A Comparison of Rock Phosphate with Superphosphate, and of Ammonium Sulphate with Sodium Nitrate, as Sources of Phosphorus and Nitrogen for Rubber Seedlings II. Association with Abnormal Growth and Effect on Wood Strength

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Symptoms of a form of physiological suppression of terminal growth in Hevea brasiliensis, *observed in pot experiments and upon rubber estates, are described. The degree to which the disorder is associated with fertilisers and soil fertility, and its occurrence and importance in practice, is discussed. The effects of differential fertiliser treatments on the fibre strength of rubber seedlings in relation to growth response are also described.*

In Part I of this paper, attention was drawn to an apparent connection between certain fertiliser treatments and abnormal growth of rubber seedlings. The abnormalities included: nutrient deficiency symptoms in young leaves, excessive lateral shooting, defoliation of the upper part of the main shoot, and death or suppression of the terminal growing point. Similar symptoms were reported in previous pot experiments (MIDDLETON, 1960); since then they have been observed at the Experiment Station of the Rubber Research Institute and on several rubber estates, in particular in nurseries and areas where rapid growth was stimulated. The symptoms could not be accounted for by disease, pest attack, mechanical injury or waterlogging of the roots; they are therefore attributable to a physiological disorder.

The disorder has been observed so far only on trees less than two years old and the problem may not in fact be important at maturity. However, excessive side shooting in a young plant is fundamentally objectionable, as a likely cause of unbalanced subsequent growth, and also of a general, if temporary, set-back in the development of the whole plant. In nurseries especially, an undesirable consequence of excessive lateral branching is limitation in the amount of budwood available. Soil infertility is a probable cause of the disorder; it is therefore likely to occur more frequently with the progressive depletion of soil nutrients which takes place in replanted areas.

The various fertiliser treatments described in Part I of this paper, in significantly affecting the growth of rubber seedlings, had produced individual plants varying widely in weight and girth, and it appeared important to measure the effect of the fertilisers upon wood strength. The acquisition by the Forest Research Institute of a new machine enabled measurements on stems, differing widely in girth, to be made with greater precision than had been possible previously, and the results obtained did in fact show a connection between wood strength and fertiliser treatment; the results are discussed later in this paper.

ABNORMALITIES IN THE GROWTH OF RUBBER SEEDLINGS

SYMPTOMS

Observations upon affected plants, both in pot experiments and in rubber plantations, had

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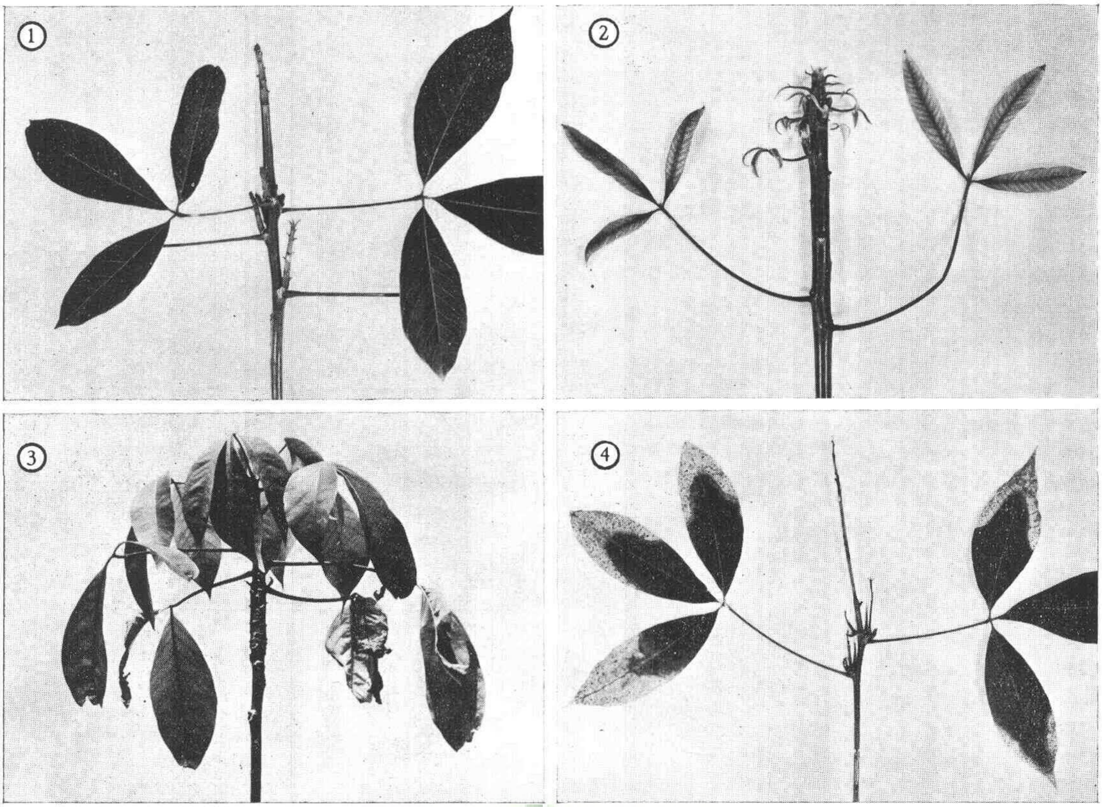

Figure 1. Suppression of the terminal growing point and excessive lateral branching in slightly affected plants. Figure 2. Swelling and defoliation of the terminal growing point, and zinc deficiency symptoms in young leaves. Figure 3. Terminal swelling and lateral branching with copper deficiency symptoms in immature leaves. Figure 4. Death of the terminal shoots of severely affected plants, with calcium deficiency symptoms in mature leaves.

indicated that there were various symptoms of abnormal growth depending upon the extent to which plants were affected.

Slightly Affected Plants

Defoliation and suppression of the terminal growing point occurs (*Figure 1*), followed by excessive lateral branching, without easily recognisable leaf symptoms.

Clearly Affected Plants

Swelling and defoliation of the terminal growing point, with lateral branching, is attended by the appearance of deficiency symptoms in immature leaves. Those shown are symptoms of zinc deficiency (*Figure 2*) and copper deficiency (*Figure 3*); symptoms of boron deficiency develop less often and are less easily recognised.

Severely Affected Plants

The terminal growing point dies, profuse lateral branching occurs and the lateral branches may also die; calcium deficiency symptoms may develop in mature leaves, but cases as severe as in *Figure 4* are rare, and are then accompanied by appreciable retardation in the general growth of the plants.

OCCURRENCE OF THE DISORDER

The disorder appears to be associated with soil infertility, especially with low levels in the soil of calcium and of certain minor elements; to some extent it is aggravated by stimulating growth through fertiliser applications.

In *Table 1*, a number of sites at which the disorder was observed are listed together with the clones concerned, the type of fertiliser applied, and the type of soil. It will be seen that the occurrence was not limited to a particular location, clone, or soil type. The nutrient status of the soils was shown by the subtractive method (MIDDLETON, 1961) to be low in all cases, and the disorder seemed generally, though not invariably, associated with the use of fertilisers containing soluble phosphates.

THE EFFECT OF FERTILISER APPLICATIONS (EXPERIMENT 1)

A pot experiment was described in Part I of this paper in which 31 plants out of a total of 144 showed symptoms of the type described above. For each of the 31 plants, the following eight fertilisers had been individually applied or withheld: ammonium sulphate, sodium nitrate*, rock phosphate, superphosphate, potassium sulphate, magnesium sulphate, limestone, and a trace element supplement (containing boron, manganese, copper, zinc, and molybdenum). For each fertiliser the number of times that it was present in affected plants, and the number of times that it was absent, may be expressed as percentages of the total number of plants which received the particular fertiliser, i.e. 48 plants for nitrogenous and phosphatic fertilisers, and 72 plants for each of the others. If the percentage found in the absence of a fertiliser is subtracted from the percentage found in the presence of the same fertiliser, a positive result is a measure of the degree to which the fertiliser is associated with the disorder; conversely a negative result indicates an association of the disorder with absence of the fertiliser. In *Figure 5*, percentages computed in this way have been plotted against growth responses and show that four fertilisers were positively associated, namely rock phosphate, sodium nitrate, superphosphate, and ammonium sulphate, that two were negatively associated namely trace elements and limestone, and that magnesium sulphate and potassium sulphate were not involved. A Chi-square test (GOULDEN, 1952) showed that four only of these associations were statistically significant: namely those for ammonium sulphate, sodium nitrate, superphosphate, and limestone.

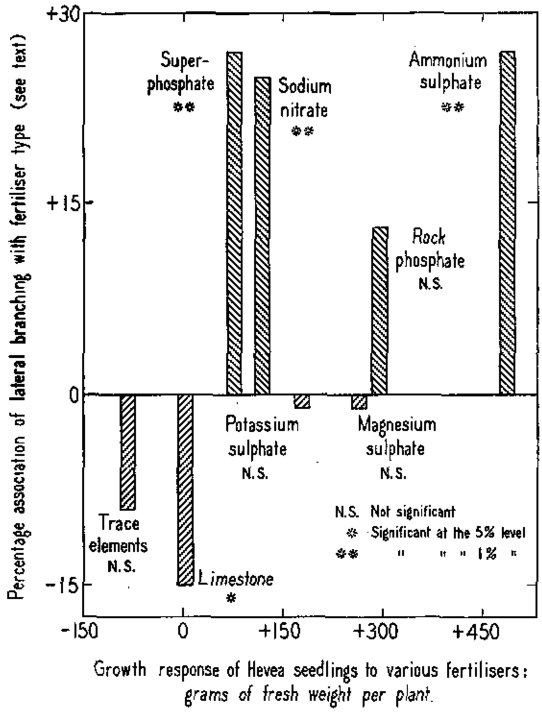

Figure 5. The association of excessive lateral branching in Hevea *seedlings with fertiliser type, and with corresponding mean growth responses.*

The mean chemical composition of the leaves of affected and unaffected pot plants was determined, and compared with that for affected plants from one of the estates listed in *Table 1*. High levels of nitrogen and phosphorus, and low levels of calcium, boron, and

* In Part 1 an assumption was made that the effect of uncompensated amounts of sodium do not account for the superiority of ammonium sulphate over sodium nitrate as a nitrogenous fertiliser for rubber seedlings grown in pots. This has since been confirmed in a pot trial (MIDDLETON, 1965).

TABLE 1. OCCURRENCE OF TERMINAL SUPPRESSION AND EXCESSIVE LATERAL BRANCHING IN IMMATURE RUBBER

Location	Age from planting, months	Clone or seedling	Fertiliser	Soil series and parent material (OWEN, 1951)	Soil nutrient deficiencies†
Johore	13	PR 107 (budgrafts)	Nitrophoska Yellow	Malacca—shale	N, P, K, Mg, Ca, Fe, Mn, B, Cu, Zn
R.R.I.M. Experiment Station	10	Tjir 1 clonal seedling	Rock phosphate or superphosphate with an N, P, K, Mg mixture	Sungei Buloh—sandy alluvium	N, P, K, Mg, Ca, S, Mn, B, Cu
R.R.I.M. Experiment Station	24	PB 5/51 (budgrafts)	Rock phosphate with an N, P, K, Mg mixture	Serdang—sandstone	N, P, K, Mg, Ca, S, B, Cu
Perak	12	PB 5/63 (budgrafts)	I.C.I. mixture NPK 4	Sogomana—clayey alluvium	N, P, K, Mg, Ca, S, Fe, B, Cu, Mo
Selangor	18	RRIM 623, RRIM 628 PB 28/59 (budded stumps)	Nitrophoska Yellow and Ternape	Rengam—granite	N, P, K, Mg, Ca, S, Fe, Mn, B
Perak	20	PB 5/51 (budgrafts)	I.C.I. mixture NPK 4	Holyrood—sandy alluvium	N, P, K, Mg, Ca, S, Mn, B
Negri Sembilan	25	PB 5/63 (budgrafts)	I.C.I. mixture NPK 4	Tampin—granite	N, P, S, B, Zn

† As indicated by the growth of an indicator plant, *Pueraria phaseoloides*, in the pot subtractive technique (MIDDLETON, 1961)

copper, were found for affected, compared with unaffected plants; sulphur, zinc, iron, manganese, and molybdenum, were also determined, but no appreciable differences were found. For the major nutrients, the ratio of anionic to cationic elements, (N+P)/(K+Mg+Ca), was greater in affected plants than in unaffected plants, suggesting a condition of nutrient imbalance in the former.

Significant effects upon anion/cation ratios of quality of phosphate and method of application, and of liming soil, are detectable in results obtained in a previous comparison of rock phosphate with superphosphate. These effects have been summarised in *Table 2*; the ratios were calculated from figures previously given for individual elements (MIDDLETON, 1960). The ratios for plants grown in the absence of applied phosphate were 1.18 for unlimed soil and 0.88 for limed soil; it will be seen that similar ratios were obtained when rock phosphate was applied, while appreciably higher ratios were obtained with superphosphate, both in the presence and in the absence of lime. The ratios were computed from analyses of whole plants (i.e. roots, stems and leaves) and are therefore not directly comparable with those given later in the paper for analyses of leaves only; they do however confirm that anion/cation ratios in plants grown with soluble phosphate are appreciably higher than those in plants grown with insoluble phosphate.

THE DEVELOPMENT OF SYMPTOMS IN SAND CULTURE (EXPERIMENT 2)

BOLLE-JONES (1956) showed that excessive lateral branching and suppression of the terminal growing point was associated in varying degree with insufficiency of the following elements: calcium, sulphur, boron, copper, and zinc. In leached acidic soils of the type in which the disorder is observed, it seemed possible that aluminium toxicity might also be involved, particularly since WAARD AND SUTTON (1960) had reported the development of aluminium toxicity in pepper on similar soils in Sarawak.

A sand culture experiment was therefore designed to investigate the effects and interactions of these six factors (i.e., Ca, S, B, Cu, Zn, and Al) in the presence of nitrogen and phosphorus, added at two levels in order to produce a differential stimulation of vegetative growth. The experiment was a 2^8 factorial arrangement using Tjir 1 clonal seedlings; all nutrients were applied in aqueous solutions containing balanced amounts of K, Mg, Fe, Mn, and Mo; six months after planting the seedlings were harvested and weighed.

A summary of the significant results of this experiment is given in *Table 3*, in terms of

TABLE 2. THE EFFECT OF PHOSPHATE QUALITY, METHODS OF APPLICATION, AND LIMING ON ANION/CATION RATIOS IN HEVEA BRASILIENSIS

(The ratios (N+P)/(K+Mg+Ca) were calculated from analyses of whole plants; individual figures in the table are means of 3 for rock phosphate, of 6 for superphosphate, and of 3 for methods of application. M.S.D. is the minimum difference between corresponding means, significant at the 5% level).

Supplementary treatment	Type of phosphate applied			Method of application				
	Rock phosphate	Super-phosphate	M.S.D.	Broadcast	Mixed	Pocketed	Mean	M.S.D.
Soil not limed	1.17	1.44	0.15	1.30	1.32	1.43	1.35	0.08
Soil limed	0.93	1.06	0.15	0.93	1.02	1.11	1.04	
M.S.D.	0.18	0.13			0.12			
Mean	1.05	1.25		1.11	1.17	1.27		
M.S.D.	0.11				0.09			

total mean dry weight of plants per treatment in grams. The main effects of sulphur, calcium, zinc and copper were shown to be beneficial, while the effect of aluminium was unfavourable. Significant two-factor interactions, some of which are shown in *Table 3*, were as follows: beneficial effects of sulphur and zinc were greater in the presence of calcium and copper than in their absence; the beneficial effect of sulphur was increased in the presence of boron, the unfavourable effect of aluminium was increased both in the presence of sulphur and of boron. The effects of different levels of nitrogen and phosphorus were not proved either as main effects or in two-factor interactions.

In the experiment, 169 out of 256 plants (i.e. 66%) exhibited suppressed terminal growing points, or an excessive number of side shoots, or both symptoms of the physiological disorder being investigated. About 50% of the plants were affected in the presence and also in the absence of sulphur, copper, zinc, and aluminium, and also at each level of nitrogen and phosphorus.

In the absence of calcium, however, 96% of the plants were affected, while in its presence only 36% were affected; corresponding figures for absence and presence of boron were 80 and 52%. Chi-square tests showed that the absence of these two elements has significantly increased the number of affected plants and also that significant two-factor interactions had developed between calcium and sulphur, and between sulphur and boron. Thus sulphur increased the number of affected plants in the absence of calcium, and it decreased the number in the presence of calcium; conversely, sulphur decreased the number of affected plants in the absence of boron, but it increased them in the presence of boron.

OBSERVATIONS IN A COMPARISON OF TEN PHOSPHATIC FERTILISERS (EXPERIMENT 3)

Excessive lateral branching, accompanied in some cases by suppression of the terminal

TABLE 3. EFFECT OF CALCIUM, SULPHUR AND MINOR ELEMENTS ON THE GROWTH OF RUBBER SEEDLINGS IN SAND CULTURE (EXPERIMENT 2)†

	Calcium absent	Calcium present	Zinc absent	Zinc present	Aluminium absent	Aluminium present	Copper absent	Copper present	Mean	M.S.D.
Sulphur absent	3.25	4.49	3.82	3.92	4.02	3.71	3.90	3.84	3.87	0.59
Sulphur present	4.68	13.94	7.84	10.78	10.10	8.51	8.67	9.95	9.31	
M.S.D.	0.84		0.84		0.84		0.84			
Calcium absent			3.92	4.01	4.31	3.62	3.80	4.13	3.96	0.59
Calcium present			7.73	10.69	9.81	8.61	8.77	9.65	9.21	
M.S.D.			0.84		0.84		0.84			
Zinc absent					6.39	5.26	5.86	5.79	5.83	0.59
Zinc present					7.73	6.97	6.70	8.00	7.35	
M.S.D.					0.84		0.84			
Aluminium absent							6.54	7.58	7.06	0.59
Aluminium present							6.02	6.21	6.11	
M.S.D.							0.84			
Means							6.28	6.89		
M.S.D.							0.59			

† Figures are mean dry weight in grams of three plants for each treatment.

M.S.D. is minimum difference between corresponding means significant at the 5 per cent level.

growing point, had also developed in a separate pot experiment, made with *Hevea* seedlings grown in pots filled with a Serdang series soil, and designed to compare six different soluble phosphatic fertilisers (double superphosphate, Nitrophoska Yellow, ammonium phosphate, magnesium ammonium phosphate, potassium metaphosphate, and dicalcium phosphate) with four insoluble types (Christmas Island rock phosphate, aluminium phosphate, and two organic forms). The effects of the fertilisers on total vegetative growth have already been described (RUBBER RESEARCH INSTITUTE OF MALAYA, 1964); their differential effects upon excessive lateral branching are summarised in *Table 4*. In *Table 5*, results of chemical analyses of leaves taken from the top expanded whorl (BOLLE-JONES, 1954) are summarised, and show appreciable differences between soluble and insoluble phosphates for anion/cation ratios among major elements, and also in minor element composition.

DISCUSSION

In a developing plant, lateral branching is a normal physiological reaction to cessation of the activity of the terminal growing point. For example, excessive lateral branching can occur where the terminal growing point, and successively produced laterals, are all killed or suppressed through an attack by a pest or disease. It is important that excessive lateral branching caused by a pest or disease should not be confused with the physiological disorder considered in this paper. In particular that the disorder should not be confused with any of the forms of pathological die-back described by HILTON (1959). A complication arises under certain conditions, where a secondary infection, caused for example by *Gloeosporium alborubrum*, occurs although the primary cause of the die-back was physiological.

The four fertilisers shown in *Figure 5* to be positively associated with the disorder, namely ammonium sulphate, sodium nitrate, superphosphate, and rock phosphate are usually considered to have a stimulating effect upon the vegetative growth of plants, and were in fact shown to have such an effect (MIDDLETON AND CHIN, 1964). On the other hand the two negatively associated fertilisers, limestone and trace elements, were found in some cases to have depressed growth (MIDDLETON AND CHIN, 1964).

Although suppression of the growing point and its accompanying symptoms appear linked with stimulation of growth (*Figure 5*), other factors are also involved. Thus magnesium sulphate stimulated growth considerably without being associated with the disorder; again insoluble rock phosphate, though stimulating

TABLE 4. COMPARISON OF TEN DIFFERENT PHOSPHATIC FERTILISERS: RELATION OF EXCESSIVE LATERAL BRANCHING TO TYPE AND AMOUNT OF FERTILISER APPLIED (EXPERIMENT 3)

(M.S.D. is the minimum difference significant at the 5 per cent level)

Type of phosphatic fertiliser applied	Percentage of plants with excessive branching		Difference: 2nd − 1st level	M.S.D.
	At the first level of application	At the second level of application		
Insoluble	1.6	0.0	− 1.6	3.1
Soluble	5.2	48.9	43.7	12.6
Difference:				
Soluble − insoluble	3.6	48.9		
M.S.D.	6.0	14.4		

TABLE 5. CHEMICAL COMPOSITION OF THE LEAVES OF RUBBER SEEDLINGS GROWN WITH SOLUBLE AND INSOLUBLE PHOSPHATES (EXPERIMENT 3)

(Within the table, figures for insoluble types are means of 16 measurements, while those for soluble types are means of 24 measurements. M.S.D. is the minimum difference between corresponding means, significant at the 5 per cent level)

Type of phosphatic fertiliser applied	Anion/cation ratio (N+P)/(K+Mg+Ca)					Concentrations in p.p.m. of oven-dry material: Boron					Copper					Zinc				
	Phosphate level 1	Phosphate level 2	M.S.D.	Mean	M.S.D.	Phosphate level 1	Phosphate level 2	M.S.D.	Mean	M.S.D.	Phosphate level 1	Phosphate level 2	M.S.D.	Mean	M.S.D.	Phosphate level 1	Phosphate level 2	M.S.D.	Mean	M.S.D.
Four insoluble types	1.60	1.68	0.20	1.64	0.13	7.9	6.3	1.5	7.1	1.0	5.4	4.1	1.0	4.8	0.6	23.9	22.7	3.4	23.3	2.2
Six soluble types	1.79	2.09	0.16	1.94		6.1	5.6	1.3	5.9		3.2	1.4	0.8	2.3		19.7	18.8	2.8	19.3	
M.S.D.	0.18	0.18				1.4	1.4				0.9	0.9				3.1	3.1			
Mean	1.72	1.93				6.9	5.9				4.1	2.5				21.4	20.4			
M.S.D.	0.13					1.0					0.6					2.1				

TABLE 6. EFFECTS OF FERTILISERS ON THE FIBRE STRENGTH OF THE STEMS OF RUBBER SEEDLINGS†

	No phosphate	Rock phosphate	Superphosphate	No potassium	Potassium sulphate	No magnesium	Magnesium sulphate	No limestone	Limestone	No trace elements	Trace elements	Mean	M.S.D.
No nitrogen	13.4	14.4	13.7	14.2	13.5	14.1	13.6	14.4	13.2	13.1	14.6	13.8	
Ammonium sulphate	14.1	11.4	11.0	14.0	10.3	12.7	11.6	12.5	11.8	11.2	13.1	12.2	1.2
Sodium nitrate	14.3	11.0	10.0	12.3	11.3	11.7	11.9	12.2	11.4	11.8	11.8	11.8	
M.S.D.		2.1		1.7		1.7		1.7		1.7			
No phosphate				14.8	13.1	14.1	13.8	14.4	13.5	13.0	14.9	13.9	
Rock phosphate				13.7	10.9	12.6	12.0	12.9	11.7	11.7	12.8	12.3	1.2
Superphosphate				12.0	11.2	11.8	11.4	11.9	11.3	11.4	11.8	11.6	
M.S.D.				1.7		1.7		1.7		1.7			
No potassium						13.8	13.2	13.9	13.0	13.2	13.7	13.5	
Potassium sulphate						11.8	11.6	12.2	11.3	10.9	12.6	11.7	1.0
M.S.D.						1.4		1.4		1.4			
No magnesium								13.6	12.0	12.5	13.1	12.8	
Magnesium sulphate								12.5	12.3	11.6	13.2	12.4	1.0
M.S.D.								1.4		1.4			
No limestone										12.2	13.9	13.0	
Limestone										11.9	12.4	12.1	1.0
M.S.D.										1.4			
Mean										12.0	13.2		
M.S.D.										1.0			

† Figures are means of two estimates of fibre strength in thousands of pounds per square inch of cross-sectional area, calculated as described by Low (1955) from results of simple bending to failure of the test pieces, by test loads applied centrally.

M.S.D. is the minimum difference between corresponding means, significant at the 5% level.

growth to a greater extent than a soluble fertiliser (superphosphate) was associated with the disorder to an appreciably smaller degree.

The excessive lateral branching caused by sodium nitrate and superphosphate, attended by relatively small growth-responses to these fertilisers, suggests that the development of severe symptoms is accompanied by a general interruption in the growth of the plants, and is a possible explanation for the very inefficient combined fertiliser effect of sodium nitrate and superphosphate upon rubber seedlings which has been discussed already (MIDDLETON AND CHIN, 1964).

CAUSES OF THE DISORDER

With the information at present available the origin and occurrence of the disorder may be best explained by making the following assumptions:

1. Suppression of the terminal growing point is caused by a shortage within the plant of calcium, or certain minor elements, of which boron, copper, and zinc are the most likely.
2. These shortages may become acute on soils containing small amounts of the elements listed above, if vigorous vegetative growth is stimulated by applying readily available nitrogenous and phosphatic fertilisers.
3. The shortages may be aggravated by applying readily available phosphatic fertilisers which in some circumstances interfere with uptake of boron, copper, and zinc from the soil.

The presence in affected plants of high levels of nitrogen and phosphorus, and low levels of calcium, boron, and copper, shown by chemical analysis, supports the above explanation; as do the results obtained in sand culture where absence of calcium and boron were found to be significantly associated with suppression of the terminal growing point and excessive lateral branching.

Additional experimental support is provided by the results given in *Table 4* in which ten phosphatic fertilisers are compared. In this experiment a significant increase in the amount of lateral branching occurred where vigorous vegetative growth was stimulated by applying a relatively large amount of soluble phosphate (i.e. at the second level); no increase was however found where corresponding amounts of insoluble fertilisers were applied, and the amount of lateral branching produced by insoluble phosphates was generally less than that produced by soluble forms.

In *Table 5*, results of chemical analyses of the leaves of rubber seedlings, grown with the four different insoluble phosphatic fertilisers, have been grouped together for comparison with results obtained with six different water-soluble types. From the two-way presentation of means, it will be seen that anion/cation ratios in the leaves of plants grown with soluble phosphatic fertilisers were appreciably higher than those for plants grown with insoluble phosphates; also for the same plants, that concentrations of boron, copper, and zinc, were significantly lower where soluble rather than insoluble fertilisers had been used.

A study of the regression of the chemical composition of the leaves upon the weights of whole plants indicated that variation in ratios and in concentrations of copper was independent of plant growth, whereas the concentration of both boron and zinc was inversely proportional to plant weight, so that uptake of these two elements was constant and independent of phosphate type. Results for chemical analyses of whole plants were not available for comparison with the weights of whole plants, and the results discussed above therefore suggest, without clearly showing, that differences in ratios and copper contents are attributable to differences in phosphate solubility; on the other hand the boron and zinc differences seem to be the result of shortages of these elements in the soil, aggravated by the increased growth produced by applying soluble phosphates.

Interference in uptake and utilisation of minor elements by soluble phosphates has been reported several times for other crops, notably by BINGHAM AND GARBER (1960) and BURLESON *et al.* (1961). Both sets of authors interpret the phosphate effect in terms either of precipitation of minor elements in the soil, or of phosphate-cation antagonism within the root—the relative importance of the two causes varying with the element involved, and with the type and reaction of the soil. An apparently similar effect by a soluble phosphatic fertiliser (triple superphosphate) has recently been reported for *Hevea brasiliensis* by MAINSTONE (1963), who has shown significantly decreased uptake of boron and copper by plants with increasing amounts of applied fertiliser.

EFFECTS OF FERTILISERS ON FIBRE STRENGTH OF HEVEA SEEDLINGS

Tests of fibre strength were carried out at the Forest Research Institute, Kepong, Selangor, using the Wiedemann-Baldwin Universal Testing Machine, set up as described by the AMERICAN SOCIETY FOR TESTING MATERIALS (1954). This machine enables precise measurements to be made on specimens differing widely in girth, and therefore in total resistance to bending stresses.

The results of testing fibre strength are summarised in the two-way presentation of means in *Table 6*. Although nitrogenous and phosphatic fertilisers produced large plants, and therefore strong plants stem for stem, their specific effect was to decrease the fibre strength of the seedlings significantly, an effect which is perhaps to be expected with fertilisers which had stimulated growth significantly (MIDDLETON AND CHIN, 1964). However, sodium nitrate and superphosphate reduced strength to a greater degree than their alternative forms, i.e. ammonium sulphate and rock phosphate, and in combination had a specially marked effect; since this combination produced no significant increase in growth, it would appear to have an independently depressive effect on wood strength.

Potassium sulphate, which produced no overall stimulation of growth, significantly reduced wood strength; but it should be noted that the reduction was most pronounced where, in combination with certain other fertilisers particularly ammonium sulphate and rock phosphate, potassium also increased growth (MIDDLETON AND CHIN, 1964).

Magnesium sulphate and limestone produced no significant effects on strength; by comparison the general effect of magnesium was to stimulate growth to a marked degree, whereas limestone had a small depressive effect.

The effect of trace elements was to increase wood strength significantly, and is in conformity with their general effect in slightly suppressing growth (MIDDLETON AND CHIN, 1964.)

Determinations of specific gravity were made on the seedlings, along with the bending tests, but no significant correlation between specific gravity and wood strength was found in a subsequent regression analysis.

It is difficult to assess the detailed significance of these results in relation to the wood strength of mature trees, in particular the differing effects of potassium and magnesium. However, fibre-strength is expressed per unit of girth and is therefore a measure of specific strength; also it seems reasonable to assume that rapid vegetative growth should decrease specific strength (i.e. after correction for girth differences); such an assumption would explain observed nitrogen and phosphorus effects. It is also interesting to note that the combination of sodium nitrate with superphosphate, an inefficient fertiliser combination which is connected with a physiological disorder, is also associated with decreased fibre strength, to some extent at least, independently of any effect it may have on growth.

CONCLUSIONS

A physiological disorder in *Hevea brasiliensis* causing excessive lateral branching and suppression of the terminal growing point appears primarily associated with insufficiency of calcium, boron, copper, or zinc. It occurs on young trees under field conditions as well as on plants grown in pot experiments, and particularly where vigorous vegetative growth is stimulated by applying readily available nitrogenous and phosphatic fertilisers. There is no conclusive evidence at present that its occurrence is linked with a particular clone of *Hevea*, nor with any one soil type; but an indirect cause may be the tendency of soluble phosphates to induce deficiencies of certain minor elements by obstructing their uptake from the soil, and this effect may be serious, where marginal deficiencies of minor elements already exist.

The association of the disorder with soluble phosphates is important in considering fertiliser schedules for immature plants; it appears that although fertilisers containing soluble phosphates have been used successfully in many areas, application rates suitable for insoluble phosphates (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963) may not always be suitable for soluble types, for which smaller applications made more frequently may often be more appropriate. The inclusion of a minor element supplement in compounded fertilisers for other crops has been found advantageous (SAUCHELLI, 1960), but more information will be needed before a recommendation can be made that fertiliser mixtures or compounds containing soluble phosphates intended for application to rubber in Malaya should be modified in this way.

Stimulation of vegetative growth, particularly during immaturity, is a general aim in rubber plantations, and has been advanced through the formulation of fertilisers more efficiently balanced in their content of major elements than those used in the past (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963). In soils with meagre reserves of natural fertility as is frequently the case in Malaya, problems involving minor elements must now be expected to arise more frequently.

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