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ABSTRACTS

EARLY RESULTS FROM AN OIL PALM PROGENY X ENVIRONMENT TRIAL AT TWELVE SITES IN PAPUA NEW GUINEA

N. J. MENDHAM. *Papua New Guin. agric. J.*, 22(4): 203-229

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PAPUA NEW GUINEA AGRICULTURAL JOURNAL

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Page 171, plate I: "Treatment 3"

Page 171, plate II: "Treatment 5"

[illegible] PALMS IN NEW BRITAIN

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Sites with volcanic soil and high rainfall in the New Britain, Bougainville and Northern Districts gave the best growth, although growth at another site in the Gulf District on recent alluvial soils was similar. Initial growth was slow at Buin in Bougainville, possibly due to low sunshine levels, but improved at a later stage. Rainfall was usually greater than the estimated evaporation rate at most sites, and the only moisture stress seen was on poor sandy soil in the Northern District, where nutrient stress also occurred. Some very low sunshine levels were recorded down to one hour per day, but no effects on growth or sex ratio were found.

Growth in New Ireland was poorer, with acute potassium deficiency at one site. In the Markham Valley, poorer growth was probably due to high pH, base-saturated soils with poor drainage. Growth at a Central District site at an altitude of 550 m was slow, with delayed planting and poor soil added to the effect of lower temperatures.

Early yields on the better sites appeared directly related to efficiency of assisted pollination, as sex ratios were high and natural pollination poor. Yields without pollination were very low at most sites, but with pollination were high and ranged from 750 to 1400 kg f.f.b./ha/fortnight over short periods, depending on efficiency of pollination.

Low leaf magnesium levels were recorded on the Islands sites and low potassium levels on the Mainland sites. Deficiencies may be occurring, and will need to be corrected if the high yields are to be maintained.

GROWTH RATE OF OIL PALMS IN NEW BRITAIN

N. J. MENDHAM. *Papua New Guin. agric. J.*, 22(4): 232-238.

The leaf area growth rate of *tenera* progenies from two genetic sources at three sites in New Britain was measured in the pre-bearing stage. It appeared to be very rapid when compared with reports from other countries. Curves fitted to the growth rate data gave very high determination coefficients (>0.98) indicating that any seasonal effects were small. The small deviations in 3-monthly growth rate from the fitted

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curves were compared with climatic data. There was weak evidence of a positive correlation with rainfall and a negative correlation with solar radiation at one site only. A lack of prolonged dry spells and high moisture-holding capacity of pumice in the recent volcanic soil appear to be responsible for the rapid and uniform growth rate.

The growth rate at Mosa was at least as rapid as at Keravat, in spite of the more seasonal climate at the former site. Slower growth at Siki was probably due only to poorer management and pest damage.

A clear and consistent difference in growth rate between the genetic sources was apparently due to the effect of inbreeding in the parentage of one of them.

MEASUREMENT OF SUNSHINE HOURS AND ITS RELATIONSHIP WITH SOLAR RADIATION IN NEW BRITAIN

N. J. MENDHAM. *Papua New Guin. agric. J.*, 22(4): 239-243.

Measurements were taken at Mosa Plantation in West New Britain and Keravat in East New Britain of sunshine hours, using Campbell Stokes and Jordan recorders, and solar radiation, using silicon solar cell radiation integrators of CSIRO design. The data analysed were the monthly means, 1969-70.

There was a seasonal difference in the relationship between Campbell Stokes and solarimeter recordings. The dry season, May to August, had reduced radiation levels for the same number of sunshine hours. This appeared to be largely due to increased atmospheric turbidity in that season, mainly smoke and haze. There appeared to be a difference in cloud type between the two rcording sites, also affecting the dry season relationships.

Over the recording period the Jordan recorder gave very similar results to the Campbell Stokes, although there was sometimes a considerable difference between the monthly means. The Jordan appears to record at lower radiation levels than the Campbell Stokes but is prone to several faults, these two factors approximately cancelling out.

OIL PALM YIELDS IN NEW BRITAIN

N. J. MENDHAM. *Papua New Guin. agric. J.*, 22(4): 244-249.

Yield, bunch weight, male inflorescence and leaf analysis data are presented for the only mature plots of oil palms in New Britain. The palms are mainly 1959 planting of *dura* x *tenera* material from Malaysia, and all records are from plots in East New Britain. Very high yields of 35 tons of fresh fruit bunches per hectare per annum were recorded for three successive years on the Keravat block, which received a fertilizer application, but reduced yields on the other plots in the last year probably indicated nutrient stress.

Leaf analysis data show low and declining nitrogen and magnesium levels. Sulphur is also declining, and there was apparently a response to all three nutrients in leaf levels, and probably yields, after fertilizing at Keravat. Other nutrients appear in adequate supply, although very low manganese levels of around 40 parts per million were recorded.

Excellent climatic conditions and the volcanic ash soil appear to be responsible for the high yields. Another plot in the same series in West New Britain, with similar soils but heavier rainfall in the wet season, was not yield-recorded but growth was good and the palms should be capable of similar yields.

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LEGUME COVER-CROPS FOR OIL PALMS IN WEST NEW BRITAIN

N. J. MENDHAM. *Papua New Guin. agric. J.,* 22(4): 250-256.

Results are reported from an observation trial of different legume cover-crop species at Dami Oil Palm Research Station, in West New Britain. Experience with legumes, mainly *Pueraria phaseoloides,* on other trials and commercial oil palm plantings in the district is also summarized. Pueraria has been the most vigorous legume, and is well adapted to the local environment of high rainfall and volcanic ash soils. It forms a dense cover with much less effort expended on establishment and maintenance than is needed in Malaysia, thus having an important weed control function, and reducing field costs. The effect on the palms appears highly beneficial, high leaf nitrogen levels and good growth being achieved.

Other creeping legumes with promises are the Cooper and Tinaroo strains of *Glycine javanica, Stylosanthes guyanensis,* and probably *Calapogonium caeruleum* and *Psophocarpus palustris.* The last two, being more shade-tolerant, may be useful after the palm canopy has closed. Seven other creeping legumes tried either did not establish a good cover at all, or failed to maintain themselves against competition from Pueraria and weeds. *Flemingia congesta* was the best of the bushy legumes tried.

OIL PALM NURSERY FERTILIZER TRIALS IN WEST NEW BRITAIN

N. J. MENDHAM. *Papua New Guin. agric. J.,* 22(4): 257-268

Fertilizer trials on recent volcanic soils in an oil palm nursery at Mosa Plantation in West New Britain are described. One trial with different rates of nitrogen and another with factorial combinations of the other major nutrients were run in 1969-70 on both topsoil and subsoil. The latter is being used mainly now as topsoil becomes scarce in the nursery vicinity. The oil palm seedling were grown in large polythene bags for 12 months, with fortnightly fertilizer applications.

Definite growth responses were found only to nitrogen and magnesium, and the latter only on the subsoil. There was an interaction between nitrogen, applied as ammonium sulphate, and magnesium. High rates of nitrogen gave reduced growth compared to lower rates on both soils, apparently due to impeded magnesium uptake, and nitrogen applied without magnesium was of little benefit. Nitrogen applied as nitrate may give different results.

The best growth on both soils was only obtained with application of the other major nutrients as well, and low leaf levels of potassium in the absence of potassium fertilizer suggest that this nutrient at least is also needed. Leaf levels of sulphur and manganese were increased considerably by ammonium sulphate application, the latter being almot certainly due to a lowering of soil pH.

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CONTENTS

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N. J. MENDHAM*

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INTRODUCTION

The oil palm has only recently been introduced as a commercial crop in Papua New Guinea. It was considered necessary therefore to study the growth and yield of modern types of oil palm under a range of environmental conditions in areas of the country likely to be suitable for the crop.

Twelve sites were chosen to represent the range of soil types and climatic conditions found in lowland areas with enough land available or potentially available to make establishment of an industry worthwhile. Sites are shown on the map (*Figure* 1). At each site, Malaysian *tenera* seed from two sources was used, with four progenies from each source. The sites selected and the establishment of the trials were discussed in DASF Annual Reports (DASF 1968, 1969),

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but will be summarized here. The growth of the palms in the pre-bearing period, and yields in the first year of bearing are discussed and interpreted with results from leaf analysis, meteorological records and observations on other factors such as pests and diseases. Results are thus preliminary in nature. The New Britain sites have been dealt with in detail by Mendham (1971a), and some of the data in this paper have been adapted from that report.

SITES

The main features of the sites are summarized in *Table* 1. The climatic details given for Keravat, Bubia and Bisianumu are from DASF (1969). The Buin rainfall figure, from McAlpine (1967), is only for five years and may normally be higher. The rest of the data is from Brookfield and Hart (1966). Five years' sunshine records at Talasea gave means ranging from 3.5 hours per day in January to 6.5 hours per day in June (records, Commonwealth Bureau of Meteorology). From maps given by Brookfield and Hart, Mosa and Siki receive more rainfall than Talasea in the dry season (May to August), and probably slightly less in the wet season (January to April). On New Ireland, Charles and Douglas (1965) showed strong responses to potassium by coconuts on soils similar to that at Katu, but no response on soils similar to Tigak. The coconuts on the Katu site were typical of poor areas on New Ireland, with many palms missing and the rest apparently dying slowly from potassium deficiency. Saiho probably has a higher and less seasonal rainfall than Sangara, being closer to a mountain range. The higher altitude of Bisianumu gives lower temperatures.

One area with potential for oil palms omitted from these trials is the Cape Rodney area of the Central District. A small observation plot of 86 palms was established at Bamguina in 1967, and two more observation plots of 1.2 hectares each were established in 1970 on the main soil types in the area, a brown alluvial clay loam and a red lateritic loam. The nearest rainfall station, Baramata, has 2,200 mm rainfall, with peaks in June and September, and a low of 90 mm in October (Brookfield and Hart).

Figure 1.—Map showing trial sites.

Table 1. — Main features of oil palm sites. Climatic details from nearest available station (see text for sources)

Site	District	Annual Rainfall (mm)	Other Climatic Features	Soil Type and Reference	Previous Site Vegetation	Planting Date
Keravat	East New Britain	2800	Little seasonal rainfall variation, mean sunshine 5.6 hours/day.	Volcanic sand, developed on ash and pumice (Graham and Baseden 1956).	Oil palms planted 1934 removed 1964	August, 1967
Mosa	West New Britain	3900 (Talasea)	Strongly seasonal: up to 700 mm per month Jan. - Apr., 100 mm per month June-Sept. (see text).	Multiple horizon pumice soil, sandy loam to clay loam surface layers (Soil Survey report, unpublished).	Forest	January, 1968
Siki	West New Britain	As above	As above.	Multiple horizon pumice soil; lighter texture than Mosa, sand mainly (Soil Survey report).	Forest	December, 1967
Aropa	Bougainville	3000 (Kieta)	Little seasonal variation.	Ash soil: brown loam with an ash pan (Scott 1967).	Forest	July, 1967
Buin	Bougainville	3300 (approx.)	Heaviest rain June-Aug., suspected low sunshine most of year.	As for Aropa; suspected nutrient deficiencies.	Forest	July, 1967
Tigak	New Ireland	3200 (Kavieng)	Little seasonal variation; apparently occasional droughts affect coconuts.	Red-brown clay loam over raised coral (van Wijk 1959), with coral outcrops.	Secondary forest	November, 1967
Katu	New Ireland	3500 (pre-1940 rec.)	As above.	Brown clay (van Wijk 1959), shallow with coral outcrops.	Very poor coconuts (see text)	November, 1967
Bubia	Morobe	3000	Heaviest rain July-Aug., with low sunshine (3.7 hours/day).	Alluvial and colluvial, base-saturated, pH up to 8.5 (DASF 1961), poor drainage on site and with gravelly patches.	Secondary regrowth	June, 1967
Saiho	Northern	3400 (Sangara)	Some seasonal variation: minimum 120-130 mm in July, Aug.; altitude about 300 m (see text).	Weathered brown ash soil, commonly stony; sandy clay loam upper layers (Haantjens 1964).	Secondary forest, old gardens	May, 1967
P.A.T.I.	Northern	2400 (Popondetta)	May-Aug. dry; 75 mm in July.	Unweathered volcanic sand with black topsoil of loamy sand (Haantjens 1964).	Grass - Imperata and Saccharum	January, 1968
Murua	Gulf	3600 (Kerema)	Maximum rainfall May-Sept. with probable low sunshine.	Undifferentiated recent alluvial soil, some areas strongly gleyed (Ruxton et al 1969).	Forest	July, 1967
Bisianumu	Central	2300	June-Aug. dry; 80 mm in July; altitude 550 m.	Chocolate clay loams overlying yellowish clay formed from volcanic agglomerate (DASF 1961); very hilly site.	Grass and regrowth	March 1968

PLANTING MATERIAL

Tenera seed is used now in almost all new commercial plantings throughout the world. Hardon and Thomas (1968) described the development of this in Malaysia. The Deli *dura* was the main planting material used until about 1956 but since then Deli *dura* x *pisifera* has mostly been used. This gives 100 per cent *tenera* progeny, and is now the standard commercial type. Hardon (1970) showed how breeding within the Deli *dura* has been done on very limited foundation material, with consequently considerable inbreeding. Selection for higher-yielding progenies has probably largely been selection of the less inbred ones. The original *tenera* selection, which formed the basis for most commercial *tenera* produced now, was in the Congo, also on a very limited genetic base (Hardon 1970) with consequent inbreeding.

The two sources of seed used in the present trials, designated "C" and "H", are from two different companies. However, both used very similar Deli *dura* female parents, and the main difference is in the *pisiferas* used as male parents.

The crosses can be summarized as follows:

Source C: Deli *dura* x (Deli x African *pisifera*)

Source H: Deli *dura* x Sumatra *pisifera*

The *pisiferas* for source C are descended from *pisifera* pollen imported from either Nigeria, the Congo or Malaya (originally from Africa). This was used on Deli *duras* closely related to those used for the female parents of the final cross and then bred for at least one generation. Thus the trial progenies have quite a high proportion of Deli "blood" and hence inbreeding. The varied origins of the *pisiferas* mean that the final four progenies should be fairly variable.

The *pisiferas* for source H are descended from three excellent quality *tenera* palms in Sumatra, one being SP540. This palm came from Eala in the Congo, from an excellent palm selected there ("Djongo"), which gave rise to much of the good quality *tenera* now found in Africa, Asia and South America (Hartley 1967). There has been considerable inbreeding in this line also, but no crossing with Deli *duras*. The parents for the final crosses are thus unrelated. However, for the four progenies from this source, the four Deli *dura* parents come from two closely related families, and only two *pisifera* parents were used, both from the same family. Thus the progenies should be very uniform in their performance.

ESTABLISHMENT

Nursery

Nursery germination, establishment and growth were dealt with in detail in an Annual Report (DASF 1969). *Tables* 2 and 3 summarize the data.

The C progenies performed poorly in all aspects. The "establishment" figure is the number of usable seedlings as a percentage of the number of seeds received. Full ger-

Table 3. — Mean seedling height (cm) of the two sources at each nursery site in April, 1967.

Nursery Site	C Mean	H Mean	Site Mean	$\frac{C}{H}$ x 100
Keravat	61.7	79.5	70.6	78
Hoskins	57.6	76.3	66.9	76
Aropa	51.8	62.7	57.2	83
Buin	42.7	51.0	46.9	84
Tigak	48.5	59.8	54.1	81
Bubia	64.0	72.9	68.4	88
Popondetta	39.6	52.8	46.2	75
Murua	56.4	67.8	62.1	83
Sogeri	31.2	32.5	31.8	96

Table 2. — Establishment and nursery growth of the eight progenies, means over all sites

	C1	C2	C3	C4	C Mean	H5	H6	H7	H8	H Mean
Estab. per cent Nov., 1966	40.5	61.3	48.7	39.2	47.4	81.6	81.7	78.5	83.2	81.3
Height (cm) April, 1967	49.8	54.9	46.7	49.8	50.3	58.4	62.7	61.3	64.0	61.6
No. of leaves April, 1967	8.6	9.5	9.1	8.9	9.0	9.3	9.4	9.5	9.3	9.4

mination of the C progenies was mostly delayed compared to the H, and hence some of the growth differences are due to the earlier establishment of most of the latter. Differences between sites were large. The poorer growth at Aropa was due to the seedlings not being spaced out properly, and shade not removed after a few months. The palms in the Sogeri nursery (used for the Bisianumu block) were also not spaced out properly, but growth was very slow as well. At Popondetta, the nursery used poor sandy soil, and even though normal watering and fertilizing were carried out, it was apparently not enough for rapid growth. The difference between the sources was most marked there. Poor growth at Buin was probably related to sunshine levels, as watering, fertilizing and nursery care were good. It was observed that conditions were very overcast up to April. Between April and planting out in July, weather was sunny and growth improved greatly. The poor germination and establishment of C4 meant that a closely related substitute progeny had to be used at Keravat, Mosa and Siki. This progeny was used for both C1 and C4 at Katu also.

Field Establishment

Planting-out dates are listed in *Table* 1. Unfortunately the Mosa and Siki plantings were delayed about four months, as Mosa Plantation was in the establishment stages and the site could not be prepared in time. The Siki planting was thus held back to give a better comparison with Mosa. Growth became very slow after about 14 months in the polybag nursery and field establishment took longer, so these sites were effectively set back four months compared to the others. Planting of the New Ireland sites was held back about two months to avoid dry weather, and the P.A.T.I. site about four months. The original site near Sogeri could not be used, and the Bisianumu planting was set back about six months. Slow growth in the nursery, combined with lack of attention, meant that the field palms there were well behind those of the other sites. Horses and cattle severely damaged the seedlings at Katu shortly after field planting. These palms were thus set back considerably compared to Tigak.

Pueraria cover-crops were established on all blocks, and most were good by July, 1968. On the P.A.T.I. and Bisianumu blocks, originally mainly grass, it proved difficult to establish full covers. At Keravat, about one third of the block (replicates 5 and 6) was covered with Para grass (*Brachiaria mutica),* and apparently poorly drained. Drains were dug and legume planted, but the effects on the palms were quite marked, in reduced growth and yellowing of the leaves. The symptoms disappeared after 1968, but the palms remained slightly smaller than those in the rest of the block. Drains were dug initially through most of the Bubia block, but several small areas later showed up as poorly drained, necessitating further treatment. Growth of palms in these areas was retarded.

Site layouts

Due to the reduced numbers of C palms available a modified design had to be used instead of normal randomized blocks. A type of split plot design was used, with two main plots per replicate, for the two sources H and C. Each main plot was divided into four subplots for the four progenies of each source — six palms per H subplot and four palms per C subplot. This design gives some complications in analysis, mainly relating to the spatial separation of the progenies of the different sources. Six replications were used at each site except Murua. Damage to nursery seedlings there by the taro beetle, *Papuana woodlarkiana,* caused quite heavy losses and only five replicates could be planted.

RECORDINGS

Crop Growth

It was intended to record leaf production on all sites, by marking the newest fully expanded leaf at regular intervals, and then counting the leaves produced between markings. This was only done regularly for the New Britain blocks and Saiho. Annual visits to the other sites meant that even if the marking was done properly by staff on the site, the older records were lost. Leaf production on all sites thus was only available for January to June, 1968 and the same period in 1969. In the former period palms at the later-planted sites were still establishing, so comparative records are only of value for the latter period.

The area of leaves increases steadily with age of the palm, and a regular estimate of area of the newest leaf is a good measure of the rate of growth of the palms. Estimates of this by the method described by Mendham (1971b) were taken every six months on all sites from early or mid 1968 to July, 1969. January, 1970 measurements were made only on the New Britain blocks, Saiho and Bisianumu, and July, 1970 measurements on all except Katu and P.A.T.I.

The two methods of measuring leaf area were:

(1) L(l x b), i.e., length of rachis (L) multiplied by the (length x breadth) of a leaflet in the region of largest leaflets; and

(2) Leaf (l x b), i.e., number of leaflets multiplied by (l x b) as above.

The first estimate was used for most of the measurements in this paper, but the second gives a simpler linear relation with area, and is more precise, so it should be used for future work, even though more tedious to carry out. Calibration curves were derived for each progeny for each method, and used to convert field data.

Flowering and Yield

The palms on all blocks except Siki and Murua were castrated, i.e., had the developing inflorescences removed, at approximately monthly intervals from late 1968 to about October, 1969. Records were kept of the number of palms of each progeny flowering, and the sex ratio of the inflorescences produced, i.e., the ratio of female to total inflorescences.

Harvesting then began in about April, 1970. However, it soon became obvious that natural fruit set was very poor on most blocks. Assisted pollination was started at Saiho in February, Mosa in June and most other blocks in about September, 1970. Records are being kept on a per plot basis, of the total weight of good fruit, number of good bunches, number of rotten bunches (usually unpollinated) and number of male inflorescences.

Data from four sites only, Keravat, Mosa, Saiho and Buin, are used in this report. Results from the first year of harvesting only are available so far.

Nutrition

Since an important aspect of these trials is the wide range of soil types being used, regular foliar samples were taken for chemical analysis of 3rd and later of 17th leaves. Leaf samples were taken monthly at Keravat to help interpretation of seasonal and longer term trends. At most other blocks they were taken annually.

In about April, 1968 a standard dressing of 230 g per palm of fertilizer 12:12:17:2 (N: P_2O_5:K_2O: MgO) was used on most sites, except for Aropa, Buin, Murua and Bisianumu where it was delayed until late 1968 by non-availability of fertilizer. At Saiho and P.A.T.I. a mixture of 15:15:15 NPK and ammonium sulphate was used, 450 g per palm at Saiho and 230 g at P.A.T.I. Thereafter only small applications were made on some of the poorer blocks, until 1971 when a general application was again to be made.

Environmental

Rainfall records from mid 1967 are available for all sites, with Campbell Stokes sunshine records from Keravat, Mosa and Bubia only. Jordan sunshine records are available for 1969 and 1970 at most sites and temperature recordings for the same period for Keravat and Bisianumu only.

CROP GROWTH RESULTS

Leaf Area

Sites. — The six-monthly estimates of leaf area are summarized in *Figure* 2, as site means. The figures represent the mean area derived from the L(l x b) estimate, of the newest fully expanded frond on the first day of the month indicated. *Tables* 4, 5 and 6 give the source and site means for July, 1968, 1969 and 1970 respectively.

The fastest growing sites were clearly Keravat, Aropa, Saiho and Murua over the whole period of recording. Bubia caught up with these in January and July, 1969, but fell behind at the last reading. These sites were significantly different from the next group both in 1969 and 1970. This second group comprises Mosa, Siki and Buin, although Siki was

Table 4. — Area of newest leaf in m^2 Source and site means, 1st July 1968.

Site	C Mean	H Mean	$\frac{C}{H} \times 100$	Site Mean
Keravat	1.08	1.25	86	1.17
Aropa	1.08	1.21	89	1.15
Saiho	1.02	1.29	79	1.15
Murua	0.92	1.02	90	0.97
Bubia	0.80	0.86	93	0.83
Siki	0.70	0.86	81	0.80
Buin	0.79	0.81	98	0.80
Mosa	0.70	0.79	89	0.75
Tigak	0.65	0.65	100	0.65
P.A.T.I.	0.53	0.61	87	0.57
Mean	0.83	0.93	89	0.88
Katu	0.46	0.41	112	0.44
Bisianumu	0.50	0.63	79	0.56

behind in July, 1969. Allowing for the four months' planting delay at the first two of these, they would be little different from the best sites, and appear to have grown at the same rate, but about four months behind. Nursery growth and initial field growth was slow at Buin, but after July, 1968 it was almost identical to Mosa. The growth rate at Tigak was slower than at the other sites until July, 1969. Growth at P.A.T.I. was poor, in complete contrast to Saiho, although the palms were from the same nursery. Even allowing for the four-month planting delay, it was well behind the other sites. Bisianumu was even poorer, with a continuing slow growth rate. At Katu, even though all palms

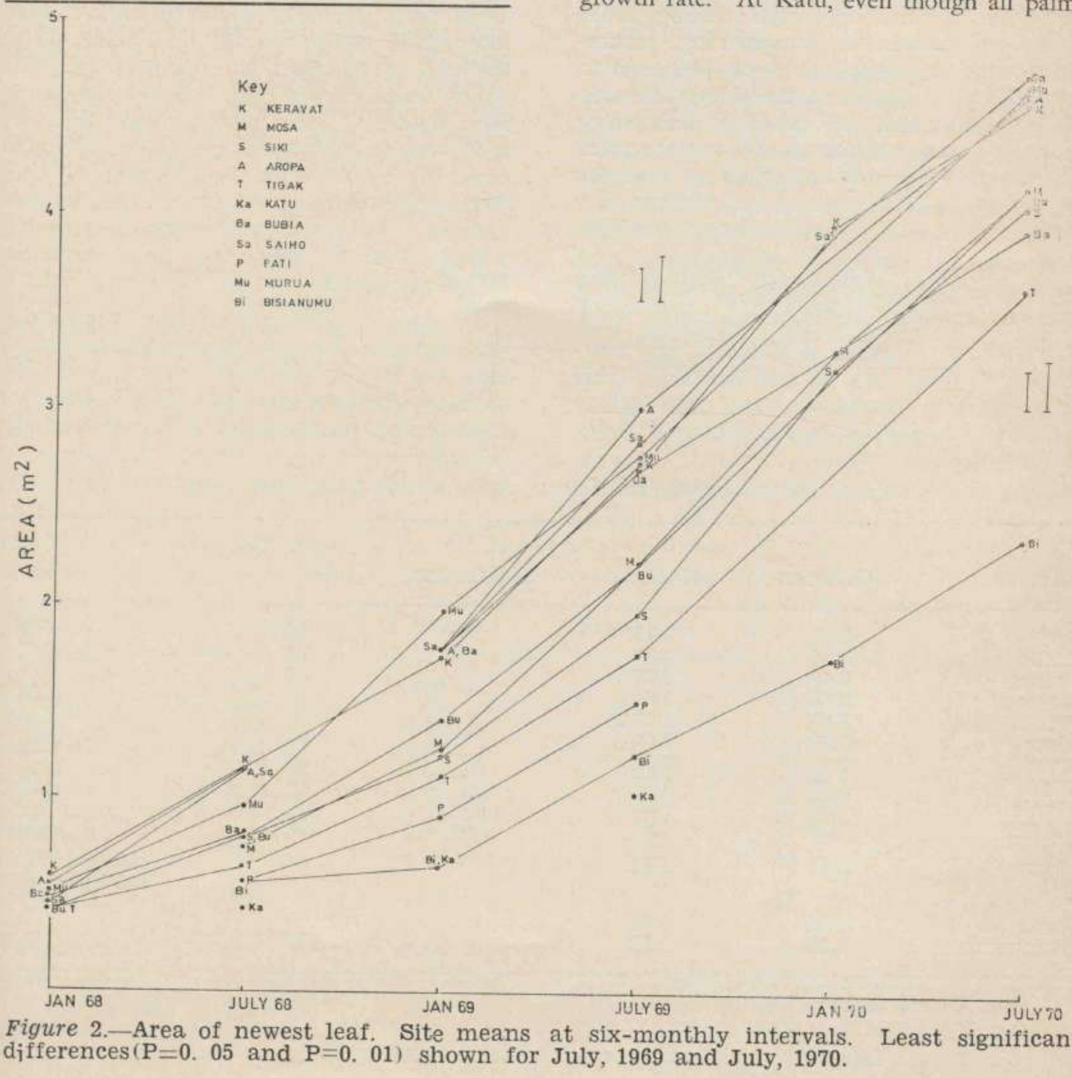

Figure 2.—Area of newest leaf. Site means at six-monthly intervals. Least significant differences (P=0. 05 and P=0. 01) shown for July, 1969 and July, 1970.

recovered from the damage by livestock, growth continued to be very slow.

Sources. — The C and H means for each site for July, 1968, 1969 and 1970 are contained in *Tables* 4, 5 and 6. The significance of the difference between them is indicated in the last two, and the C means are also given as a percentage of the H means. These can be compared with the corresponding mean heights in the nursery (*Table* 3).

For 1968 (*Table* 4), the differences between the sources at most sites were much reduced compared to the nursery. This is normal, as transplanting effects are large, and tend to cancel out differences. Larger seedlings suffer more root damage on transplanting, particularly when seedlings are kept longer than about 10 to 12 months in the nursery. Hardon (1970) notes that the effect of inbreeding depression on growth is usually lost (presumably temporarily) after transplanting from the nursery to the field, and this is probably due to the greater growth check to larger seedlings.

By July, 1969 (*Table* 5), differences between sources had become quite large again, and mostly significant or highly significant. The poorest sites, Tigak and P.A.T.I., had non-significant differences, as also had Buin. This last is rather anomalous, and was 'mainly cause by the high C1 mean (*Figure* 3).

The July, 1970 differences (*Table* 6) were fairly similar to those of 1969, although there was some variation. The differences over all sites were still highly significant. Only four replicates were measured at Murua, Aropa, Tigak and Bubia, thus contributing to the reduced significance compared to *Table* 5. Also, the large differences between the C progenies in their leaf area calibration curves at high values (Mendham 1971b) contribute to the reduced significance for the better sites.

The difference between sources was visibly apparent on most of the blocks. The C palms were generally smaller, with smaller fronds and shorter, less sturdy developing trunks. On aerial photographs of Mosa Plantation taken from 3,000 metres altitude in October, 1970, the trial block could be clearly seen by the darker strips of the H main plots alternating with lighter C main plots. Larger diameter and increased height of the H palm crowns were the main factors contributing to this. Examined under a stereoscope it could be seen that there was some variation in this pattern, where not all C palms were smaller than the H palms, but the overall effect was clear.

Progenies. — The best available comparative data between the individual progenies for all sites was for the July, 1969 measurement. The calibration curves, especially for C3, were not fully reliable for the July, 1970 measurements

Table 5. — Area of newest leaf in m². Source and site means, 1st July, 1969.

Site	C Mean	H Mean	Difference	C x 100 / H	Site Mean
Aropa	2.63	3.36	**	78	3.00 a
Saiho	2.38	3.27	**	73	2.83 b
Murua	2.46	3.07	*	80	2.76 b
Keravat	2.50	2.93	*	85	2.71 b
Bubia	2.35	3.01	*	78	2.68 b
Mosa	2.03	2.42	**	84	2 22 c
Buin	2.08	2.33	NS	89	2.21 c
Siki	1.69	2.22	**	76	1.95 d
Tigak	1.59	1.87	NS	85	1.73 e
P.A.T.I.	1.39	1.61	NS	86	1.50 f
Mean	2.11	2.61	**	81	lsd 0.05 = 0.17 lsd 0.01 = 0.23
Katu	1.03	1.04		99	1.03
Bisianumu	1.24	1.22		102	1.23

* Significant at P = 0.05
** Significant at P = 0.01
Site means followed by the same letter are not significantly different at P = 0.05

(Mendham 1971b). The 1969 data are contained in *Figure* 3.

The difference between the sources was large, although only at Aropa, Saiho and Siki were all H progenies significantly different from all C progenies. The only consistent differences between progenies over most sites were that H8 tended to be the lowest of the H progenies and C3 and C4 tended to be the lowest C progenies, especially at the better sites. This trend can be clearly seen in the combined, or overall mean data. These differences largely arose from the calibration curves (Mendham 1971b). In the general area of the curves from which these figures were taken, H8 gave slightly lower area readings than the other H's for the same L(l x b). C3 and C4 gave lower readings than the other C's. These differences may be real ones, as the fitted calibration curves differed significantly from each other.

Leaf Production

Figure 4 shows the monthly rates of leaf production at two representative sites, Mosa and Saiho. These have been adjusted to account for months of unequal length.

The effect of late planting at Mosa is obvious in the rapid increase in production up to the end of 1968, as the palms recovered from the setback of being held in the nursery and then transplanted at a large size. In 1969 and 1970 leaf production at Mosa was mainly higher than Saiho, considerably so at the last readings. Decreasing production at Saiho, although slight, is probably the normal result of onset of fruit bearing, and the same trend was likely at Mosa after recording ceased. Variation between months was greater at Mosa, although this is probably just the effect of using a shorter measuring period. Differences between the source means at each site were very small at all times, with no consistent difference emerging, in contrast to the leaf areas. There were, however, differences between individual progenies. C3 normally produced the most leaves and C1 the least of all progenies.

The best set of comparative data for all sites was for January to June, 1969, and this is given in *Table* 7. The later-planted blocks had mainly attained normal growth by then (*Figure* 4). The figures given for Siki in *Table* 7 are based on estimates for January to March. These may have been too low as production was rising rapidly then. Some of the differences between sites may be due to variation in marking dates, which were not recorded at some sites. Hence the figures for Murua are probably too high.

The means over the better sites show that there was no difference between the two sources. There was little difference between the H progenies, but C1 was low and C3

Table 6. — Area of newest leaf in m². Source and site means, 1st July, 1970.

Site	C Mean	H Mean	Difference	$\frac{C}{H}$ x 100	Site Mean
Saiho	4.26	5.25	*	81	4.75 a
Murua	4.34	5.05	NS	86	4.70 a
Aropa	4.28	5.06	*	85	4.67 a
Keravat	4.24	4.98	NS	85	4.61 a
Mosa	3.78	4.54	*	83	4.16 b
Buin	3.74	4.56	*	82	4.15 bc
Siki	3.58	4.56	**	79	4.07 bc
Bubia	3.54	4.38	*	81	3.96 c
Tigak	3.32	3.96	*	84	3.64 d
Mean	3.90	4.70	**	83	lsd 0.05 = 0.20 lsd 0.01 = 0.26
Bisianumu	2.26	2.46		92	2.36

* Significant at P = 0.05
** Significant at P = 0.01
Site means followed by the same letter are not significantly different at P = 0.05

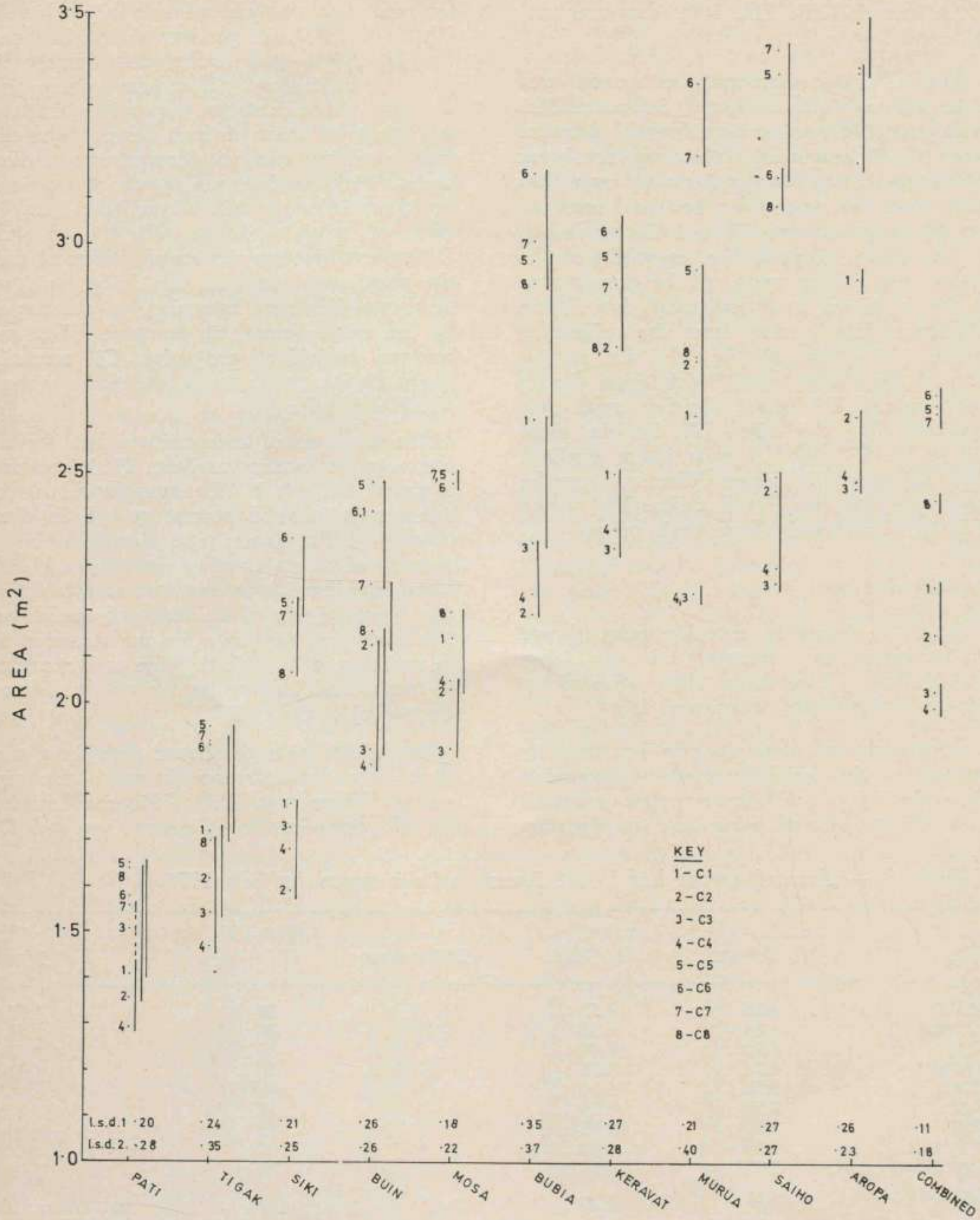

Figure 3.—Area of the newest leaf on 1st July, 1969. Progeny means for 10 sites. Means connected by the same line are not significantly different at P=0.05. Least significant differences 1 and 2 are for comparisons within the same source and from different sources respectively.

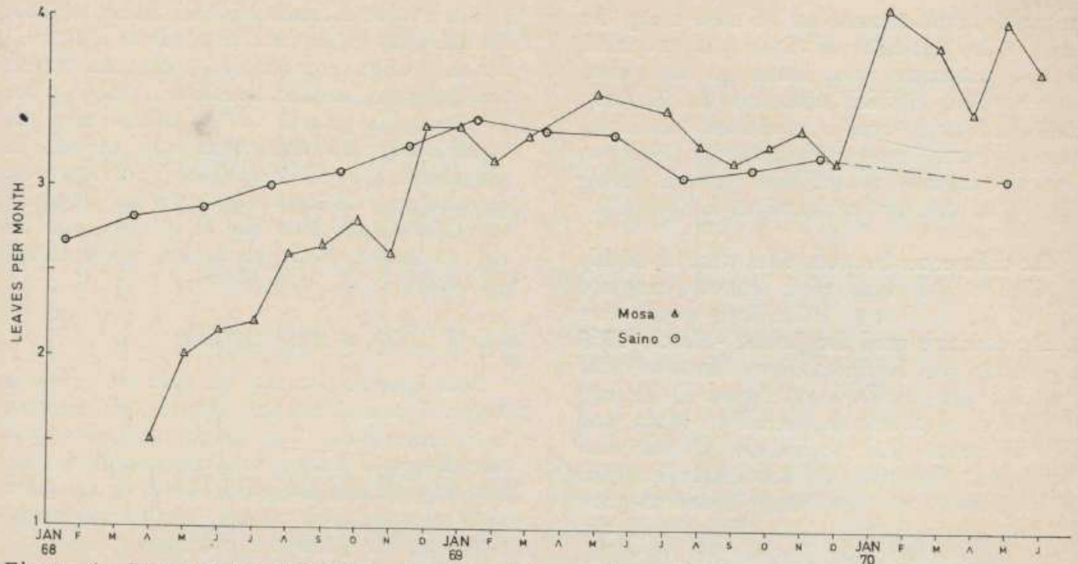

Figure 4.—Mean rate of leaf production at two sites. Mosa data monthly, Saiho two-monthly.

high. The substitute progeny for C4 on the New Britain blocks had a low rate of leaf production similar to C1. These trends were followed for most sites, and throughout the recording period. Generally there was little difference between the better sites, but production was greatly reduced on the poorer ones.

When these results are considered together with progeny leaf areas as in *Figure* 3, the rate of leaf area growth of the different progenies would have been of the same ranking as the area of individual fronds, except for C1, which would have been reduced, and C3 which would have been increased. Thus, progeny C3 tended to produce a larger number of small fronds.

Leaf Area Combined with Production using leaf(l x b)

To confirm the difference in leaf area between sites, sources and progenies found by the above method, using the L(l x b)

Table. 7. — Number of leaves produced January to June, 1969

Site	C1	C2	C3	C4	H5	H6	H7	H8	C Mean	H Mean
Keravat	20.3	21.0	23.0	19.9*	21.6	21.1	21.9	22.0	21.0	21.6
Mosa	19.0	21.0	22.1	19.2*	21.2	19.8	20.7	20.8	20.3	20.6
Aropa	20.9	21.0	21.9	22.4	20.6	20.9	21.5	19.6	21.6	20.7
Buin	19.4	20.8	21.6	20.7	20.4	19.8	19.1	19.7	20.6	19.7
Tigak	18.0	19.5	19.3	20.1	20.0	19.2	18.8	19.8	19.2	19.5
Bubia	17.6	19.3	21.2	19.1	19.6	19.1	19.5	20.1	19.3	19.6
Saiho	16.9	21.0	20.9	20.1	20.2	19.3	20.0	20.2	19.7	19.9
Murua	20.0	21.5	24.3	22.6	22.7	21.2	23.0	22.0	22.1	22.2
Mean of 8 sites	19.0	20.6	21.8	20.5	20.8	20.1	20.6	20.5	20.5	20.5
Siki**	17.9	18.1	18.8	16.0*	17.0	17.8	19.7	17.9	17.9	18.1
Katu	16.0	17.9	19.0	17.2	17.7	17.7	18.7	17.3	17.5	17.8
P.A.T.I.	14.5	14.6	15.5	15.4	16.5	15.0	17.1	15.9	15.0	16.1
Bisianumu	16.1	13.6	14.7	13.3	14.4	13.0	12.8	13.6	14.4	13.5

* Substitute progeny

** Estimate for January to April used

estimate, an alternative set of data using the leaf(l x b) estimate of area was prepared. This measurement was done on all palms on the New Britain sites on 1st January, 1969 and 1970, and is used here combined with the total leaf production for 1969, to give an estimate of leaf area growth during 1969. The data are summarized in *Table* 8.

The differences between sites were all highly significant. As mentioned above, the low figures for Siki may have been partly due to the estimate used for January-March, 1969 leaf production being too low. However, leaf areas for Siki (*Table* 6 and *Figure* 2) in July, 1969 were also low compared to Mosa, and the difference was apparently a real one. Maintenance on the Siki block was irregular in 1968, and cover-crop was allowed to grow up the palms several times. There was also considerable damage by *Scapanes* sp., the New Guinea rhinoceros beetle, and the difference in leaf area production between Mosa and Siki is probably explained by these factors.

Table 8. — Leaf area production for the New Britain sites, 1969, in m^2 per palm, using the leaf(lxb) estimate

Progenies	Keravat	Mosa	Siki	Combined
C1	119.8	90.0	79.8	96.5
C2	132.2	89.5	74.6	98.8
C3	123.7	84.3	85.0	97.7
C4	119.7	86.1	71.8	92.5
C Mean	**123.8**	**87.5**	**77.8**	**96.4**
H5	134.3	108.3	90.5	111.0
H6	131.8	102.9	96.0	110.2
H7	135.2	113.5	91.7	113.5
H8	140.2	106.3	101.6	116.0
H Mean	**135.4**	**107.8**	**94.9**	**122.7**
Difference in the means	NS	**	**	**
Site mean	129.6	97.6	86.4	
lsd 1	12.4	9.1	8.9	8.4
lsd 2	13.9	9.1	10.1	9.4

** Significant at $P = 0.01$

lsd (sites) $0.01 = 7.3$

lsd 1 Least significant difference at $P = 0.05$ for comparison of progenies of the same source

lsd 2 Least significant difference at $P = 0.05$ for comparison of progenies of the same source

The source differences were similar to those for the July, 1969 L(l x b) data (*Table* 5) for these sites. The difference between sources was generally smaller at Keravat, largely due to the good growth of C2, which was not significantly different from any of the **H** progenies (*Table* 8 and *Figure* 3). There were no consistent differences between the progenies of either source over the three sites, and for the combined data the means were closely grouped.

NUTRITION

Leaf analysis data for all sites are given in *Tables* 9 and 10 for the Islands and Mainland sites respectively. The Keravat samples were monthly, and means over approximately six-monthly periods are given. Most of the other sites were sampled annually, with some special sampling for particular problems.

The "tentative critical levels" given in *Table* 9 are based on those given by Ollagnier, Ochs and Martin (1970) with some modifications based on levels used in Malaysia, and what appear to be appropriate for Papua New Guinea. A higher third leaf critical level for magnesium, 0.30 per cent, is usually used in Malaysia. Manganese levels in Malaysia are usually above 200 p.p.m., but on local soils levels as low as 8 p.p.m. have been found. This may be related to the generally higher soil pH here, as manganese is less readily available under neutral than under acid conditions. The above authors quote levels of about 50 p.p.m., as found in Colombia, as being low. A critical level for SO_4-S has not been established for oil palms, and the suggested levels given here are based on experience with coconuts, and the oil palm samples so far analysed. Levels of the other minor elements are just "normal" levels from Malaysia, as responses have not been shown to any of them except boron, where certain leaf symptoms such as "hook leaf" are often associated with low boron levels (around 3 p.p.m.) and can sometimes be cured with boron fertilizer applications (Turner and Bull 1967).

Keravat. — With the large number of samples taken, the mean figures presented here should be quite reliable. Generally the levels appear adequate. Some low nitrogen levels were recorded in the last half of 1968, but the mean of 2.77 was near the critical level. Manganese appeared to be decreasing

Table 9. — Selected leaf analysis data from oil palm trial blocks, New Guinea Islands 1968-70. 3rd and 17th leaf samples

Site	Leaf	Date & Notes	% on dry basis					p.p.m. on dry basis					
			N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu	B
Keravat*	3rd	9/67-12/67 (6)	3.12	0.210	1.67	0.81	0.27	188	94	70	20.4	10.2	18.0
		1/68-6/68 (5)	3.13	0.196	1.54	0.87	0.34	189	64	65	20.9	6.8	14.4
		7/68-12/68 (6)	2.77	0.213	1.68	0.70	0.32	240	39	59	23.6	11.6	17.0
		1/69-7/69 (7)	2.93	0.211	1.81	0.75	0.40	431	39	61	23.0	3.5	14.1
	17th	9/69-12/69 (4)	2.59	0.175	1.20	0.94	0.25	123	52	72	30.5	10.5	12.2
		1/70-7/70 (6)	2.59	0.215	1.34	0.90	0.31	112	67	65	16.2	9.5	13.8
Mosa	3rd	5/68-7/68 (2)	3.14	0.216	1.53	0.96	0.44	282	101	57	23.6	6.3	13.3
	17th	1/70	2.60	0.162	1.03	1.16	0.26	140	23	28	15.5	10.3	11.5
		1/70 orange frond	2.62	0.163	1.20	1.16	0.18	140	17	42	16.0	8.8	11.8
		10/70 H	2.53	0.160	1.15	0.98	0.20	115	33	57	16.3	6.0	14.3
		10/70 C	2.56	0.150	0.95	1.05	0.15	130	29	60	15.4	5.0	15.0
Siki	3rd	7/68	3.15	0.215	1.44	1.27	0.79	180	106	63	22.5	10.5	14.1
		1/70	3.17	0.209	1.90	0.69	0.31	280	21	69		8.8	12.3
	17th	11/70 H	2.51	0.130	0.90	1.07	0.22	105	35	51	14.0	5.8	11.0
		11/70 C	2.61	0.150	1.00	1.18	0.18	95	35	47	14.8	5.4	11.5
Aropa	3rd	7/68		0.249	1.84	0.68	0.36	205	35	61	23.3	7.2	13.3
		8/69	2.89	0.190	1.40	0.60	0.19	370	43	92	34.3	5.2	14.0
	17th	8/70	2.88	0.180	1.00	1.05	0.20	145	71	63		7.1	15.7
Buin	3rd	7/68		0.236	1.47	0.75	0.44	187	69	66	25.5	8.5	12.5
		8/69	3.06	0.173	1.12	0.60	0.20	277	61	60	26.0	5.5	9.1
	17th	8/70	2.75	0.160	0.95	1.05	0.30	175	91	100	18.7	8.2	15.0
Tigak	3rd	7/68	3.08	0.194	1.57	0.88	0.44	197	112	52	22.5	6.3	14.2
		8/69	2.98	0.195	1.26	0.74	0.25	214	122	58	27.2	5.4	14.0
	17th	8/70	3.12	0.190	1.25	1.23	0.23	205	200	79	24.3	10.2	18.0
Katu	3rd	7/68	3.20	0.201	1.09	1.34	0.76	140	116	56	19.0	9.3	19.0
		8/69	2.62	0.175	0.64	0.76	0.25	235	166	51	28.8	4.5	9.0
		8/70	3.11	0.230	0.55	0.68	0.35	190	162	66	27.1	10.1	14.5
Tentative critical levels (see text)		3rd leaf	2.8	0.19	1.30	0.30	0.24	200	50	60	15.0	5.0	10.0
		17th leaf	2.5	0.15	1.00	0.60	0.24	150	50	60	15.0	5.0	10.0

* For Kerevat and Mosa, number of samples indicated in brackets

on the third leaf samples, but seemed to stabilize at over 50 p.p.m. on the 17th leaf samples. The later sulphur levels were quite low, and may indicate an incipient deficiency, as sulphur deficiency is common on the Gazelle Peninsula in other crops.

Mosa and Siki. — Results from these two were quite similar, as expected since they are on similar soils. Owing to the large growth difference that had developed between the two sources H and C, separate samples were taken. It had been observed that the C source palms, as well as being slower growing, seemed to be more susceptible to symptoms resembling magnesium deficiency, "orange frond" (Turner and Bull 1967). This had been noticed on many other sites also. The "orange frond" sample from Mosa, taken from the 20 worst affected palms, did show lower magnesium levels than the general sample taken at the same time. Also, the C magnesium level was lower than H for Mosa and Siki on the October, 1970 samples. All levels were low for these samples, and it appears that magnesium declined from an initially high level to quite a low level, indicating the possibility of a response to fertilizer. Potassium levels were fairly low for the later samples and were grouped around the critical level of 1.0 per cent, and a deficiency of this nutrient may also have been developing. Both sulphur and manganese appeared low also.

Aropa and Buin. — The Aropa figures showed low magnesium in 1969 and 1970, and marginal potassium in 1970. At Buin, potassium was low in 1969 and 1970, and magnesium only in 1969. At both sites in 1970 nitrogen was higher than on the New Britain sites.

Tigak and Katu. — With the expected potassium deficiency in New Ireland, 230 g per palm of 16:0:28 ($N:P_2O_5:K_2O$) was applied in October, 1968 and the same amount of 12:12:17:2 in May, 1969. Leaf levels at Tigak were surprisingly good and mostly normal. At Katu, however, extremely low potassium levels occurred in spite of the applied fertilizer. The palms were slow-growing and visible symptoms were apparent on some palms, similar to "confluent orange spotting" described by Turner and Bull.

Bubia. — This site had been poorly drained, and this was reflected in the 1968 nitrogen level. Samples taken in January, 1968 from drained and waterlogged areas gave 2.65 per cent and 2.05 per cent N respectively. 1969 and 1970 potassium levels were low. A deficiency would be quite likely on this base-saturated, high pH soil, and would be increased by high soil calcium and magnesium. Leaf calcium levels were high, but magnesium seemed normal. Sulphur levels were very high initially, but may have been declining in the 1970 samples. The difference in magnesium level between the C and H sources was apparent, as at Mosa.

Saiho. — A considerable amount of "white stripe" (Turner and Bull) occurred on these palms, and on most other sites also. For most palms it seems a transient stage, but some are affected more seriously. C2 particularly appeared to be susceptible at Saiho and also at some other sites. A separate leaf sample was taken from the 20 worst affected palms in 1969. The only difference from the general sample was that sulphur levels were lower. However, later samples did not show this difference (K. A. Handreck, personal communication). In 1970 samples were taken from H and C palms separately. The difference in magnesium levels between the sources was clear, and it seems that the C palms generally tend towards lower magnesium uptake and more magnesium deficiency symptoms. Potassium levels were low on the 1970 samples.

P.A.T.I. — Levels of some nutrients tended to be low on this poor sandy soil, as expected. The palms were very yellow in September, 1968, so a dressing of 450 g ammonium sulphate per palm was given, after which the yellowing rapidly disappeared. The 1968 leaf levels showed very low nitrogen and quite low potassium, whereas the 1969 levels (after fertilizing) were normal. In 1970, nitrogen was marginal and some deficiency symptoms appeared to be returning. Potassium was very low and sulphur also rather low.

Murua. — Most levels appeared normal, although potassium levels were low in 1969 and especially in 1970. Sulphur levels may also be low. Nitrogen levels were very high.

Bisianumu. — On this uneven site, palm growth was observed to be satisfactory on the lower parts of the slope and on a flat area at the end of the block, but poorer on the

Table 10. — Selected leaf analysis data from oil palm blocks, Mainland New Guinea and Papua, 1968-70. 3rd and 17th leaf samples

Site	Leaf	Date & Notes	% on dry basis					p.p.m. on dry basis					
			N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu	B
Bubia	3rd	10/68	2.67	0.178	1.40	0.64	0.31	610	39	71	17.3	6.3	16.0
		10/69	2.89	0.180	0.93	1.23	0.28	830	82	104	12.0	4.5	18.5
	17th	9/70 H	2.69	0.220	0.83	1.14	0.34	210	116	40	16.5	6.6	18.5
		9/70 C	2.70	0.215	0.90	1.10	0.25	170	124	53	13.5	6.5	16.3
Saiho	3rd	9/68	2.93	0.225	1.52	0.78	0.36	275	72	51	17.0	16.7	17.5
		10/69	2.88	0.180	1.48	0.74	0.28	285	58	80	19.5	4.2	12.0
		10/69 white stripe	3.02	0.181	1.43	0.68	0.24	117	55	72	17.0	4.5	14.5
	17th	9/70 H	2.91	0.225	0.78	1.14	0.34	228	80	49	14.8	6.9	16.5
		9/70 C	3.00	0.225	0.79	1.08	0.27	188	78	56	16.5	9.3	16.5
		10/70 H white stripe	2.92	0.190	1.20	1.06	0.32	173	98	57	16.0	7.7	18.0
		10/70 C white stripe	2.88	0.190	1.20	1.04	0.22	125	94	49	17.0	6.6	17.0
P.A.T.I.	3rd	9/68	2.34	0.180	1.13	0.85	0.58	185	96	65	17.5	18.7	15.8
		10/69	2.83	0.170	1.30	0.55	0.34	205	48	80	21.5	4.2	8.9
	17th	9/70	2.54	0.205	0.75	1.02	0.42	133	75	63	15.0	6.2	14.5
Murua	3rd	10/68		0.150	1.65	0.33	0.26	185	55	57	13.0	4.5	12.0
	17th	10/69	3.10	0.182	0.93	0.96	0.27	520	157	66	15.5	5.1	10.5
		9/70	3.17	0.220	0.75	0.86	0.33	135	170	56	20.0	5.2	
Bisianumu	3rd	9/68	2.77	0.173	1.77	0.48	0.44	425	335	80	14.3	13.8	15.0
		10/69	2.36	0.147	1.50	0.40	0.28	420	96	70	18.5	4.1	12.0
		9/70 bottom	3.13	0.240	1.08	0.64	0.38	250	145	56	24.0	8.2	14.3
		9/70 hillside	2.83	0.235	0.99	0.60	0.39	185	77	51	22.0	8.3	16.8
Cape Rodney	3rd	10/68 Bamguina	3.18	0.230	1.45	0.65	0.41	125	42	52	21.0	7.4	14.3
	17th	10/69 Bamguina	2.24	0.148	0.75	1.00	0.31	173	50	71	18.0	4.8	11.0
		9/70 Bamguina	2.63	0.225	0.68	1.02	0.40	145		56	14.5	6.9	12.0
	3rd	9/70 alluvial	3.27	0.325	1.10	0.66	0.39	233	149	68	18.0	10.5	12.3
		9/70 laterite	3.50	0.275	1.10	0.66	0.38	238	280	79	20.5	10.3	14.0

upper parts of the slope. Fertilizer applications were as follows: 300 g 15:15:15 per palm in December, 1968 and 450 g 12:7:7:2 in April and also September, 1970. The 1969 levels of nitrogen and phosphorus were very low, in spite of the fertilizer applied 10 months previously, but the fertilizing in 1970 increased all nutrients except potassium to adequate levels. Lower levels of most nutrients can be seen on the "hillside" samples compared to the "bottom" one.

Cape Rodney. — The observation plot at Bamguina was partly sited on an old rubber nursery, and palm growth was very uneven, many being quite poor. 900 g per palm of an NPK fertilizer had been applied in July, 1968, and leaf levels were all adequate by October, except possibly for sulphur. In 1969, however, levels of nitrogen, phosphorus and potassium were all low and would indicate quite marked deficiencies. 1350 g per palm of an NPK fertilizer was applied in May, 1970, and by September nitrogen and phosphorus were adequate, but potassium even lower than previously. This seems odd in view of the heavy fertilizer application. However, from experience with coconuts in this area (K. A. Handreck, personal communication), high rates of potassium chloride (2 kg per palm) did not raise leaf levels, but increased K levels in the nut water and probably gave a growth response. The high exchangeable Mg to K ratio in the base-saturated soil is probably the reason for this.

The new plots on the two different soils were well established with a good Pueraria cover-crop by September, 1970, and leaf levels were high except for potassium.

FLOWERING PATTERNS

The flowering pattern of some of the sites is summarized in *Figures* 5 and 6, for the period when castration was carried out. *Figure* 5 shows that the Saiho palms commenced flowering earlier than the other sites. Over 90 per cent of palms were flowering by January, 1969, which was about 19 months

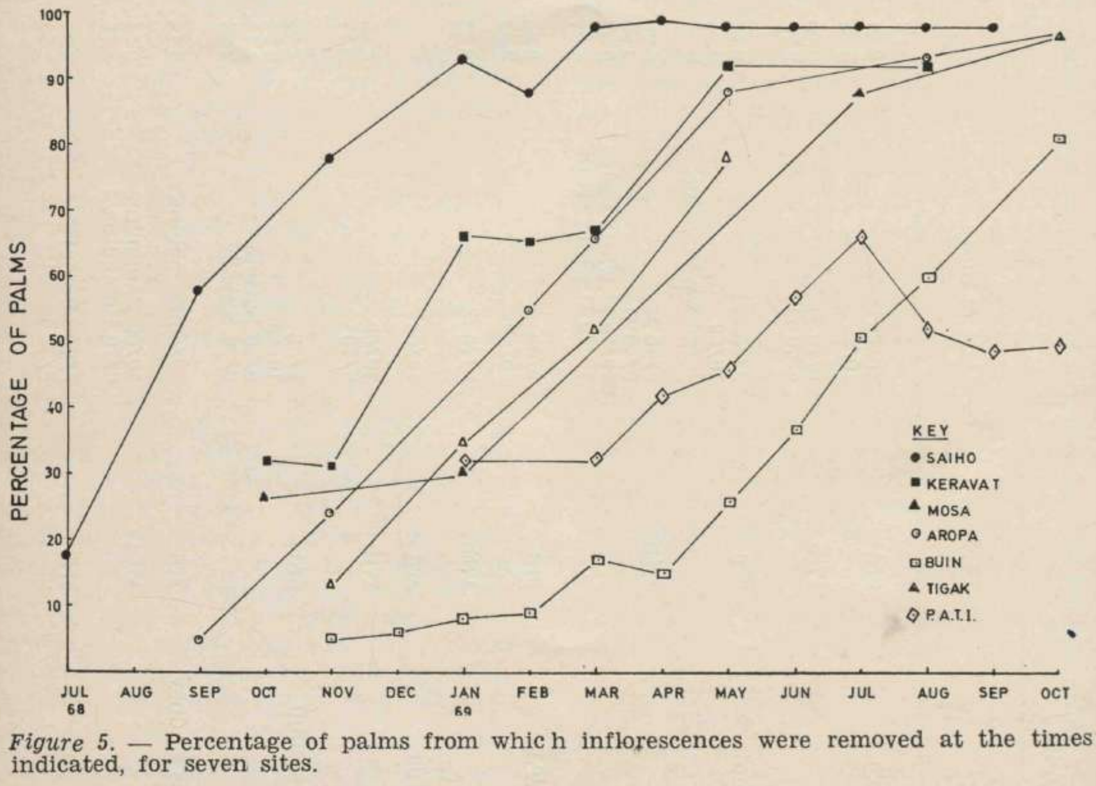

Figure 5. — Percentage of palms from which inflorescences were removed at the times indicated, for seven sites.

after field planting. The main increase in the proportion of palms flowering at all sites except P.A.T.I. occurred at a similar rate, comparing the slopes of the lines in *Figure* 5, but there were large differences between sites when this stage occurred. Thus, Keravat was about 3½ months behind Saiho, Aropa 4½ months, Tigak and Mosa about 6 months and Buin about 10 months. The increase at P.A.T.I. was slower than for the other sites, and broke down after July, 1969. The rate of leaf production was only about two per month there, and this, possibly combined with abortion of some inflorescences, meant that some palms, although they had produced inflorescences previously, over a month did not produce any. In this way, the data given in *Figure* 5 are not identical to the percentage of palms "flowering" which would have been carrying inflorescences if castration had not been done.

The changes in sex ratio with time can be seen from *Figure* 6. Initially at all sites most inflorescences produced were males, but after January, 1969 there was a rapid rise in sex ratio at Saiho, reaching over 90 per cent by September. Aropa followed this pattern closely, but about two months behind Saiho. Bubia (not shown) was similar. The Keravat pattern was initially similar to Saiho, but tapered off at about 60 per cent. This has continued since, with the ratio rising slowly, and many more male inflorescences have been produced there than on the other well-grown blocks. At Tigak (not shown) there was an increase similar to Aropa until May, 1969 when castration ceased, but observations showed that the sex ratio then followed a similar pattern to Keravat. At P.A.T.I. the trend was similar to this, but several months behind again. At Buin, the ratio appeared to be increasing until February, but then dropped right back until May, after which the increase was normal, tapering off at around 90 per cent. However, in the early months there were only a few palms flowering, so the trend is not of much significance. At Mosa there was a long delay until the sex ratio started to rise, but the increase was then rapid, to about 95 per cent in December, 1969. Differences between sources and progenies were small and not consistent between sites.

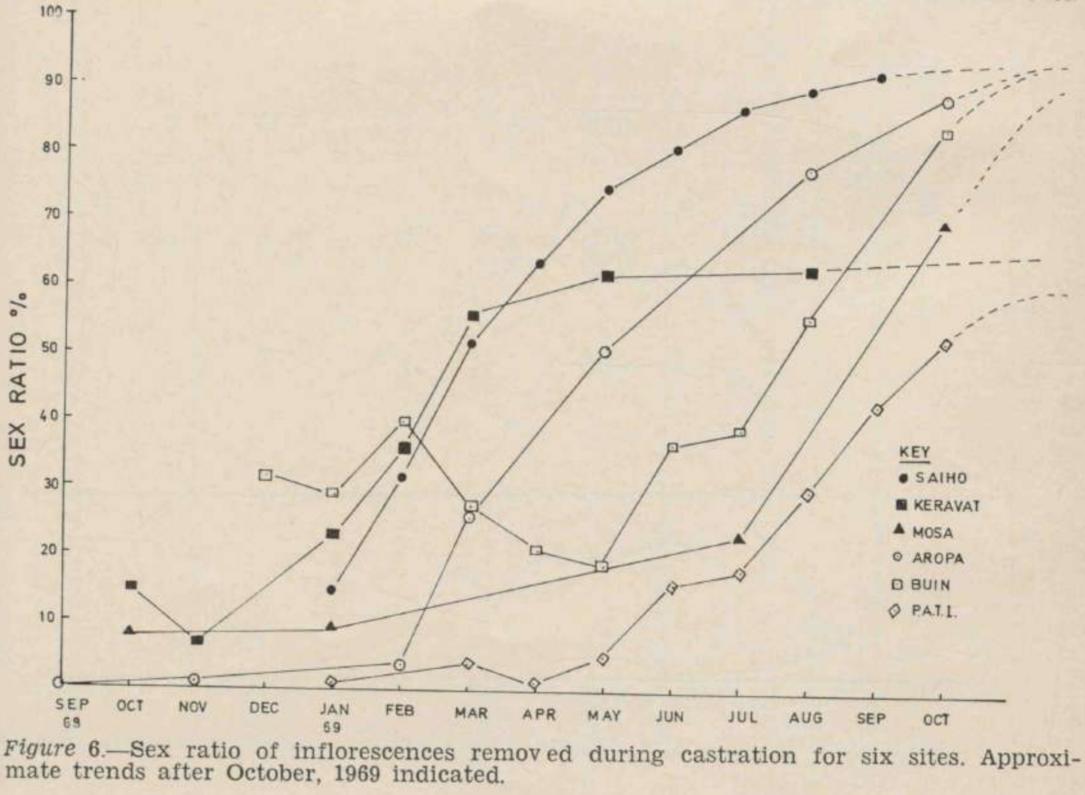

Figure 6.—Sex ratio of inflorescences removed during castration for six sites. Approximate trends after October, 1969 indicated.

YIELD

Figure 7 shows the results of the first year's harvests at three sites, as yield of f.f.b. and proportion of good bunches. *Table* 11 summarizes results for the two sources at each of the above sites plus Buin with the proportion of good bunches for Mosa and Saiho only. *Table* 12 gives the approximate male inflorescence production at three of the sites during 1970.

Keravat. — Yields without pollination were moderately good, and came from a large number of small bunches with some pollination and some parthenocarpic development. The fruit set was better than at the other sites, and was due to the lower sex ratio, with more male inflorescences (*Table* 12). Assisted pollination increased yields greatly to 1500 kg/ha/fortnight, and bunch weights increased to 6.5 kg. This was lower than for pollinated bunches at the other sites, and there was still a considerable number of bunches with inadequate fruit set. The C source palms consistently produced a larger number of bunches than the H source. This result is suspect, and on subsequent checking of the recording technique it appears that there was some confusion between palms of the four-palm C plots and the six-palm H plots. Later harvests since *Table* 11 was compiled have shown the expected trend, with the H palms yielding more than the C palms.

Mosa. — The yield and proportion of good bunches at Mosa were very low until October, 1970, indicating very poor natural pollination. With assisted pollination, yields increased to 756 kg/ha/fortnight, considerably lower than for the other sites. The low number of good bunches (38 per cent) explains the poor result, and the standard of assisted pollination was generally not high. There was a period of ineffective pollination in February to March, 1971 due to staff changes. Consistently higher yields were produced from the H source palms, corresponding with their more rapid growth.

Saiho. — Yields without assisted pollination were low and similar to Mosa. High yields with 65 per cent good bunches were recorded for a period of 10 harvests when pollination was effective. After June, 1970, fresh pollen

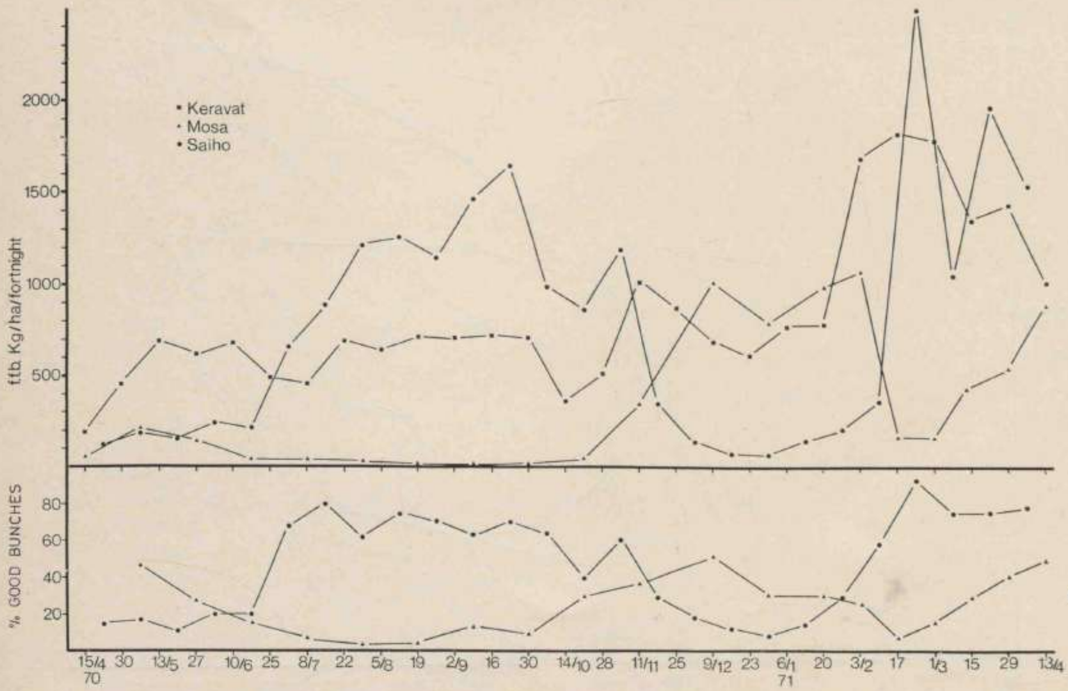

Figure 7.—Fortnightly bunch yields, Kerevat, Mosa and Saiho, and percentage of good bunches.

Table 11. — Summary of yields for the two sources at four sites. Periods of effective assisted pollination separated from unpollinated and ineffective periods.

Site	No. of Harvests	Yields of f.f.b. (kg/ha/fortnight) C	H	Mean	Mean Bunch Weight (kg) C	H	Mean	% Good Bunches C	H	Mean
Keravat										
unpollinated	21	703	569	636	3.69	3.73	3.71			
pollinated	6	1728	1310	1519	6.48	6.50	6.49			
Mosa										
unpollinated	12	60	99	79	4.07	3.77	3.92	12.5	20.4	16.4
pollinated	8	655	857	756	7.90	9.45	8.67	34.9	41.0	37.9
Saiho										
unpollinated	11	130	289	210	5.82	6.43	6.12	16.8	25.5	21.1
pollinated	15	1014	1428	1221	8.76	9.64	9.20	61.1	71.8	66.4
Buin										
unpollinated	16	134	257	195	3.1	2.9	3.0			
pollinated	5	977	1185	1081	7.8	7.7	7.7			

Table 12. — Male inflorescence production. Approximate total per hectare per month in 1970, Keravat, Mosa and Saiho

	J	F	M	A	M	J	J	A	S	O	N	D	Mean
Keravat				75	128	107	82	55	52	52	34	25	68
Mosa	23	19	37	39	26	20	18	24	24	32	26	40	27
Saiho	27	22	36	24	12	16	17	11	17	11	15	13	18

was mixed in error with old stored pollen, which meant that viability was lost and subsequent yields severely reduced. Effective pollination was resumed in September, with a dramatic effect on yields in February. The H source palms gave substantially higher yields than the C source over the whole recording period, being 40 per cent greater for the period of effective pollination.

Buin. — Yields during the unpollinated period were similar to those at Saiho and Mosa. Pollinated yields were better than at Mosa due to more effective fruit set, but were not quite as high as at the other sites, probably due to the poorer vegetative growth.

Thus, these preliminary results indicate that yields in the early part of the bearing life of palms will be dominated by effectiveness of pollination, either natural or assisted. Natural pollination was very poor at most sites, probably due to:—

(1) A very high sex ratio, giving few male inflorescences;

(2) Rapid vegetative growth of palms and cover-crop, giving a dense screen which could hinder pollen dispersal in young palms; and

(3) High rainfall and humidity at some sites, also hindering pollen dispersal.

Yields with assisted pollination were very high. 1000 kg/ha/fortnight would give 26 tons/ha/yr, a very high rate of yield for palms in their first bearing year, and "overbearing" (Turner and Bull 1967) may occur if nutrition and management are neglected. If this happens the frequency of pollination rounds can be reduced.

Gray (1969) gives comparable figures for the first year of bearing of *tenera* palms in Malaysia. In his Table 11, the average yield for the first six months without pollination was 360 kg/ha/fortnight (his figures were monthly), less than Keravat but more than at the other sites. For the next four months with assisted pollination (presumably with at least 60 per cent good bunches), yields were 900 kg/ha/fortnight, less than at Saiho, Keravat and Buin, and only slightly more than at Mosa where assisted pollination was not carried out properly.

PESTS AND DISEASES

Generally the effects of pests and diseases were negligible on growth and yield of the palms. However, certain conditions were serious or fatal for individual palms, and may increase in importance in the future.

Pests. — The only pest of note was the New Guinea rhinoceros beetle, *Scapanes* sp. This only caused important damage at Siki, which is a small clearing in the forest. Some palms attacked at other sites (e.g. Mosa and Buin) contracted secondary bud rots and died.

Diseases. — The only appreciable number of palms lost was at Keravat, where five palms died with a condition apparently identical to "stem wet rot" (Turner and Bull 1967). Six other palms contracted "bud rot", similar to the condition of that name described by Turner and Bull, and only three recovered. Only about two of these cases appeared to be initiated by beetle damage. Odd palms with bud and stem rots were found at other sites, and it is possible that the larger number at Keravat may have been due to a build-up of pathogenic organisms in the previous oil palm stand.

CLIMATIC DATA

Available climatic data are given in the Appendix.

Rainfall and Evaporation

Evaporation rates, as measured with U.S. Class A pans at Mosa and Keravat, ranged from 110 to 160 mm per month, with a mean of about 130 mm. Evapotranspiration would probably be slightly lower than this normally. The monthly rainfall at most sites normally exceeded 130 mm, with usually one or two months per year below it. For the Islands sites, two consecutive months below 130 mm were recorded only at Siki in 1970, and this had little effect on soil moisture levels due to the high water storage capacity of the pumice soil (Mendham 1971c). Dry periods were more frequent at the Mainland sites, except for Saiho. Drought symptoms were only observed on the P.A.T.I. palms in September, 1969, after four relatively dry months, and on the sandy soil there. The dry season was similar in severity at Bisianumu in 1969, but the palms did not show such marked effects. This was presumably due to the greater moisture-holding capacity of the soil, and possibly also due to the lower temperatures and hence evapotranspiration rates.

Mosa and Siki have the most distinct wet seasons, with the highest rainfall usually in January or February. Buin can also have heavy rain in the wet season (around August), although this occurred in only two years out of the four recorded. The mean annual rainfall for three full years recorded was 4300 mm, compared to 3300 mm in *Table* 1, and the latter figure is probably too low.

Sunshine

Hartley (1967) states that the areas of the world with highest oil palm yields have at least five hours sunshine per day in all months of the year, and considers that high sunshine levels are an important factor in yield determination. The limited data given in the Appendix show that some sites have months with very low sunshine levels, particularly Mosa, Hoskins, Buin and Murua. Nearly all sites have numerous months with less than four hours per day. Levels in 1970 were generally higher than in 1969 (by about one hour per day on the annual means), and it may be that 1969 was a period of particularly low levels.

Temperature

Data for Keravat and Bisianumu show little seasonal variation. Generally maximum temperatures are about 2 degC lower at Bisianumu than at Keravat, and minimum temperatures only 1 to 2 degC lower. The lowest temperatures were generally recorded during the dry seasons (July to August at both sites), and at Bisianumu the absolute lowest temperature was 16 degC.

DISCUSSION

There appears to have been little or no restriction to the growth or early yield of palms at the better sites, namely Keravat, Aropa, Saiho and Murua. Mosa and Siki are similar to these if the planting delay is allowed for. Moisture shortage did not appear to have occurred at any of these sites. Quite low sunshine levels at some sites did not appear to impede growth, flowering or yield. African workers considered that low sunshine levels gave low sex ratios (Broekmans 1957), but sex ratios increased to high levels on most sites. Lower soil fertility was possibly responsible for lower sex ratios at Keravat and Tigak.

Growth at Bubia was poor initially, then improved, and at the last leaf area recording again appeared to lag behind. Poor drainage appeared to be the main trouble initially. High pH, base saturation and possible potassium deficiency are likely to have caused the poorer growth in the later stages.

The slower growth at Buin in the nursery and in the first year after field planting remains a puzzle, as the palms grew well subsequently. This initially poor growth was reflected in the late flowering and sex ratio changes. Unfortunately no sunshine data are available before late 1968, but observations by local residents indicated that periods of very overcast weather had occurred, and a period of sunny weather in April to June, 1967 appeared to greatly improve growth, as mentioned previously. However, low sunshine levels were also experienced at Hoskins in early 1967 without marked effects on the oil palms. A nutritional deficiency or imbalance is the other possible cause of the trouble, but fertilizers were applied in the nursery and early field stages, and leaf analysis results were generally normal. Initial yields with assisted pollination were good, but it remains to be seen whether these will continue, as coconut yields are very poor in this area.

Growth at Tigak was slower than at the above-mentioned sites, in spite of fertilizer application, and generally adequate leaf nutrient levels. Restricted nutrient uptake is still a possible cause of the poorer growth although the soil also has rather unfavourable physical characteristics. It is a stiff red clay which tends to dry out and crack, and is rather shallow (over coral). These factors probably restrict rooting and hence uptake of nutrients and water. Very poor growth at Katu, initially due to livestock damage, was later almost certainly due to acute potassium deficiency, probably aggravated by the same physical characteristics as at Tigak.

The poor growth and flowering at P.A.T.I. was expected, and was due to both nutrient and moisture shortage. The sandy soil is poor in nutrients, particularly nitrogen, and has a low moisture-holding capacity, and this combined with the likelihood of a marked dry season makes the environment unfavourable for palm growth and yield. The situation is aggravated by the growth of coarse grasses which are difficult to eradicate on the low fertility soil.

At Bisianumu it has not been possible so far to identify the limiting factors. However, a combination of nutrient deficiencies, lower temperatures and occasional dry spells makes the environment unfavourable. Part of the poor growth was also due to delayed planting and poor nursery treatment.

Thus, on the better soils very good growth and early yields were achieved, and the technical prospects seem favourable for commercial development of the crop in New Britain, Bougainville and the better areas of Papua such as parts of the Northern and Gulf Districts. With the high yields which can apparently be achieved, nutrition by fertilizing will be a very important aspect of research and field practice if development is undertaken. Magnesium deficiency is likely in the Islands region and potassium in the Mainland. Nitrogen may be important also in some areas, as in 1970 leaf levels were mostly not far above 2.5 per cent, whereas in Malaysia a critical level of 2.7 per cent is often used for adult palms

The H source, Deli *dura* x Sumatra (originally Congo), *pisifera*, should prove very suitable for commercial development. Reduced growth and yield of the C source palms is apparently due to inbreeding, and was rather severe at the better sites such as Aropa and Saiho. Out-crossed types such as the H source are likely to be able to take advantage of the excellent conditions for growth in the better areas, and inbreeding should thus be completely avoided when selecting material for commercial development. The greater susceptibility of the C source palms to magnesium deficiency symptoms and low leaf Mg levels may be due to the greater proportion of Deli in their parentage, as the Deli type apparently has a higher magnesium requirement than the African types (Ollagnier, Ochs and Martin 1970).

Yield recording and collection of other data are continuing on these trials and are required before more definite conclusions can be drawn.

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APPENDIX

Climatic Data

(a) Monthly rainfall, in mm

Site	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Keravat													
1967							280	221	285	239	337	252	
1968	296	288	201	425	266	65	147	178	146	163	169	274	2618
1969	309	256	280	281	238	68	258	246	307	216	338	279	3076
1970	271	568	219	251	118	319	215	55	277	284	269	235	3081
Mosa													
1967							149	206	304	252	375	261	
1968	614	662	244	244	155	222	190	183	158	170	103	134	3079
1969	633	752	366	531	197	72	162	146	264	88	344	531	4086
1970	352	1012	398	400	130	72	131	189	259	220	180	758	4101
Siki													
1967							136	121	128	67	191	482	
1968	859	730	286	410	172	228	150	191	194	146	92	383	3841
1969	653	767	417	757	173	80	197	177	288	180	287	492	4468
1970	476	999	493	488	524	52	93	180	237	215	220	604	4581
Aropa													
1967							345	278	104	131	348	198	
1968	268	449	138	187	348	101	392	277	141	171	182	151	2805
1969	106	211	226	299	169	403	347	386	381	251	142	273	3194
1970	167	316	389	310	202	309	156	335	265	267	211	435	3362
Buin													
1967							367	316	171	223	490	182	
1968	205	152	203	330	100	541	710	518	216	440	407	233	4055
1969	338	307	453	274	274	271	453	1165	870	520	158	289	5372
1970	269	384	380	209	286	375	297	208	228	471	94	256	3457
Tigak													
1967							205	319	228	195	234	418	
1968	355	266	192	461	439	54	190	277	141	443	253	338	3409
1969	297	131	436	298	97	236	224	348	331	359	405	496	3658
1970	275	409	666	206	188	246	168	138	136	278	164	362	3236

Site	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Bubia													
1967							506	301	257	191	143	232	
1968	264	147	76	103	270	271	274	314	357	246	110	325	2757
1969	165	122	322	231	184	287	291	480	346	471	263	176	3338
1970	105	182	278	203	382	283	418	345	302	481	363	188	3530
Saiho													
1967							214	193	309	498	468	574	
1968	528	424	329	310	199	111	221	171	487	230	701	426	4137
1969	307	589	595	340	339	203	215	224	66	235	377	365	3855
1970	159	377	619	405	487	238	234	253	303	471	425	380	4351
P.A.T.I.													
1967							133	145	84	350	148	657	
1968	205	261	137	265	163	47	153	150	58	96	333	264	2132
1969	389	349	323	344	266	112	12	122	55	93	233	306	2604
1970	433	323	320	316	328	135	129	224	250	284	213	180	3135
Murua													
1967							428	447	127	242	34	132	
1968	267	150	59	51	230	198	245	274	518	259	61	170	2432
1969	704	203	80	56	163	353	441	587	127	242	39	132	3127
1970	188	151	200	302	526	258	448	475	284	466	155	272	3725
Bisianumu													
1967							81	151	164	129	94	167	
1968	218	278	280	159	218	33	102	205	156	201	49	321	2220
1969	389	443	215	429	103	79	12	30	97	176	206	266	2445
1970	200	475	344	237	154	89	154	152	246	442	231	358	3082
Cape Rodney													
1967							545	275	261	322	95	43	
1968	240	76	84	170	215	75	158	326	255	201	25	111	1936
1969	361	149	118	704	227	388	152	150	109	197	39	133	2727
1970	348	286	353	70	194	176	325	423	178	488	316	98	3255

(b) Jordan sunshine recordings, in hours per day

Site	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Keravat													
1968							5.7	4.6	7.0	5.9	5.5	5.2	
1969	3.2	3.5	4.5	4.2	6.0	7.2	5.9	5.1	3.9	5.3	5.5	3.6	4.8
1970	5.3	4.3	4.7	5.3	5.3	4.6	5.6	6.0	5.8	5.9	6.5	4.2	5.3
Mosa													
1968							4.0	6.2	6.1	5.2	5.4	5.1	
1969	2.9	1.0	3.2	1.2	4.0	4.7	2.8	2.6	3.8	5.7	5.8	4.0	3.5
1970	3.7	3.4	3.7	4.8	4.9	5.3	5.2	6.2	5.4	4.8	6.6	3.3	4.8
Hoskins													
1968									6.3		5.8		
1969	3.3	1.9	6.0	3.0	5.4	4.0	3.3	3.6	4.0	7.1	6.5	5.3	4.5
1970	5.7	3.6	5.1	6.1	5.1	5.9	6.4	7.5	6.2	5.9	5.7	2.9	5.5
Aropa													
1969	4.2	4.4	6.3	5.4	6.6	6.4	6.5	4.6	6.3	6.0	6.4	5.0	5.7
1970	7.1	4.5	6.2	6.3	6.1	5.1	6.4	5.7	6.4	6.5	7.1		6.1
Buin													
1968										4.3	2.8	3.7	
1969	2.8	3.5	4.0	4.6	4.6	4.2	3.7	2.1	2.6	4.5	5.7	3.9	3.8
1970	6.0	4.8	4.2	5.0	5.4	4.3	5.6	5.7	6.1	6.5	6.2	5.5	5.4
Tigak													
1968									6.3	5.6	4.8	4.7	
1969	4.4	5.3	4.3	4.2	6.5	5.2	3.4	4.3	3.0	4.7	4.6	3.1	4.4
1970	4.7	4.3	3.7	5.3	6.1	5.1	6.5		6.6	5.9	7.0		5.5
Bubia													
1970	7.2	6.0	5.1	6.5	5.1	3.7	3.9	5.6	5.8	4.3	7.4	5.0	5.5
Saiho													
1968											4.5	3.9	
1969	4.6	4.9	5.8	5.1	5.9	5.4	5.8	5.1	3.4	4.9	4.3	5.4	5.1
1970	7.2	5.3	5.2	6.1	5.8	6.3	4.8	6.3	5.7	5.3	6.6	5.4	5.8
P.A.T.I.													
1968										4.4	4.4	4.2	
1969	4.3	3.7	4.3	4.1	5.9	4.8	5.7	5.4	4.1	5.1	4.9	4.6	4.7
1970	6.7	4.8	5.2	6.3	5.7	5.9	4.7	6.9	6.9	5.2	5.6	4.5	5.7
Murua													
1968										3.9	5.6		
1969	5.1	3.2	5.9	5.2	3.3	2.9	2.7	3.2	1.8	4.5	4.4	5.2	3.9
1970	7.7	4.9	5.7	6.2	4.8	2.6	2.6	2.3	4.7	5.6	6.4	5.9	5.0
Bisianumu													
1969	3.3	3.9	4.3	3.7	5.8	3.2	4.6	2.9	3.7	3.1	5.6	5.2	4.1
1970	6.6	4.2	5.3	5.6	4.2	5.7	5.3	4.3	4.8	4.8	5.7	5.0	5.1

(c) Campbell Stokes sunshine recordings for three sites, in hours per day

Site	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Keravat													
1967	4.2	5.2	3.8	5.5	6.2	6.7	5.8	5.5	7.3	6.1	4.9	5.7	5.6
1968	4.3	3.3	7.3	4.8	6.4	6.8	5.6	5.9	7.2	6.7	5.2	5.0	5.7
1969	3.8	4.0	5.2	4.6	7.0	6.9	5.4	5.1	3.3	5.2	5.6	3.1	4.9
1970	5.1	3.9	4.1	5.1	5.6	4.9	6.0	6.4	5.8	6.4	6.8	3.8	5.3
Mosa													
1968	2.2	2.7	6.5	5.1	6.4	5.7	4.1	5.4	6.0	4.0	4.5	3.4	4.7
1969	3.1	1.2	3.0	1.2	4.4	4.6	3.5	3.8	3.8	5.8	5.7	3.5	3.6
1970	4.4	3.4	3.2	5.5	5.1	4.8	5.9	7.5	5.4	4.9	6.3	3.3	5.0
Bubia													
1967	4.6	6.4	5.5	7.1	5.1	6.4	4.2	4.3	5.6	4.6	7.9	7.4	5.8
1968	5.1	4.6	6.5	6.9	6.2	4.9	3.1	4.9	6.0	5.9	6.0	6.9	5.6
1969	6.3	5.1	5.9	6.7	7.1	4.8	4.1	4.5	4.4	5.4	7.0	5.7	5.6
1970	7.2	5.7	5.1	6.2	5.2	3.5	3.6	5.7	6.3	5.5	7.0	5.2	5.5

(d) Monthly mean maximum and minimum temperatures for two sites

Site	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
					Maximum temperatures, degC								
Keravat													
1969		30.6	30.9	30.9	32.5	32.1	31.4	31.0	30.8	32.2	31.9	28.0	31.1
1970	31.0	31.1	31.1	31.4	32.0	31.5	31.1	31.7	31.6	31.8	32.0	30.9	31.4
Bisianumu													
1969		27.8	28.9	27.8	29.5	27.8	27.8	29.5	28.9	29.5	30.6	28.9	28.8
1970	30.0	28.9	29.5	30.0	28.9	28.9	27.8	28.4	29.5	29.5	30.0	28.4	29.1
					Minimum temperatures, degC								
Keravat													
1969		22.7	22.9	23.0	22.4	22.0	21.8	20.9	21.5	21.2	21.7	22.3	22.0
1970	21.7	22.6	22.6	22.5	22.1	21.7	21.0	20.8	21.4	22.0	21.6	22.3	21.9
Bisianumu													
1969		21.1	21.1	21.7	21.7	21.1	19.5	20.0	20.0	21.1	20.6	21.1	20.8
1970	21.1	21.1	21.1	21.1	21.1	20.0	19.5	20.6	21.1	21.1	21.1	21.1	20.8

NOTE ON LEAF AREA MEASUREMENT IN OIL PALMS

N. J. MENDHAM*

As part of a study of the growth of eight *tenera* oil palm progenies in Papua New Guinea (Mendham 1971a), it was necessary to devise a method for estimating leaf area. Fuller details are given elsewhere (Mendham 1971b).

The method developed was similar to that subsequently published by Hardon, Williams and Watson (1969), and was influenced by discussions with the first two of these authors in 1965. Studies in the Keravat nursery indicated that the area of individual leaflets was linearly related to a rectangular length x maximum width measurement. The area of the whole frond could be accurately estimated by summing the individual leaflet rectangular measurements.This is too tedious for field use, and of the approximations tried, the best relationship to the above was given by measuring the length x width of a leaflet in the region where they are largest (about two thirds of the distance from the base to the tip of the rachis), and multiplying this by the total number of leaflets on the frond. Measuring two or more leaflets did not appear to increase precision greatly. What appeared to be nearly as good a linear relation as this was if the length of the rachis was measured, and multiplied by the same leaflet measurement. This last measurement is much quicker than counting leaflets and was thus used as the standard field measurement on the present trials. As the palms grew, several series of calibration measurements were done on some of the Mosa palms, both of leaflet and whole leaf area.

Leaflet area. — The linear regression of (l x b) of leaflets on "actual" area was calculated. The method of Hardon *et al* (1969) was used for this of summing the length x midwidths of the leaflet cut into about 10 sections. For the Keravat nursery measurements, the weight of paper outlines of the leaflets had been used to estimate actual area from the known weight per unit area of the paper. Regressions were calculated for each progeny of the form Y = bX, with values of b as follows, for the Mosa measurements. b is a "leaflet shape factor". About 40 leaflets per progeny were used.

Progeny	Regression coefficient(b)	Determination coefficient(r^2)
C1	0.774	0.997
C2	0.755	0.982
C3	0.787	0.987
C4	0.772	0.986
C mean	0.772	
H5	0.755	0.978
H6	0.752	0.993
H7	0.758	0.989
H8	0.754	0.980
H mean	0.755	

A highly significant difference was shown to exist between the C slopes, but a negligible difference between H slopes. Thus, the individual coefficients were used for the C progenies, and the mean for the H ones. Hardon *et al* found a coefficient of 0.838, but they used the midwidth of the leaflets instead of the maximum width as used here. Differences between progenies were apparently not tested.

Whole leaf area. — The first estimate of area mentioned above, number of leaflets x (l x b) of the largest leaflet, subsequently referred to as "leaf(l x b)", was found to have the best relationship with area measured by summing the (l x b) of the individual leaflets, subsequently referred to as "Σ(l x b)". The relationship was linear, of the form Y = bX, where $Y = \frac{\Sigma(l \times b)}{100}$, $X = \frac{leaf(l \times b)}{100}$

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and b is a regression coefficient. The regression coefficient for all progenies combined was 0.55, but the progenies differed significantly at the 5 per cent level. Individual coefficients were thus used to convert field data and these are as follows:

Progeny	b	r^2	Progeny	b	r^2
C1	0.58	0.998	H5	0.57	0.996
C2	0.54	0.997	H6	0.54	0.991
C3	0.54	0.998	H7	0.54	0.998
C4	0.55	0.995	H8	0.59	0.999
C mean	0.55		H mean	0.56	

The second estimate, rachis length x (l x b) of the largest leaflet, subsequently referred to as "L(l x b)", gave not such a simple and precise relationship. The differences between progenies were significant at the 1 per cent level, with quadratic equations giving the best relationship, of the form $Y = b_0 + b_1 X + b_2 X^2$, where $Y = \frac{\Sigma(l \times b)}{100}$ and $X = \frac{L(l \times b)}{100}$.

The coefficient for the eight progenies were:

Progeny	b_0	b_1	$b_2(x10^{-1})$	r^2
C1	−0.533	0.448	−0.892	0.981
C2	5.692	0.428	−0.652	0.997
C3	29.081	0.394	−0.997	0.996
C4	41.500	0.307	−0.134	0.995
H5	−10.611	0.516	−0.972	0.986
H6	−16.662	0.470	−0.751	0.991
H7	22.426	0.417	−0.618	0.982
H8	57.703	0.288	+0.088	0.979

C3 is the only curve to diverge markedly from the rest at higher levels. All have a downward curve (b_2 negative), C3 being the most pronounced, except for H8 which has a slight upward trend (b_2 positive). The value of these curves is limited, as they are derived from a small number of points (seven) per progeny. They are not accurate for measurements of individual progenies on the trials before July, 1968 and after about January, 1970, as there were no points for leaf sizes on some progenies outside this period.

The "C4" used in the above calibration is in fact the substitute progeny used at Mosa, Siki and Keravat, but the curve for it was used for C4 at all sites. This should cause small or negligible errors.

The shapes of the calibration curves and the larger difference between the progenies mean that the L(l x b) estimate is less precise and more difficult to use than leaf(l x b). However, it was used for most of the measurements in Mendham (1971a) before these regression analyses were available. The leaf(l x b) estimate corresponds closely to the method of Hardon *et al,* and it or a modification of it should be used for future work. To convert a field measurement (plot mean) of L(l x b) to "actual area", the Σ(l x b) value was taken off curves drawn from the above equations, and multiplied by the appropriate leaflet regression coefficient for the progeny.

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GROWTH RATE OF OIL PALMS IN NEW BRITAIN

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ABSTRACT

The leaf area growth rate of tenera *progenies from two genetic sources at three sites in New Britain was measured in the pre-bearing stage. It appeared to be very rapid when compared with reports from other countries. Curves fitted to the growth rate data gave very high determination coefficients (>0.98) indicating that any seasonal effects were small. The small deviations in 3-monthly growth rate from the fitted curves were compared with climatic data. There was weak evidence of a positive correlation with rainfall and a negative correlation with solar radiation at one site only. A lack of prolonged dry spells and high moisture-holding capacity of pumice in the recent volcanic soil appear to be responsible for the rapid and uniform growth rate.*

The growth rate at Mosa was at least as rapid as at Keravat, in spite of the more seasonal climate at the former site. Slower growth at Siki was probably due only to poorer management and pest damage.

A clear and consistent difference in growth rate between the genetic sources was apparently due to the effect of inbreeding in the parentage of one of them.

INTRODUCTION

A previous paper (Mendham 1971a) described the establishment of and early results from a progeny x environment trial at 12 sites in Papua New Guinea. A more detailed study (Mendham 1971b) was made of the New Britain sites, as this is where initial development is taking place, and where major expansion of the industry is likely to occur. The purpose of this paper is to summarize some of the results obtained from the New Britain sites, of growth rate of the palms in the pre-bearing stage and the relationships between growth and environmental factors.

EXPERIMENTAL METHODS

The three sites are at the Lowlands Agricultural Experiment Station, Keravat, in East New Britain, and at Mosa Plantation and Siki in West New Britain. The climates and soils were described in the previous paper (Mendham 1971a). The soils are all of recent volcanic origin, and contain large amounts of pumice and ash. The soils at Siki and Keravat have a sandier texture than at Mosa. The climate at Keravat is very uniform, with 2800 mm rainfall evenly distributed over the year, and normally at least 5 hours of sunshine per day. The normal daily temperature range is about 22 to 32 degC. The climate at Mosa and Siki is more seasonal. The wet season, January to April, normally has up to 700 mm rainfall per month, and sunshine levels can be low. Dry season rainfall is still moderate, and normally no more than one month in each year has less than 100 mm rainfall. Temperatures are similar to Keravat.

The genetic material used and the site layouts were described previously. Four *tenera* progenies from each of two genetic sources were used. The sources can be described as:

Source C: Deli *dura* x (Deli x African *pisifera*)

Source H: Deli *dura* x Sumatra (originally Congo) *pisifera*

The main difference was in the *pisifera* parents. The male parents for source C were produced by using African *pisifera* pollen of varied origin on Deli *duras* already in Malaysia. These Delis were related to those used for the female parents of the final cross, hence some inbreeding resulted. The male parents for source H were descended from excellent *tenera* palms in Sumatra originally introduced from the Congo, where all the early *tenera* selection was done.

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The leaf area growth rate of these two sources was measured in the pre-bearing period, up to about 30 to 36 months from field planting. Recordings were of monthly leaf production, and 3-monthly estimates of the area of the newest fully opened leaf. The area estimates were made using the L(l x b) method described by Mendham (1971c). This involves measuring the length of the rachis (L), and multiplying by (l x b), the length x maximum breadth of a leaflet in the region of the leaf where leaflets are largest. Individual progeny calibration curves were used for both the leaflet and whole leaf area, to convert field readings of L(l x b) to area in m^2. For each 3-monthly period, a mean was taken of the area of the newest leaf at the beginning and end of the period. This was multiplied by the leaf production for the three months to give dL, the estimate of the increase in leaf area.

The Keravat seedlings were planted in August, 1967 at the optimum age of 12 months. However, there were delays in site preparation at the other two sites and seedlings had to be held back in the nursery. Planting was done in December, 1967 at Siki and early January, 1968 at Mosa. These sites were thus delayed 4 months compared to Keravat.

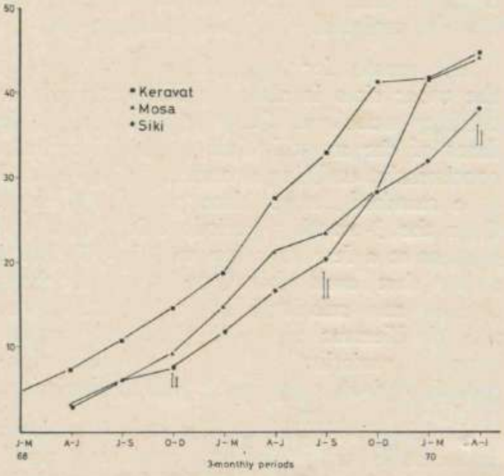

Figure 1. — Leaf area growth rate for the three sites. Vertical bars indicate least significant difference (P = 0.01 and 0.05) for three periods.

RESULTS AND DISCUSSION

Sites

The site means for each period are given in *Figure 1*. The data for three of the time periods were analysed, and the values for the least significant difference are indicated. Differences between all sites were highly significant for the first two periods, but at the last period Mosa is similar to Keravat. This was due to the high leaf production at Mosa in the last six months of recording (Mendham 1971a, Figure 4) at up to 4 leaves per month. The leaves were still smaller than at Keravat. The mean area of the newest leaves on 1st July, 1970 was 4.16 m^2 at Mosa and 4.61 m^2 at Keravat, the two being significantly different at $P=0.01$ (Mendham 1971a, Table 6). Allowing for the 4-month delay in planting, the growth rate at Mosa has been at least as rapid as at Keravat. The growth during the last two periods at Keravat may have indicated that the previously rapid growth rate was lessening, probably with the onset of bearing.

There was considerable variation in the differences between sites at the other periods. For the first two periods Mosa and Siki were nearly identical, but then the latter began to lag behind. Subsequently the Siki mean was only close to the Mosa mean at one period, when the Mosa curve was at a low point. The difference between Siki and Mosa is likely to be due to poorer management and pest damage at the former site. Weeding was infrequent in 1968, the legume cover-crop being allowed to grow up the palms several times. Also there was considerable damage by *Scapanes*, the New Guinea rhinoceros beetle, although no palms were killed. Thus it was not possible to isolate these effects from those due to the sandier soil.

Sources

The means of dL for the two sources are given in *Figure* 2 for the three sites separately. Various types of curves were fitted to the data. The form giving the best fit was:

$$\log Y = a + b_1X + b_2X^{\frac{1}{2}}$$

where Y = dL and X = time (3-monthly periods)

Curves of this type are plotted in *Figure 2* for each source at each site, with the appropriate equations and determination coefficients (r^2). An outstanding feature is the very high values of r^2 obtained. These are all 0.98 or higher, indicating that over 98 per cent of the variability in the data can be accounted for by the curves fitted. The fit was better at Mosa and Siki ($r^2 = 0.991 — 0.996$) than at Keravat ($r^2 = 0.979 — 0.981$). Thus any seasonal effects on the growth rate are small, and would be of little practical significance. Even so, the deviations of the observed means of the two sources from the fitted curves were consistent for each time period, both usually being either above or below their respective fitted curves.

From the curves, the difference between the sources increased with time at each site. The difference was largest at Siki and smallest at Keravat. The significance of the difference between the observed means at three time periods is also indicated in *Figure 2*. In October to December, 1968 the difference was only significant at Siki but for the other periods it was significant at all sites.

The effect of inbreeding was discussed by Hardon (1970), and it seems that almost all the difference between the sources found in the present trials is likely to be due to the effects of inbreeding in the parentage of the C source progenies. It can be expected that yields of the two sources will follow the same trends as the growth rates, with the C source being inferior.

Effects of climatic factors

The main climatic variation was in rainfall and solar radiation or sunshine hours, as temperatures were rather uniform (see previous paper for monthly data). For comparison with the growth rate curves, 3-monthly totals of rainfall and means of radiation and sunshine hours are given in *Table 1*.

The deviations in log dL from the fitted curves in *Figure 2* were compared with the data in *Table 1*. For each site the nine H means and the nine C means were pooled to give 18 points for correlation analysis (20 at Keravat), thus using the climatic data twice. The determination coefficients (r^2), correlation coefficients (r) and the significance of the latter are given in *Table 2*. In view of the limited data available, no great weight can be attached to the results, but their interpretation is discussed below.

The only significant correlations, and in fact the only ones which explained more than 5 per cent of the variation in the dL deviations ($r^2 > 0.05$) were at Mosa. The scatter diagrams for the two best correlations are given in *Figure 3*.

The effect of rainfall is quite striking, and the correlation would have been higher but for what may have been a "carry-over" effect in April to June, 1969, when there was a peak in growth (*Figure 1*), but the rainfall peak was in January to March. April rainfall was also high.

The approximate pan evaporation (U.S. Class A) at Mosa was 110 to 160 mm per month, which would indicate potential evapotranspiration of about 90 to 130 mm. The rainfall in almost every month was higher than this, hence the correlation found with growth is surprising. However, in view of the very small actual deviations from the fitted growth rate curves (*Figure 2*, where $r^2 > 0.99$) the effect is likely to be of little practical significance. Also, the determination coefficient and hence the predictive value of the correlation with rainfall was rather low.

The negative correlation found between growth deviations and solar radiation is probably not a real effect, as rainfall is itself negatively correlated with radiation. There does not appear to be any reason why increased radiation should depress growth unless the moisture supply is limiting.

The reason for lack of any correlation at the other sites is almost certainly in the recording technique. Only at Mosa were the dates of the monthly leaf markings recorded consistently, enabling a correction to be made to a standard length time period (30 days). Over the 3-monthly periods this would only amount to a few days (up to 3 in 90), but it seems that even this has been enough to obscure any relationships with climatic factors at Keravat and Siki. The less marked seasonal variation at Keravat would have probably given only small growth deviations.

At Mosa and Siki, studies of soil moisture were made using indirect methods, namely the stomatal opening method of Rees (1961), and tensiometer recordings. By either method, soil moisture stress did not occur. During the driest period recorded (2 months with less than 100 mm per month), and on the sandy

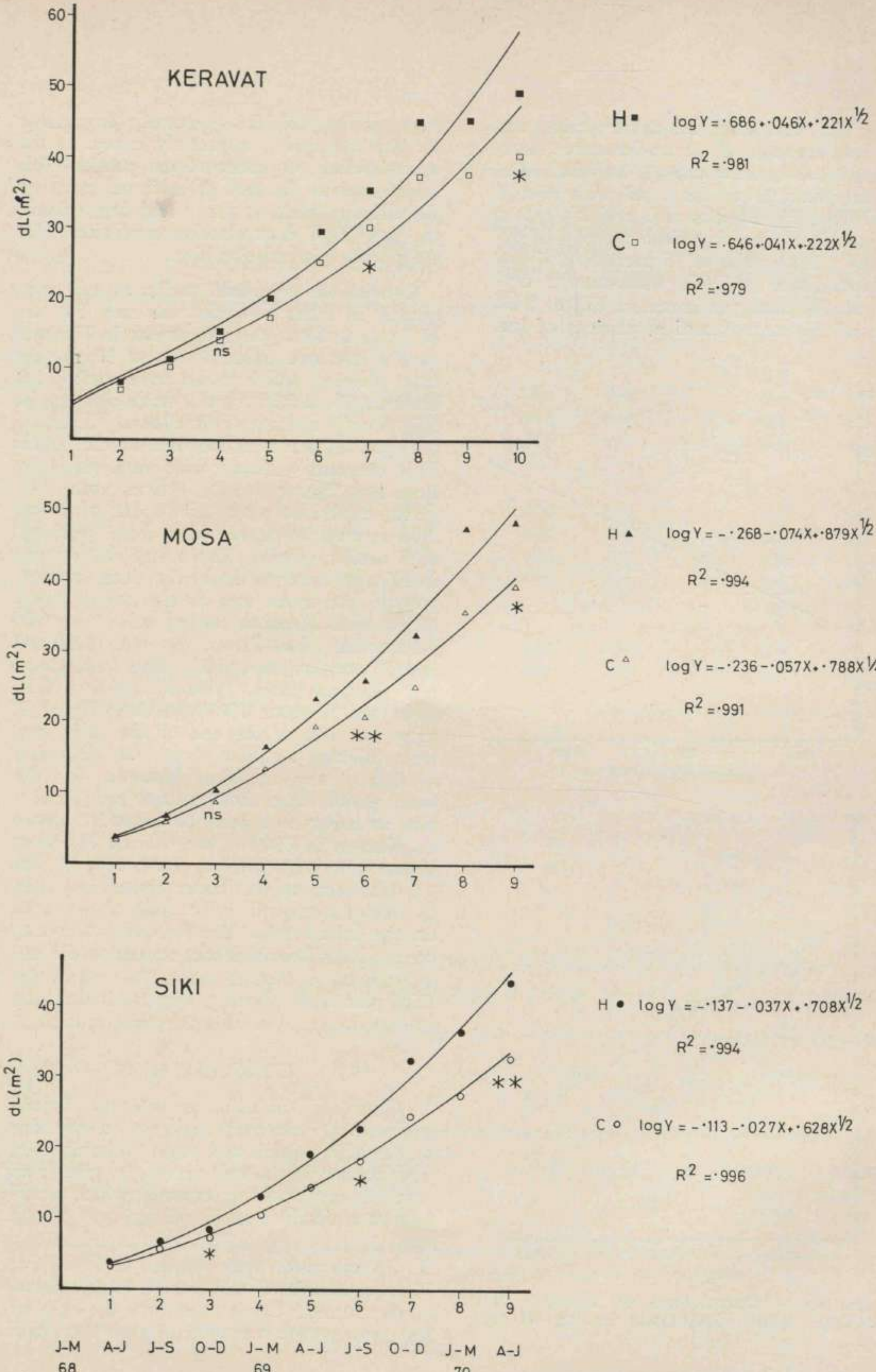

Figure 2. — Leaf area growth rate of the two sources at each site.
Y = dL and X = 3-monthly periods

* = observed means different at P = 0.05
** = observed means different at P = 0.01
ns = difference not significant

soil at Siki, maximum soil water tension was 0.36 bars (average of six tensiometers). Scotter (personal communication) has derived a moisture characteristic for a soil with pumice gravel from the Hoskins area, and his results indicated that, assuming field capacity as 0.1 bar and wilting point as 15 bars, the soil had an approximate available water-storage capacity of 440 mm per metre of depth. Two thirds of this was released at tensions of less than one bar. This is an unusually large value for any soil, and is apparently related to the water-holding properties of the pumice. This would explain the lack of moisture stress on the oil palm trials. It also would help explain the very high determination coefficients for the growth rate relationships.

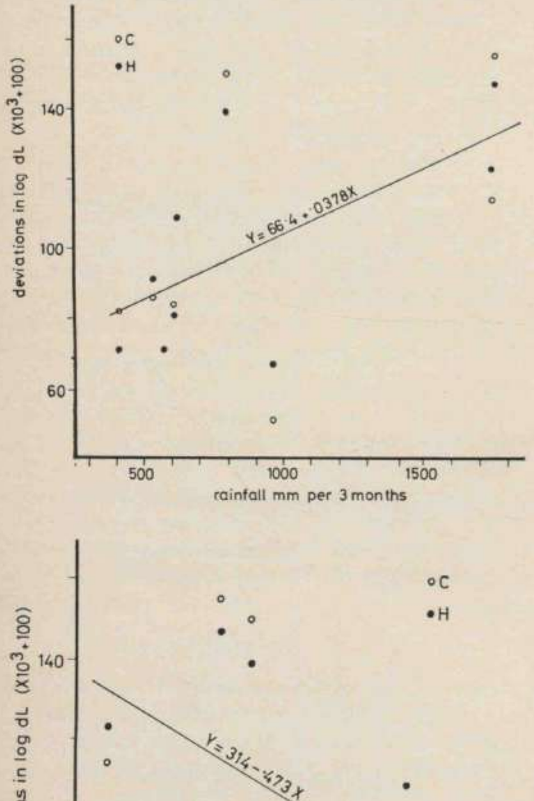

Figure 3. — Correlation of rainfall and radiation with deviations in log dL for Mosa.

Comparable published studies of oil palm growth in other countries are rare. For the H source at Mosa, the growth rate in *Figure 2* gave a leaf area index of 2.5 at 30 months from planting, and it should have reached 3.0 between 33 and 36 months from planting, at this 9-metre spacing. This allowed for senescence of old leaves at the base of the palms. This contrasts strongly with data given by Rees and Tinker (1963), where under Nigerian conditions a leaf area index of 3 was only reached at seven years from planting, at a similar spacing. The severe dry seasons in Nigeria were no doubt the cause of slow growth. The mean area of the newest leaves of the Mosa H palms reached 4.5 m^2 and the Keravat H palms 5.0 m^2 by July, 1970, 30 and 35 months respectively after field planting (previous paper, Table 6). Hardon, Williams and Watson (1969), in their Figure 2, show the area at the end of the third year from planting as about 4 m^2, for Deli *dura* on inland soils in West Malaysia. For the same period they show annual leaf production as being at a peak of about 32 leaves. At Keravat in 1969 it was 44, and for Mosa in the year July, 1969 to June, 1970 it was 43. However, on the better coastal clay soils in Malaysia growth is normally faster than on the inland soils. The *Pueraria* cover-crop on the New Britain blocks started to die out through heavy shading before the end of the third year from planting, whereas it normally persists longer than this in other countries.

CONCLUSIONS

1. Growth of oil palms in the New Britain environment was very rapid, apparently due to the high rainfall and recent volcanic soils. The pumice in the soil appears to give it an excellent water-holding capacity, which would help to maintain a rapid and uniform growth rate.

2. Growth rates were similar at Mosa and Keravat, in spite of the more seasonal climate at the former. Curves fitted to the data of leaf area growth versus time gave very high

Table 1. — Climatic data for the three sites for 3-monthly periods

Period	Rainfall (mm per 3 mths)			Radiation (mWhr cm^{-2} per day)		Sunshine Hours per Day (Campbell Stokes)	
	Keravat	Mosa	Siki	Keravat	Mosa	Keravat	Mosa
1968							
Jan.-Mar.	785					5.0	
Apr.-June	756	621	810	487	478	5.0	5.7
July-Sept.	471	531	535	518	486	6.2	5.2
Oct.-Dec.	606	407	621	505	499	5.6	4.0
1969							
Jan.-Mar.	845	1751	1837	468	385	4.3	2.4
Apr.-June	587	800	1010	484	429	6.2	3.4
July-Sept.	811	572	662	439	421	4.6	3.7
Oct.-Dec.	833	963	959	476	497	4.6	5.0
1970							
Jan.-Mar.	1058	1762	1968	480	420	4.4	3.7
Apr.-June	688	602	1064	457	457	5.2	5.1

Table 2. — Determination and correlation coefficients for climatic data versus deviations in log dL from the fitted curves

Deviations in log dL on:	Mosa		Siki		Keravat	
	r^2	r	r^2	r	r^2	r
Rainfall	0.352	+0.593**	0.016	+0.127	0.0005	+0.022
Solar radiation	0.337	—0.580*			0.041	—0.202
Sunshine	0.188	—0.433			0.0002	—0.014

* significant at 5 per cent level

** significant at 1 per cent level

determination coefficients (>0.98) indicating that seasonal effects were small.

3. At Mosa only, there was a significant relationship between the small deviations in growth rate and rainfall, high rainfall appearing to give the best growth rate. However, the effect is not likely to be of much practical importance. Periods of high rainfall were associated with low sunshine and solar radiation levels, and this is probably why a significant negative correlation was found between deviations in growth rate, and solar radiation.

4. A clear and consistent difference in growth rate between the two genetic sources was apparently due to the effect of inbreeding in the parentage of one of them.

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MEASUREMENT OF SUNSHINE HOURS AND ITS RELATIONSHIP WITH SOLAR RADIATION IN NEW BRITAIN

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ABSTRACT

Measurements were taken at Mosa Plantation in West New Britain and Keravat in East New Britain of sunshine hours, using Campbell Stokes and Jordan recorders, and solar radiation, using silicon solar cell radiation integrators of CSIRO design. The data analysed were the monthly means, 1968-70.

There was a seasonal difference in the relationship between Campbell Stokes and solarimeter recordings. The dry season, May to August, had reduced radiation levels for the same number of sunshine hours. This appeared to be largely due to increased atmospheric turbidity in that season, mainly smoke and haze. There appeared to be a difference in cloud type between the two recording sites, also affecting the dry season relationships.

Over the recording period the Jordan recorder gave very similar results to the Campbell Stokes, although there was sometimes a considerable difference between the monthly means. The Jordan appears to record at lower radiation levels than the Campbell Stokes but is prone to several faults, these two factors approximately cancelling out.

INTRODUCTION

The Campbell Stokes sunshine recorder is the standard instrument used for measuring hours of bright sunshine in most countries, including Papua New Guinea. There have been attempts to correlate oil palm flowering behaviour and yield with sunshine hours, for example by Sparnaaij, Rees and Chapas (1963). Uniformly high sunshine hours throughout the year, coupled with an adequate soil moisture supply, are generally thought to be desirable for high production in the oil palm (Hartley 1967), and this is considered one of the reasons why oil palm yields are much higher in Malaysia and Indonesia than in Africa. Mean sunshine levels in Malaysia are generally at least 5 hours per day in all months of the year, rising to 7 hours per day in some months.

In New Britain, the north coast (West New Britain) has a much more seasonal climate than the Gazelle Peninsula (East New Britain). Records from Talasea on the north coast (Commonwealth Bureau of Meteorology) show heavy rainfall in the wet season, with a mean of 3 hours sunshine per day in January, the wettest month. Keravat, on the Gazelle Peninsula, has a climate similar to West Malaysia, with no clearly defined pattern of strongly seasonal rainfall and sunshine variation (DASF 1969).

Oil palm development is taking place near Talasea, hence it was considered desirable to study the relationships between sunshine hours and solar radiation, as the latter is more likely to be related to crop growth and yield, particularly in a cloudy environment. Periods of light cloud may give adequate radiation in spite of low sunshine levels.

A network of Jordan type sunshine recorders, which are much cheaper than the Campbell-Stokes instruments, has been established in Papua New Guinea in conjunction with oil palm trials (Mendham 1971a), and a secondary aim of the present study was to compare these two instruments under different conditions.

For this study, the seasonal divisions of Brookfield and Hart (1966) have been used, as they seem to be the most appropriate. These are:—

Wet season: January to April

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Dry season: May to August

Intermediate season: September to December.

The main wind system in the region is the south-east "trades" which blow strongly from May to August, and then gradually taper off until December. Brookfield and Hart consider that there is no "north-west monsoon" in this region, the heavy rainfall on the north coast of New Britain in January to April being due to the effect of the crescent of land formed by New Britain, New Ireland and the New Guinea mainland ponding up northerly air, causing it to stagnate and become increasingly unstable.

EQUIPMENT AND METHODS

The three recording instruments used are described below.

(1) *Campbell Stokes.* — Standard instruments, as described by Anon. (1954) were used.

(2) *Solarimeter.* — Silicon solar cell radiation integrators were used. These were manufactured by Rauchfuss Instruments and Staff Pty Ltd, Burwood, Victoria, to a CSIRO design (Collins 1967) and were similar to that described by Whillier (1964). These instruments use silicon solar cells connected in parallel and wired directly to a d.c. ampere hour meter. The spectral response curve of the cells is between wave lengths of 0.4 and 1.1 microns, peaking at about 0.8 microns. This is approximately the range used by plants in photosynthesis, and covers visible plus some infra-red radiation. Each instrument is calibrated against a standard instrument before sale. The sensitivities of the Keravat and Mosa instruments were 120 and 107 mW hr cm^{-2} per ampere hour respectively.

(3) *Jordan.* — These instruments are manufactured by Negretti and Zambra Limited. They are much simpler and cheaper than the Campbell Stokes instruments. They consist of a metal barrel oriented north-south, with slits for morning and afternoon sunshine. Photo-sensitive papers are used, these fitting inside the barrel. The papers have two holes in them to correspond with the slits in the recorder. The papers are developed by washing in water.

A meteorological station was set up at Mosa Plantation in the centre of the oil palm development area. Recordings have been taken with a Campbell Stokes instrument since December, 1967, a Jordan instrument since July, 1968 and a solarimeter since February, 1968. At the Lowlands Agricultural Experiment Station, Keravat, recordings have been taken with a Jordan recorder since July, 1968 and a solarimeter since May, 1968, in addition to the Campbell Stokes recordings (since 1955).

The monthly mean data from all three instruments up to the end of 1970 were analysed. This is likely to be more useful than daily data with a perennial crop such as the oil palm. The monthly data for the Campbell Stokes and Jordan recordings have been given in a previous paper (Mendham 1971a). The data from the Campbell Stokes and solarimeter recordings were presented and examined by Mendham (1971b), and the comparisons between these two in this paper have been adapted from that report.

RESULTS AND DISCUSSION

Comparison of Campbell Stokes and Solarimeter recordings

The monthly data for Mosa and Keravat are given in *Figure* 1. Regression lines were fitted on a seasonal basis, and the appropriate equations and determination coefficients are indicated on the Figure. The mean values of the two parameters for the different seasons, in hours per day and mW hr cm^{-2} per day were:

	Wet Season		Dry Season		Intermediate Season	
	Sunshine	Radiation	Sunshine	Radiation	Sunshine	Radiation
Keravat	4.48	475	6.01	472	5.32	501
Mosa	3.64	423	5.10	459	4.71	492

At Keravat the regression lines for the wet and intermediate seasons are almost identical. The dry season line, however, is clearly separated, but with a similar slope. It appears that for a given level of sunshine hours the radiation is lower in the dry season. The mean radiation levels are almost the same for the wet and dry seasons, but the sunshine levels differ by over 1.5 hours per day. One possible explanation for this difference is the amount of haze and smoke normally present in the atmosphere in the dry season. Another factor could be the angle of the sun, which reaches its lowest point on 21st June, roughly in the middle of the dry season. However, at this latitude (4° S.), the sun is at almost as low an angle on 21st December, and if this were an important factor radiation levels should be low then also. In fact, some of the highest values of radiation relative to sunshine levels were received around that time. The earth is at its furthest distance from the sun in the period May to August, and this may also explain some of the reduction.

At Mosa, the wet and intermediate season lines are again very similar. They both have a slightly greater slope than at Keravat, but this may be of no significance. It could be a difference in calibration of the solarimeters, although both were initially tested against a standard instrument and a correction factor

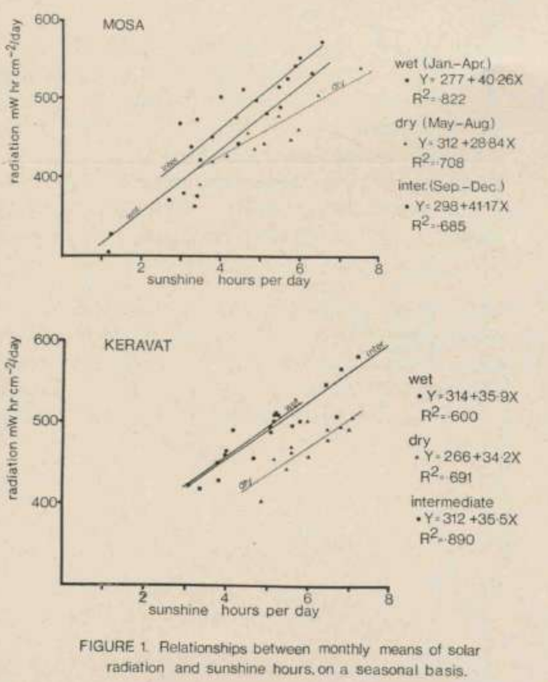

FIGURE 1. Relationships between monthly means of solar radiation and sunshine hours, on a seasonal basis.

Figure 1.—Relationships between monthly means of solar radiation and sunshine hours, on a seasonal basis. Wet season — January to April; dry season — May to August; intermediate season — September to December.

applied to the data of each. The dry season line is again different from the other two. The difference in slope was tested by the t test, but it was not significant for the limited data presented here ($t = 1.60$, for 19 degrees of freedom). A test of identity, however, again showed the difference between the lines to be significant at the 1 per cent level. A noticeable difference between Keravat and Mosa is that sunshine hours in the dry season at the former site were all high (around 5 to 7 hours per day), but at the latter site some months were quite low, down to 3.5 hours per day. Radiation levels in some of these low sunshine months were relatively high, and this appears to have given the apparently different slope. It was observed that frequently in the dry season there is a lot of high, thin cloud at Mosa, presumably blowing across from the south coast, which is having its wettest period from May to August. This may be causing the apparent difference in slope of the regression lines of the dry season compared to the other seasons. Again, smoke and haze could cause the reduction in radiation at higher levels of sunshine, and the angle of the sun and its distance from the earth could also be factors. Radiation was normally high relative to sunshine hours in the period November to January, so the angle of the sun is not likely to be of great importance.

A study of this type was also made by Rijks and Huxley (1964) in Uganda, at a similar latitude to New Britain. They showed that, even when corrections were made for latitude, altitude and other factors such as the angle of the sun, no general relation between sunshine hours and solar radiation was likely to be applicable. This was due to the effects of local climatic factors such as atmospheric turbidity and differences in cloud type.

Comparison of Jordan and Campbell Stokes recordings

The monthly data for the two recorders at Mosa and Keravat are given in *Figure* 2. There was no evidence of any seasonal differences in the relationships between the two recordings so a combined regression line was fitted for each recording site. If the two instruments gave equal recordings, the regression equation would be $Y = X$. Both equations are close to this and the line $Y = X$ is within the 95 per cent confidence bands for the lines fitted to the data at both sites. There was no significant difference in either slope or identity tests between the Mosa and Keravat fitted lines. It can therefore be assumed that, in the long term, there was little difference in the records of the two instruments.

However, as can be seen from *Figure* 2, there is sometimes considerable variation in the monthly means between the two instruments and daily variation can be quite large.

Observations of the daily and monthly recordings at Mosa have indicated that the Jordan will record more sunshine than the Campbell Stokes under conditions of light and intermittent cloud, and it seems that it is slightly more sensitive and requires a lower degree of "brightness", or radiation intensity, for recording to begin. Also, after a shower of rain the Campbell Stokes may be slow in starting recording if there is water on the record card.

However, the Jordan recorder is prone to several faults. These are as follows.

(1) The record paper can curl inside the recorder, and the hole in the paper does not then correspond with the slit in the barrel of the instrument. Part of the day's record is then lost. This is usually seen as a gap in the record either before or after midday.

(2) Rain can enter the recorder and spoil the record by prematurely developing part or all of the paper. Initially, plastic covers over the recorders were tried, but these deteriorate rapidly and cut down on the intensity of the trace. These were thus discarded, and it seems that under normal conditions very little of the monthly record is lost. If night rain is common, the papers should be changed in the early morning to avoid premature development.

The effect of these two faults seems to be that, over a month or more, the extra sensitivity of the Jordan is cancelled out by the lost record. If these faults could be eliminated, then it is likely that the Jordan would give slightly higher recordings than the Campbell Stokes.

If there is a difference between the two instruments in the radiation intensity needed to start the recording, then there should be some relationship betwen radiation and the two sunshine recordings. This was confirmed by multiple regression analyses. There was a trend, for a constant Jordan level, for Campbell Stokes levels to vary with radiation. This trend was stronger at Keravat than at Mosa, but significant at both sites.

In other countries, the Campbell Stokes recorder has generally been found to give more reliable and reproducible results than the Jordan recorder (Rijks 1968, quoting "Handbook of Meteorological Instruments Part I",

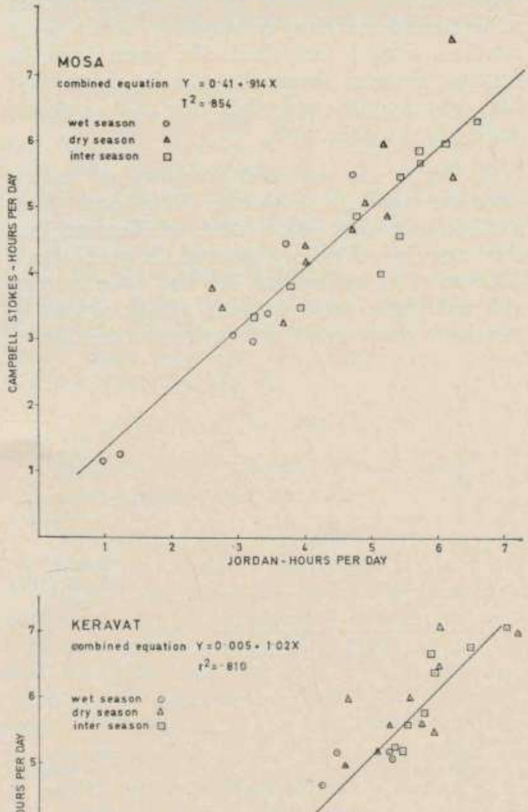

Figure 2.—Relationships between monthly means of sunshine hours measured by Jordan and Campbell Stokes recorders.

Met. Office publ. MO577, H. M. Stationery Office, London: 1956). Rijks suggested that the Jordan recorder could be used in ecological studies with untrained operators where absolute accuracy is not required.

CONCLUSIONS

(1) The relationship between solar radiation and sunshine hours varied with season at both sites. The dry season (May to August) differed from the other two seasons in that for the same number of sunshine hours there was reduced radiation. The reason appears to be increased turbidity of the atmosphere, mainly due to smoke and haze. An additional factor may be the greater distance of the sun from the earth during that period.

(2) There may have been a difference in cloud type between the two sites during the dry season, although a significant difference in the slopes of the regression lines was not obtained.

(3) Further data are needed before these relationships can be interpreted with confidence. However, it is obvious that interpretation of oil palm growth and yield in terms of sunshine hours only would be of little value and corrections would need to be made to sunshine data using relationships as in *Figure* 1 if radiation data were not available to be used directly.

(4) The Jordan recorder gave comparable results to the Campbell Stokes. If several faults could be corrected it would probably give slightly higher readings as it appears to commence recording at lower radiation levels.

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OIL PALM YIELDS IN NEW BRITAIN

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ABSTRACT

Yield, bunch weight, male inflorescence and leaf analysis data are presented for the only mature plots of oil palms in New Britain. The palms are mainly 1959 plantings of dura x tenera *material from Malaysia, and all records are from plots in East New Britain. Very high yields of 35 tons of fresh fruit bunches per hectare per annum were recorded for three successive years on the Keravat block, which received a fertilizer application, but reduced yields on the other plots in the last year probably indicated nutrient stress.*

Leaf analysis data show low and declining nitrogen and magnesium levels. Sulphur is also declining, and there was apparently a response to all three nutrients in leaf levels, and probably yields, after fertilizing at Keravat. Other nutrients appear in adequate supply, although very low manganese levels of around 40 parts per million were recorded.

Excellent climatic conditions and the volcanic ash soil appear to be responsible for the high yields. Another plot in the same series in West New Britain, with similar soils but heavier rainfall in the wet season, was not yield-recorded but growth was good and the palms should be capable of similar yields.

INTRODUCTION

Commercial plantings of oil palms in Papua New Guinea only commenced in 1967 in West New Britain, and no yield data are available yet, but the favourable rainfall distribution and fertile volcanic soils should mean that high yields can be achieved. The purpose of this paper is to give yield and associated data from the few existing plots of mature oil palms in New Britain.

The oil palm, although grown in many parts of the tropics, produces its highest yields in south-east Asia. For example, Ng Siew Kee (1968) gives yield data for the range of soils used for oil palms in West Malaysia, which has the largest area of high-yielding palms. The coastal alluvial clays, represented by the Selangor series, are regarded as the best soils, and they can give 22 to 30 metric tons of fresh fruit bunches (f.f.b.) per hectare per annum under good management. The other major classification, referred to as the "inland" soils, can give 20 to 25 tons per hectare, quoted for the granite-derived Rengam series. The reasons for these high yields, as compared to Africa where yields are usually less than half these figures, are generally claimed to be the even rainfall distribution with no marked dry periods, and high temperatures and sunshine levels (Hartley 1967). This and general information about the oil palm and the industry in Malaysia were reviewed by Mendham (1967).

The climate at Keravat, in East New Britain, is similar to that of West Malaysia. Total annual rainfall is about 2800 mm, mean monthly rainfall varies between 170 mm and 280 mm, mean monthly sunshine between 5 and 6.5 hours per day, and daily temperatures are usually in the range 21 to 32 deg C. At Talasea in West New Britain, the climate is more seasonal. Total rainfall is about 3900 mm and the mean monthly rainfall varies between 110 mm and 700 mm, January to April being the wettest months. Sunshine varies from a mean of 3 hours per day in January to 6.5 hours per day in June. Temperatures are similar to those at Keravat.

The first observation block of oil palms in New Britain was planted at Keravat in 1934. About 12 hectares were planted with Deli *dura* seed introduced from Sumatra. The palms grew well and bore abundant fruit, although

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no records were taken. They were cut out in 1964.

In 1957 a local plantation company imported some *dura* x *tenera* seed from Malaysia, and planted some blocks on plantations in East New Britain and one in West New Britain. Some of the seed was also used to plant a block at the Lowlands Agricultural Experiment Station at Keravat, the Malaysian seed being surrounded by open-pollinated progeny from the older Keravat palms. Nursery and early field treatments for all these blocks were poor, planting being done in 1959. The spacing used was much too close, at about 7 metres triangular. All blocks contain a number of undesirable types that should have been culled in the nursery.

EXPERIMENTAL METHODS

In 1965 it was decided to clean up and commence yield-recording the Keravat block and a selection of the plantation blocks. To thin them out to something like a normal density, every second palm in every second line was removed. For the Keravat block, this left 212 palms on 1.24 hectares, or about 170 palms per hectare. Blocks were selected on two plantations, Gunanur and Taboona, in each case the plots for recording being chosen from larger blocks. Both plantations are in the drier Kokopo area, and receive about 2000 mm annual rainfall. The Gunanur plot is 1.54 hectares, and after thinning contained 253 palms, or 164 per hectare. These palms are uniformly well grown. The Taboona plot has 106 palms on 0.7 hectares, or 152 palms per hectare. These palms had grown more slowly than at Gunanur and were apparently on an area used as a food garden during the Japanese occupation.

Another plot in the same series had been planted on Numundo Plantation, about 22 km from Talasea, which is close to the present centre of oil palm development. It was not possible to yield-record this plot, which was only cleaned up in 1970, and observations only are recorded here.

The East New Britain soils are fairly uniform volcanic sands, and the soils of the trial sites are similar to those described by Graham and Baseden (1956), derived from recent volcanic ash and pumice. The soils at Numundo are also derived from recent volcanic depositions, but are of somewhat heavier texture.

Records. — Fortnightly harvesting rounds have been carried out since mid 1965. For the first year, yields were very low as the palms were still being pruned and fruit set was poor, so yields from mid 1966 to mid 1970 only are given here. Records were on a per palm basis, but only the block totals are used here. The number and weight of bunches, and the number of male inflorescences produced were recorded. Some errors were found in transcription of field notes into record books, and these may have slightly affected the 1968-69 and 1969-70 figures. However, taken over the whole year these differences would be small or negligible. Leaf samples were also taken for chemical analysis. All samples were taken from the 17th leaf, the standard one sampled on mature palms in other countries. Samples were usually taken monthly at Keravat, and at irregular intervals at Gunanur and Taboona.

Fertilizer was applied to the Keravat palms only on 3rd February, 1969, as follows, per palm:

- 2.3 kg ammonium sulphate
- 0.9 kg potassium chloride
- 0.9 kg magnesium sulphate
- 60 g manganese sulphate

Some of the earlier results in this paper have been given previously in Annual Reports (DASF 1969). A summary was also included as part of a study on oil palm growth and yield in New Britain by Mendham (1971a).

RESULTS

A summary of the yield, bunch weight and male inflorescence data is given in *Table* 1, on a yearly basis.

The most obvious feature is the very high yields being obtained. During the first year, 1966-67, the fortnightly yields were rising rapidly, and the figures given include quite low yields in the earlier part of the year. Since then the yield has remained steady at Keravat at about 35 tons per hectare, which is very high by any standards, and exceptional considering the poor treatment the palms had had previously. Yields on the plantation blocks were lower than at Keravat in the first two years, then in 1968-69 were higher, but dropped back again in 1969-70, to a level which was still high. Yields on all blocks have fluctuated, often greatly, between harvests, but no consistent seasonal pattern has emerged. This is in contrast to other countries, even Malaysia, where there is normally a high- and low-yielding part of the year.

Mean bunch weights generally increased throughout the recording period. This was partly the normal increase with age, but was also due to poorer fruit set in the first year, and possibly in the second also, mainly the result of low male inflorescence production. In Malaysia, at least 50 male inflorescences per hectare per month (600 per year) appear to be required for good fruit set (Gray 1969), and this was only exceeded on these blocks in the last two years. Some errors may have been made in the 1967-68 recordings of male inflorescences, as the system used was not fully efficient, and the actual numbers produced may have been higher. Fruit set was generally quite good in 1967-68, and a big improvement over the previous year, as can be seen from the bunch weights.

The low male inflorescence production in the first two years was almost certainly a result

Table 1. — Yield, bunch weight and male inflorescence production for three oil palm blocks in East New Britain, 1966-70

	Yield of Fresh Fruit Bunches (metric tons per hectare per annum)			
	1966-67	1967-68	1968-69	1969-70
Keravat	24.0	34.6	35.4	35.7
Gunanur	20.4	30.2	36.4	29.2
Taboona	20.4	31.5	38.8	27.9

	Mean Bunch Weight (kg)			
	1966-67	1967-68	1968-69	1969-70
Keravat	8.0	10.5	12.3	12.8
Gunanur	7.3	10.3	13.2	12.0
Taboona	7.8	9.9	11.7	11.7

	Male Inflorescence Production (per hectare per annum)			
	1966-67	1967-68	1968-69	1969-70
Keravat	425	263	890	941
Gunanur	277	219	769	729
Taboona	470	345	983	939

of the previous treatment. No fruit had been harvested from the blocks until mid 1965, so there had been little stress on the palms, from either pruning or fruit production, and the small amount of fruit produced fell to the ground and rotted. Thus the sex ratio (the ratio of female to total inflorescences) remained high. Approximately two years after heavy crops of fruit began to be taken from the palms, the sex ratio dropped greatly and a normal number of male inflorescences began to be produced. This two-year period corresponds approximately to the period between sex differentiation and flowering of an inflorescence (Hartley 1967).

The main factor contributing to the high yields was the large number of bunches produced, as the mean weight per bunch was not high, and was lower than normal for palms of this age in Malaysia. The large number of bunches was due in part to higher palm density, but even the number of bunches produced per palm was higher than normal. Now that more male inflorescences are being produced, the number should drop. It may be, however, that more leaves, and hence more potential bunches, are produced under these favourable conditions of soil and climate.

The palms at Numundo in West New Britain have grown as well as the East New Britain ones, and appear healthy except for probable magnesium deficiency symptoms on some palms. The sex ratio was observed to be high after cleaning up in 1970, resulting in poor fruit set. However, the bunches that were set developed normally and there would seem to be no reason for the yielding ability there to be substantially different from the other plots, unless the more seasonal climate has a marked effect on the seasonal yield pattern or overall yields. This could come about through effects on sex ratio or fruit set — pollination could be poor in the wet season.

Nutrition. — A summary of the leaf analysis data obtained is given in *Table* 2. Tentative "critical levels" are given also. These are based on Ollagnier, Ochs and Martin (1970), with the minor elements as in Mendham (1971b). For the major elements at least, if levels drop substantially below these critical levels a response to fertilizer would be expected. However, the levels vary with different soil types and management conditions, and are only given here as a guide.

Table 2. — Leaf analysis data for three blocks in East New Britain, 1966-70
All samples 17th leaf. The figures given are means of the stated number of samples. "Critical levels" are also included for comparison (see text)

		No. of Samples	per cent on Dry Basis					p.p.m. on Dry Basis					
			N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu	B
Keravat	1966-67	9	2.40	0.159	1.37	0.61	0.39	175	39	62	35	8.9	11.9
	1967-68	16	2.23	0.170	1.23	0.67	0.20	143	44	64	20	6.1	14.8
	1968-69 a*	6	2.05	0.153	1.30	0.76	0.21	230	53	80	26	11.0	12.8
	b*	5	2.17	0.158	1.31	0.70	0.29	269	49	81	28	4.0	11.5
	1969-70	8	2.05	0.170	1.17	0.72	0.19	127	57	64	22	3.9	9.9
Gunanur	1966-67	5	2.28	0.165	1.64	0.59	0.37	190	27	62	38	7.7	13.9
	1967-68	9	2.45	0.192	1.36	0.76	0.26	115	28	59	30	6.5	13.5
	1969-70	2	2.16	0.169	1.24	0.69	0.15	104	44	49	25	5.4	10.1
Taboona	1966-67	6	2.43	0.170	1.46	0.66	0.39	175	51	64	31	6.6	13.9
	1967-68	9	2.50	0.197	1.30	0.66	0.24	137	69	62	23	6.8	13.7
	1969-70	2	2.12	0.165	1.27	0.70	0.13	121	47	71	28	5.4	9.4
"Critical levels"			2.5	0.15	1.00	0.60	0.24	150	50	60	15	5	10

* a = July, 1968 to January, 1969 (before fertilizing)

b = February, 1969 to June, 1969 (after fertilizing)

Low and declining nitrogen levels are the most important feature of these results. They would indicate a marked deficiency in Malaysia. Generally a reduction in yield is obtained if levels drop below 2.5 per cent, and visible foliar symptoms become apparent below about 2.2 per cent. However, the New Britain palms still appear quite healthy. There was apparently some response in leaf levels at Keravat to fertilizer, as they reached 2.5 and 2.4 per cent in May and June, 1969 (after fertilizer was applied in February), but then dropped again to around 2.0 per cent.

The other nutrient with clearly declining levels is magnesium. Levels were quite high initially, but dropped rapidly at Keravat. There appears to have been a response in leaf levels to this nutient also, as they increased to above the critical level after fertilizing, but have since dropped again. The most recent levels are low on all blocks, particularly Gunanur and Taboona. Symptoms resumbling magnesium deficiency, namely bronzing of the lower leaves, have been obvious on many palms in all plots since recording began, but have not become noticeably worse.

Phosphorous levels are generally adequate, and do not appear to be declining. The mean figures for potassium are well above the critical level given. However, there was apparently a response in leaf level to fertilizing. The levels were 1.1 per cent in February, March and April. 1969, 1.33 per cent in May, 1.86 per cent in June, and then there was a fall to 0.9 per cent in July and 0.8 per cent in September. These low levels did not persist subsequently.

No critical levels are available for sulphur in oil palms, as it has not been considered in overseas work. However, this nutrient has been shown to be important in most other Papua New Guinea crops, and will presumably also be with oil palms. A tentative level of 150 p.p.m. is suggested. Again there may have been a response after fertilizing at Keravat, as the levels appear to be declining on the other blocks, and for the last year at Keravat.

Manganese levels are all far lower than is normal in Malaysia, but similar to results from other Papua New Guinea samples on younger palms, so 50 p.p.m. may be a normal level here, as in Colombia (Ollagnier, Ochs and Martin 1970). On low-yielding acid sulphate soils in west Malaysia, manganese sulphate application raised leaf levels from 50 to 90 p.p.m. and gave a significant yield response (B. S. Gray, personal communication). However, a yield response in New Britain is not likely, and there is no marked response in leaf levels after fertilizing at Keravat. The other minor elements appear to have normal levels.

DISCUSSION

Very high yields have been obtained on these blocks in spite of early neglect and close spacing. About 35 tons of f.f.b. per hectare (14 tons per acre) have been obtained for the last three years of recording at Keravat. Deli *dura* material normally gives about 17 per cent oil in the bunch, and modern *tenera* about 23 per cent. The Keravat block, which is about 60 per cent *dura* x *tenera* (usually with an average of 20 per cent oil to bunch) and 40 per cent Deli *dura,* would give fruit with an average oil content of about 19 per cent. This would give about 6.5 tons of palm oil and 1.3 tons of palm kernels per hectare, which is a very high yield indeed. The more modern *tenera* material now being planted, with its higher extraction rate, will give correspondingly more oil, which at 35 tons f.f.b. per hectare would be about 8 tons of oil per hectare, or over 3 tons per acre.

However, it seems that nutrition will be important in maintaining these yields. High yields continued on the Keravat block, which was fertilized, but lower yields were recorded on the other unfertilized blocks for the last year of recording. It appears that nitrogen and magnesium particularly will be needed to maintain yields, considering the low leaf levels now being recorded on all blocks. The moderate single dressing of fertilizer applied at Keravat was apparently not enough to boost leaf levels for longer than a few months, and larger regular dressings may be needed to maintain leaf levels and yields. Sulphur levels also appear to be decreasing and there may have been a response in leaf levels at Keravat after fertilizing. Manganese levels are very low by Malaysian standards, but apparently normal for Papua New Guinea. The importance of all these factors can only be studied in a proper fertilizer trial, but these results give some clear indication as to the problems likely to be encountered.

Provided close attention is paid to nutrition, it seems that excellent yields could be obtained commercially in East New Britain, and probably West New Britain. However, the more seasonal climate in the latter, particularly the heavy wet season with reduced sunshine hours, may give greater seasonal yield fluctuation, and possibly lower overall yields. The effects on growth, sex ratio and fruit set can only be studied in further trials and by observation of commercial plantings in that district.

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LEGUME COVER-CROPS FOR OIL PALMS IN WEST NEW BRITAIN

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ABSTRACT

Results are reported from an observation trial of different legume cover-crop species at Dami Oil Palm Research Station, in West New Britain. Experience with legumes, mainly Pueraria phaseoloides, *on other trials and commercial oil palm plantings in the district is also summarized. Pueraria has been the most vigorous legume, and is well adapted to the local environment of high rainfall and volcanic ash soils. It forms a dense cover with much less effort expended on establishment and maintenance than is needed in Malaysia, thus having an important weed control function, and reducing field costs. The effect on the palms appears highly beneficial, high leaf nitrogen levels and good growth being achieved.*

Other creeping legumes with promise are the Cooper and Tinaroo strains of Glycine javanica, Stylosanthes guyanensis, *and probably* Calopogonium caeruleum *and* Psophocarpus palustris. *The last two, being more shade-tolerant, may be useful after the palm canopy has closed. Seven other creeping legumes tried either did not establish a good cover at all, or failed to maintain themselves against competition from Pueraria and weeds.* Flemingia congesta *was the best of the bushy legumes tried.*

INTRODUCTION

Leguminous cover-crops have been generally grown in most oil palm areas of the world, with more emphasis in some countries than others. In Malaysia their cultivation is a standard practice in the early years of the life of the palms. The reasons put forward for this, and the species generally used, have been discussed in an earlier article (Mendham 1967). Control of weeds, and the effect on soil erosion and fertility are the most important aspects. Considerable effort is expended in establishing a cover (Bevan, Fleming and Gray 1966) with complete clean-weeding initially, then sowing seed in drills over the whole area except near the palms. A high standard of weeding for the first two years is required to keep the legumes free of undesirable plants, particularly *Imperata cylindrica,* known as kunai in Papua New Guinea. The main species used have been *Pueraria phaseoloides,* which is slow to establish, the faster-growing but less permanent *Calopogonium mucunoides,* and *Centrosema pubescens,* a useful addition to Pueraria in the longer term. These creeping legumes have generally given beneficial effects to palm yields, compared with natural regrowth and grass. Bushy legumes, particularly *Flemingia congesta,* are also sometimes used, and have an additional value in restricting the flight, and hence damage to palms, of rhinoceros beetles (*Oryctes rhinoceros*). In Africa there is less emphasis on establishing cover-crops (Hartley 1967), although Pueraria often forms a volunteer cover, and seems to establish much more readily than in Malaysia. The soils in Malaysia are generally acid, and often low in nutrients, and it seems that none of the legumes normally used are really well adapted (B. S. Gray, personal communication), hence the difficulty in establishment and maintenance. For this reason a cover-crop is not as useful there for controlling weeds as it is in some other countries.

Since Pueraria has normally been one of the best legumes in other countries for oil palms, and has been used with some success with other crops in Papua New Guinea, it was decided to standardize on it for commerial oil palm planting in West New Britain. It normally establishes fairly readily on fertile soils, forming a good cover under coconuts.

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OBSERVATIONS AND EXPERIMENTS

Nahavio Observation Plots

Small plots of various species of legume were established at Nahavio Agricultural Extension Station in West New Britain in early 1967, for observation and possible seed production. The species used were *Pueraria phaseoloides, Centrosema pubescens, Calopogonium mucunoides, Glycine javanica, Phaseolus lathyroides, Phaseolus atropurpureus* (cv. Siratro) and *Flemingia congesta.* The last species established poorly and needed replanting several times to get a good stand, but the others established quite well. No records of growth were kept, but observations by the author indicated that *Phaseolus lathyroides* only lasted a few months before dying off. Centrosema did not seem to be vigorous. The others formed good covers. Observations on all plots in January, 1969 ($1\frac{1}{2}$ to 2 years after planting) showed that Pueraria had maintained a good cover and was spreading well. Glycine and Siratro were also quite good, with however, more grass and vines in evidence than in the Pueraria plot. Calopogonium did not appear vigorous, and many parts of the plot were covered with grass and weeds. Much of the Calopogonium was yellowish, resembling sulphur deficiency. The Centrosema plot was even poorer, and had been partly taken over by Pueraria. After the slow establishment, Flemingia grew well, and formed a dense high cover in most parts of the plot.

Pilot Blocks

The first oil palm plantings in the area were two pilot blocks at Mosa and Siki in December, 1967 (Mendham 1971). At Siki a cover was obtained by the following simple method. After felling of the rainforest and a superficial burn, Pueraria seed was broadcast at about 1 kg per hectare. Forest regrowth then occurred as well as Pueraria establishment, and about a year later this was cut back ready for lining and planting. Pueraria then rapidly (about three months) formed a good cover with little assistance, and has since been easily maintained by periodic cutting back of any growth that emerges through it. At Mosa the Pueraria was planted along the palm lines, on a cleared strip about 2 metres wide, and at the same time as the palms, using about 2 kg of seed per hectare. This was then weeded regularly for about three months until the Pueraria established itself. After this the legume spread rapidly over the interline, which had been slashed several times, and by six months a complete cover had been achieved. Maintenance has since involved only ring-weeding of the palms plus cutting back the small amount of regrowth that emerges through the cover.

Commercial plantings on smallholder and plantation areas have had good covers established relatively easily using methods similar to that used on the Mosa pilot block. It seems that in this area, with the initially fertile volcanic soils, cleared from forest, Pueraria can be much more easily established than in Malaysia, and it can be maintained as a nearly pure stand with very little effort. Small areas that had been felled previously, such as old village garden areas, are harder to establish cover-crops on. This is probably partly due to the reduced soil fertility, and partly to the presence of more competitive grass and other regrowth. However, even here, with adequate planting of legume and attention to weeding during establishment, a cover will be formed quickly, although it usually takes about two to three months longer than in forest areas.

Legume Observation Plots, Dami

Observation plots were set up at Dami Oil Palm Research Station in 1969, to compare Pueraria with other possibly useful species of legumes. Dami soils were described by Aland (unpublished report), and have developed on volcanic effluvium, which has been conditioned by alluvial deposition. The sandy loam topsoil is derived from recent volcanic ash. The climate is equatorial lowland, with usually no marked dry spells, and a heavy rainfall maximum in January to April. Annual rainfall is approximately 3500 mm.

The main planting, in March, 1969, consisted of unreplicated 28-palm (0.2 hectare) plots of 12 legume species and varieties. These legumes are listed in *Table* 1, with the approximate seeding rate used, and estimates of the growth and spread of the legumes after four months from germination. Also included are estimates of the percentage of good legume and other types of cover on the plots in April, 1970, 13 months from planting.

Table 1. — Main planting, Dami legume observation plots. Seeding rate, early growth and persistence.

	March, 1969	Observations July, 1969*		Estimated Percentage Cover April, 1970				
	Seed Rate kg/ha	Growth	Spread	Good Legume	Legume with Grass and Weeds	Legume with Pueraria	Pueraria	Weeds and Grass
Pueraria phaseoloides	4	4	4	96	4			
Centrosema pubescens	4	2	2	8	34	8	50	
Phaseolus calcaratus	8	3	1	13	11	26	50	
Glycine javanica cv. Tinaroo	4	3	1	46		42	12	
Cooper	4	3	3	54	8	13	25	
Clarence	4	1	0		13	12	68	17
Stylosanthes guyanensis	4	4	2	54		46		
Phaseolus atropurpureus cv Siratro	4	4	3		29	25	34	12
Dolichos lablab	9	3	3		8	12	68	12
Dolichos axillaris	3	4	3		25	25	42	8
Vigna luteola	3	4	3			25	75	
Flemingia congesta	8	3	0			83	17	

* Early growth scores (July, 1969): growth 1-5 (5 = very vigorous growth)

spread 0-5 (5 = full cover of planting strips and interlines)

Establishment. — Planting strips 2 metres wide were cleared and legumes and palms planted along these, the palms being at a 9-metre triangular spacing. All legumes were inoculated with the appropriate Rhizobium strain, except for a small patch in each plot kept as a control. Establishment of legumes was good, except for Flemingia, the seed of which was of poor quality giving a patchy stand. Birds ate some of the *Dolichos lablab* seed, and a sparse stand also resulted, although the remaining plants grew well and formed quite a good cover. Observations of root nodules and plant vigour of the 12 legumes showed little difference between inoculated and uninoculated plants, all plants being healthy and with a fair number of nodules. It appears that inoculation may not be required at Dami, although observations of commercial planting in other nearby areas indicated poor growth and nodulation if this was not done.

Early growth. — The figures for growth and spread (i.e. cover of the interline vegetation) four months after planting (*Table* 1) show that Pueraria formed the best and quickest cover. A nearly complete cover was attained by this time. Siratro, *Dolichos axillaris* and *Vigna luteola* had formed almost as good a cover, with slightly poorer weed exclusion. *Dolichos lablab* and Cooper Glycine were not so good as these. Stylosanthes grew well, but did not spread so rapidly away from the planting strips. Tinaroo Glycine and *Phaseolus calcaratus* were similar, although less vigorous in growth. Centrosema grew poorly, and Clarence Glycine hardly at all, in surprising contrast to the other Glycines. Flemingia, a bushy legume, grew well. Pueraria was planted with it, and this grew out to cover the interlines.

Persistence after one year. — The percentage ground cover given in *Table* 1 after 13 months was largely influenced by the degree to which Pueraria had taken over. This invaded from adjacent areas of palms planted with a normal Pueraria cover. A small amount had also been planted on the trial site before it was decided to use it for the other legumes, and, in spite of attempts to eradicate it by hand-weeding, still persisted. The amount of the original legume still remaining is generally a good indication of its competitive ability against Pueraria and, to a lesser extent, other growth such as grass, vines and tree regrowth from stumps. At this stage, Pueraria formed an almost complete cover. The only others with a high proportion of planted legume were Stylosanthes, and the Tinaroo and Cooper strains of Glycine. The remainder of these plots were mainly a mixture of Pueraria and the planted legume.

On the other plots, no legumes are maintaining dense covers. *Dolichos axillaris,* Siratro and Centrosema seem to reach a balance with grasses and weeds as would be expected for pasture species. The first is a twining type and is unlikely to form a thick mat needed for a cover-crop. Siratro, although initially growing well, later became sparse and badly infested with weeds. *Phaseolus calcaratus* is an annual and went through about three cycles in the first 18 months. Each time it seeded and died off, Pueraria and weeds invaded further. Neither *Dolichos lablab* nor *Vigna luteola* have persisted in spite of early good growth, and both are probably out of their environmental range. Clarence Glycine at no stage grew well. Flemingia remained in balance with Pueraria although Pueraria tended to climb over it.

Pests and disease. — Continuous attack by a ladybug, *Henosepilachna signatipennis,* contributed to the weakness of *Vigna luteola.* The only other legume attacked, Siratro, was not as severely infested. In May and June, 1970, heavy infestations of a leaf-rolling caterpillar, *Hedylepta diemenalis,* were recorded on all plantings of Pueraria at Dami, destroying an appreciable proportion of the leaf area. Most of the other legumes had some damage also. This came in three waves, approximately three weeks apart. The amount of damage decreased after the second wave, and since then there have been no significant numbers of the insects. Some damage also occurred at that time on Pueraria on other oil palm plantings in the district, although none appeared as serious as this. Pueraria recovered rapidly and produced new leaves after the infestation ceased, and the vigour of this legume is such that even sporadic heavy attacks should not cause it to die out. This pest species, synonymous with *Lamprosema diemenalis,* is a recognized pest of legume cover-crops in Malaysia (Bevan, Fleming and Gray 1966), occurring mostly in dry weather.

A leaf-rot occurred in patches on the Glycines, Siratro, *Dolichos axillaris* and to a small extent on Pueraria in the 1970 wet season. The pale brown fungal hypha associated with this rot was identified as *Rhizoctonia solani.* This is reported from Malaysia (Bevan, Fleming and Gray 1966) as the only significant disease on Pueraria and Calopogonium, occurring in wet weather.

Flowering. — Legumes which flowered and set seed in the first six months were *Phaseolus calcaratus, Vigna luteola,* Siratro, Centrosema and Flemingia. The latter has continued to produce abundant seed since then. In the 1970 dry season between June and September, Pueraria, Cooper Glycine and *Dolichos lablab* also flowered and set seed, although subsequent wet weather spoiled much of it. The only legumes which have not flowered are *Dolichos axillaris,* Stylo and Tinaroo Glycine.

Effects on palms. — No effect of any of the legumes on palm growth has been noticed, and as the trial is unreplicated, only a large effect would be apparent. Leaf length measurements after 13 months indicated that palms on all plots were similar, except for Flemingia, where the bushy habit of the legume caused an increase in leaf length and hence palm height. presumably by competition for light. Third leaf samples taken for chemical analysis showed no important differences except that in plots where a lot of grass had invaded, such as Clarence Glycine and Centrosema, nitrogen levels tended to be lower.

Mosa Fertilizer Trial

The effect of a Pueraria cover-crop on oil palm leaf nitrogen levels is shown clearly by early results from a fertilizer trial at Mosa Plantation. The trial has 64 plots, of 16 palms each. Cover-crop establishment was uneven, the majority of plots having good cover when treatments started, but some having grass and vines, and varying amounts of legume. A sample was taken from the third leaf of all palms in each plot in December, 1969, one year after the palms were planted and four months after the fertilizer treatments commenced. There was no effect of any of the fertilizers on leaf levels, but there was a close relation between the type of ground cover, estimated in August, 1969, and leaf nitrogen levels, analysed by the Oil Palm Research Station, Banting, Malaysia. The results are given in *Table* 2.

The generally used "critical level" for palms of this age in Malaysia is 2.8 per cent nitrogen, and only the plots with mainly Pueraria exceeded this. The main reason for this effect is probably the removal of competition for nitrogen by the ground cover. It is not likely that the legume is returning significant quantities of nitrogen to the soil for use by the palms at this age, as measurements on the palms showed a significant response in leaf growth (measured by increase in leaf length) to nitrogen fertilizer, and the response was similar for both good and poor cover plots. The palm measurements showed a small difference in growth of the palms on good and poor cover-crop plots, in favour of the former, again probably due to removal of competition for nutrients.

Additional Plots

Bushy legumes. — Plots of the following were established adjacent to the trial at Dami:

Crotolaria anagyroides 16-palm plot (0.1 hectare) planted May, 1969.

C. laburnifolia 16-palm plot (0.1 hectare) planted September, 1969.

C. striata 16-palm plot (0.1 hectare), planted September, 1969.

Tephrosia candida 16-palm plot (0.1 hectare) planted May, 1969.

T. noctiflora 0.8-hectare plot, planted September, 1969.

All species established well. The Crotolarias grew to between 2 and 4 metres in height (*Crotolaria anagyroides* being the tallest species) and then seeded heavily and have since died back, about 12 to 18 months from planting. They would thus only be useful as

Table 2. — Relation between ground cover and leaf nitrogen levels, Mosa fertilizer trial.

Cover	No. of Plots	% N Mean	% N Range
Mainly grass	4	2.51	2.36-2.66
Grass and vines	10	2.56	2.43-2.70
Mainly vines	7	2.61	2.51-2.78
Vary amount Pueraria	6	2.76	2.62-2.91
Good Pueraria	37	2.91	2.74-3.07

a temporary cover, for example if cocoa was to be interplanted with the oil palms. The Tephrosias are rather more permanent, although *Tephrosia candida* had mostly died out by 18 months, possibly due to a root rot. It had flowered after about six months, at a height of 2 metres. *Tephrosia noctiflora,* which formed a dense stand, flowered heavily at a height of 1 to 1.5 metres after four months. It has since increased slowly in height, flowering continuously, and it has become rather spindly.

Calopogonium caeruleum. — Seed of this could not be obtained in time for the main planting. It has shown great promise in Malaysia and has grown well in the Sogeri area of Papua. A 0.8-hectare plot was planted at Dami in October, 1969. It established well, and by about 7 months had formed a good cover, although not excluding weeds in the interlines. By 13 months about a third of the plot had been taken over by Pueraria. The rest was maintaining a fair cover, although with more weeds than the Pueraria plot at that age, and probably not as good as the Glycines or Stylosanthes. This species has not flowered yet.

Psophocarpus palustris. — This African species has grown exceptionally well as an oil palm cover-crop on certain soils in Sumatra, but poorly on other soils, and in Malaysia (T. Fleming, personal communication). A 0.4-hectare plot was planted at Dami in February, 1970 with seed from Sumatra. The normal Rhizobium strain used for Pueraria, CB756, was used. The plants mostly appeared yellowish, and grew very poorly for two or three months. However, after this they came away well to form a good cover in most parts of the plot by about 8 months. Studies of inoculated and uninoculated plants at 5 months showed that both had nodulated well, and were healthy dark green. By about 12 months the plot had suffered the usual Pueraria invasion, but the remaining Psophocarpus was growing strongly forming an effective cover on most of the plot. A small number of flowers, which set seed, were seen in the 1970 dry season.

DISCUSSION AND CONCLUSIONS

Pueraria phaseoloides has shown itself to be very vigorous and well adapted to conditions in West New Britain, and its choice as the legume for commercial oil palm growing is well justified. It can be established by a number of methods, but the principle seems to be to establish it in clean-weeded areas, either planting strips or patches, which are approximately a quarter of the area to be covered. One effective method is to clear 2-metre wide planting strips along the palm lines, and sow two or three drills of Pueraria along these. An additional narrow strip cleared in the middle of the interline and sown with a single drill encourages an even quicker cover. If these are then weeded several times until the legume is established and starting to run, it will spread over the rest of the area and form a good cover in four to six months. The area can then be maintained by ring-weeding the palms, and slashing any regrowth that appears through the Pueraria. The cover takes longer to establish if smaller areas are sown, or if grass or other strongly competing species are present. At Dami, an observation block of about one hectare was planted in 1970 with a single drill line of Pueraria along the palm lines on a narrow planting strip less than 1 metre wide. Seven to ten months were needed before a good cover was established, and some parts of the plot with grass were not covered even after one year.

The ease of establishment and maintenance of Pueraria in West New Britain contrasts strongly with Malaysia, and this has a marked effect on reducing field costs in the early years of a palm planting. The exclusion of grasses and other weeds which compete for nutrients, especially nitrogen, probably has a beneficial effect on palm growth, and certainly a good Pueraria cover gives high leaf nitrogen levels. The longer-term effect of the legume should be to build up soil nitrogen and reduce the need for fertilizers, although moderate dressings of nitrogen should be beneficial to palm growth in the early years.

Of the other creeping legumes tried, the Cooper and Tinaroo strains of *Glycine javanica, Stylosanthes guyanensis* and possibly *Calopogonium caeruleum* and *Psophocarpus palustris* are the only ones with any promise. Tinaroo Glycine and Stylosanthes spread fairly slowly, and hence would not be of such value in giving a quick cover. The Glycines are apparently more susceptible than Pueraria to attack by *Rhizoctonia solani,* and this would be a factor against their use. Cooper Glycine will apparently flower and set seed whereas Tinaroo and

Stylosanthes probably do not, under West New Britain conditions.

Psophocarpus palustris may prove to be a useful species, if the initial establishment problem can be overcome. Another strain of inoculum may be required. Further observations are needed, as this species was planted much later than the others. *Calopogonium caeruleum* does not appear superior to Pueraria in growth or weed suppression, but has grown well enough to warrant further study. It does not appear to flower under these conditions.

The fact that some of these legumes are less vigorous than Pueraria may not necessarily be a disadvantage. Very regular and thorough ring-weeding of the oil palms is needed with Pueraria, as otherwise it climbs into the palms and, on neglected areas, causes a marked check in growth. During dry weather Pueraria competes strongly with palms for soil moisture, and in Africa cutting back of Pueraria before the dry season can be highly beneficial to palm growth. Dry weather of this intensity is not likely in West New Britain, although on light sandy soils there may be an effect with even a short dry spell. It may be worthwhile considering some of these other legumes, as the effect on growth may more than compensate for the extra effort needed to establish and maintain them. To achieve a quick cover as with Pueraria, a higher seeding rate, greater coverage and better early weeding standards than are used for Pueraria would probably be required. These points would need careful checking, however, before a recommendation could be made.

If a bushy legume is required, there would be no need to go past *Flemingia congesta* unless a temporary cover only was required, in which case *Crotolaria anagyroides,* for a short period, or *Tephrosia noctiflora* for a longer period would be satisfactory. While a bushy legume has been shown in Malaysia to reduce palm damage by *Oryctes rhinoceros,* it does not follow that it will reduce damage by *Scapanes* sp. in West New Britain, as the two probably have different habits. Oryctes has not been found in West New Britain yet. Any of these bushy legumes grown in association with Pueraria may have a short life, since Pueraria would probably take over if they were slashed back to reduce palm shading. This occurred at Dami with the *Crotolaria anagyroides* plot.

The trials and observations reported here do not consider the legume cover after the palm canopy has closed. Observations on the better grown pilot blocks show that a nearly closed canopy is reached at about three years from planting and that much of the Pueraria rapidly dies out after this, presumably from lack of light. The main function of the cover has been fulfilled by then, but it may be useful to have a more shade-tolerant legume such as Centrosema to plant then. If this was planted when the palms and Pueraria were planted, it would probably not survive until the canopy closed, although small amounts of Centrosema have persisted under the shade of a few young palms in the Centrosema plot at Dami. *Psophocarpus palustris* and *Calopogonium caeruleum* are both more shade-tolerant than Pueraria, and may be more useful than Centrosema for mature palms.

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OIL PALM NURSERY FERTILIZER TRIALS IN WEST NEW BRITAIN

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ABSTRACT

Fertilizer trials on recent volcanic soils in an oil palm nursery at Mosa Plantation in West New Britain are described. One trial with different rates of nitrogen and another with factorial combinations of the other major nutrients were run in 1969-70 on both topsoil and subsoil. The latter is being used mainly now as topsoil becomes scarce in the nursery vicinity. The oil palm seedlings were grown in large polythene bags for 12 months, with fortnightly fertilizer applications.

Definite growth responses were found only to nitrogen and magnesium, the latter only on the subsoil. There was an interaction between nitrogen, applied as ammonium sulphate, and magnesium. High rates of nitrogen gave reduced growth compared to lower rates on both soils, apparently due to impeded magnesium uptake, and nitrogen applied without magnesium was of little benefit. Nitrogen applied as nitrate may give different results.

The best growth on both soils was only obtained with application of the other major nutrients as well, and low leaf levels of potassium in the absence of potassium fertilizer suggest that this nutrient at least is also needed. Leaf levels of sulphur and manganese were increased considerably by ammonium sulphate application, the latter being almost certainly due to a lowering of soil pH.

INTRODUCTION

The rapidly developing oil palm industry in West New Britain is being served by one central irrigated nursery at Mosa Plantation. Nursery techniques are similar to those used in Malaysia (Bevan, Fleming and Gray 1966), where seedlings are grown in large polythene bags with sprinkler irrigation, fertilizing and pest and disease control as necessary.

Good topsoil, normally recommended for filling bags, has become scarce in the nursery area, and hence for each successive crop of seedlings more subsoil has had to be used, making correct nutrition by fertilizing increasingly important. Proper use of fertilizers on the subsoil should give good results in the artificial nursery environment, and is preferable to the carting of topsoil from a long distance.

Little is known of exact nutrient requirements of oil palms at the nursery stage. In Malaysia, a compound fertilizer is generally used such as NPKMg in the ratio 12:12:17:2 ($N:K_2O:P_2O_5:MgO$), at rates ranging from 7 to 28 g per seedling per month at 5 to 12 months old respectively (Bevan, Fleming and Gray 1966). Rates have been doubled recently for some plantations by the above amounts being applied fortnightly instead of monthly. This has been the standard amount used at Mosa to date. Hartley (1967) states that fertilizers, particularly nitrogen, are always required in the nursery, except where very fertile topsoil is used. If nitrogen and potassium are applied without magnesium, deficiency symptoms of the latter can appear. These can be removed by application of magnesium fertilizer but growth improvements have not been shown.

MATERIALS AND METHODS

Soils

The soils of the area are of recent volcanic origin. There is little profile differentiation, and the sequence of horizons is an expression of volcanic deposition, variation being due to location in relation to the last centre of

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volcanic activity (DASF 1966). A typical profile in the vicinity of the nursery and chemical analyses from a similar profile are given in *Table* 1. These are based on an unpublished soil survey report of the Mosa area, with minor changes to the profile descriptions. The major proportion of all exchangeable cations, carbon and nitrogen is in the top 15 cm. The heavier textured, darker coloured layer from 53 to 60 cm probably represents a buried previous topsoil, as levels of most nutrients and carbon are higher than in the layers above it. Compared to oil palm soils in other regions (Ollagnier, Ochs and Martin 1970), the pH is higher and calcium tends to dominate the exchange complex, which approaches base saturation. However, levels of the other nutrients are quite high also, especially in the topsoil, compared to minimum levels quoted by these authors (1 per cent C, 0.1 per cent N, 0.2 m-equiv. per cent K, O.4 m-equiv. per cent Mg). They regard the ratio Mg/K as being more important than the absolute amount of Mg, and it should exceed 2 for Mg deficiency not to appear on adult palms, and 4 on young palms. The ratios for the data in *Table* 1 are, in order of depth: 2.9, 2.4, 0.6, 0.5, 1.5. All are below 4, and only the top 15 cm above 2.

Two types of soil were used for the trials, designated as follows:

Topsoil: A substantial amount of humic loam topsoil was included in each bag, and all soil was from approximately the 0 to 15 cm depth.

Subsoil: Any remaining topsoil was scraped off the experimental site with a grader, and the subsoil, mainly yellow-brown sandy loam with ash, used to fill the bags.

Trials

On each type of soil two trials were set out. One used different rates of nitrogen with a basal dressing of the other major nutrients. The other used factorial combinations of major nutrients with a basal nitrogen dressing and additional "nil" and "complete" treatments.

Rates of Nitrogen Trials. — The rates of ammonium sulphate are given in *Table* 2, and the basal application rates of phosphorus, potassium and magnesium in *Table* 3. These rates are the same as for the Other Nutrients trials. Rate 2 in *Table* 2 corresponds to the amount of nitrogen being applied in the compound fertilizer at the present commercial rates. The total amounts applied during the course of the trials were about 100, 200, 300

Table 1. — A typical soil profile in the Mosa nursery area, with chemical analyses from a nearby site

Depth (cm)	Soil Description
0 to 8	Dark brown humic loam
8 to 23	Yellow-brown sandy loam with pumice grains
23 to 38	Pockets of raw grey ash mixed with the sandy loam described above
38 to 50	Brown heavy sandy loam, some pockets of pumice sand
50 to 80	Dark brown sandy clay loam with pumice grains

Chemical Analysis										
						Exchangeable Cations m-equiv. per cent				
Depth (cm)	pH	P (Olsen) p.p.m.	C per cent	N per cent	C/N	Ca	Mg	K	Na	Total
0 to 5	6.8	9	7.9	0.96	8.2	30.0	3.2	1.1	0.2	38.8
10 to 15	6.9	6	3.2	0.43	7.5	12.2	1.2	0.5	0.6	14.4
20 to 25	6.9	6	1.0	0.20	4.9	5.0	0.4	0.7	1.4	6.2
30 to 35	6.7	5	1.4	0.20	7.3	8.3	0.6	1.1	0.4	5.9
53 to 60	6.7	7	2.5	0.36	6.8	10.1	0.9	0.6	0.5	17.0

and 400 g of ammonium sulphate for rates 1 to 4 respectively.

There were six replications of the treatments on topsoil, and four on subsoil. Sixteen seedlings per plot were used on the topsoil, and 12 on the other. Before the first growth measurement any poor seedlings were culled, either genetically poor or suffering from disease or pest attack. Growth measurements were then done on 9 seedlings per plot on both soils.

The germinated seed was planted directly into large polybags (38 x 50 cm layflat) at a 90 cm square spacing, each bag containing approximately 12 kg of soil. Regular sprinkler irrigation was done in periods of drier weather. The topsoil trial was planted in June, 1969 and the subsoil trial in October. Fertilizer applications commenced two months after planting. The solid fertilizers were distributed around the bases of the seedlings inside the polybags.

Recordings on both trials were of seedling height and leaf number at 4, 8 and 12 months. Statistical analysis of the plot means were carried out. Samples for chemical analysis were taken from the third leaves of all seedlings in each plot at 12 months, all plots with the same treatment being bulked to give a single sample for each treatment.

Other Nutrients Trials. — The following treatments were used:

(1) "Complete"
(2) NPKMg
(3) NPK
(4) NPMg
(5) NKMg
(6) NP

Table 2. — Rates of Nitrogen trials. Rates of ammonium sulphate in g per seedling per fortnight

Age (months)	Ammonium Sulphate Rate 0	1	2	3	4
2 to 5	0	2	4	6	8
6 to 8	0	4	8	12	16
9 to 10	0	6	12	18	24
11 to 12	0	8	16	24	32

(7) NK
(8) NMg
(9) N
(10) Nil

Treatment 2 to 9 form a factorial set of combinations of P, K and Mg, with nitrogen as a basal treatment.

A single rate of each individual nutrient was used, and the rates of all fertilizers are given in *Table* 3.

The rates of the individual nutrients correspond approximately to those given in the "complete" treatment except for magnesium, which is approximately tripled, and phosphorus, which is about half. The phosphorus was intended to be equal but rates were based on disodium phosphate as having 21.8 per cent P, which is actually the content of the anhydrous, not the hydrated form.

Three replications of the above treatments were used on each soil type. Twelve seedlings per plot were used, with recording the same as for the Rates of Nitrogen trials. The trials were planted in October, 1969 together with the Rates of Nitrogen trial on subsoil, and fertilizer applications commenced in December.

Plate I shows part of the trials.

Table 3. — Other Nutrients trials. Rates of the fertilizers used, in g per seedling per fortnight

Age (months)	Fertilizer Rate N	P	K	Mg	"Complete"
2 to 5	4	2	2	2	7
6 to 8	8	4	4	4	14
9 to 10	12	6	6	6	21
11 to 12	16	8	8	8	28

N — ammonium sulphate, 21 per cent N

P — disodium phosphate (hydrated) 8.7 per cent P

K — KCL, 52.5 per cent K

Mg — dolomite, 13.2 per cent Mg

"Complete" — 12:12:17:2 ($N:P_2O_5:K_2O:MgO$).

+ minor elements including S

Table 4. — The effect of the five nitrogen rates on height and leaf number. Orthogonal components of the treatment sums of squares are given.

Rate of Nitrogen	Height (cm) 4 months		8 months		12 months	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
0	29.7a	26.6a	63.4a	49.6a	101.2a	84.0a
1	29.1a	28.6ab	68.9b	62.6b	119.2c	122.4bc
2	28.8a	30.0b	66.2ab	63.9b	115.5bc	130.2c
3	29.1a	29.1b	68.8b	60.8b	113.5b	121.0bc
4	29.4a	29.0b	65.8ab	61.3b	114.3bc	118.0b
Least significant difference 0.05	NS	2.3	3.2	3.7	5.4	10.6
Components						
Linear		4.9*	1.9NS	31.5**	12.6**	37.1**
Quadratic		5.6*	8.5**	41.8**	22.5**	59.8**
Cubic		<1 NS	<1 NS	16.3**	18.8**	11.4**
Deviations		<1 NS	7.06*	<1 NS	2.1 NS	<1 NS

Rate of Nitrogen	Leaf Number 4 months		8 months		12 months	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
0	4.9a	4.8a	10.1a	9.9a	15.0a	15.7a
1	4.9a	5.3b	10.6a	11.4b	15.5a	17.9ab
2	5.1a	5.4b	10.4a	11.1b	14.9a	17.8b
3	4.9a	5.4b	10.4a	10.9b	15.1a	17.5b
4	4.8a	5.3b	10.1a	11.0b	15.0a	17.1b
Least significant difference 0.05	NS	0.4	NS	0.8	NS	1.0
Components						
Linear		6.5*		4.5NS		4.7NS
Quadratic		6.0*		8.4*		17.1**
Cubic		<1 NS		8.1*		4.0 NS
Deviations		<1 NS		<1 NS		<1 NS

* Significant at P = 0.05

** Significant at P =0.01

NS Not significant

Means within each column followed by the same letter are not significantly different at P = 0.05

RESULTS AND DISCUSSION

Rates of Nitrogen Trials

Growth. — Results are given in *Table* 4, with the relative heights at each stage of growth in the *Figure*. Growth was substantially increased by ammonium sulphate application on both soil types, but the effect was larger and appeared earlier on the subsoil (*Plate II*). Visible nitrogen deficiency symptoms (Turner and Bull 1967) appeared by about 6 months on the topsoil and 3 months on the subsoil, and were very marked on both soils by 12 months. The first rate gave the best response on the topsoil and the second on the subsoil. The rather odd cubic type response curve indicates an imbalance or toxicity at higher levels on both soils. The effect is similar on height and leaf number although less pronounced on the latter. On the topsoil there was no significant effect of the fertilizers on leaf number.

The height means on the topsoil at 8 months tended to be higher than on the subsoil, but the position was reversed at 12 months. This may be the effect of external factors. The topsoil trial was in the 8 to 12 month stage in February-June, and the subsoil in June-October. Mean sunshine levels for these periods were 4.3 and 5.9 hours respectively (wet and dry seasons), and the difference in growth may be due to solar radiation. February was very wet (1000 mm rainfall) and there may also have been an effect of excessive leaching of soil or applied nutrients.

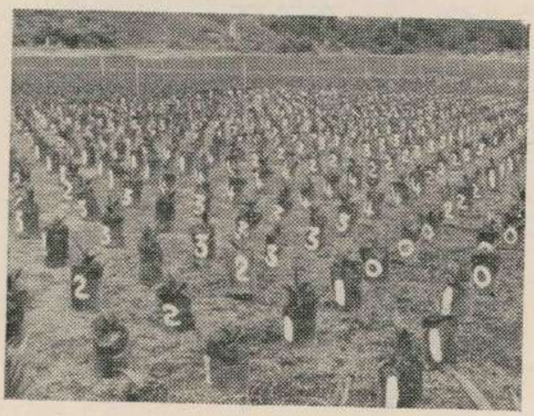

Plate I.—A general view of part of the fertilizer trials in the Mosa nursery, at about 5 months.

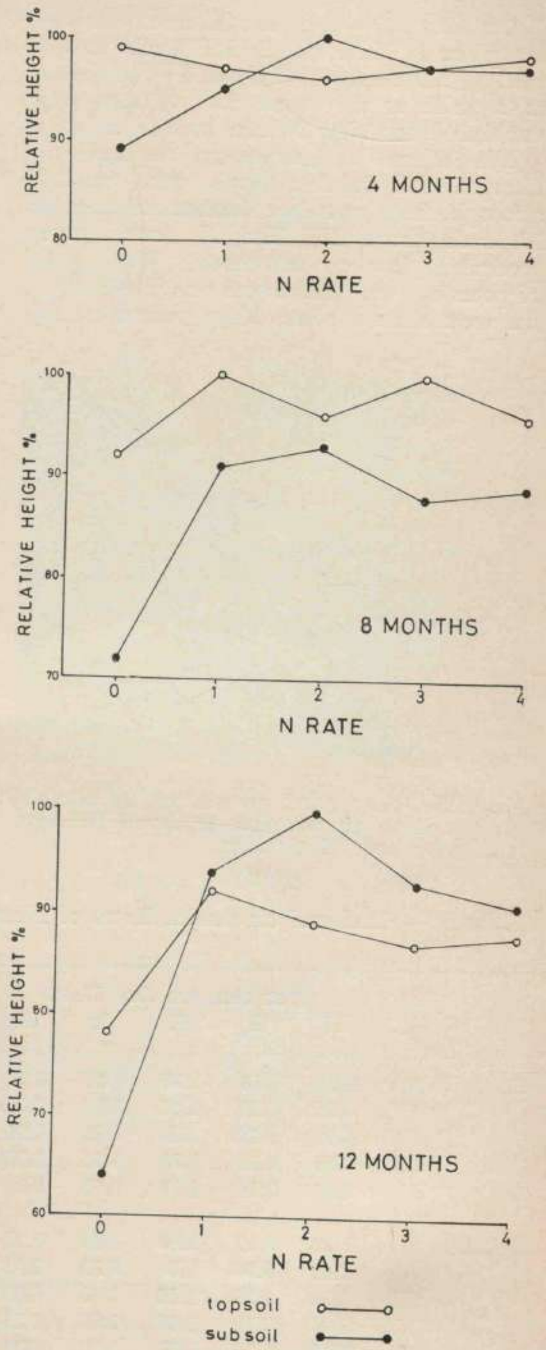

Figure 1.—Relative response in height growth at 5 nitrogen levels. Treatment means expressed as percentages of the highest mean for both soil types at each of three stages of growth.

Leaf analysis. — Results of chemical analyses are given in *Table* 5. "Critical levels" are as used by Mendham (1971), and are only given as a guide as they have not yet been well established for New Britain conditions.

The effects of ammonium sulphate on nitrogen and sulphur levels were marked, although there was little further response in N levels above N_1. The N_0 levels were particularly low on the subsoil. The uptake of potassium and phosphorus was increased by the ammonium sulphate. Magnesium decreased to quite a low level on the topsoil plots with higher nitrogen rates, but not on the subsoil. An antagonism between ammonium sulphate application and magnesium uptake was noted by Chapman and Gray (1949) for field palms, and this apparently occurred here. The high rainfall in the last four months of the topsoil trial may have caused the difference between the two trials through leaching, although May rainfall was moderate (125 mm). There was a very marked effect of ammonium sulphate on manganese uptake, leaf levels increasing from around 50 to over 200 parts per million. This is almost certainly due to a lowering of the soil pH. There appeared to be a similar but much smaller effect on iron levels.

Plate II.—Very good growth of an N0 plot compared to an N1 plot. Rates of Nitrogen trial poor soil, 12 months.

Other Nutrients Trials

Growth. — The treatment means are given in *Table* 6. The values for the least significant difference are large, and were calculated for the 10 treatments ignoring the factorial arrangement of treatments 2 to 9. Generally treatments 1 and 2 were the best, with little difference between the two, and treatment 10 the poorest.

The main effects and interactions of phosphorus, potassium and magnesium were calculated from the totals of treatments 2 to 9, and are given in *Table* 7. The only certain

Table 5 — Leaf analysis results, Rates of Nitrogen trials. Third leaf samples

Trial	No.	per cent on Dry Basis					p.p.m. on Dry Basis					
		N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu	B
Topsoil	N0	2.52	0.16	1.15	0.90	0.25	220	52	78	17.3	6.4	13.9
	N1	3.95	0.23	1.75	0.93	0.24	346	440	94	18.5	7.5	14.6
	N2	3.63	0.20	1.85	0.82	0.20	370	380	92	18.1	7.3	11.6
	N3	3.85	0.18	1.80	0.90	0.20	375	420	100	16.2	7.1	14.0
	N4	3.07	0.19	1.70	0.73	0.18	608	360	88	17.8	7.1	11.3
Subsoil	N0	2.27	0.17	1.20	1.00	0.22	213	39	54	16.5	6.7	10.3
	N1	3.49	0.20	1.50	0.60	0.22	345	200	68	15.7	6.9	11.8
	N2	3.39	0.20	1.50	0.60	0.23	435	280	81	15.5	6.5	8.6
	N3	3.46	0.19	1.65	0.56	0.21	640	790	87	15.7	6.7	10.0
	N4	3.44	0.20	1.60	0.68	0.23	860	280	76	16.0	6.2	11.3
Tentative critical levels (3rd frond)		2.8	0.19	1.30	0.30	0.24	200	50	60	15.0	5.0	10.0

Table 6. — Treatment means or Other Nutrients trials. Height and leaf number at three stages of growth

Treatment	Height (cm) 4 months Topsoil	4 months Subsoil	8 months Topsoil	8 months Subsoil	12 months Topsoil	12 months Subsoil
Complete	28.6	29.7	67.0	66.5b	135.2c	129.9cd
NPKMg	30.0	30.4	66.1	63.9b	130.1bc	131.6d
NPK	28.7	28.6	60.6	58.4ab	124.9abc	112.2abc
NPMg	28.8	26.7	61.2	61.6ab	127.0abc	126.7cd
NKMg	28.3	29.6	64.8	61.0ab	129.3bc	124.0cd
NP	28.9	29.3	65.7	59.4ab	125.7abc	121.6bcd
NK	28.6	29.3	65.3	59.7ab	128.5abc	113.0abc
NMg	26.6	26.4	58.7	57.5ab	119.9ab	116.1abcd
N	27.7	28.0	62.4	58.9ab	120.7ab	104.9ab
Nil	28.4	26.1	59.6	52.3a	118.4a	103.2a
Least significant difference	NS	NS	6.5	10.2	10.6	17.9

Treatment	Number of Leaves 4 months Topsoil	4 months Subsoil	8 months Topsoil	8 months Subsoil	12 months Topsoil	12 months Subsoil
Complete	5.3	5.5	10.9	11.5bc	18.1abc	18.3b
NPKMg	5.5	5.5	11.4	11.4bc	17.7abc	18.3b
NPK	5.4	5.5	10.9	11.2b	17.1ab	17.9b
NPMg	5.3	5.1	11.4	11.4bc	18.6c	18.2b
NKMg	5.3	5.6	10.9	12.0c	17.8abc	18.0b
NP	5.6	5.5	11.7	11.0b	18.4bc	17.7ab
NK	5.4	5.5	11.3	11.1b	17.4ab	17.8b
NMg	5.1	5.1	11.0	10.8ab	17.6abc	17.9b
N	5.1	5.1	11.1	10.9b	18.0abc	17.2ab
Nil	5.2	4.7	10.8	10.1a	17.2a	16.2a
Least significant difference	NS	NS	0.8	0.8	1.2	1.6

Means followed by the same letter are not significantly different at P = 0.05, using the indicated values for the least significant difference.
NS = not significant.

effect is that of magnesium on height of seedlings on the subsoil at 12 months. The visible growth response was very marked, most palms in all plots without magnesium developing deficiency symptoms (Turner and Bull 1967). These ranged from severe stunting, with necrosis of older leaves and bronzing of all except the newest leaves to normal growth with slight bronzing on the lowest leaves (*Plate* III). One plot, treatment 6 replicate 1, was observed to have very few deficiency symptoms and normal growth. This plot was on the outside of the trial, and it appeared that the roots, growing through the bottoms of the bags by 10 to 12 months, had contacted some topsoil which had not been completely removed and thus avoided the deficiency. If this plot is treated as "missing" in the analysis the magnesium effect on height becomes highly significant.

The negative effect of potassium on leaf number for the topsoil is odd, particularly as there appeared to be a small but not significant positive effect on height for the same seedlings. The effect of phosphorus on height on the subsoil at 12 months approached significance, but a contributing factor to this was the high mean for treatment 6 replicate 1, discussed above. With this plot treated as "missing" the P main effect on height reduced to 87 cm, which is still quite high, giving a variance ratio near the 10 per cent level. Further work is needed to elucidate these apparent effects of potassium and phosphorus. Even though only magnesium deficiency was demonstrated on the subsoil, the best growth on both soils was obtained with either the complete or the NPKMg treatments. Treatment 8, NMg only, gave generally rather poor results (*Table* 6).

The nil treatment (10) was the poorest, but was not generally significantly different to the N treatment (9). Application of nitrogen only, at least as ammonium sulphate, will thus be of little benefit on either soil. The nil treatments on both soils were not as severely reduced in growth as the N_0 treatments on the Rates of Nitrogen trials, and the basal applications of P, K and Mg on the latter appeared to considerably aggravate the nitrogen deficiency.

Leaf analysis. — Results of chemical analyses are given in *Table* 8. All fertilizers except phosphorus have increased the leaf levels of their particular nutrient. *Table* 9 summarizes

Table 7. — Main effects and interactions of phosphorus, potassium and magnesium. Height and leaf number at two stages of growth

		8 months		12 months	
Soil	Treatment	Height (cm)	Number of Leaves	Height (cm)	Number of Leaves
Topsoil	P	7.0	3.6	27.0	1.3
	K	25.4	-2.0	58.3	-7.5*
	Mg	-9.6	-0.8	19.9	2.3
	PK	27.6	-3.0	-44.5	-5.1
	PMg	15.6	2.2	19.5	2.3
	KMg	40.4*	1.8	16.3	3.9
	PKMg	20.6	3.6	6.7	-1.3
Subsoil	P	18.4	0.4	103.6	3.7
	K	17.0	4.6	34.6	3.0
	Mg	22.4	5.4	140.0*	5.6
	PK	-8.8	-4.2	-62.6	-1.6
	PMg	23.4	-0.8	8.0	-0.1
	KMg	18.0	2.2	42.2	-2.2
	PKMg	1.4	-3.4	43.0	1.2

* Variance ratio significant at P = 0.05

this. The only exception to this general increase was with magnesium where the nil treatment (10) had an adequate level on both soils, and this is deleted from *Table* 9. The effect is that if nitrogen fertilizer in the ammonium form is used, magnesium is also required or leaf levels will drop greatly. Although reduced growth and deficiency symptoms only occurred on the subsoil, magnesium levels were similarly reduced on the topsoil. Antagonisms between ammonium and magnesium have been reported for oil palms (Chapman and Gray 1949) and other crops. For example, Mulder (1956) showed that severe magnesium deficiency in wheat, oats and potatoes could be induced on acid soils by ammonium sulphate applications, but not by calcium or sodium nitrate. This effect was assumed to be due to a competitive effect by ammonium and hydrogen ions on magnesium uptake. The pH of the present soils, initially about 6.8, had probably been substantially reduced by ammonium sulphate application. giving the reduced magnesium and increased manganese uptake.

The levels of nitrogen on the nil treatments (10) were not as low as on the N_0 treatments of the Rates of Nitrogen trials, further illustrating the antagonism in the latter mentioned above. Potassium levels without fertilizer were lower than is considered desirable in young palms, and it is surprising that a growth response was not obtained. Low leaf potassium

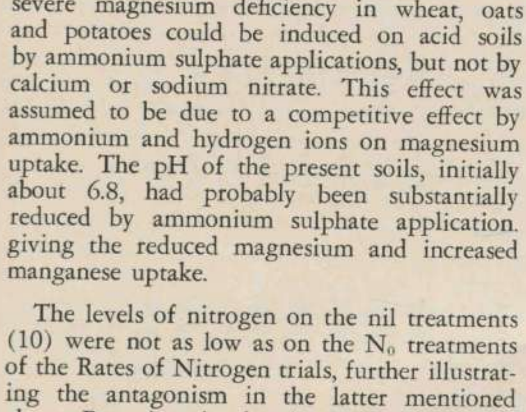

Plate III.—Examples of the range in size and extent of magnesium deficiency of treatment 6 (NP) compared to normal growth in treatments 1 (complete and 8 (NMg), and poor growth due to nitrogen deficiency in 10 (nil). Poor soil, 12 months.

levels were the only abnormal feature of the NMg treatments (8), and poor uptake of this nutrient probably gave the reduced growth of these seedlings compared with the complete treatments. The effects on the minor elements were similar to those on the Rates of Nitrogen trials, and were almost identical for the two soils. Sulphur levels were not increased as much by the complete fertilizer as by the ammonium sulphate. The complete fertilizer raised the boron level greatly on the subsoil but not on the topsoil.

There was no difference in the phosphorus levels for any treatment, and this contrasts with the Rates of Nitrogen trials where for N_0 the phosphorus levels were rather low. This was apparently induced by the nitrogen deficiency and was in spite of basal phosphorus application. Ollagnier, Ochs and Martin (1970) note that low leaf nitrogen levels are often associated with low phosphorus levels.

A small nursery fertilizer trial with oil palms at Vudal Agricultural College in 1969 (Gwaibo Banaga, unpublished report) gave some results similar to those of the present trials. Two rates of ammonium sulphate were compared with one rate of the same complete fertilizer. The complete treatment gave better results (weight of seedlings) than just ammonium sulphate, which in turn was better than the control treatment. However, leaf levels of phosphorus, potassium and magnesium were very high on all plots. The effects of the fertilizers on leaf levels of nitrogen, sulphur and manganese were very similar to those found in the present trials. The leaf level of boron was raised by the complete fertilizer, as on the subsoil trial.

CONCLUSIONS AND RECOMMENDATIONS

1. Nitrogen was required for good growth on both topsoil and subsoil. The first rate gave the best growth on the topsoil and the second, equivalent to the amount of nitrogen used in the present commercial treatment, was best on the subsoil. Higher rates gave reduced growth, apparently due to impeded magnesium uptake.

2. Magnesium was essential at least on the subsoil and with ammonium sulphate as the source of nitrogen. The soil Mg/K ratio

Table 8. — Leaf analysis results, Other Nutrients trials. All samples third leaf.

Soil	Treatment	per cent on Dry Basis					p.p.m. on Dry Basis					
		N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu	B
Topsoil	1 complete	3.51	0.22	1.45	0.68	0.24	265	220	75	17.3	7.4	13.5
	2 NPKMg	3.57	0.19	1.50	0.62	0.20	478	340	75	17.2	7.0	9.6
	3 NPK	3.66	0.20	1.35	0.66	0.17	410	460	75	19.0	6.9	10.7
	4 NPMg	3.62	0.20	1.10	0.66	0.30	398	320	75	18.4	4.8	11.0
	5 NKMg	3.34	0.19	1.30	0.64	0.23	335	300	71	19.6	7.1	10.4
	6 NP	3.52	0.19	1.20	0.56	0.17	395	250	80	16.0	5.1	12.4
	7 NK	3.55	0.21	1.40	0.68	0.18	439	440	81	20.6	7.0	11.3
	8 NMg	3.77	0.19	0.95	0.52	0.29	472	260	74	18.5	6.2	12.4
	9 N	3.78	0.18	0.85	0.56	0.17	385	320	77	19.0	5.1	13.3
	10 Nil	2.96	0.21	1.05	0.82	0.34	223	42	63	18.2	6.8	10.2
Subsoil	1 complete	3.39	0.19	1.45	0.60	0.23	240	200	75	17.3	7.0	33.5
	2 NPKMg	3.39	0.19	1.30	0.58	0.25	446	220	75	16.4	7.0	11.1
	3 NPK	3.35	0.18	1.25	0.62	0.17	534	300	75	15.3	6.2	13.3
	4 NPMg	3.78	0.23	1.05	0.44	0.25	580	200	73	16.6	5.4	13.5
	5 NKMg	3.52	0.18	1.45	0.48	0.23	390	240	72	17.0	8.0	11.3
	6 NP	3.84	0.21	1.15	0.52	0.16	378	250	84	18.1	5.7	13.3
	7 NK	3.56	0.17	1.25	0.52	0.14	390	280	81	20.3	8.0	12.5
	8 NMg	3.68	0.21	1.10	0.46	0.24	478	150	78	17.8	6.5	15.0
	9 N	3.74	0.19	1.05	0.50	0.15	390	150	71	16.3	7.0	12.8
	10 Nil	2.85	0.19	1.15	0.68	0.25	200	54	61	16.3	7.0	12.0

for the subsoil is low, and may be causing this deficiency as the absolute level of soil Mg is moderately high. Use of nitrate rather than ammonium may not give such a severe deficiency.

3. The best growth on both soils was only achieved when all major nutrients were applied. Even though no growth response was shown to potassium or phosphorus, leaf levels of the former were low without K fertilizer, and this was probably the cause of poor growth of treatments receiving nitrogen and magnesium only.

4. Using all the major nutrients growth was equally good on the two soils.

5. Application of the other major nutrients without nitrogen induced a severe nitrogen deficiency on both soils.

6. Leaf levels of sulphur and manganese were increased by either the complete fertilizer or ammonium sulphate. Without fertilizer the levels of both still appeared normal for Papua New Guinea conditions, and a growth response may not have occurred. The effect of ammonium sulphate on manganese uptake is almost certainly due to a lowering of soil pH.

7. The commercial fertilizer to be used on the poor soil should still be a compound, as this is easier to use than a mixture. The present 12:12:17:2 does not seem to be the best combination, although good growth can be achieved with it. The fertilizer should contain more nitrogen, preferably in the nitrate form, and magnesium. Phosphorus is probably not required but could be included at a low rate, and potassium should be included at a moderate rate only in view of the major importance of nitrogen and magnesium. Sulphur should probably be included also.

8. Further work is needed on forms of nitrogen fertilizer and their effect on magnesium uptake, and the importance of potassium and sulphur could be investigated. Different compound fertilizers could be tried, possibly at different rates.

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Table 9. — Summary of treatment effects on individual nutrient levels. For each nutrient the means given are for all plots with and without that nutrient, except Mg (see text)

Nutrient	Treatments	Number of Samples	Topsoil	Subsoil
N per cent	with N	9	3.59	3.58
	without N	1	2.96	2.85
P per cent	with P	5	0.20	0.20
	without P	5	0.20	0.19
K per cent	with K	5	1.40	1.34
	without K	5	1.03	1.10
Mg per cent	with Mg	5	0.25	0.24
	without Mg	4	0.17	0.16
S (p.p.m.)	with S	9	398	425
	without S	1	223	200

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