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Residual Effect of Applied Phosphates on Performance of Hevea brasiliensis and Pueraria phaseoloides

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Inorganic P in the soils of two field experiments receiving either double superphosphate or rock phosphate was fractionated into Al, Fe and Ca phosphate fractions. Mobility of the applied phosphate in the soil and distribution of the various soil-P fractions were found to be significantly different when superphosphate and rock phosphate were applied.

Attempts were made to determine the influence of Al, Fe and Ca phosphates on the availability of residual P to growth, yield and uptake of a legume (Pueraria phaseoloides) *and of* Hevea brasiliensis.

Available data indicated that rock phosphate had a higher residual effect on Pueraria phaseoloides *and* Hevea brasiliensis *compared to double superphosphate.*

Phosphatic fertilisers are required to maximise growth and yield of *Hevea* in Malaysia. It has been shown that application of 200 kg to 300 kg P_2O_5 per hectare during the immature phase of *Hevea* results in a build-up of phosphorus in the soil[1]. This soil-P, accumulated during the immaturity period, was found to be sufficient in sustaining the trees' requirement of P in the early years of maturity when the trees are in production.

The highly weathered Malaysian soils which are dominated by iron and aluminium are known to have very high phosphate-fixing capacity[2]. The phosphorus content in the soils can be divided into three major fractions, *viz.* acid-soluble, alkali-soluble and the inert fractions[3]. Distribution of the different P fractions were found to be variable in soils derived from different parent materials; in inland soils, the inert fractions were higher. Available data showed that the phosphorus nutrition of *Hevea* can be reliably assessed if the distribution of the different phosphate fractions are determined. Lau *et al.*[4] related soil-P (as determined by the conventional methods of using NaOH, $NaHCO_3$, H_2SO_4 and NH_4F as extractants) to growth, yield and P-uptake of *Hevea*. NaOH-soluble P was better related to uptake by *Hevea* in the coastal alluvial clays which were found to contain large amount of organic P, while for other soils NH_4F-extractable P was the best index.

This paper assesses the long-term residual effect of applied rock phosphate and superphosphates on *Hevea* and a legume, *Pueraria phaseoloides.* The relative amounts of inorganic soil-P which are present as Al, Fe and Ca phosphates are also determined and discussed.

EXPERIMENTAL

Field Application of Phosphate

Two field experiments, *Expt SE 1/28* and *SE 1/4*, which were respectively located on Rengam and Serdang series soils (both Typic paleudults) were studied. In *Expt SE 1/28*, the total amount of P_2O_5 per effective area applied to experimental plots either as double superphosphate or Christmas Island rock phosphate were 4165 kg per hectare for the period between 1959 and 1976. In *Expt*

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SE 1/4, for the residual treatment, the combined P_2O_5 applied as double superphosphate and rock phosphate were 2030 kg P_2O_5 per hectare from 1937 to 1963. For plots with continued application, an additional 2561 kg P_2O_5 per hectare had been applied since 1969 when a new stand of rubber was established.

Glasshouse Experiments

In *Expt SE 1/28* soils at different depths were sampled from plots receiving either double superphosphate or rock phosphate; they were exhaustively cropped with a legume, *Pueraria phaseoloides*, in pots containing 600 g of soil. Total dry matter (shoots and roots), phosphorus and calcium contents were determined from three croppings harvested at eight-week intervals.

Soil Analyses

Soils taken from field experiments were air-dried and ground to pass through a 2 mm sieve before they were analysed for soluble P by the procedure of Bray and Kurtz[5], total P and Ca by digestion with $HClO_4/H_2SO_4$[6].

Fractionation of soil phosphates was carried out by the modified method of Chang and Jackson[7]. One gram soil sample was successively extracted with 0.5 *N* NH_4F, 0.1 *N* NaOH and 0.5 *N* H_2SO_4 to determine the 'A1-, Fe- and Ca- bound phosphates.'

RESULTS AND DISCUSSION

Phosphate Fractions in Soil

In *Expt SE 1/28*, where two different types of phosphatic fertilisers were applied, the distributions of the three phosphate fractions were found to be different *(Table 1)*. Where superphosphate was applied, a relatively large portion of the phosphate remained as A1-P. However, when rock phosphate was used, Ca and Fe phosphates seemed to be dominant. The dominance of Ca phosphate was reflected in the high calcium content which was about ten times as much at the surface layer of soil when rock phosphate as against superphosphate was applied. Since superphosphate is much more soluble than rock phosphate, the calcium was more easily removed by crops, leached or converted to other less soluble forms. Chang and Chu[8] showed that application of soluble phosphates favoured the fixation of P as A1 phosphate. However, on prolonged contact with the soil, the A1 and Ca phosphates initially present were gradually converted to the less soluble Fe phosphate. The rate of transformation increased with the moisture content of the soil.

Soluble phosphorus, as determined by Bray's No. 2 method, appeared to be higher when superphosphate was applied. These differences could have been caused by the unequal A1, Fe and Ca phosphate fractions in the soils and the preferential extraction of A1 phosphate by this method.

In *Expt SE 1/4*, where phosphate was continuously applied (fresh P + residual P), the largest fraction of soil-P was Ca-bound and the smallest was A1-bound *(Table 2)*. In plots where application of phosphate was terminated fourteen years ago (residual plots), Fe phosphate was found to dominate. A1 and Ca phosphate fractions in both the control and residual P plots appeared to be similar; in *Expt 1/28*, levels of A1 and Ca phosphates were significantly increased where phosphate fertilisers had been freshly applied *(Table 2)*. These phosphates tend to be transformed to Fe phosphates as was indicated by results from the residual plot.

An increase in pH of the soils was observed when both rock phosphate and superphosphate were used in *Expt SE 1/28*. The increase was larger with rock phosphate than with superphosphate. When application of these phosphates, particularly the rock phosphate, was discontinued in *Expt SE 1/4* *(Table 2)*, the soil regained its original pH, reflecting the highly acid nature of the soils.

TABLE 1. PHOSPHATE FRACTIONS IN SOILS OF *EXPERIMENT SE. 1/28*[a]

Treatment	Depth (cm)	pH	Phosphate fraction (mg/treatment) Al-P	Fe-P	Ca-P	(Total)	Total P[b] (g/treatment)	Soluble P[c] (mg/treatment)	Total Ca (mg/treatment)
Control	0 – 2.5	4.0	20.2	38.7	5.0	(63.9)	0.27	19.8	172.8
	2.5 – 7.5	4.2	13.7	39.2	5.0	(57.9)	0.27	19.8	46.8
	7.5 – 15.0	4.4	6.5	22.3	2.6	(31.4)	0.23	10.8	64.8
	15.0 – 30.0	4.5	5.0	16.7	2.5	(24.2)	0.21	9.0	25.2
	30.0 – 45.0	4.6	3.6	14.2	2.0	(19.8)	0.21	7.2	46.8
	45.0 – 60.0	4.6	2.5	13.1	2.2	(17.8)	0.22	9.0	25.2
Double superphosphate	0 – 2.5	4.5	446.8	189.5	118.7	(750.0)	1.24	552.6	219.6
	2.5 – 7.5	4.6	440.7	207.4	112.6	(760.7)	1.09	552.6	108.0
	7.5 – 15.0	4.4	193.7	135.0	56.9	(385.6)	0.63	268.3	61.2
	15.0 – 30.0	4.4	330.9	50.0	64.6	(445.5)	0.33	28.8	32.4
	30.0 – 45.0	4.6	6.3	22.9	5.2	(34.4)	0.25	10.8	27.6
	45.0 – 60.0	4.6	6.5	21.6	5.1	(33.2)	0.24	10.8	25.2
Christmas Island rock phosphate	0 – 2.5	4.8	186.1	408.9	643.5	(1 233.5)	1.69	284.4	2 550
	2.5 – 7.5	4.6	95.0	271.8	178.6	(545.4)	0.95	237.6	727.2
	7.5 – 15.0	4.6	28.8	102.6	25.6	(157.0)	0.48	59.4	241.2
	15.0 – 30.0	4.6	9.8	37.4	6.3	(53.5)	0.29	18.0	190.8
	30.0 – 45.0	4.6	9.8	28.8	4.5	(40.1)	0.29	14.4	103.4
	45.0 – 60.0	4.6	4.5	29.8	3.2	(37.5)	0.26	12.6	72.0

[a] 1800 g of soil

[b] By $C10_4/H_2SO_4$ digestion

[c] By Bray's No. 2 method [Bray and Kurtz (1945)]

TABLE 2. PHOSPHATE FRACTIONS IN SOILS OF *EXPERIMENT SE 1/4*[a]

Treatment	Depth (cm)	Phosphate fraction (mg/treatment)			Total P[b] (g/treatment)	Soluble P[c] (mg/treatment)	pH
		Al-P	Fe-P	Ca-P			
Nil P	0 – 2.5	2.3	10.7	3.8	115	3.0	4.5
	2.5 – 7.5	1.3	8.7	4.8	100	2.0	4.3
	7.5 – 15.0	0.7	9.3	2.0	100	2.0	4.2
	15.0 – 30.0	0.7	8.7	1.5	100	1.0	4.3
	30.0 – 45.0	0.7	7.3	1.5	100	1.0	4.2
	45.0 – 60.0	–	6.3	1.0	80	1.0	4.3
Residual P	0 – 2.5	3.0	24.3	2.2	150	6.0	4.4
	2.5 – 7.5	2.0	28.7	1.8	150	5.0	4.5
	7.5 – 15.0	–	17.7	1.2	150	2.0	4.8
	15.0 – 30.0	–	12.3	1.2	135	2.0	4.5
	30.0 – 45.0	–	10.7	1.0	135	1.5	4.5
	45.0 – 60.0	–	9.3	1.0	125	1.0	4.5
Fresh P + residual P	0 – 2.5	93.3	162.0	580.0	985	396.0	5.1
	2.5 – 7.5	43.7	98.0	77.8	375	100.0	4.9
	7.5 – 15.0	18.0	59.3	85.8	218	51.0	4.7
	15.0 – 30.0	8.3	35.0	40.5	200	30.0	4.7
	30.0 – 45.0	5.7	23.0	18.0	160	15.0	4.7
	45.0 – 60.0	4.0	19.3	19.0	115	13.0	4.7

[a]1800 g of soil
[b]By $HClO_4/H_2SO_4$ digestion
[c]By Bray's No. 2 method [Bray and Kurtz (1945)]

Movement of Phosphate down the Profile

Although Malaysian soils have high phosphate-fixing capacities[1], P movement down the profile was significant in *Expt SE 1/28* and *SE 1/4*; mobility of phosphate was greatest when superphosphate was used. With superphosphate, more than 90% of the phosphate (total of all forms) was in the 0–30 cm depth; with rock phosphate, concentration was in the 0–15 cm zone. At lower depths, Al and Ca phosphates were dominant in superphosphate-treated plots, whereas with rock phosphate, Fe phosphate was dominant.

Where rock phosphate was applied, there was an accumulation of Ca down the profile which was much greater than when superphosphate was used. Considering the amount of CaO per unit weight of P_2O_5 in the two phosphates, it would be expected that an increase in Ca in the soils would be greater with rock phosphate (CaO:50%) than with superphosphate (CaO : 10%) application. Particularly with the acid soils (pH 4.5) dissolution of rock phosphate could be enhanced and downward movement of phosphate and calcium could take place separately. On the other hand, physical movement of the phosphate could have taken place especially in the sandy soils in *Expt SE 1/4* where porosity was high, or additionally, the P movement down the profile could have been through channels created by root activity of plants.

Availability of Phosphate

Pueraria cropping. Availability of residual P from the applications of rock phosphate and superphosphate was assessed by cropping with Pueraria *(Table 3)*. Dry matter yield of Pueraria obtained for any given depth of soil was consistently higher where rock phosphate was applied *(Figure 1)*. Particularly in the surface soils (0-2.5 cm and 2.5-7.5 cm depth) three croppings with Pueraria resulted in over 35% of the soluble P in the soil (determined by Bray's No. 2 method) being taken up by the plants. Where superphosphate was applied, the amount taken up was only 14% to 20% of the soluble P.

Total Ca uptake by Pueraria in the top-soils was greater following the rock phosphate treatment. The better performance in terms of growth and uptake in the rock phosphate-

TABLE 3. PHOSPHORUS UPTAKE BY *P. PHASEOLOIDES* IN SOIL OF *EXPERIMENT SE 1/23*

Treatment	Depth (cm)	Phosphorus uptake[a] (mg/treatment)
Control	0 – 2.5	4.4 (14.4)
	2.5 – 7.5	3.0 (9.0)
	7.5 – 15.0	3.6 (12.2)
	15.0 – 30.0	3.1 (1.0)
	30.0 – 45.0	2.2 (8.1)
	45.0 – 60.0	2.2 (8.2)
	Total	18.5 (52.9)
Double superphosphate	0 – 2.5	109.4 (123.4)
	2.5 – 7.5	76.5 (52.0)
	7.5 – 15.0	55.1 (69.0)
	15.0 – 30.0	25.4 (35.5)
	30.0 – 45.0	5.0 (16.2)
	45.0 – 60.0	4.1 (16.1)
	Total	275.5 (312.2)
Christmas Island rock phosphate	0 – 2.5	120.3 (265.5)
	2.5 – 7.5	83.3 (159.8)
	7.5 – 15.0	54.8 (84.7)
	15.0 – 30.0	25.0 (26.1)
	30.0 – 45.0	5.7 (19.3)
	45.0 – 60.0	5.1 (17.9)
	Total	294.2 (573.3)

[a] 1800 g of soil (total of three pots)
Values within brackets indicate total calcium uptake per treatment.

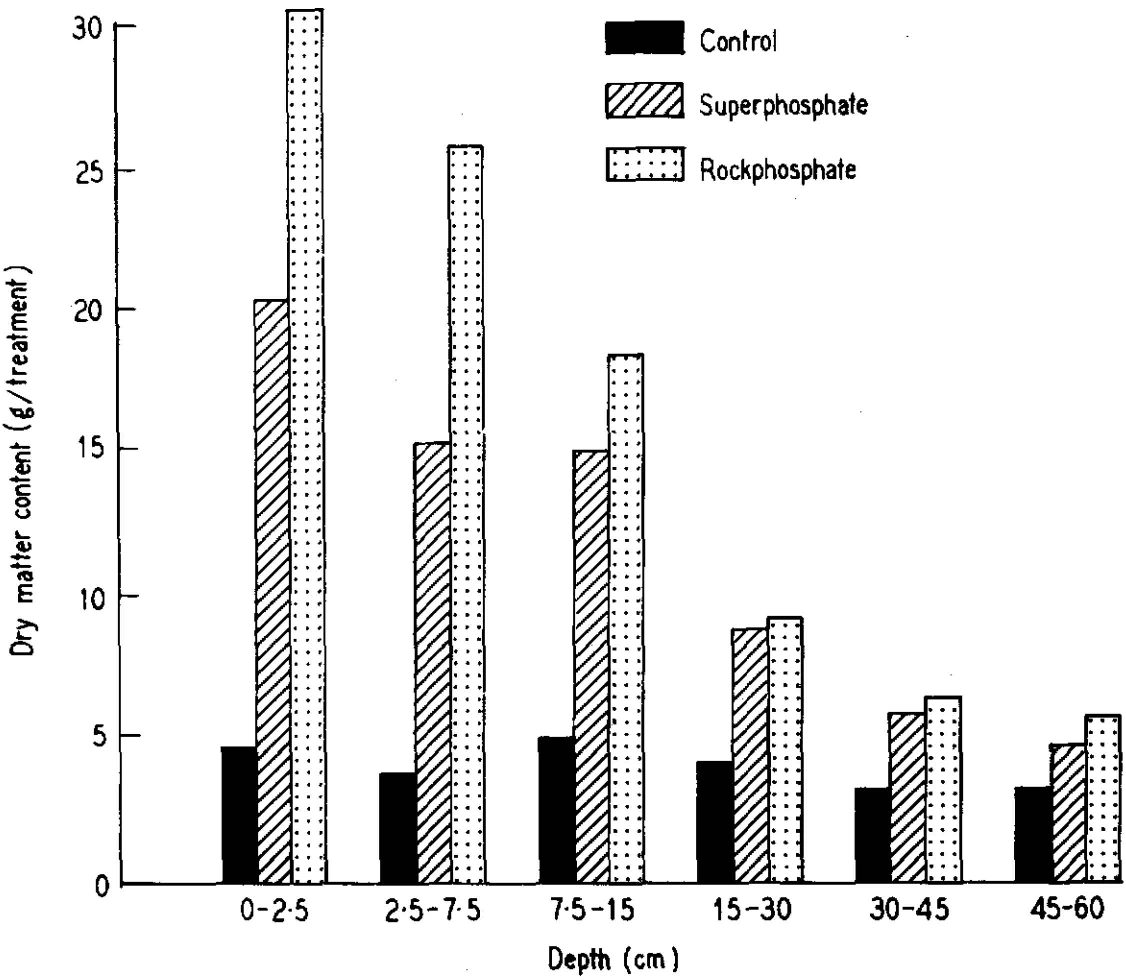

Figure 1. Dry matter content of Pueraria phaseoloides *in soils (Expt SE 1/28)*

treated plots could be attributed partly to the liming effect of the phosphate which could make calcium and phosphate more available.

Cropping with rubber. In *Expt SE 1/4*, a new stand of rubber was established in the old planting rows at the time of replanting to assess the availability of residual P. Girth measurement, latex yield and P and Ca levels in the leaves showed that the residual P was available to the rubber *Table 4).* Leaf-P values in residual P plots (where phosphate applica-cation was discontinued) eight years after application of P was 0.23% compared with 0.21% and 0.27% for the control and fresh P + residual P plots. Similarly, the leaf-Ca values for the respective plots were 0.97%, 0.87% and 1.12%.

Residual P effect on growth and dry rubber yield was also found to be significant. Mean girth measurement of 51.9 cm was obtained in the residual P plots compared with 47.8 cm in the control plots. Lower dry rubber yield was obtained in the fresh P + residual P plots although girth measurement had indicated the

TABLE 4. GROWTH, YIELD OF DRY RUBBER AND PHOSPHORUS UPTAKE OF *HEVEA* IN *EXPERIMENT SE 1/4*

Description	Control	Residual P	Fresh and residual P
Girth measurement (cm)	47.8	51.9	54.9
Yield of dry rubber (kg/ha)	1 592	1 889	1 869
Leaf P (% in dry matter)	0.21	0.23	0.27
Leaf Ca (% in dry matter)	0.87	0.97	1.12

beneficial effect of applying fresh phosphates. The adverse effect of continuous phosphate application, particularly rock phosphate, has been attributed to the higher Ca uptake and the influence of Ca in latex flow, thus resulting in lower yield[1]. On the other hand, the lower yields could also have been due to reduced availability of zinc[9].

Despite the observed beneficial effect of residual P on growth and yield in the residual P plots, leaf-P content of 0.23% is considered to be marginal[10]. With the exhaustion of soil phosphates (particularly the Ca and Al fractions) by the new stand of rubber over eight years of growth, there is a need for a fresh application of phosphate. Elsewhere, Ca-P has been shown to be more available to rubber. On the other hand, Al-P can be useful since other investigations showed that phosphate in Phosphal (an aluminium phosphate) is slowly available to rubber[11].

CONCLUSION

Differences in the distribution of the various forms of soil phosphate in two field experiments have been shown to affect growth, uptake and yield of *Hevea brasiliensis* and *Pueraria phaseoloides*. To better understand the phosphate requirement of rubber, it is desirable to study the end-effect of the applied phosphate in the soils and the value of the residues which accumulate in the various phosphate fractions.

The current investigations show that availability of residual P to rubber is relatively large. This will have considerable implications in the use of P fertilisers especially in replantings.

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