from eight localities in the Iaro River area on Mt Giluwe about 31 miles (approximately 50 km) in direct line from the town of Mount Hagen in the Western Highlands and consisted of two samples from each of three sites at each of eight localities, the three sites in each case being from: (1) beneath recently dead *Nothofagus* spp‡; (2) the margin between dead and normal patches; and (3) beneath trees showing no deterioration.

The soils (with any roots at all which happened to be in them) were taken from the 0 to 4 inch (10 cm) layer after removal of surface litter. In the laboratory at Konedobu, Port Moresby, they were baited for *Phytophthora cinnamomi* and other species of *Phytophthora* and *Pythium* as reported in a previous study (Stamps, Shaw and Cartledge 1972) using the lupin-baiting technique, with slight modifications, of Chee and Newhook (1965). Microscopic check for sporangia on radicles was made in only a few cases, but all radicles were plated on to nutrient antibiotic agars even if not showing lesions, or not showing sporangia when examined. Pure cultures were established on potato dextrose agar (PDA), maize meal-vitamin E agar, on sterile bean pod, on boiled grass in water and with sterile soil extract.

## RESULTS

Only one type of sporangium was recorded on the radicles, and only one type of culture was isolated. The cultures were somewhat lobate, young hyphae were coralloid, and on boiled grass in water abundant hyphal swellings, irregularly botryose and somewhat smaller than those reported for *P. cinnamomi*, were produced, together with a few sporangia which were also smaller than those seen on the radicles and those reported in the literature. No sporangia were obtained on the agar media and no oospores were found on any media in Papua New Guinea. None of the isolates formed sex organs when paired with an A1 culture of *P. cryptogea* at the Commonwealth Mycological Institute, but all the isolates formed abundant sex organs when grown with an A2 *P. cinnamomi* isolate. The isolates are identified as *P. cinnamomi* Rands, of the A1 compatibility type.


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‡ The identities of the various species of Nothofagus on the mountain are still being determined by botanists.

The fungus was isolated from two sites (under dead Nothofagus and from the marginal area) at Locality No. 3, and from one site (under dead Nothofagus) at Locality No. 7. Sporangia of a type similar to *P. cinnamomi* were noted on radicles in the test of the marginal area soil from Locality No. 6, and from the soil under the apparently healthy trees in Locality No. 5, but no isolates were obtained in pure culture. The results are shown in the *Table*.

It should be noted that, although other species of *Phytophthora* and *Pythium* were isolated by the lupin-baiting method from soil/root samples (none of which, however, were from dead or dying Nothofagus) in a previous study (Stamps, Shaw and Cartledge 1972), no isolates of *P. cinnamomi* were recorded at that time. During the present study no species of *Phytophthora* other than *P. cinnamomi* and no species of *Pythium* were isolated from the Giluwe soil samples.

## DISCUSSION

The A1 compatibility type appears less common in *P. cinnamomi* than the A2, which occurs in many countries on many hosts. The type A1 was first isolated from the trunks of Macadamia trees in Hawaii (Galindo and Zentmyer 1964) and later isolated in southern California from Camellia roots (Zentmyer and Erwin 1969); recently one of us (Stamps) has examined A1 isolates from South Africa, Australia and New Zealand at the Commonwealth Mycological Institute.

Although this paper records the occurrence of *P. cinnamomi* A1 from two sites with dead Nothofagus and from one marginal site (between an area with dead trees and apparently healthy ones), no claim is made that this fungus is the cause of the dead patches. To date no diseased Nothofagus roots have been available for study and no inoculation tests have been carried out. Isolations from Nothofagus roots will need to be made and inoculation tests on Nothofagus as well as on other plants carried out with *P. cinnamomi* as well as with other fungi if any are isolated in further studies.

The eight localities are situated on the south-east flank of Mt Giluwe at 8000 to 8,500 ft (2440 to 2593 m) altitude, in a region with stands of mainly Nothofagus interspersed with areas of mixed Nothofagus and montane forest species, and areas classed as "poor" montane forest by the Department of Forests. The localities sampled occur within a strip about 2 miles long by ½ mile wide (approximately 3218 by 805 m) either on or just off the main walking track to the summit of the mountain, or on a nearly parallel foot track leading to a Forestry Trial Block where introduced species of *Pinus* (60 plants each of *P. elliotti*, *P. kesiya*, *P. patula* and *P. taeda*) were planted in June, 1971, in a suitability study, after transport to the area by helicopter.

*Table.*—Presence (+) or absence (−) of *P. cinnamomi* in soil/root samples from different localities on Mt Giluwe

| Locality | Apparently healthy Nothofagus | Marginal Zone | Dead Nothofagus | Estimated extent of dead Nothofagus* | |
|---|---|---|---|---|---|
| | | | | (acres) | (hectares) |
| No. 1, Mabelgema | − | − | − | 0.1 | 0.04 |
| 2, Nongupiri | − | − | − | 0.02 | 0.008 |
| 3, Tibugu | − | + | + | 0.1 | 0.04 |
| 4, Miginzega 1 | − | − | − | 3.0 | 1.2 |
| 5, Sibuga | † | − | − | 3.0-4.0 | 1.2-1.6 |
| 6, Miginzega 2 | − | † | − | 0.5 | 0.2 |
| 7, Koipu | − | − | + | 0.1 | 0.04 |
| 8, Mauvi | − | − | − | 0.5 | 0.2 |

* Estimations by Mr B. Zaneky, Department of Forests.

† P. *cinnamomi-cambivora* type sporangia seen on the radicles, but no isolations were obtained in pure culture.

The area of each dead patch, as estimated by Mr Zaneky, is shown in the *Table*. The marginal zones around the patches were reported to be roughly in the order of half a chain (approximately 10 m) wide.

No details of the symptoms of the deteriorating Nothofagus or photographs of individual trees or of the dead patches are as yet available. It is stated, however (pers. comm. from Mr J. E. N. Smith, Regional Forest Officer), that there appears to be immediate regrowth of as yet unidentified species in the patches.

Also, no information is to hand regarding the rate of deterioration of the patches, if indeed they are deteriorating. However, aerial photographs* of the region, taken in 1959 at 25,000 ft (approximately 7625 m), are available, and these have been studied stereoscopically by the senior author. No sign could be detected on the 1959 aerial photographs of any break in the canopies at positions approximating to Localities 1, 3, 4, 6, 7 and 8 as designated in this paper; there may be a slight break in the canopy at Locality No. 2. A comparison could not easily be made of Locality No. 5, which is in areas of broken canopy shown in the 1959 aerial photos, which are interpreted as "grassland and regrowth" on relatively large-scale maps of the vegetation produced by the Department of Forests. Locality No. 5 is at the lowest altitude sampled and the nearest to the irregular interface of the forest and the artificial grassland of the high plains surrounding the mountain.

* Reference C. A. J. 121-5050 Mt Giluwe 5044-5065 (Run 3, taken on 18.6.1959 at 25,000 feet.

What is required is another aerial reconnaissance at 25,000 ft, so that a direct comparison can be made of the canopies of stands of Nothofagus and other tree species on the mountain, as shown in the aerial photographs of 1959 and the present day. This would reveal the occurrence of dead patches which did not occur in 1959, or the enlargement of patches, or regrowth of patches present in 1959. Allied with this, investigations will need to be carried out on the ground to determine which if any patches may be man-made.

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