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The Response of Hevea to Fertilisers on a Sandy Latosol

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The results of a simple NPK fertiliser trial on Hevea brasiliensis carried out on a sandy latosolic soil are discussed in terms of the response occurring in growth and yield over 10 years of immaturity and the first 12 years of tapping. The main response has been to phosphatic fertilisers with a smaller response to nitrogen but little to potassium. There are some indications that the responses may have been influenced by low magnesium levels in the trees. Clonal sub-plots have given some interesting details of monthly yields throughout the year and yields from different heights of tapping of virgin and renewed bark of five of the older clones. The results emphasise the importance of good growth in the period of immaturity.

There have been few long term fertiliser experiments on *Hevea brasiliensis* reported in the literature, and reports of experiments continued for more than twenty years are particularly rare. The reason for this is not difficult to find when all the hazards which can occur are enumerated and the mass of data which can accumulate is realised. This paper is an account of such a fertiliser experiment carried out in Field 31 at the Experiment Station of the Rubber Research Institute of Malaya which exemplifies the complex nature of even a simply designed experiment on a perennial crop. It is the most accurate and detailed fertiliser experiment carried out on *Hevea* by the Institute since experiments were started in the late 1920's. The volume of data which has accumulated over twenty-four years includes over 90,000 measurements of tree girth and nearly 50,000 measurements of plot latex yield, each of these being cup-coagulated, collected, creped, dried and weighed. Apart from these data, many other supplementary figures have been collected including bark thickness measurements, leaf and latex analyses and soil analyses. Some of this work has been published previously as sections of different papers, but there is a great deal of interesting data which is published here for the first time.

DETAILS OF THE EXPERIMENT

The history of the experiment is most easily set out in tabular form and is given in Table 1. The essential features are the six main fertiliser treatments arranged in a Latin square design and the sub-plots made up of five different clones. The design using only six of the eight fertiliser treatments of a $2 \times 2 \times 2$ NPK factorial layout has already been criticised by OWEN *et al.* (1957) as being unorthogonal, and main effects and interactions cannot be estimated by combining treatment means. An estimate can be obtained by making certain assumptions, the main alternatives being to regard K and PK effects as negligible or to assume all the first order interactions to be zero. The former alternative was used in Owen's paper, but the assumption of a zero K effect when there have been many reports of negative K responses in *Hevea* trials (AKHURST AND OWEN, 1950) seems to be questionable. The second alternative also seems inadvisable as significant positive NK interactions were found by Owen *et al.* in the 17 trials reported in their paper. No valid assumptions can therefore be made to enable combinations of treatment means to give the effects of the main fertilisers but, fortunately, a low coefficient of variance (probably due to the large plots and

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TABLE 1. DETAILS OF THE EXPERIMENT

Design	6 × 6 Latin Square
Fertiliser treatments	Control, N, NP, NK, PK, NPK
Sub-plots	Planted with Tjir 1, PB 86, Pil B84, Pil D65, BD 5
Planted	December 1935 with unselected pencil stump seedlings
Budded	November 1937
Plot size	1.08 acres, with 194 tree points per plot, divided into 5 clonal sub-plots each of 39 points
Planting distance	22 × 11 ft on contour terraces
Covers	Natural. Controlled by periodic slashing
Tapping system	Full spiral, 4th daily, S/1.d/4.100%
Tapping panels	1st Panel—opened at 36 in. above the union, August 1947. Lowest part tapped out half spiral alternate daily, S/2.d/2.100%, during 6 months in 1953
	2nd Panel—opened at 41 in. above the union October 1953 thus creating a virgin bark island. Below the virgin bark island, tapping was on first renewed bark.

latin square design) enables each treatment mean to be considered individually and this procedure will be followed in the following account.

Topography

The area is not ideal for experimental purposes being on the western slopes of a quartzite hill. Several deep gullies run down the hill towards a comparatively level low-lying flat area, which is, however, reasonably well drained. The whole area was planted on terraces built on level contours approximately 22 ft apart and the plots were laid out on a superimposed grid which kept all the plot and sub-plot boundaries straight. Care was taken at planting and at each thinning to ensure a uniform tree density throughout the experiment. This method has been found quite satisfactory in practice and has been subsequently used in experiments on several other hillside sites.

Soil

The soil, a sandy loam, was derived initially from quartzite which weathers at an early stage to sandstone. It has been described by OWEN (1951) as of the Kedah Series, although, in subsequent more detailed studies of similar soils, PANTON (1954) reserves this name for a more eroded phase of quartzite-derived soils. The latter author's description of the Serdang Series is more similar to that found in the experimental area. Mechanical analyses of samples taken in 1951 from the terraces and from under the covers of the control plots are given in Table 2. Additional soil analyses of samples taken during 1959 from all the plots are discussed in detail in a later section.

TABLE 2. ANALYSES OF SOIL SAMPLES (0–6 INCHES) TAKEN IN 1951 FROM THE CONTROL PLOTS. THE RESULTS ARE QUOTED AS PERCENTAGES OF AIR DRIED SOIL

Sampling area	Gravel	Sand		Silt	Clay	Loss on Ignition	pH	N	C
		Coarse	Fine						
Terraces	Nil	41.6	41.4	3.5	10.9	3.39	5.18	0.067	0.91
Under cover	Nil	42.1	39.4	4.0	10.9	4.70	5.02	0.108	1.46

TABLE 3. SCHEDULE OF FERTILISER APPLICATIONS (OZ PER TREE)

	Ammonium sulphate	Rock phosphate	Double super-phosphate	Potassium	
				chloride	sulphate
Immature					
April 1936			Basic dressing		
May 1937	3½	—	2	—	2
November 1937			Budded		
May 1938 and Oct. 1938	3½	—	2	—	2
April 1929 and Nov. 1939	5	—	2.5	—	2.5
April 1940	10	—	5	4	—
April 1941	12	—	6.25	5	—
Mature					
July 1947 and biennially	40	16	—	8	—

Manuring

A programme of manuring was followed from planting in 1936 up to the end of 1941 when, owing to the war, treatments had to be stopped (Table 3). In the pre-war treatments, soluble phosphates were used and the ratios of $N : P_2O_5 : K_2O$ were 1 : 1 : 1.2, while in later years when the trees were in tapping rock phosphate was used and the ratios were 1 : 0.7 : 0.6. The post-war proportion of potassium was presumably reduced when the results showed no beneficial effects from this nutrient.

Since 1947, fertilisers have been applied biennially, usually in the May–July period. The rates of these applications are also shown in Table 3.

All the fertilisers were applied on the contour terraces which have been kept clean of weeds. Dressings of ammonium sulphate and potassium chloride were broadcast while from 1947 the rock-phosphate fertiliser was applied in 'pockets' around each tree, but this practice was discontinued in 1957–58 when this fertiliser was also broadcast. The effect of this method of application on the results of soil analyses on each plot is discussed further below.

Recording

Pre-war girth measurements and two sets of measurements in 1947 were made at 50 inches above the union of stock and scion; all others, including the annual measurements since 1947, were made at 60 inches.

Latex yield measurements were started on opening the trees for tapping in 1947 using a cup-coagulation technique. After collection, the cup lumps from each sub-plot were washed, creped and dried in the smoke-house for ten days, then weighed. Recordings were made on two tapping days per month from opening in 1947 until 1955, and on one tapping day thereafter.

Soil samples were collected from the terraces of each plot in 1959, leaf samples (from the Tjir 1 trees only) in 1954, and latex samples from three clones in 1957. In 1950 the thickness of both virgin and first renewed bark was also measured using a Schlieper gauge. The construction and use of this instrument has been described previously by DE JONGE (1957).

RESULTS

In order to avoid the presentation of extensive tables of girth, girth increments and yields for both the different fertiliser treatments and the five different clones, most of the data have been summarised in graphic form. In this way, the main feature of the results can be more easily seen but less prominence is given to the standard errors and statistical significance of the results, although these have been indicated wherever possible.

Effect of Fertilisers on Growth

The effects of the different fertilisers on growth in the immature stage have been briefly discussed, along with the results of other experiments, by AKHURST AND OWEN (1950). There was a marked response to soluble phosphate fertilisers with a smaller response to nitrogen, but little evidence of any additional benefit from potassium. Figure 1 shows the mean growth curves for the control and NPK plots over the 22-year period from budding to mid-1959.

The best growth up to the sixth year was in the NP plots (omitted from the graph for the sake of clarity), but in the 1943–46 period (when no further fertilisers were applied) these were overtaken by the NPK plots. From 1945 to 1947 there was less than 2% difference in growth (non-significant) between all six treatments, which suggests that the residual effect of the earlier fertilisers had died out.

After fertiliser dressings were resumed in 1947, significant differences in annual growth

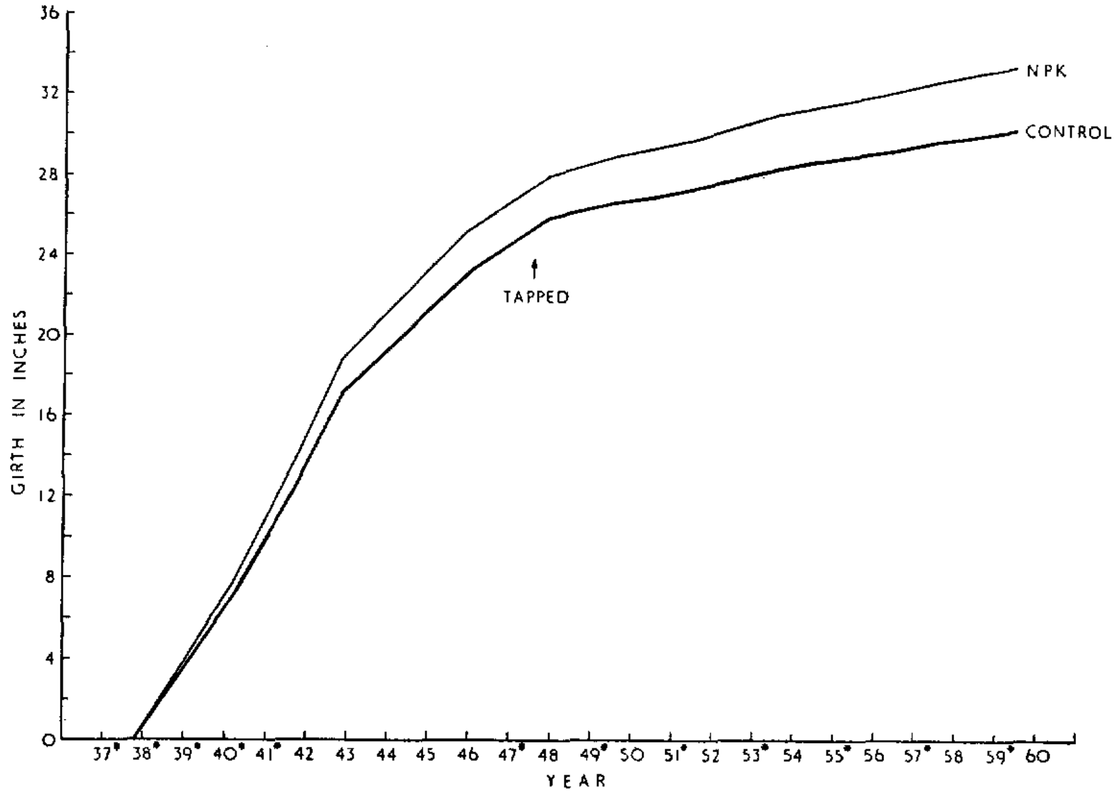

Figure 1. Growth curves for the control and NPK plots.
** Year of fertiliser application.*

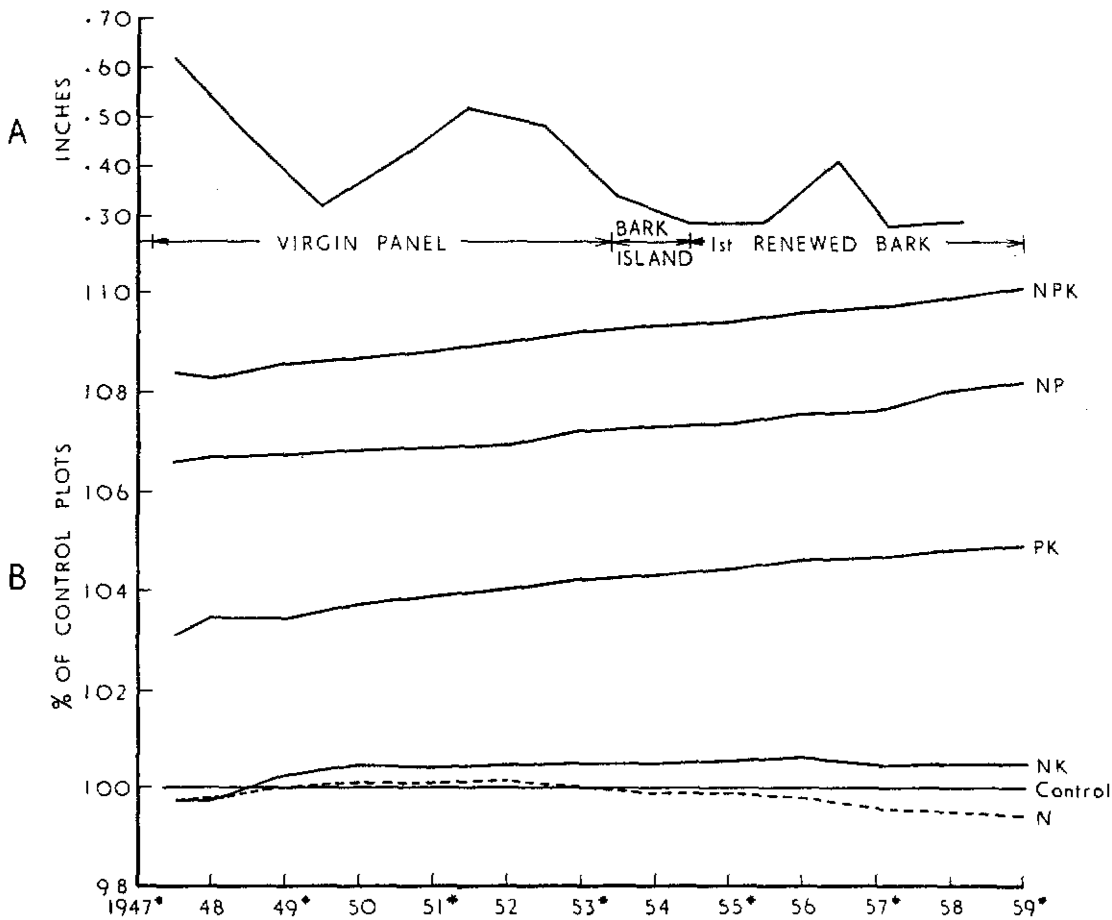

Figure 2. Girth, as a percentage of the control, for each fertiliser treatment (B), together with the annual girth increments of the control plots (A).
** Year of fertiliser application.*

were again measured and these are illustrated in Figure 2(B) where the mean girths for the different treatments are given as a percentage of the control plots. Growth in the NPK plots was slightly better than in the NP plots but in no year was the difference between them statistically significant. Potassium has had therefore a very minor, if any effect on growth. Nitrogen too seems to have had little effect on growth after maturity, the growth curves for the NPK and the PK plots being almost parallel. In the absence of P and K however, the effect of the nitrogen fertiliser had a definite trend from slightly beneficial in 1948 to a deleterious effect, particularly in the 1956–59 period, although in no year were the differences statistically significant from the control. This trend might be explained in terms of the effect of sulphate of ammonia on the magnesium nutrition of the trees and is discussed further below in relation to the leaf and soil analyses.

The annual girth increments of the control plots (Fig. 2A) are interesting in that they show regular differences as the tapping cut moves down the panel on both virgin and renewed bark.

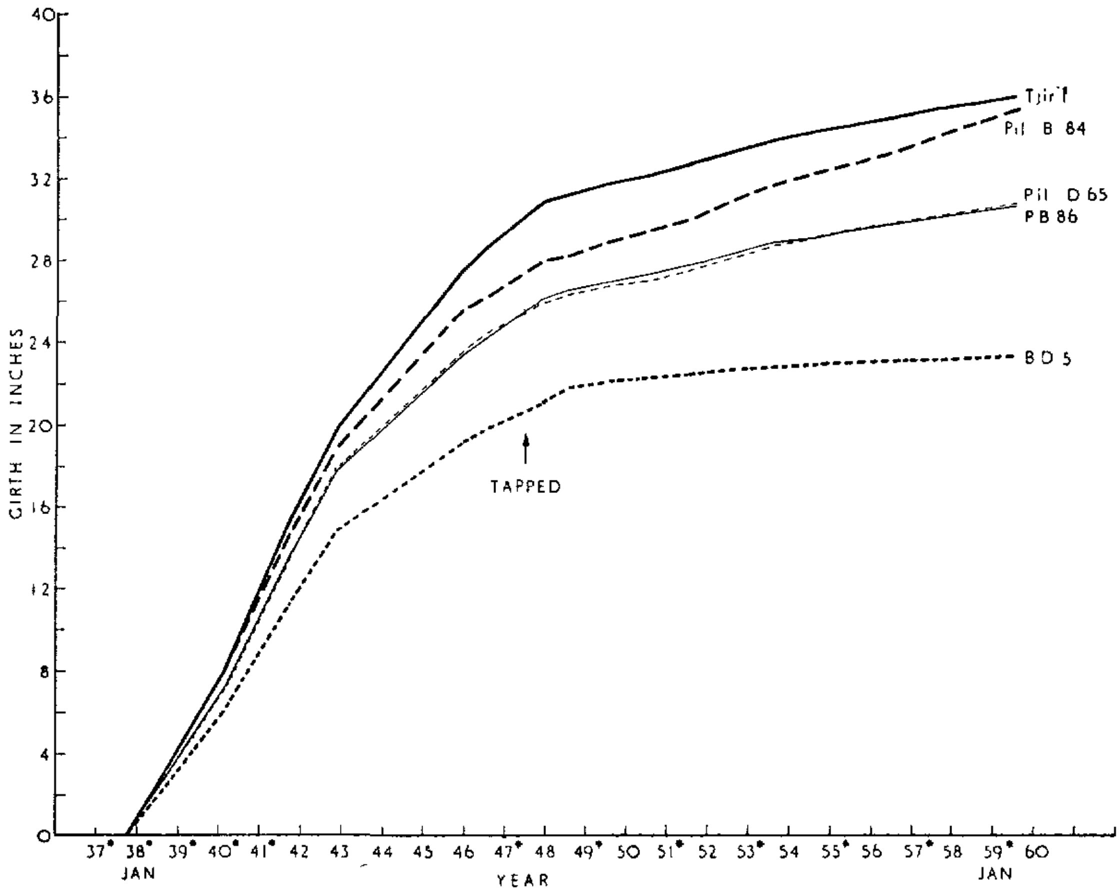

Figure 3. Growth curves for each of the five clones.
** Year of fertiliser application.*

There was no evidence of any differential clone reaction to the fertilisers.

Clonal Differences in Growth

Growth curves for the five clones are shown in Figure 3. Differences in the form of the curves both before and after tapping are readily apparent and call for little further comment. The more prominent features are the very poor growth of the clone BD 5 after tapping, when the girth increased by only 1.7 inches in a period of 11 years, and the comparatively good growth of Pil B84 which grew at a rate almost double that of PB 86, Pil D65 and Tjir 1 after opening. The poor growth of BD 5 was apparent from the first girth measurements taken 2½ years after budding.

The Effect of Fertilisers on Yield

Of more direct interest to the industry is the effect of continued application of fertilisers on yield. In this experiment, the yield responses have closely followed the responses in girth but have been much more pronounced. This can be seen in Table 4 where the girth and yields for the different fertiliser treatments are set out as percentages of the control plots at the beginning and the end of the tapping period. These figures show that the increases in yield due to the treatments cannot be fully explained solely by increased

TABLE 4. GIRTH-YIELD RELATIONSHIP GIVEN AS A PERCENTAGE OF CONTROL PLOTS

		O	N	NK	NP	PK	NPK	s.e.±	L.S.D.*
1947	Girth	100	101	100	107	103	108	1.5	4.3
	Yield	100	104	105	106	109	116	3.1	9.2
1959	Girth	100	99	100	108	105	110	1.3	4.0
	Yield	100	96	97	121	116	129	5.2	15.3

*p = 0.05

girth and the consequently greater length of the tapping cut, i.e. by a linear girth-yield relationship.

Correlations between girth and yield have been made at several times during the life of the experiment. The first was in 1947 when highly significant correlations were found within the different classifications of the experiment, i.e. between clones, between manurial treatments and between main plots. It was suggested from these measurements that the true regression is curved in the sense that larger trees yield more per inch of the tapping cut than the smaller trees.

In 1949 further calculations were made and again a highly significant correlation ($r = +0.475$) was obtained. Similar calculations carried out subsequently on the 1949 plot data supported the view that the true regression was curved and a log girth—log yield regression gave a highly significant correlation ($r = +0.663$) and a relationship of the form yield $\propto$ girth^M where $M = 1.2$. Data from other areas give figures nearer $M = 1.5$ (PAARDEKOOPER, 1960).

There is no obvious explanation of the cause of this relationship. It was thought that perhaps the larger trees had thicker bark and that this might be the cause of the curvature, but measurements taken in 1950 showed no significant differences between the bark thickness of the different main plots for either virgin or renewed bark (Table 5). There were however, marked differences in bark thickness between the five clones. Further investigation of girth-yield relationships are required, on both individual trees and on differently treated plots.

Figure 4 shows the yield for the different treatments as a percentage of the control plots. All the phosphate treated plots showed an increase in yield compared with the controls, whereas, as for the growth rate, there was a tendency for yield in the nitrogen treated plots to decrease. If the curves for NPK and NP are smoothed out, it is found that the rate of increase of both treatments over the control is the same, showing that K has had a small and non-significant positive effect in the presence of the other two nutrients.

The rate of increase of both these curves over the control is about 1.25% per annum. The significance of this figure is discussed further below, in relation to the costs of the fertiliser applications and the effects of the fertiliser applied during immaturity.

Clonal Differences in Yield

The mean yield for all five clones was surprisingly uniform throughout the 12-year period, the only fall being in 1953 when the tapping system was changed to S/2.d/2 for a few months, after which a new panel was opened 6 inches above the old panel and a bark 'island' created (Figure 4).

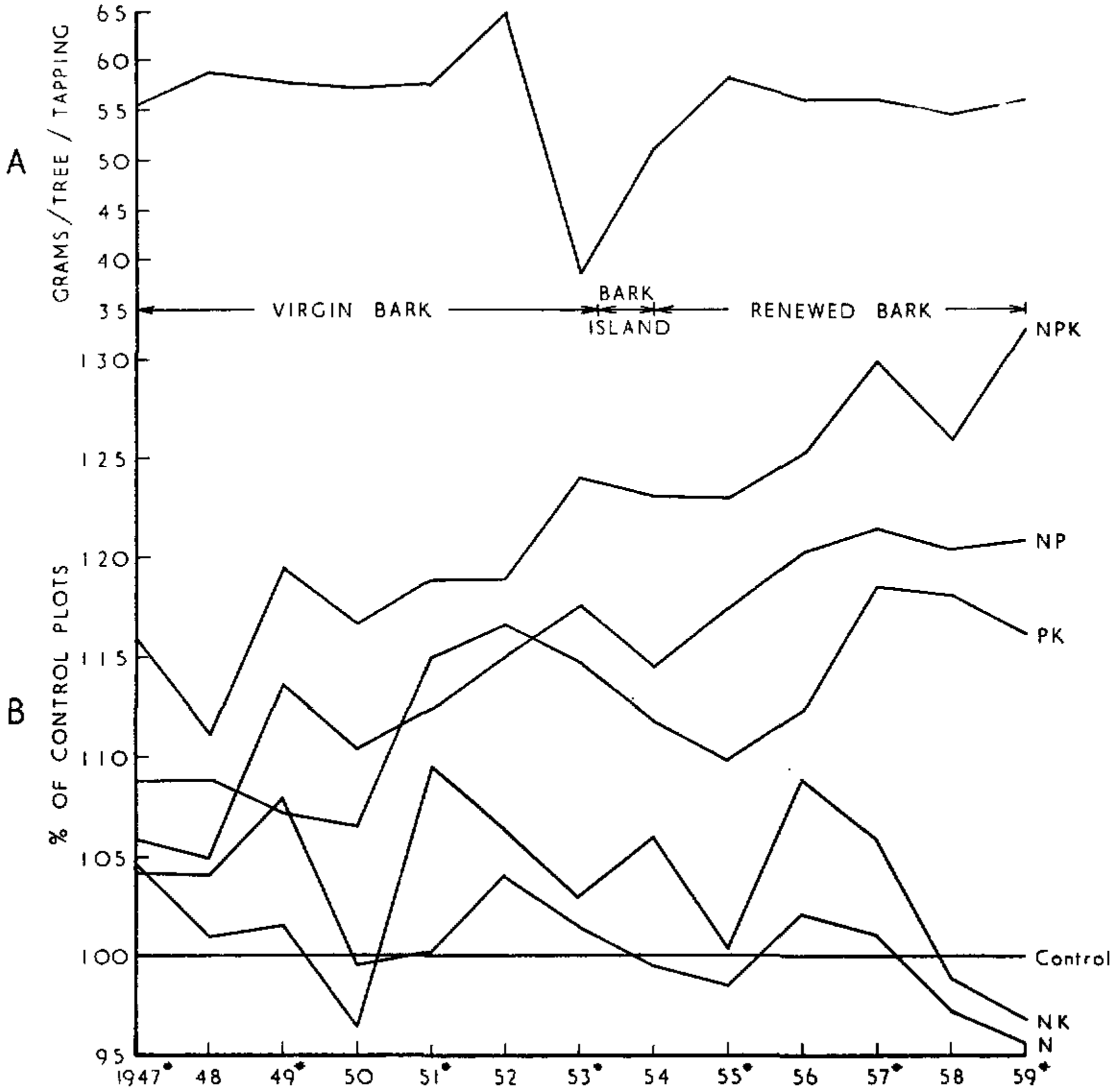

Figure 4. Annual yield, as a percentage of the control, for each fertiliser treatment (B) together with the annual yields of the control plots (A)
** Year of fertiliser application.*

Yields from the first renewed bark were slightly less than for virgin bark but the difference was only about 4%, when averaged for all the clones.

(a) *Annual yields.* A graph of the annual yields for each clone is given in Figure 5, and this shows quite clearly the different reaction of each clone to tapping. Tjir 1 gave an increased yield as the cut approached the union on both virgin and renewed bark. The other clones however showed a slight drop in yield after the first two years and then a sharp increase nearer the union. The poorest clone, BD 5, showed a 30% decrease in yield when tapped on first renewed bark and, in 1959, could not be tapped again on the lower

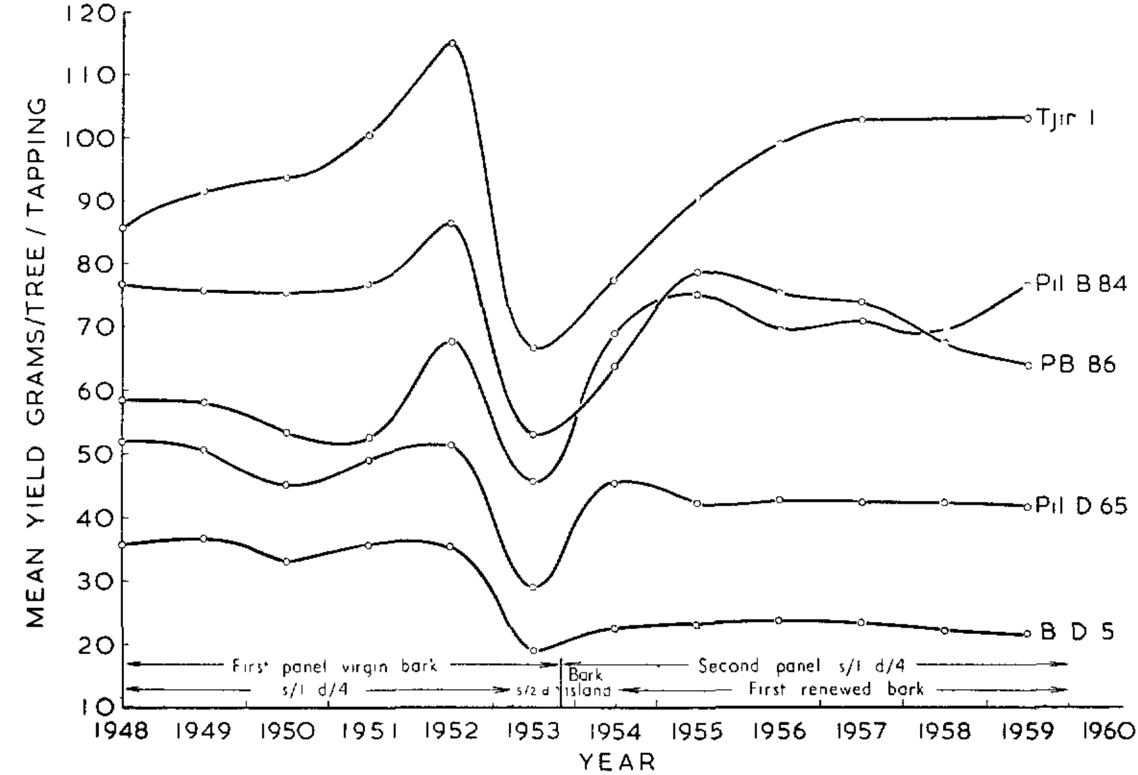

Figure 5. Annual yields for the five clones.

panel because of the very poor bark renewal. A surprising feature of the Pil B84 curve is the higher yield on renewed bark than on virgin bark. This may be a consequence of the outstanding growth of this clone whilst in tapping.

(b) *Monthly yields.* The mean yield of the different clones month by month is of some interest (Figure 6). The graph shows the different response to wintering for each of the five clones, Tjir 1 having a 38% reduction in yield as compared with a reduction of 22% for PB 86. The Tjir 1 also has a different shape of yield curve after wintering, there being a steady increase in yield from June to December. The other clones however gave more uniform yields in the same period, although there was a tendency for yields to rise in the months of November, December and January. The slight drop in yield for some of the clones in the August–October period is also interesting but no satisfactory explanation can be given.

No simple relationship was found between yield and rainfall on a long or short term basis.

LEAF, LATEX AND BARK ANALYSES

Leaf samples were taken together with bark samples from the Tjir 1 trees in 1953 and have been fully reported by Bolle-Jones (1957). Standards for satisfactory levels of nutrients in the leaf laminae have been formulated since this work was reported and on the basis of these the area would be considered as adequately supplied with potassium, slightly deficient in nitrogen and magnesium and very low in phosphate. This agrees substantially with the responses which have occurred. The phosphate level in the phosphate-treated plots was also low by the

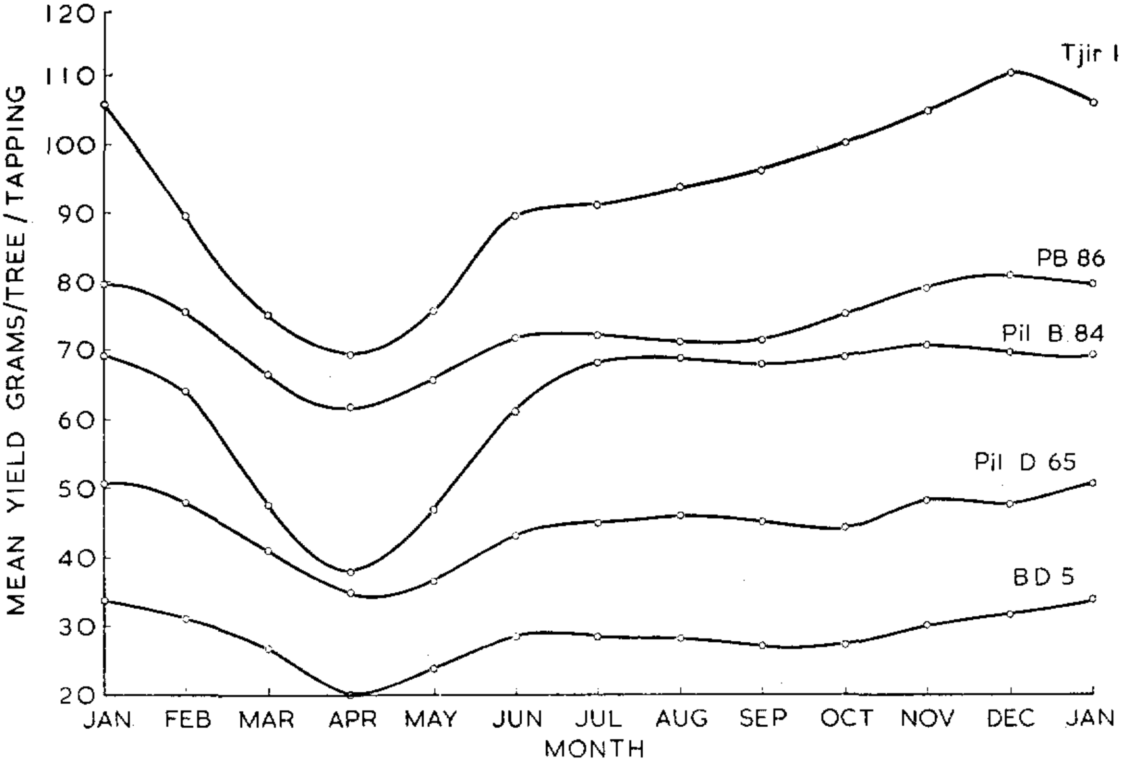

Figure 6. Mean monthly yields for the five clones.

standards now used, which suggests that the amounts of rock phosphate used were too low for optimum growth and yield.

Samples of latex were collected from three clones in 1957 and the analyses were compared with standards published by BEAUFILS (1957). Assessed solely on the latex analyses, the trees would be considered adequately supplied with potassium but sub-optimum in nitrogen and magnesium. Phosphate was below optimum for two clones Tjir 1 and PB 86 but not for Pil B84, although phosphate responses have been observed on all three clones. Details of the leaf and latex analyses, together with the standards used, are given in Table 5.

SOIL ANALYSES

In 1959, soil samples were taken from the terraces of each plot, these being the areas where all the fertilisers had been applied. The results are summarised with the other analyses in Table 5. The main effects observed were large increases in exchangeable potassium and available phosphate due to the potassium chloride and rock phosphate applications, and highly significant depressions in pH due to the ammonium sulphate. As would be expected, there were also increases in exchangeable calcium due to the rock phosphate applications.

OWEN (1953) has suggested that a response to phosphate should be obtained at levels of available phosphate in the soil below 25 p.p.m. (using the same analytical method as used in these studies). Values of 8–9 p.p.m. would therefore indicate a severe deficiency, which has been confirmed by the large growth and yield responses obtained. The phosphate analyses were also rather variable owing to the method of application previously mentioned. The figures for untreated plots ranged from 2–15 p.p.m., whereas the phosphate treated plots gave a range of from 7 to

TABLE 5. LEAF, LATEX AND SOIL ANALYSES FOR EACH FERTILISER TREATMENT TOGETHER WITH BARK THICKNESS MEASUREMENTS

Treatment	Leaf analyses Tjir 1 (1953) N (percentage of dry matter)	P	K	Mg	Ca	Mn (p.p.m.)	Soil analyses (1959) pH	Av. P_2O_5 (p.p.m.)	Exchangeable K (m-equiv./100g)	Mg	Ca
O	3.19	0.15	1.18	0.23	0.49	114	4.93	8.8	0.047	0.043	0.057
N	3.02	0.15	0.97	0.19	0.58	93	4.46	8.0	0.040	0.041	0.051
NK	3.27	0.15	1.20	0.18	0.38	56	4.58	7.8	0.056	0.045	0.051
NP	3.27	0.18	1.19	0.22	0.39	77	4.34	25.1	0.049	0.044	0.059
PK	3.15	0.18	1.08	0.22	0.49	76	5.06	38.0	0.080	0.045	0.071
NPK	3.11	0.18	1.15	0.20	0.46	104	4.46	10.7	0.077	0.051	0.066
s.e.	0.09	0.01	0.10	0.01	0.06	25	0.07	14.9	0.012	0.04	0.005
L.S.D.*	0.27	0.03	0.30	0.05	0.19	75	0.21	43.9	0.035	0.11	0.016
Standard	3.25	0.20	0.80	0.20	0.40	50	—	25	0.035	0.110	—

Treatment	Latex analyses (1957) N (percentage of total solids)	P	K	Mg	Mg/P	Bark thickness (1950) Virgin (mm)	Renewed (mm)
O	0.573	0.096	0.397	0.070	0.73	8.37	6.49
N	0.581	0.090	0.387	0.069	0.77	8.27	6.47
NK	0.575	0.096	0.402	0.070	0.74	8.43	6.40
NP	0.603	0.122	0.386	0.075	0.61	8.29	6.48
PK	0.589	0.126	0.427	0.066	0.53	8.35	6.50
NPK	0.575	0.114	0.412	0.070	0.61	8.58	6.56
s.e.	0.007	0.004	0.011	0.004	0.04	0.11	0.09
L.S.D.*	0.019	0.011	0.033	0.011	0.13	0.34	0.28
Tjir 1	0.590	0.101	0.374	0.077	0.79	9.02	7.13
PB 86	0.562	0.098	0.405	0.080	0.85	8.27	6.37
Pil B84	0.595	0.122	0.427	0.052	0.43	9.12	7.37
Pil D65	—	—	—	—	—	8.13	5.83
BD 5	—	—	—	—	—	7.36	5.72
s.e.	0.006	0.003	0.011	0.003	0.03	0.11	0.10
L.S.D.*	0.019	0.008	0.035	0.008	0.09	0.32	0.29
Standards					0.71–1.26	—	—

* $p = 0.05$

229 p.p.m. Obviously the highest figures are due to a number of phosphate 'pockets' being sampled.

BOLTON (1961) has tentatively suggested threshold levels of magnesium (0.11 m-equiv/100g) and potassium (0.035 m-equiv/100g) and on this basis the control plots would be considered magnesium deficient but above the 'deficiency' level in potassium.

Reductions of exchangeable calcium, magnesium and potassium associated with the lowering of pH in the nitrogen plots were not statistically significant. However, subsequent lysimeter experiments carried out by BOLTON (1960) on the same soil type have shown definite reductions to occur. Such depressions in pH and exchangeable cations resulting from applications of ammonium sulphate are reported by the same author (1961) in several other field experiments on *Hevea in* Malaya.

The pH measurements showed that there was a gradient over the field, the lower slopes having higher pH values than the upper slopes.

DISCUSSION

Comparing the effects of fertiliser applications, before and after maturity, it is obvious that by far the greatest return is from the former dressings. In total amount, the fertilisers applied from planting to four years after budding were equivalent to just over 2½ lb of ammonium sulphate, 1½ lb of concentrated superphosphate and 1 lb of potassium chloride per tree and this resulted in an initial yield response of about 14%. After maturity, *each* biennial application of fertilisers at 2½ lb ammonium sulphate, 1 lb rock phosphate and ¾ lb of potassium chloride (approximately the same amount) resulted in a mean increase in yield of only 2.5% (assuming no residual effects from the pre-war fertilisers).

In using these figures to calculate the economics of the fertiliser applications, it must be assumed that the total response is the sum of the response to the pre-war and post-war applications and that the latter can be divided into equal responses for each dressing. If these assumptions are accepted then a 2.5% increase in annual yield from the time of each post-war fertiliser application will easily pay the costs at present prices of fertilisers and dry rubber (disregarding the value of residual effects which almost certainly occur). The conditions in the experiment are not however directly comparable with commercial conditions in that all the trees were opened for tapping at the same time. Normally, the trees would be opened at a fixed girth—usually 20 in.—and there would merely be a time interval between the opening of different plots.

This experiment does emphasise the importance of adequate care and fertiliser dressings during immaturity. If girth is the main determining factor for yield from any particular clone then it is far easier to increase the girth during immaturity when the trees are growing at a rate of four to five inches per annum than after tapping when the girth increments are reduced to less than one inch.

The rate of yield increase of the NP plots over the control has been just as great as for the NPK plots, the potash seemingly having little or no extra effect. Ammonium sulphate alone, as has already been mentioned, tended to depress both growth and yields and this effect is rather difficult to explain solely on the data from the trial. It may have been due to the effect of the fertiliser on soil, leaf and latex magnesium, since these were all rather low, but there is no direct evidence of this The use of ammonium sulphate by itself on young mature trees does however seem questionable, at least where other nutrients such as magnesium or potassium are likely to be sub-optimal. The results obtained from potassium fertiliser may also have been influenced by the low levels of magnesium and this may be an important point when translating these results into specific recommendations to planters. The low level of available magnesium, as well as the unsatisfactory design, has severely limited the utility of the trial and emphasises the care which should be taken in establishing long term trials with perennial crops, which take up so much time and labour over a period of many years.

ACKNOWLEDGEMENTS

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