A Comparison of Rock Phosphate with Superphosphate, and of Ammonium Sulphate with Sodium Nitrate, as Sources of Phosphorus and Nitrogen for Rubber Seedlings I. The Effect upon Growth and Soil pH

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The results of a factorial pot experiment are described in which ammonium sulphate was compared with sodium nitrate, and simultaneously rock phosphate with superphosphate, as sources of nitrogen and phosphorus respectively for rubber seedlings.

The interactions between these fertilisers and potassium sulphate, magnesium sulphate, limestone and a trace element supplement were also investigated.

In addition, measurements were made of the acidifying effects of all the fertilisers upon the soil used in the experiment.

In Malayan rubber plantations considerable amounts of Christmas Island rock phosphate and ammonium sulphate have been used during the past fifty years, and it is therefore true to say that the bulk of fertiliser phosphorus has been applied in a comparatively insoluble form (RUBBER RESEARCH INSTITUTE OF MALAYA, 1959), while nitrogen has been added in a form which increases the acidity of naturally acidic soils (BOLTON, 1960). Current fertiliser recommendations (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963) are based mainly on experience with rock phosphate and ammonium sulphate and are usually expressed in terms of these ingredients. Recently, more soluble forms of phosphorus have been used to a limited extent in compound fertilisers, and less acidifying nitrogenous fertilisers are also being marketed, but there are differences of opinion about the relative merits of the different forms.

The results of comparisons between soluble and insoluble phosphates are inconsistent (MIDDLETON, 1961 and WATSON, 1962) and there are few published data comparing the effects on the rubber plant of ammonium salts and nitrates (BOLLE-JONES, 1955). It would take a considerable time to obtain additional information from field experiments, and although the results of pot experiments are not easily related to plantation practice, they at least point to the lines of field experimentation which may be most profitably followed. This paper therefore describes the findings of a pot experiment with rubber seedlings, where rock phosphate has been compared with superphosphate and ammonium sulphate with sodium nitrate. The effects upon the comparison of the presence and absence of potassium, magnesium, calcium and a trace elements supplement were also investigated. Their inclusion was considered necessary because previous work by OWEN *et al.* (1957) and BOLLE-JONES (1954a) had shown that interactions between them and both phosphorus and nitrogen were to be expected, and also because the apparent inconsistencies in previous comparisons may

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have been the result of insufficient knowledge about the nature of such interactions (MIDDLETON, 1961).

The two forms of nitrogen applied were expected to have different effects upon soil reaction, since ammonium sulphate is a strongly acidifying fertiliser (PIERRE, 1928), whereas sodium nitrate should produce a smaller effect in the opposite direction. Rock phosphate, which contains a definite excess of calcium over its acidic components, should also tend to reduce soil acidity. A subsidiary aim in this investigation was therefore to study the effect of the various treatments upon soil pH; by applying limestone to the soil in half of the experiment, the effect of liming in combination with other fertilisers has also been studied.

EXPERIMENTAL

Large earthenware pots, coated inside with bituminous paint, and each filled with 75 lb of soil, were used as experimental units; one vigorous clonal seedling (self-pollinated, Tjir 1) was transplanted from sand into each pot. The soil, taken from Field 19 at the R.R.I.M. Experiment Station, was a permeable, sandy loam, classified by PANTON (1954) as belonging to the Serdang series.

Treatments

An examination of the soil by the subtractive technique (MIDDLETON, 1961), using *Pueraria phaseoloides* as an indicator plant, had shown actual or potential deficiencies of the following elements under the conditions of intensive culture intended in the present experiment: nitrogen, phosphorus, potassium, magnesium, calcium, sulphur, boron, and copper.

In order to take into account all the nutrient requirements, the investigation was designed as a $3^2 \times 2^4$ factorial experiment, giving 144 treatments: in other words, all combinations of two forms of nitrogen, and two forms of phosphorus, with one form each of potassium, magnesium, calcium, and a trace element supplement; each element was applied at two levels, i.e. present or absent (see *Table 1*). Because of the large number of treatments, no replication could be provided and in the subsequent statistical analysis, error was obtained from high-order interactions of the factors which could not be otherwise interpreted.

Fertilisers

Ammonium sulphate and sodium nitrate were used as sources of ammoniacal and nitrate nitrogen, while Christmas Island rock phosphate and double superphosphate, each of which contains about 36 per cent P_2O_5, were used as sources of insoluble and water-soluble phosphate respectively. Although rock phosphate is insoluble in water, about a third of its P_2O_5 content is soluble in one per cent citric acid and available to plants in acidic soils (RUBBER RESEARCH INSTITUTE OF MALAYA, 1959). In a previous comparison (MIDDLETON, 1960) broadcasting rock phosphate and pocketing superphosphate had been found to be the most effective methods of applying the fertilisers and were therefore employed in this comparison; both fertilisers were applied at the rate of three ounces per pot in one application at the beginning of the experiment.

Forty-five grams of ground limestone were thoroughly mixed with the soil in 72 pots, in order to raise the pH of the soil in one half of the experimental units from 4.5 to about 6.5. Fertiliser elements other than phosphates and limestone were applied weekly in dilute aqueous solution and provided the following total amounts during the fifteen-month period of the experiment: 106.15 g $(NH_4)_2SO_4$, 136.60 g $NaNO_3$, 27.86 g K_2SO_4, and 45.61 g $MgSO_4$, $7H_2O$. The five trace elements were added monthly in 500 ml of water containing the following concentrations in milliequivalents per litre: boron 1.32, manganese 0.40, copper 0.04, zinc

TABLE 1. MEAN DIMENSIONS OF RUBBER SEEDLINGS AND SOIL pH VALUES ASSOCIATED WITH VARIOUS FERTILISER TREATMENTS

Treatment	Height (cm)	Girth (cm)	Fresh weight (g)	pH
No nitrogen	105	4.44	209	5.41
Ammonium sulphate	158	6.25	695	3.60
Sodium nitrate	121	4.86	328	5.45
No phosphate	114	4.43	286	4.72
Rock phosphate	*145*	*5.96*	*581*	*4.96*
Superphosphate	126	5.15	364	4.78
No potassium	124	4.91	321	4.83
Potassium sulphate	131	5.45	500	4.81
No magnesium	121	4.52	279	4.85
Magnesium sulphate	135	5.84	543	4.78
No calcium	127	5.08	409	4.38
Limestone	129	5.28	412	5.26
No trace elements	133	5.41	452	4.83
Trace elements	122	4.95	369	4.81

0.04, and molybdenum 0.024. These amounts correspond to a field application of three ounces per tree annually of ammonium sulphate, with potassium sulphate and magnesium sulphate added in somewhat smaller balancing amounts than those recommended by HEWITT (1952) as complete nutrient solutions for sand culture.

Measurements

Monthly recordings of heights and girths of the plants were made and showed regular fertiliser effects starting after the end of the third month. Final measurements are given in *Table 1,* and since they show variations similar to those found for fresh weights, they will not be considered further. Notes on the occurrence of a form of terminal die-back together with excessive lateral shooting were also made; these symptoms were associated with certain treatments and are discussed in Part II of this paper (to be published later). Determinations of pH in the top six inches of soil in each of the 144 pots were also made after 15 months when the experiment was terminated.

RESULTS

After fifteen months of growth, the various combinations of factors produced plants varying in fresh weight from 2988 to 34 grams. The weights of the five best and the five poorest plants, which had received nitrogen and phosphate in one or other form, and also potassium and magnesium, are plotted in *Figure 1* to give a picture of the wide variation in the size of plants receiving different forms of nitrogen and phosphate.

A more detailed examination of the fresh weights, and also of the final heights and girths, enables a ranking of factors in terms of their average beneficial effect upon growth to be made in the following decreasing order:

1. ammonium sulphate
2. rock phosphate
3. magnesium sulphate
4. superphosphate
5. potassium sulphate
6. sodium nitrate
7. limestone
8. trace elements

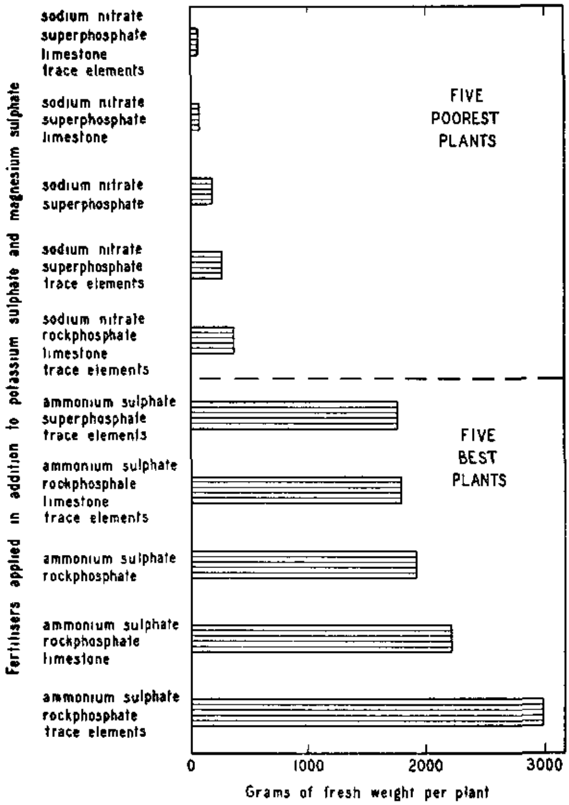

Figure 1. Effect of type of nitrogenous and phosphatic fertilisers on growth of rubber seedlings.

The results of an analysis of variance of the fresh weights has demonstrated that four of the eight factors produced highly significant effects, and that seven two-factor interactions and two three-factor interactions were also significant. The analysis of variance is summarised in *Table 2,* and the two-factor interactions are shown in detail in two-way tables of means given in *Appendix A.*

The heterogeneity of variation among treatments was considerable and, in order to estimate the significance of effects accurately, an analysis of logarithmically transformed results was carried out. The treatment means are therefore antilogarithms of arithmetic means of logarithms of fresh weights, and the effects shown in *Table 2* are differences between these treatment means. The transformed figures give a better measure of the central tendency than arithmetic results, because they give less weight to extreme values.

Main (average) Effects and Two-Factor Interactions

As may be seen from *Table 2,* ammonium sulphate, rock phosphate, and magnesium sulphate gave highly significant positive effects, while trace elements on average significantly depressed growth. The main effects and significant two-factor interactions are discussed below.

Nitrogen and phosphate. In the absence of phosphate and magnesium sulphate, neither form of nitrogen gave a significant response; the general effect of ammonium sulphate was to increase growth significantly, and when it was applied with magnesium sulphate, limestone, potassium sulphate, and phosphate, even greater responses were obtained, in the order given for the amount of additional fresh weight. On the other hand the average effect of sodium nitrate was not significant, and it produced a significant increase in weight only in the presence of rock phosphate; with superphosphate it gave a significantly adverse effect.

While the average effect of rock phosphate was significantly beneficial, the average increase for superphosphate was significant only at the 10 per cent level; neither form of phosphate gave a significant response in the absence of nitrogen. Rock phosphate responses were significantly increased by additions of ammonium sulphate, limestone, potassium sulphate, magnesium sulphate, and sodium nitrate. On the other hand superphosphate produced a significant increase in growth only in the presence of ammonium sulphate or limestone; in the presence of sodium nitrate it gave a significant depression.

TABLE 2. AVERAGE EFFECTS OF VARIOUS FERTILISERS UPON THE WEIGHTS OF RUBBER SEEDLINGS

Associated treatment	Fertiliser effects expressed as geometrical means of fresh weight in grams							
	Nitrogen		Phosphate		Potassium sulphate	Magnesium sulphate	Limestone	Trace elements
	Ammonium sulphate	Sodium nitrate	Rock phosphate	Super-phosphate				
No nitrogen			31	32	–25	37	–52 †	–83 **
Ammonium sulphate			318 ***	309 ***	229 ***	520 ***	254 ***	–158 *
Sodium nitrate			214 ***	–70 *	1	41	–78 *	–48
No phosphate	55	28			–1	107 **	–51	–147 ***
Rock phosphate	342 ***	211 ***			119 *	206 ***	95 †	–45
Superphosphate	332 ***	–74 *			25	109 **	–4	–44
No potassium	101 *	15	104 **	31		62 †	–33	–90 **
Potassium sulphate	355 ***	41	224 ***	57		230 ***	37	–89 *
No magnesium	46	26	117 ***	38	–26		98 ***	–46 †
Magnesium sulphate	529 ***	30	216 ***	50	142 **		–168 ***	–155 ***
No calcium	77 †	43	88 *	19	2	276 ***		– 47
Limestone	383 ***	17	234 ***	66 *	72 *	10		–132 ***
No trace elements	253 ***	8	96 †	–20	36	201 ***	49	
Trace elements	178 ***	43	198 ***	83 **	37	92 **	–36	
Average effects	213 ***	29	160 ***	47 †	37	138 ***	–1	–90 ***

Significant at the: † 10 per cent level * 5 per cent level ** 1 per cent level *** 0.1 per cent level

The interactions between nitrogen and phosphate varied according to the forms of the factors involved, and significant effects upon weight may be ranked in the following decreasing order: ammonium sulphate with rock sulphate, ammonium sulphate with superphosphate, sodium nitrate with rock phosphate and sodium nitrate with superphosphate. All were positive responses except the last one which was negative, but within the ranking the only established difference was between sodium nitrate added with superphosphate and all other combinations.

Nitrogen and potassium. Potassium sulphate produced a small negative effect in the absence of nitrogen, a marked positive response in the presence of ammonium sulphate, and a negligible effect with sodium nitrate.

Nitrogen and magnesium. A very marked increase in growth was produced by the combined effect of ammonium sulphate and magnesium sulphate, whereas sodium nitrate combined with magnesium sulphate produced no significant effect. Neither ammonium sulphate nor magnesium sulphate produced a significant effect independently of the other.

Nitrogen and calcium. The effect of limestone in the absence of nitrogen was adverse, significant at the 10 per cent level only; but the two forms of nitrogen produced opposite effects: thus limestone gave a marked positive response when used with ammonium sulphate, and a depression when used with sodium nitrate.

Magnesium and potassium. Potassium sulphate in the absence of magnesium sulphate produced a small negative effect, while magnesium sulphate in the absence of potassium sulphate produced a small positive effect; together they produced a large, positive, highly significant effect.

Magnesium and calcium. Magnesium sulphate applied without limestone produced a large positive effect, and limestone applied without magnesium sulphate produced a small positive effect. On the other hand magnesium sulphate in the presence of limestone produced a negligible increase over magnesium sulphate alone, and limestone in the presence of magnesium sulphate depressed growth significantly compared with limestone alone; this interaction suggests an antagonistic effect between magnesium and calcium.

Trace elements and phosphate. The average trace element effect was significantly adverse, and was most marked in the presence of ammonium sulphate, magnesium sulphate, and limestone; the adverse effect was also marked in the absence of phosphate. On the other hand the effect of trace elements in the presence of phosphate was not significant, while the effect of superphosphate in the presence of trace elements was beneficial.

Three-factor Interactions

The interdependence of nitrogen, phosphate, potassium, magnesium, and calcium in developing fertiliser effects is clearly shown in the two significant three-factor interactions summarised in *Table 3.* The inability of ammonium sulphate and sodium nitrate to produce positive effects in the absence of both magnesium sulphate and limestone may be seen; also shown is the antagonism between magnesium sulphate and limestone in the presence of both forms of nitrogen, but particularly in the presence of sodium nitrate. The two forms of phosphate are shown to give their best results in the combined presence of potassium sulphate and magnesium sulphate; but the unfavourable effect upon phosphate responses of withholding either of these two fertilisers separately, is greater than that caused by withholding them together.

The Effect of Fertilisers on Soil pH

The main fertiliser effects are shown in *Figure 2,* and an analysis of variance of pH measurements made at the end of the experiment is summarised in *Table 4;* interactions are given in detail in two-way tables of means shown in *Appendix B.*

TABLE 3. THREE-FACTOR INTERACTIONS BETWEEN NITROGEN, MAGNESIUM AND CALCIUM, AND BETWEEN PHOSPHATE, POTASSIUM AND MAGNESIUM

Associated treatment	Effects expressed as differences between geometric means of fresh weights in grams	
	For ammonium sulphate	For sodium nitrate
Magnesium sulphate and limestone absent	–97 **	–30
Magnesium sulphate absent, limestone present	310 ***	84 *
Magnesium sulphate present, limestone absent	596 ***	165 *
Magnesium sulphate and limestone present	471 ***	–43
	For rock phosphate	For superphosphate
Potassium sulphate and magnesium sulphate absent	155 **	48
Potassium sulphate present, magnesium sulphate absent	84 *	29
Potassium sulphate absent, magnesium sulphate present	38	5
Potassium sulphate and magnesium sulphate present	500 ***	102

Significant at the: * 5 per cent. level ** 1 per cent. level *** 0.1 per cent. level

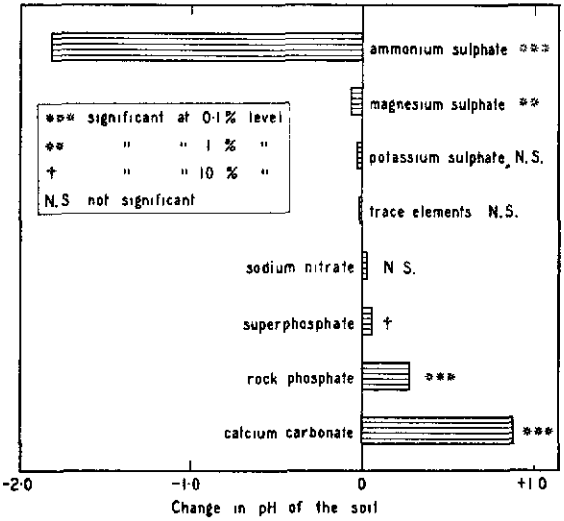

Figure 2. Changes in soil pH caused by application of various fertilisers.

The significant effects were: a large depression of pH by ammonium sulphate and a considerably smaller decrease caused by magnesium sulphate; a marked elevation of pH by limestone, a smaller increase caused by rock phosphate, and a much smaller increase by superphosphate, significant only at the 10 per cent level. There were also three highly significant two-factor interactions: *(i)* the general effect of rock phosphate was to elevate pH, except in the presence of ammonium sulphate, when a small depression was recorded; *(ii)* limestone failed to produce its customary elevation in the presence of ammonium sulphate; *(iii)* the combined effect of limestone and rock phosphate was less than the combined effect of limestone and superphosphate, although the effect of the latter separately was less than that of rock phosphate.

DISCUSSION

Effect of Nitrogen

In the experiment ammonium sulphate proved on average to be markedly superior to sodium nitrate as a source of nitrogen for rubber seedlings. This result is surprising because in a sand-culture experiment, Bolle-Jones (1955) had found that ammonium and nitrate ions were similar in their effects upon the weight of rubber seedlings, and also because it implies that ammonium ions were taken up before they could be nitrified to an appreciable extent by soil organisms.

Neither experiment may however be regarded as a strict comparison of ammonium and nitrate nitrogen, since possible sodium and sulphate effects are confounded in both sets of results. In particular, an amount of sodium equivalent to four times the amount of potassium applied was added with sodium nitrate in the present experiment, and in both cases, large amounts of sulphate accompanied applications of ammoniacal nitrogen. In the experiment now being described, differential amounts of sulphate had been added as potassium and magnesium sulphates, but an examination of the results has not shown an appreciable differential effect upon growth. It may therefore be correct to ignore the sulphate effect, as Bolle-Jones (1955) chose to do in his experiment, but it seems incorrect to ignore a large uncompensated amount of sodium, and a depression in growth by sodium ions is a possible indirect cause of the superiority of ammonium sulphate over sodium nitrate.

If this explanation is correct it seems logical to expect that, since sodium is not a toxic element, enough would be taken up by plants receiving sodium nitrate to interfere with some physiological process. The leaves from six plants which had received sodium nitrate were chemically analysed and found to contain sodium ranging from 38 to 899 parts per million with a mean value of 221. Corresponding values for plants which had received ammonium sulphate and no-nitrogen, were: 18 to 27 (mean 21), and 23 to 73 (mean 41) parts per million respectively. The figures for the sodium nitrate

TABLE 4. AVERAGE EFFECTS UPON SOIL pH OF VARIOUS FERTILISERS APPLIED TO RUBBER SEEDLINGS

Associated treatment	*Effect of fertilisers upon mean pH in top 6 inches of soil*							
	Nitrogen		Phosphate		Potassium *sulphate*	Magnesium *sulphate*	Limestone	Trace *elements*
	Ammonium sulphate	*Sodium* nitrate	*Rock* phosphate	*Super-* phosphate				
No nitrogen			0.23 ***	−0.02	−0.01	−0.13 **	1.29 ***	0.01
Ammonium sulphate			−0.06	0.03	−0.04	−0.04	0.03	−0.04
Sodium nitrate			0.54 ***	0.16 **	−0.03	−0.03	1.32 ***	−0.02
No phosphate	−1.73 ***	−0.12 *			0.00	−0.09 *	0.94 ***	−0.04
Rock phosphate	−2.03 ***	0.19 ***			0.00	−0.08 †	0.64 ***	−0.02
Superphosphate	−1.68 ***	0.06			0.08 †	−0.03	1.05 ***	−0.03
No potassium	−1.80 ***	0.05	0.24 ***	0.10 *		−0.10 ***	0.90 ***	−0.03
Potassium sulphate	−1.83 ***	0.03	0.24 ***	0 02		0 04	0.86 ***	−0.01
No magnesium	−1.18 ***	−0.01	0.23 ***	0.03	−0.06		0.87 ***	−0.02
Magnesium sulphate	−1.77 ***	0.10 *	0.24 ***	0.09 †	0.00		0.89 ***	−0.02
No calcium	−1.18 ***	0.03	0.39 ***	0.00	−0.01	−0.08 *		−0.02
Limestone	−2.45 ***	0.06	0.09 †	0.11 *	−0.05	−0.06		−0.02
No trace elements	−1.79 ***	0.06	0.21 ***	0.05	−0.03	−0.07 †	0.88 ***	
Trace elements	−1.84 ***	0.03	0.27 ***	0.06	−0.02	−0.07 †	0.88 ***	
Average effects	−1.81 ***	0.04	0.24 ***	0.06 †	−0.03	−0.07 **	0.88 ***	−0.02

Significant at the: † 10 per cent level * 5 per cent level ** 1 per cent level *** 0.1 per cent level plants, though very variable, are appreciably higher than those for either ammonium sulphate or no-nitrogen; but all the amounts are very small and similar to those normally found for minor elements. It is difficult to believe that such small amounts of a non-toxic element could be responsible for the large differences shown between ammonium sulphate and sodium nitrate, and it therefore appears that the experiment is in fact a valid comparison of the effects of ammonium and nitrate nitrogen upon the growth of rubber seedlings.

Effect of Phosphate

Under the conditions of the experiment, relatively insoluble rock phosphate proved on average to be superior to soluble super-phosphate, and this result appears to contradict the result of a previous experiment (MIDDLETON, 1960) in which, however, lower rates of phosphate were applied. A result of the larger applications of phosphate has been the appearance of a form of suppression of the terminal growing point and excessive lateral shooting in a preponderant number of plants supplied with the soluble form. The symptoms could be attributed to no pathological disease or pest attack and it is probable that the growth of the plant as a whole received a set-back as a result of the abnormal development. Since the symptoms were exhibited by more plants receiving soluble than insoluble phosphate it nows seems that the experiment was biased in favour of the latter, and that super-phosphate was applied at an excessive rate. Preliminary work had however shown that a three-ounce application was the optimum amount for rock phosphate in pots of this size and this was taken as the standard for comparison in the experiment, because it roughly corresponds to the four-ounce planting hole application widely used in the field (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963).

Effect of Trace Elements

The depressive effect of the trace element supplement and its interaction with phosphate is a feature of the experiment. Trace elements were added because in previous experiments with the same soil (MIDDLETON, 1960) trace-element deficiencies in the plants had been observed, particularly in the presence of soluble phosphate, and also because preliminary tests had indicated low levels of boron and copper in the soil. The appropriate level for the application of boron was difficult to judge in planning the experiment, and although BOLLE-JONES (1954b) claimed that *Hevea brasiliensis* tolerated an excess of this element, it is possible that too much of it was added for the slowly-growing plants. It should however be mentioned that the depressive effect of trace elements was not general, and where plants were growing vigorously trace elements were beneficial (*Figure 1*). Observations on the growing plants showed that the occurrence of terminal suppression was less frequent in the presence of trace elements, and this is probably the cause of the phosphate/trace-element interaction in which a favourable effect of super-phosphate in the presence of trace elements is shown. The relation of trace elements to the incidence of terminal suppression is discussed in more detail in Part II of this paper.

CONCLUSIONS

An average superiority of ammonium sulphate over sodium nitrate, and of insoluble Christmas Island rock phosphate over soluble double superphosphate has been found in this experiment, in which the fertilisers are compared under intensive conditions of pot culture, using a relatively infertile soil, on which, nevertheless, *Hevea brasiliensis* is commonly grown.

Both findings require qualification because all the results, except those precluded by the design of the experiment, are influenced by an unfavourable interaction between sodium nitrate and superphosphate. Thus *although superphosphate with sodium nitrate* gave a very unfavourable result, both superphosphate with ammonium sulphate, and sodium nitrate with rock phosphate, gave results not significantly inferior to rock phosphate in combination with ammonium sulphate. The adverse effect of sodium nitrate *combined with superphosphate* (which is included in all other treatment effects) is however sufficient to give significantly inferior average results for sodium nitrate and superphosphate, in comparison with ammonium sulphate and rock phosphate respectively. The results of this investigation do not therefore contradict the findings of a previous experiment (MIDDLETON, 1960) which, in the absence of differential additions of ammonium sulphate and sodium nitrate, indicated that rock phosphate and superphosphate had similar effects upon the weights of immature rubber plants.

It seems logical to conclude, however, that where soluble phosphate is applied at a rate which experience has shown to be suitable for slowly available phosphate, a less favourable result may be obtained (probably connected with a physiological disorder to be discussed in Part II of this paper); this conclusion does not preclude the possibility of obtaining comparable results with soluble phosphates when applied at appropriate rates.

The experiment indicates the importance of having present adequate quantities of all the nutrient elements (including trace elements) when attempting to obtain the maximum rate of growth in immature trees. In particular the potassium/magnesium interaction is interesting, because the response to applications of potash, tested largely in the absence of supplementary magnesium, has been erratic in Malayan rubber plantations on inland soils generally (OWEN *et al.*, 1957). The beneficial effect of combined applications of potassium sulphate and ammonium sulphate is in accord *with observations of a similar effect in several* field experiments recently and the magnesium/calcium antagonism may be important because of the common estate practice of applying the two elements together as dolomitic limestone.

Since the pH measurements have shown a marked depression by ammonium sulphate, even in the presence of sufficient limestone to elevate the pH of the soil at the beginning of the experiment from 4.5 to 6.5, and since magnesium sulphate also produced a significant depression in pH, prolonged use of these two sulphate-containing fertilisers in the field will necessitate compensating applications of limestone, even although the plant *(Hevea brasiliensis)* is insensitive to calcium deficiency (BOLLE-JONES, 1954a). Rock phosphate however produced a small but significant increase in pH, and this result points to the supplementary value of this fertiliser when used on acidic soils deficient in calcium (RUBBER RESEARCH INSTITUTE OF MALAYA, 1959).

The results have confirmed that ammonium sulphate is a highly effective nitrogenous fertiliser, but it should be remembered that it also supplies sulphur, and therefore that most field experiments already carried out in Malaya are strictly tests of nitrogen and sulphur applied together. In this experiment a slight, but non-significant, beneficial effect of sulphur was found; small scale pot tests using the subtractive technique (MIDDLETON, 1961) have moreover shown low sulphur levels in this soil and in a number of other Malayan soils. This point should therefore be borne in mind when contemplating the replacement of ammonium sulphate by fertilisers which, although less acid-forming, do not contain sulphur. A more satisfactory alternative to replacement may be to apply supplementary dolomitic limestone in order to prevent the development of calcium deficiencies, which is a long-term hazard where ammonium sulphate is employed. Such a combination would have the added advantage of providing a cheap supply of magnesium, the shortage of which in Malayan soils is now widely recognised.

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APPENDIX A: LOGARITHMIC FRESH WEIGHT RESULTS, TWO-WAY TABLES OF MEANS

(m.s.d. = minimum difference between two corresponding means significant at the 5 per cent level)

Nitrogen × Phosphate

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No phosphate	2.233	2.354	2.298	2.295	
Rock phosphate	2.306	2.735	2.616	2.552	0.097
Superphosphate	2.307	2.729	2.112	2.383	
m.s.d.		0.168			
Means	2.282	2.606	2.342		
m.s.d.		0.097			

Nitrogen × Potassium

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No potassium	2.310	2.484	2.341	2.379	
Potassium sulphate	2.253	2.728	2.343	2.441	0.079
m.s.d.		0.138			
Means	2.282	2.606	2.342		
m.s.d.		0.097			

Nitrogen × Magnesium

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No magnesium	2.239	2.342	2.301	2.294	
Magnesium sulphate	2.324	2.870	2.383	2.526	0.079
m.s.d.		0.138			
Means	2.282	2.606	2.342		
m.s.d.		0.097			

Nitrogen × Limestone

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No limestone	2.341	2.472	2.420	2.411	0.079
Limestone	2.223	2.740	2.264	2.409	
m.s.d.		0.138			
Means	2.282	2.606	2.342		
m.s.d.		0.097			

Nitrogen × Trace Elements

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No trace elements	2.375	2.690	2.390	2.485	0.079
Trace elements	2.188	2.522	2.294	2.335	
m.s.d.		0.138			
Means	2.282	2.606	2.342		
m.s.d.		0.097			

Phosphate × Potassium

	No phosphate	Rock phosphate	Super-phosphate	Means	m.s.d.
No potassium	2.296	2.479	2.360	2.379	
Potassium sulphate	2.294	2.625	2.405	2.441	0.079
m.s.d.		0.138			
Means	2.295	2.552	2.383		
m.s.d.		0.097			

Phosphate × Magnesium

	No phosphate	Rock phosphate	Super-phosphate	Means	m.s.d.
No magnesium	2.178	2.429	2.277	2.294	
Magnesium sulphate	2.412	2.676	2.489	2.526	0.079
m.s.d.		0.138			
Means	2.295	2.552	2.383		
m.s.d.		0.097			

Phosphate × Limestone

	No phosphate	Rock phosphate	Super-phosphate	Means	m.s.d.
No limestone	2.351	2.495	2.386	2.411	0.079
Limestone	2.239	2.610	2.379	2.409	
m.s.d.		0.138			
Means	2.295	2.552	2.383		
m.s.d.		0.097			

Phosphate × Trace Elements

	No phosphate	Rock phosphate	Super-phosphate	Means	m.s.d.
No trace element	2.454	2.579	2.422	2.485	0.079
Trace elements	2.136	2.525	2.343	2.335	
m.s.d.		0.138			
Means	2.295	2.552	2.383		
m.s.d.		0.097			

Potassium × Magnesium

	No magnesium		Magnesium sulphate	Means	m.s.d.
No potassium	2.323		2.434	2.379	
Potassium sulphate	2.266		2.617	2.411	0.079
m.s.d.		0.112			
Means	2.294		2.526		
m.s.d.		0.079			

Potassium × Limestone

	No limestone		Limestone	Means	m.s.d.
No potassium	2.409		2.348	2.379	
Potassium sulphate	2.412		2.470	2.441	0.079
m.s.d.		0.112			
Means	2.411		2.409		
m.s.d.		0.079			

Potassium × Trace Elements

	No trace elements		Trace elements	Means	m.s.d.
No potassium	2.460		2.297	2.379	
Potassium sulphate	2.511		2.372	2.441	0.079
m.s.d.		0.112			
Means	2.485		2.335		
m.s.d.		0.079			

Magnesium × Limestone

	No magnesium		Magnesium sulphate	Means	m.s.d.
No limestone	2.188		2.633	2.411	0.079
Limestone	2.401		2.418	2.409	
m.s.d.		0.112			
Means	2.294		2.526		
m.s.d.		0.079			

Magnesium × Trace Elements

	No trace elements		Trace elements	Means	m.s.d.
No magnesium	2.345		2.244	2.294	
Magnesium sulphate	2.625		2.426	2.526	0.079
m.s.d.		0.112			
Means	2.485		2.335		
m.s.d.		0.079			

Limestone × Trace Elements

	No trace elements		Trace elements	Means	m.s.d.
No limestone	2.450		2.372	2.411	0.079
Limestone	2.521		2.298		
m.s.d.		0.112		2.409	
Means	2.485		2.335		
m.s.d.		0.079			

APPENDIX B: SOIL pH RESULTS, TWO-WAY TABLES OF MEANS

(m.s.d. = minimum difference between two corresponding means significant at the 5 per cent level)

Nitrogen × Phosphate

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No phosphate	5.34	3.61	5.22	4.72	
Rock phosphate	5.57	3.54	5.76	4.96	0.06
Superphosphate	5.32	3.64	5.38	4.78	
m.s.d.		0.11			
Means	5.41	3.60	5.45		
m.s.d.		0.06			

Nitrogen × Potassium

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No potassium	5.41	3.62	5.47	4.83	
Potassium sulphate	5.40	3.58	5.44	4.81	0.05
m.s.d.		0.09			
Means	5.41	3.60	5.45		
m.s.d.		0.06			

Nitrogen × Magnesium

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No magnesium	5.48	3.62	5.47	4.85	
Magnesium sulphate	5.34	3.58	5.44	4.79	0.05
m.s.d.		0.09			
Means	5.41	3.60	5.45		
m.s.d.		0.06			

Nitrogen × Limestone

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No limestone	4.76	3.58	4.79	4.38	0.05
Limestone	6.05	3.61	6.11	5.26	
m.s.d.		0.09			
Means	5.41	3.60	5.45		
m.s.d.		0.06			

Nitrogen × Trace Elements

	No nitrogen	Ammonium sulphate	Sodium nitrate	Means	m.s.d.
No trace elements	5.40	3.62	5.46	4.83	0.05
Trace elements	5.41	3.58	5.44	4.81	
m.s.d.		0.09			
Means	5.41	3.60	5.45		
m.s.d.		0.06			

Phosphate × Potassium

	No potassium	Potassium sulphate	Means	m.s.d.
No phosphate	4.72	4.72	4.72	
Rock phosphate	4.96	4.96	4.96	0.06
Superphosphate	4.82	4.74	4.78	
m.s.d.	0.09			
Means	4.83	4.81		
m.s.d.	0.05			

Phosphate × Magnesium

	No magnesium	Magnesium sulphate	Means	m.s.d.
No phosphate	4.77	4.68	4.72	
Rock phosphate	5.00	4.92	4.96	0.06
Superphosphate	4.79	4.76	4.78	
m.s.d.	0.09			
Means	4.85	4.79		
m.s.d.	0.05			

Phosphate × Limestone

	No limestone	Limestone	Means	m.s.d.
No phosphate	4.25	5.19	4.72	
Rock phosphate	4.64	5.28	4.96	0.06
Superphosphate	4.25	5.30	4.78	
m.s.d.	0.09			
Means	4.38	5.26		
m.s.d.	0.05			

Phosphate × Trace Elements

	No trace elements	Trace elements	Means	m.s.d.
No phosphate	4.74	4.70	4.72	
Rock phosphate	4.95	4.97	4.96	0.06
Superphosphate	4.79	4.76	4.78	
m.s.d.	0.09			
Means	4.83	4.81		
m.s.d.	0.05			

Potassium × Magnesium

	No magnesium	Magnesium sulphate	Means	m.s.d.
No potassium	4.88	4.78	4.83	0.05
Potassium sulphate	4.83	4.79	4.81	
m.s.d.	0.07			
Means	4.85	4.79		
m.s.d.	0.05			

Potassium × Limestone

	No limestone	Limestone	Means	m.s.d.
No potassium	4.38	5.28	4.83	0.05
Potassium sulphate	4.38	5.24	4.81	
m.s.d.	0.07			
Means	4.38	5.26		
m.s.d.	0.05			

Potassium × Trace Elements

	No trace elements	Trace elements	Means	m.s.d.
No potassium	4.84	4.82	4.83	0.05
Potassium sulphate	4.81	4.80	4.81	
m.s.d.	0.07			
Means	4.83	4.81		
m.s.d.	0.05			

Magnesium × Limestone

	No magnesium	Magnesium sulphate	Means	m.s.d.
No limestone	4.42	4.34	4.38	0.05
Limestone	5.29	5.23	5.26	
m.s.d.	0.07			
Means	4.85	4.79		
m.s.d.	0.05			

Magnesium × Trace Elements

	No trace elements	Trace elements	Means	m.s.d.
No magnesium	4.86	4.84	4.85	0.05
Magnesium sulphate	4.79	4.78	4.79	
m.s.d.	0.07			
Means	4.83	4.81		
m.s.d.	0.05			

Limestone × Trace Elements

	No trace elements	Trace elements	Means	m.s.d.
No limestone	4.39	4.37	4.38	0.05
Limestone	5.27	5.25	5.26	
m.s.d.	0.07			
Means	4.83	4.81		
m.s.d.	0.05			