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

Depth (cm)	pH	P (Olsen) p.p.m.	C per cent	N per cent	C/N	Exchangeable Cations m-equiv. per cent 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
(7) NK
(8) NMg
(9) N
(10) Nil

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

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 Topsoil	4 months Subsoil	8 months Topsoil	8 months Subsoil	12 months Topsoil	12 months 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 Topsoil	4 months Subsoil	8 months Topsoil	8 months Subsoil	12 months Topsoil	12 months 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.

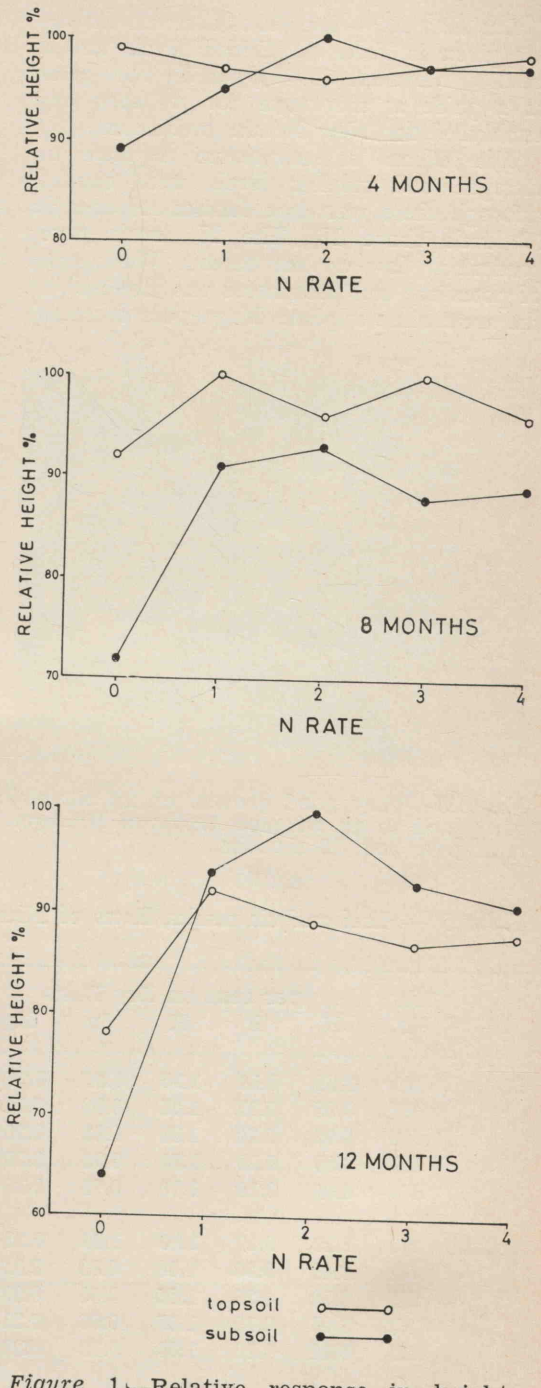

Figure 1.—Relative response in height growth at 5 nitrogen levels. Treatment means expressed as percentages of the highest mean for both soil types at each of three stages of growth.

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 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.

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.

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.

		per cent on Dry Basis					p.p.m. on Dry Basis					
Soil	Treatment	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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