The Response of Immature Hevea brasiliensis to Fertilisers in Malaya I. Experiments on Shale-derived Soils

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Trees in three fertiliser experiments on shale-derived clay loam soil have shown positive growth responses to nitrogen, phosphate and potassium, their relative importance being in this order. The effects of the treatments up to the time the trees were first tapped are discussed in relation to current fertiliser recommendations. It is concluded that the fertiliser responses (particularly for nitrogen) occurred mainly in the early years of immaturity and that the recommendations could be modified to take this factor into account.

Fertiliser programmes for immature rubber in Malaya have been based to a large extent on data from field experiments published by AKHURST (1937), HAINES AND CROWTHER (1940) and AKHURST AND OWEN (1950). These data were incorporated in fertiliser recommendations issued in 1953 by the RUBBER RESEARCH INSTITUTE OF MALAYA (1953) but were later modified (RUBBER RESEARCH INSTITUTE OF MALAYA, 1958) in the light of further unpublished experiments which showed a higher fertiliser requirement than was at first thought necessary. The full results of these and other field experiments on immature *Hevea* are now available, and will be published in a series of papers of which this is the first.*

For the formulation of general fertiliser recommendations, Malayan soils have been grouped into three main classes: the fertile coastal alluvial soils which require either no fertilisers or nitrogen only, the inland loams and clay loams which require mainly nitrogen and phosphate, and the inland sandy soils which respond to nitrogen, phosphate and potassium fertilisers. This rather crude classification has been retained despite the fact that a much more detailed description of the major soil types of the country has been available for some time (OWEN, 1951); this is because precise information from fertiliser experiments is still not available for all the major soil types. There are however, recognisable differences in fertility between soil types within the broad groupings; these must become more important as fertiliser recommendations improve in precision. This paper is particularly concerned with soils in the group of inland loams and clay loams, for which a fertiliser containing a low percentage of potassium (Mixture M, *Table 7*) is recommended.

The extensive experiments of HAINES AND CROWTHER (1940) were sited on soils derived from 'quartzitic shales' and would be classified by OWEN (1951) as of the Batu Anam series. The main characteristics of this group of clay loam soils are comparatively high levels of total and exchangeable potassium and very low levels of total and 'available' phosphate. The series also contains a relatively high percentage of silt which probably accounts for the compact structure and impeded drainage. The experiments reported in this paper were sited on a different group of free-draining shale-derived soils with a lower percentage of silt, a much redder colour and with laterite occurring as an important feature in the profile. These soils are broadly classified by OWEN (1951) as 'Malacca' and 'Seremban' series soils derived from shale (or possibly schist) parent material. From a recently published geological map (ALEXANDER, 1958) it appears that the underlying shales are of different geological ages,

*Since this paper was written new fertiliser recommendations have been published (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963).

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TABLE 1. SOIL ANALYSES (0-12 INCHES)

Experiment	A and B	C[2]	'Haines and Crowther'
Parent material	Shale	Schist (?)	Shale
Coarse sand %	13	17	16
Fine sand, %	10	40	35
Silt, %	15	1	26
Clay, %	55	38	23
pH 1:5 soil/water	4.6	4.8	4.1
Total P, p.p.m.	594	151	100
'Available' P, p.p.m. (Bray & Kurtz)	3	9	4[1]
Total K m. equiv./100g (5*N* HCl)	0.299	0.440	1.402
Exchangeable K m. equiv./100g	0.10	0.01 (?)	0.151[1]
Exchangeable Mg m.equiv./100g	0.18	0.07	—
Exchangeable Ca m.equiv./100g	0.08	0.30	—

(1) A different method of extraction was used, but the results should be comparable with the other figures.

(2) This sample was separate from those in *Table 8* taken at the end of the experiment and showed much lower levels of exchangeable K.

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the Batu Anam shales being of Mesozoic age and the others of Palaeozoic age.

Both the Malacca and Seremban series soils have a yellow-brown clay loam topsoil with concretionary laterite horizons at depths ranging from the surface to 60 inches or more. It is known that tree growth is restricted where the laterite concretions occur at the surface and accordingly such areas were excluded from the experimental sites. In spite of this precaution however, it was found that growth in some plots was poor because of the shallow depth of the topsoil.

Two of the experiments (A and B) were carried out in field No. 54 of the Rubber Research Institute Experiment Station at Sungei Buloh, Selangor, on shale-derived soil of the Malacca series. The third (C) was on an estate in Malacca where the soil (Seremban series) was probably derived from schist. Soil analyses for both areas together with analyses of the Batu Anam series taken from the paper by HAINES AND CROWTHER (1940) are given in *Table 1*.

Two experiments (A and B) were budded with the high-yielding clone RRIM 501, the other (C) with PB 86. In some plots of Experiment C however, it was evident after a few years that some of the trees were budded with the clone RRIM 501 and not PB 86. Unfortunately the distribution of the rogues was such that they could not be excluded from the measurements without losing a substantial proportion of the trees in several plots. Examination of the data did not suggest that the fertiliser response had been affected to any large extent by the rogues. All the trees have therefore been included in the growth measurements.

EXPERIMENTAL

3^3 factorial designs were used with three replicates in Experiment A, and a single

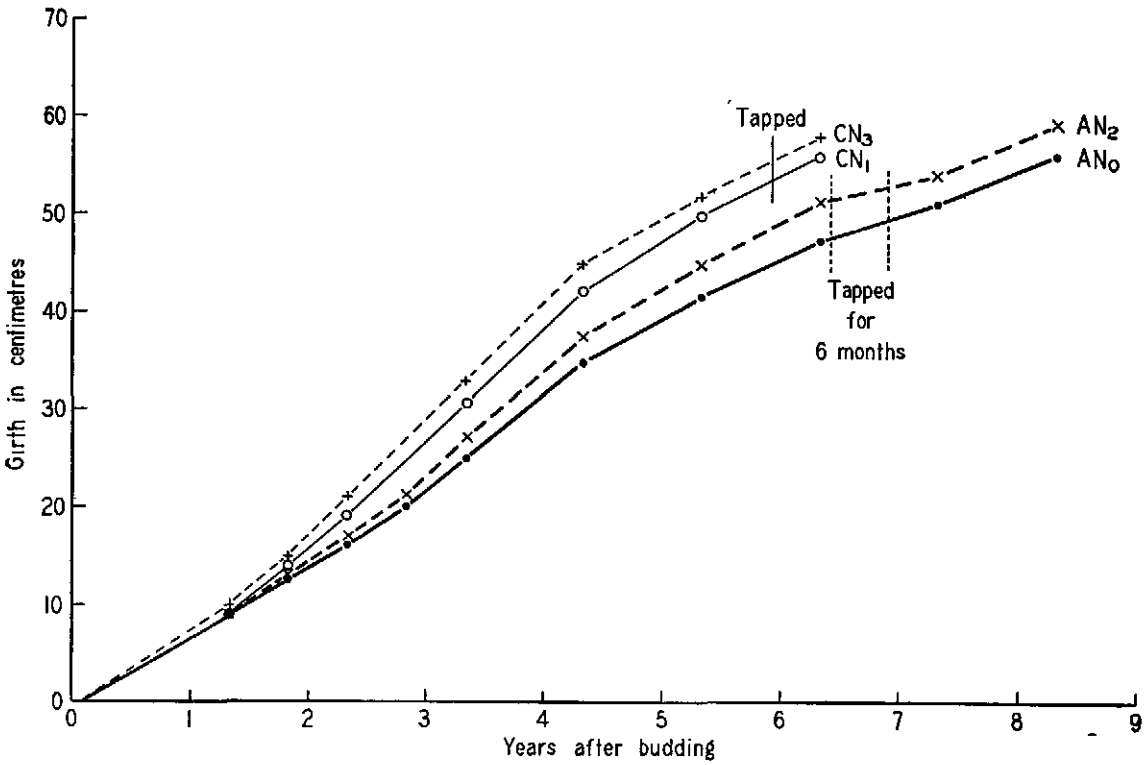

Figure 1. Growth curves for the extreme nitrogen treatments in Experiments A and C (Growth in Experiment B was similar to that in A).

TABLE 2. DETAILS OF THE 3^3 EXPERIMENTS

Experiment	A and B	C
Planted	December 1951	October 1954
Budded	January 1953	November 1955
Clone	RRIM 501	RRIM 501 (Some PB 86 rogues)
Spacing	60′ × 4′ (avenue)	14′ × 14′ (square)
Plot size	1 row × 45(A), 36(B) points	16 rows × 14 points
Covers	*Lalang* for 6 months then legumes	Mixed legumes mainly *Pueraria phaseoloides*
Experimental treatments first applied	June 1954	December 1954
Opened for tapping	July 1959	October 1961

replicate in B and C. The latter two experiments tested three levels (frequencies of application) of ammonium sulphate, rock phosphate and potassium chloride, whereas Experiment A included a control and each fertiliser at two levels.

Details of the planting and budding dates, plot size, spacing etc. are given in *Table 2*, and of the fertiliser applications in *Table 3*.

In Experiment C, the fertiliser treatments at the lowest level were approximately the same as the recommendations of the Institute. Levels 2 and 3 were twice and four times this level respectively. In Experiments A and B however, the experimental treatments did not start until more than one year after budding and it is more difficult to relate the growth effects to the recommendations. Nevertheless, the order of magnitude of the growth responses is of some interest in relation to the amounts of the different nutrients applied.

Records

Measurements of tree girths have been made in each experiment at six-monthly intervals up to about three years after budding, and annually thereafter. Records are given up to a girth of between 55 and 60 cm, by which time the trees at all the sites were in tapping.

Leaf samples were collected every three to four months in Experiment A; the results of analyses have already been published, together with other data by SHORROCKS (1961). Leaf samples were collected only during the latter stages of Experiment C. None were taken from Experiment B.

Soil samples (0-12 inches) were collected from the planting rows and interrows of each plot of Experiment C (where most of the fertiliser was applied) at the time the trees reached maturity. Methods of analysis were the same as those used previously (BOLTON, 1961).

RESULTS

The growth curves for the *extreme* nitrogen treatments in Experiment A and C are given in *Figure 1*. These show that growth was much better in C than in A (and hence in B also, since growth in this trial was approximately the same as in A). This is probably due to the different soil types and planting systems, and to the lack of fertiliser applications in A and B from planting up to sixteen months after budding.

Girths and girth increments for the main effects of nitrogen, phosphate and potassium are given in *Tables 4, 5* and *6* for Experiments A, B and C respectively. Interactions were not important and are not included in the tables. The slight discrepancies between

TABLE 3. FERTILISER APPLICATIONS IN OZ PER TREE OF AMMONIUM SULPHATE : ROCK PHOSPHATE : POTASSIUM CHLORIDE

The number of applications in each period is given in brackets

Expt	Rate	Prebudding†	Months after budding								Total
			0-12	12-24	24-36	36-48	48-60	60-72	72-84	84-96	
A	0	—	—	—	—	—	—	—	—	—	—
	1	—	—	10:10:2.5 (2)	8:8:2 (1)	10:10:2.5 (1)	16:16:4 (1)	20:20:5 (1)	24:24:6 (1)	28:28:7 (1)	116:116:29 in 96 months
	2	—	—	20:20:5 (2)	16:16:4 (1)	20:20:5 (1)	32:32:8 (1)	40:40:10 (1)	48:48:12 (2)	56:56:14 (2)	232:232:58 in 96 months
B	1	—	—	6:6:1.2 (1)	8:8:2 (1)	16:16:4 (1)	—	—	—	—	30:30:7.5 in 48 months
	2	—	—	12:12:3 (2)	16:16:4 (2)	16:16:4 (1)	—	16:16:4 (1)	—	—	60:60:15 in 72 months
	3	—	—	18:18:4.5 (3)	30:30:7.5 (4)	24:24:6 (2)	16:16:4 (1)	16:16:4 (1)	16:16:4 (1)	—	120:120:30 in 84 months
C	1	4:4:1 (1)	6:6:1.5 (1)	8:8:2 (1)	12:12:3 (1)	—	24:24:6 (1)	—	—	—	54:54:13.5 in 60 months
	2	8:8:2 (2)	12:12:3 (2)	16:16:4 (2)	12:12:3 (1)	12:12:3 (1)	24:24:6 (1)	24:24:6 (1)	—	—	108:108:27 in 72 months
	3	16:16:4 (4)	24:24:6 (4)	32:32:8 (4)	24:24:6 (2)	24:24:6 (2)	48:48:12 (2)	48:48:12 (2)	—	—	216:216:54 in 72 months
Recommendation (clay loam soils)		6.6:6.6:0.8 (3)	8.5:8.5:1.1 (3)	9.4:9.4:1.2 (2)	16.9:16.9:2.2 (2)	20.8:11.2: (1)	20.8:11.2: (1)	—	—	—	83.0:63.8:5.3 in 60 months

† In all three experiments rock phosphate was applied in the planting hole in all plots at 4 oz per point.

final girths and the sum of the initial girths and the girth increments are due to tree losses and thinning during immaturity.

Overall effects of the fertilisers on final girth are shown in *Figure 2*.

Nitrogen Responses

Applications of ammonium sulphate significantly increased growth in the early years of each experiment; but the overall effect was negligible in B, quite significant in C and more so in A which was the only experiment with untreated control plots. In all three experiments, nitrogen slightly reduced girth increments at some stage during the last two years. This effect is discussed in more detail later.

Phosphate Responses

Rock phosphate also improved growth at some stage in all three experiments, although only minor effects due to the level of application were recorded in Experiments B and C. In Experiment A, final girth was increased 5.5% by the highest level of phosphate applications over the plots without any phosphate after planting. In Experiment C, the highest level of phosphate increased overall growth by 2.5% over the lowest level — statistically significant at the 10% level but not at 5%. In B, overall increase was only 1.5% and not statistically significant (*Figure 2*).

Potassium Responses

Statistically significant increases in growth due to potassium fertilisers were measured in Experiments A and B but not in Experiment C, although in the latter the effects on girth at the time of tapping were significant at the 10% probability level and nearly so at the generally accepted level of 5% (*Figure 2*).

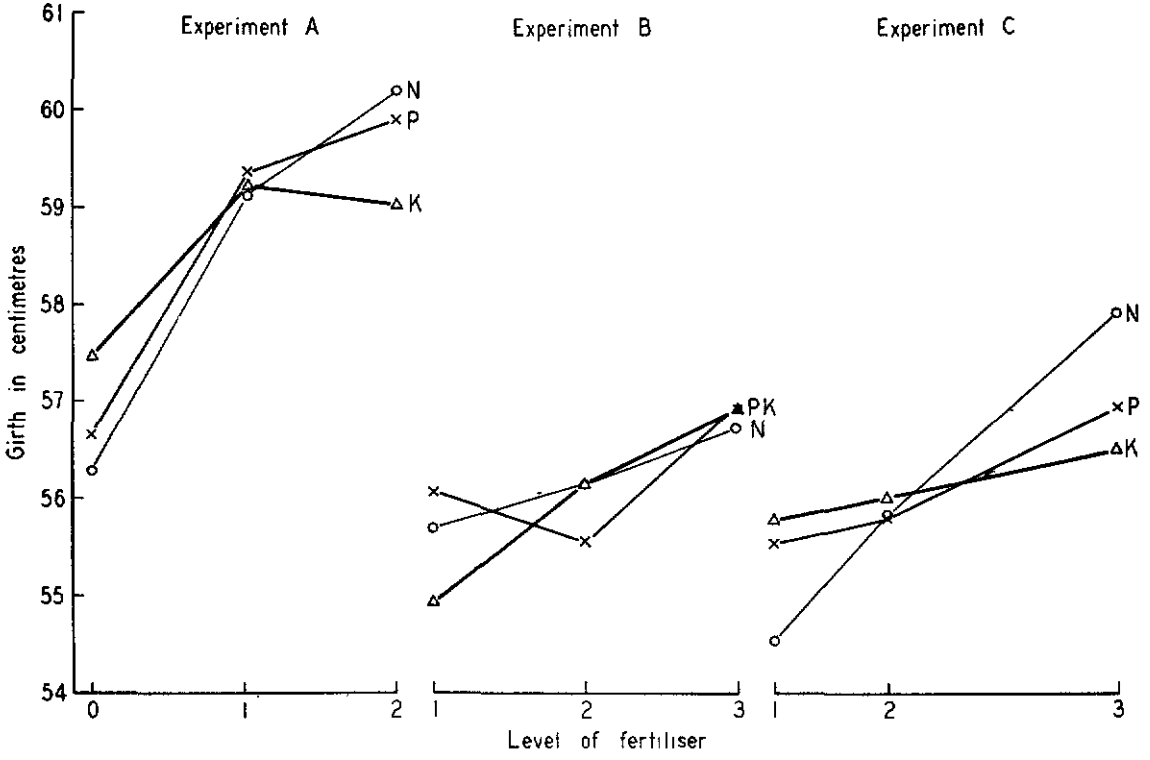

Figure 2. Effects of the fertilisers on final girth.

TABLE 4. EXPERIMENT A. MAIN EFFECTS OF FERTILISERS ON GROWTH (CM)

	Pretreatment girth	Girth increments									Girth
Months after budding	14	14-20	20-26	26-32	32-38	38-50	50-62	62-74	74-86†	86-98	98
N_0	8.98	3.64	3.60	3.70	4.88	9.89	6.84	6.15	3.68	4.65	56.31
N_1	8.90	3.94*	3.94*	4.42	5.26*	10.35*	7.35*	6.74*	3.06	5.10*	59.18*
N_2	8.93	4.05*	4.01*	4.51*	5.57*	10.45*	7.34*	6.63*	2.80*	5.30*	60.27*
P_0	8.84	3.80	3.75	4.00	5.02	10.09	7.05	6.15	3.10	4.75	56.65
P_1	8.94	3.91	3.88	4.28	5.32	10.34*	7.29	6.71*	3.17	5.10*	59.38*
P_2	9.01	3.92	3.92*	4.36*	5.37	10.26	7.18	6.66*	3.27	5.19*	59.74*
K	8.97	3.75	3.72	4.01	5.14	10.05	7.32	6.36	3.22	4.85	57.45
K_1	8.99	3.96*	3.95*	4.32*	5.35	10.30	7.08	6.52	3.16	5.04	59.22*
K_2	8.84	3.92	3.89*	4.30*	5.21	10.36	7.12	6.63*	3.17	5.15*	59.10*
s.e. ±	0.101	0.068	0.057	0.063	0.078	0.087	0.089	0.071	0.070	0.080	0.503
l.s.d. (P=0.05)	0.286	0.192	0.161	0.178	0.220	0.246	0.252	0.201	0.200	0.226	1.421

* denotes a significant difference from the control.
† trees tapped for 6 months out of 12.

TABLE 5. EXPERIMENT B. MAIN EFFECTS OF FERTILISERS ON GROWTH (CM)

	Pretreatment girth	Girth increments								Girth
Months after budding	14	14-20	20-26	26-32	32-38	38-50	50-62	62-74	74-86†	86
N_1	8.55	4.29	4.90	4.85	6.10	11.13	7.49	6.69	2.08	55.69
N_2	9.24	4.45	5.04	4.71	5.96	10.78	7.02	6.68	1.96	56.15
N_3	9.16	4.36	5.17*	4.67	6.05	10.72*	7.56	6.86	1.83*	56.76
P_1	9.08	4.47	4.83	4.58	5.93	10.80	7.39	6.77	1.91	56.10
P_2	8.89	4.23	4.96	4.74	6.00	10.96	7.33	6.71	1.98	55.56
P_3	8.99	4.40	5.32*	4.90*	6.18	10.87	7.36	6.75	1.97	56.94
K_1	9.23	4.26	4.82	4.46	5.75	10.58	6.96	6.55	1.97	54.96
K_2	8.63	4.34	5.05	4.83	6.11	10.95*	7.56*	6.86	1.94	56.16
K_3	9.09	4.50	5.24*	4.93*	6.25*	11.10*	7.55*	6.82	1.95	56.94*
s.e. ±	0.247	0.177	0.079	0.092	0.132	0.123	0.197	0.109	0.064	0.516
l.s.d. (P=0.05)	0.734	0.525	0.235	0.273	0.456	0.365	0.585	0.325	0.193	1.535

* denotes a significant difference from the lowest level.

† trees tapped at 75 months after budding.

TABLE 6. EXPERIMENT C. MAIN EFFECTS OF FERTILISERS ON GROWTH (CM)

	Heights	Heights	Girth	Girth increments						Girth	Product of mean girth at 71† months and increment 65-77 months
Months after budding	— 2	11	17	17-23	23-39	29-41	41-53	53-65	65-77	77	
N_1	137.2	252	9.04	5.02	5.53	10.79	11.72	7.81	6.31	54.55	324.3
N_2	145.2*	287*	10.17*	5.13	5.94*	10.86	11.30	6.20*	6.23	55.84	328.5
N_3	155.8*	281	9.99*	5.22*	6.11*	11.66*	11.89	7.04	6.12	57.91*	335.7
P_1	147.9	270	9.54	5.08	5.84	10.76	11.53	6.92	6.42	55.55	336.0
P_2	142.5	277	9.79	5.03	5.83	11.10	11.65	6.97	6.09	55.80	321.3
P_3	147.7	273	9.87	5.25*	5.91	11.46*	11.73	7.16	6.14	56.95	330.8
K_1	145.7	279	9.88	5.11	5.89	11.07	11.43	6.44	6.15	55.77	324.1
K_2	144.7	266	9.52	5.15	5.86	11.03	11.69	7.60	6.18	56.03	327 2
K_3	147.8	276	9.80	5.11	5.84	11.22	11.79	7.02	6.32	56.51	337.2
s.e. ±	2.66	11.5	0.26	0.067	0.127	0.193	0.289	0.429	0.096	0.518	
l.s.d. (P=0.05)	7.90	34.2	0.78	0.198	0.378	0.573	0.858	1.274	0.285	1.540	

* denotes a significant difference from the lowest level.
† girth at 77 months — girth at 65 months

Leaf Analyses

It is not the purpose of this paper to discuss the detailed results of leaf analyses in these experiments. As already mentioned, the results from Experiment A have been published elsewhere by SHORROCKS (1961). The first leaf samples from C, taken at four and half years after budding, showed levels of magnesium lower than those which have been shown to be deficient (BOLTON AND SHORROCKS, 1961), and supplementary magnesium fertiliser (kieserite) was applied to all the plots. It is possible that potassium responses in this experiment have been limited to some extent by this low magnesium level as a result of potassium-magnesium antagonisms. In Experiment A also, low magnesium levels and symptoms of magnesium deficiency were found (particularly in the last year) but no magnesium fertilisers were applied.

Soil Analyses

The analysis of soil samples (0 – 12 inches) taken from both the planting rows and the interrows of Experiment C at the time of tapping will be fully reported elsewhere; a summary of some of the results is given in *Table 8*. Effects similar to those previously reported by BOLTON (1961) were found, including appreciable depressions in exchangeable calcium, magnesium and potassium following applications of ammonium sulphate. A statistically significant increase in pH was also observed in the rock phosphate treated plots.

DISCUSSION

The results from these experiments confirm the conclusions of OWEN AND AKHURST (1950) that the major response on these shale-derived soils is to nitrogen and phosphate fertilisers. In two experiments however (A and B) there have also been definite increases in growth from potassium. This is contrary to the findings of HAINES AND CROWTHER (1940) on soils of the Batu Anam series. The difference in results could be explained by the higher total and exchangeable potassium in Batu Anam soils; possibly also by the much higher rates of potassium chloride used by these authors in their experiments — rates which may have been much higher than the optimum and might possibly have checked rather than improved tree growth (AKHURST AND OWEN, 1950). Ratios of the major fertilisers used in the different experiments are shown in *Table 7* together with the ratios contained in the fertiliser mixture recommended for these soils. A further possibility is that the clone RRIM 501 has a higher requirement for potassium than the older clones used in previous experiments. In two other fertiliser experiments in mature areas of this clone, unpublished results have shown positive potassium effects on growth on soils which would be considered adequately supplied with this nutrient, on the basis of soil analyses (BOLTON, 1961); leaf analyses however showed levels bordering on deficiency in the control plots. BOLLE-JONES AND RATNASINGAM (1954) have reported that leaves from RRIM 501 are consistently lower in potassium content than those from Tjir 1 or PB 86. The results from Experiments A and B may therefore be indirect evidence of clone × potassium interaction.

Another difference from the experiments of HAINES AND CROWTHER (1940) is that the main response on final girth has been to nitrogen rather than phosphate, particularly in Experiment C (*Figure 2*). This nitrogen response, as measured by the rate of girthing, was most evident in the earlier stages of growth in all the trials; in the later stages there were in fact suggestions of a reversal in response, statistically significant negative effects on girth increment being recorded (*Tables 4, 5 and 6*). This cessation of the nitrogen effect might be partly explained by the release of nitrogen from the cover plants which die out during the later years of immaturity (RUBBER RESEARCH INSTITUTE, 1961); but it is difficult to see why there should be apparent depressions in growth on the high nitrogen plots. Part of the reduction in girth increment on the high nitrogen plots can be explained by the relation between total growth and girth increment. The latter is only a crude measurement of growth and it can easily be shown that an increase in cross-sectional area of the trunk is proportional to the pro-

TABLE 7. RATIOS OF UNIT LEVELS OF THE MAIN FERTILISERS USED IN THE EXPERIMENTS AND IN RECOMMENDATIONS OF THE RUBBER RESEARCH INSTITUTE (1958) FOR CLAY LOAM SOILS

	Ammonium sulphate 21% N	Rock phosphate 36% P_2O_5	Potassium chloride 60% K_2O
Experiment A	100	100	25
Experiment B	100	100	25
Experiment C	100	100	25
Haines and Crowther (1940)	100	72	45
Recommendations for clay loam soils (Mixture M)	100	76.9	6.4

duct of girth and girth increment*. When, after some years, girth differences exist between treatments in a long-term experiment, there must be corresponding differences in girth increment for the same total growth. This effect is well illustrated by the measurements in Experiment C in the final year. Girth increments decrease (non-significantly) with increasing nitrogen level, whereas there is an increase in the product of the girth at 71 months and the girth increment over the period 65 - 77 months after planting (*Table 6*). This difficulty is inherent in any trial with tree crops where treatments are applied to the same plots year after year. In such cases, the product of mean girth and girth increment would seem to be a better measure of total growth.

In Experiments A and B, when fertilisers were first applied in the second year after budding, immediate responses to the application of phosphate were recorded. In Experiment C, however, where the differential fertiliser treatments were applied from planting, the first statistically significant increase in growth due to phosphate was measured only between seventeen and twenty-three months after budding. This seems to indicate that the rock phosphate applied in the planting holes and during the first year at the lowest levels (P_1) was adequate for early growth. A further significant response occurred between twenty-nine and forty-one months, but since it is impossible to differentiate between direct and residual effects of applied phosphate, all that can be said is that in this experiment, up to forty-one months after budding, the P_3 level of application was more effective than the P_1 level. Large reserves of both 'available' and total phosphate were built up in the higher phosphate plots in this experiment (*Table 8*); since this phosphate will remain in the surface soil for many years (BOLTON, 1961), long term residual effects will almost certainly occur as a result of the treatments.

One further aspect of the phosphate responses should be mentioned. In normal estate practice, rock phosphate is applied to the cover plants at a rate of about 2 cwt per acre per annum, but in these experiments no phosphate was applied to the covers (except in C where a small amount of phosphate was applied by mistake in the first year). Such phosphate applications would be expected to reduce the response to phosphate applied to the trees in the planting rows, and when

* Increase in cross-sectional area of the trunk where r = radius of trunk and g = girth = 2r,

$$= \pi r_2^2 - \pi r_1^2$$

$$= \frac{1}{4\pi}\left(g_2^2 - g_1^2\right)$$

$$= \frac{1}{2\pi} \times \frac{(g_2 + g_1)}{2} \times (g_2 - g_1)$$

= constant x mean girth x girth increment.

TABLE 8. SOIL ANALYSES (0-12 INCHES) IN THE PLANTING ROWS OF EXPERIMENT C

Treatment	pH	Total P (p.p.m.)	Avail. P (p.p.m.)	Exchangeable (m.equiv./100 g)		
				K	Mg	Ca
N_1	4.80	353	110	0.132	0.111	0.491
N_2	4.59*	308	96	0.114	0.088	0.396
N_3	4.39*	331	86	0.106	0.057*	0.289*
P_1	4.49	183	22	0.122	0.080	0.252
P_2	4.63*	328*	93*	0.110	0.083	0.389
P_3	4.66*	481*	177*	0.120	0.092	0.534*
K_1	4.61	352	112	0.104	0.086	0.459
K_2	4.56	327	98	0.124	0.084	0.352
K_3	4.60	314	81	0.123	0.086	0.364
±	0.04	26	15	0.011	0.010	0.049
l.s.d. (P=0.5)	0.13	79	45	0.034	0.029	0.145

*denotes a significant difference from the lowest level.

making fertiliser recommendations the relation between them needs to be considered.

At the time that these experiments were initiated, the importance of magnesium in the nutrition of *Hevea* was not fully appreciated; unfortunately differential magnesium treatments were not included in the designs. In two of the trials magnesium deficiencies occurred and soil analysis in Experiment C showed that the deficiency would have been accentuated by the application of ammonium sulphate. Until more information is available concerning response to magnesium during immaturity, the final form of fertiliser recommendations, particularly for formulations containing magnesium, must remain obscure.

CONCLUSIONS

In spite of the above limitation regarding the absence of any treatment with magnesium fertilisers, the experiments have given useful information on fertiliser responses during immaturity. Current fertiliser recommendations seem reasonably accurate as a first approximation but the results for these three experiments — particularly Experiment C — suggest that they might be improved by increasing the amounts of fertiliser mixtures applied during the first three years after budding; the subsequent rates could perhaps be reduced. This would confirm similar suggestions for nitrogenous fertilisers which have been put forward by MAINSTONE (1961) and by the RUBBER RESEARCH INSTITUTE OF MALAYA (1961) as a result of research into the relationship between cover plants and fertiliser response.

ACKNOWLEDGEMENTS

The generous assistance of the managers and staff of the Rubber Research Institute of Malaya Experiment Station and Kempas (Malaya) Ltd (Devon Division) in carrying out these experiments is gratefully acknowledged.

Soils Division
Rubber Research Institute of Malaya
Kuala Lumpur *April 1963*

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