

Leaching of Fertilisers Applied to a Latosol in Lysimeters

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Uncropped lysimeters were used to study fertiliser leaching through a Malayan latosol at two pH values. Chloride leached rapidly. Nitrate derived from ammonium sulphate or urea leached more slowly especially in the more acid soil in which nitrification was slower. Sulphate leached much more slowly especially in the more acid soil. Soil analyses after leaching showed that sulphate was strongly adsorbed (and this affected pH measurements). The rates cations leached depended on the anions moving through the profile and the base exchange characteristics of the soils. Fertiliser potassium leached faster from the more acid soil (pH 4.8). At pH 5.2, added potassium remained in the profile but the depth it penetrated depended on the amounts of anions added concurrently. Fertiliser magnesium also leached more quickly when nitrogen or chloride was added to it.

Rock phosphate, superphosphate and limestone affected soil composition, mostly in the surface 2.5 cm and little below this depth.

The results are discussed in relation to current fertiliser and agronomic practices on rubber estates in Malaya.

It is now well established that fertilisers are necessary for optimum growth of *Hevea brasiliensis* on latosols in Malaya, and mixtures containing ammonium sulphate, rock phosphate, potassium chloride and kieserite are widely used (BOLTON, 1964). Analyses of soil from long-term experiments have shown that fertilisers, besides improving tree growth and yield, change soil composition such that fertility may be affected for many years. For example, MAINSTONE (1963) showed that rock phosphate applied before 1941 affected the phosphate content of rubber leaves twenty years later; BOLTON (1961) showed that soil pH and exchangeable cations were less where ammonium sulphate had been applied in small amounts four years previously.

The rate at which fertilisers are leached from these soils has been little studied, therefore two lysimeter experiments were conducted to follow in detail the leaching of cations and anions in commonly used fertilisers. No crop

was grown in the lysimeters so that complications from nutrient uptake and recycling were avoided. However, it was recognised that such phenomena are of major importance for maintaining the fertility of leached soils in the tropics (NYE AND GREENLAND, 1960). This paper describes fertiliser effects on leachate composition when the equivalent of 710 mm of rain water was applied to the lysimeters in six months (average rainfall in the same period was about 1150 mm). The residual soils in the lysimeters were then analysed to recover unleached fertiliser residues at different depths.

EXPERIMENTAL

The concrete lysimeters (25 cm in diameter and 60 cm deep, and painted inside with bitumen) were filled with 47 kg (Experiment 1) or 50 kg (Experiment 2) of air-dried and sieved (2 mm) soil taken from 10–90 cm depth in a field first planted with *Hevea* in 1929. Although soil for both experiments was taken from the same site, pH and exchangeable calcium were inexplicably different. The sandy loam (Serdang series) is derived from mixed

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TABLE 1. SOIL ANALYSES BEFORE LEACHING

Experiment	Coarse sand, %	Fine sand, %	Silt %	Clay %	pH (water)	C %	Total N %	P p.p.m.
1	52	31	2	15	4.8	0.47	0.05	94
2	47	35	2	15	5.2	0.55	0.06	116

Experiment	N ammonium acetate exchangeable (m-equiv./100 g)					
	K	Mg	Ca	Mn	SO ₄	CEC
1	0.03	0.04	0.11	0.0018	0.09	2.8
2	0.04	0.04	1.10	0.0012	0.09	2.8

quartzite-shale deposits and in the field has a uniform profile up to 150 cm. It would be called a yellow latosol according to the classification scheme of KELLOG (1950). *Table 1* gives the analyses on the original soils.

After packing, the lysimeters were saturated with rain water and the first leachates rejected. One litre of rain water (13.7 mm) was then applied every Monday and Wednesday, and the leachates were removed on every Friday. Volumes were measured and leachates analysed every two weeks. This routine was continued for five weeks (to check for uniformity in leachate volumes and analyses) before the fertilisers were applied. Both experiments were done in a glasshouse designed for use in tropics (BOLLE-JONES, 1956).

Experiment 1

Ammonium sulphate, rock phosphate, potassium chloride and magnesium sulphate were applied in all combinations to the surface of sixteen lysimeters using a single replicate 2⁴ factorial design. Extra lysimeters outside the factorial scheme were treated with urea. *Table 2* gives the amounts applied, together with the equivalent amounts of anions and cations added in each fertiliser.

Experiment 2

A similar factorial arrangement as in the first experiment was used with ammonium sulphate, triple superphosphate, potassium chloride and calcium carbonate as the main treatments. Two extra lysimeters were given no fertiliser or rock phosphate. *Table 2* gives the amounts of fertiliser cations and anions applied.

The two experiments were not conducted concurrently.

Methods of Analysis

Full details of the analytical methods are given elsewhere (BOLTON, 1963). Briefly, neutral *N* ammonium acetate was used to extract cations and sulphate from the soils. Conductivity and pH were measured in 1:5 soil: water suspensions. Available phosphate was measured colorimetrically in an 0.03N NH₄F/HCl extract at pH 1.8 (BRAY AND KURTZ, 1945).

RESULTS

Similar volumes of leachate were collected in both experiments every two weeks from 4 litres of added rain water. Average evaporation losses were 25.9% of the added water in the first

TABLE 2. RATES OF FERTILISERS APPLIED TO THE LYSIMETERS

Treatment	Fertiliser	Amount (cwt/acre)	M-equiv./lysimeter						
			N	P*	K	Ca	Mg	S	Cl
N	Ammonium sulphate	3.0	41.6					41.6	
P _r	Rock phosphate	3.0		14.1		38.9			
P _s	Superphosphate (triple)	3.0		17.6		23.4		ND	
K	Potassium chloride	1.5			18.4				18.4
Mg	Magnesium sulphate (7H ₂ O)	1.5					11.1	11.1	
Ca	Calcium carbonate	9.0				164.7			
U	Urea	1.5	45.7						

* As the H₂PO₄⁻ anion

ND: = Not determined

experiment and 28% in the second. Rates of leaching are therefore comparable between the two successive experiments.

Leaching of Anions

Figure 1 shows that fertilisers first affected leachate composition in both experiments after 12 litres of water had been applied, when chloride concentrations increased in leachates from lysimeters given potassium chloride. During this time, 9 litres of leachate were collected. The mean weight of water in the lysimeters after drainage ceased was about 9 kg. Therefore, water containing the dissolved chloride had moved down the profile displacing the soil solution already present. This result confirms that the lysimeters were well packed and there was no gross channelling. The patterns of chloride leaching were slightly different. Most chloride was measured in the first experiment when between 16 and 20 litres of water had been added; in the second, the maximum was at 16 litres. Also, more leaching was required to remove the added chloride from the more acid soil—shown by the 'tailing' in Figure 1. For the soil with pH 5.2, the chloride in successive leachates gave an

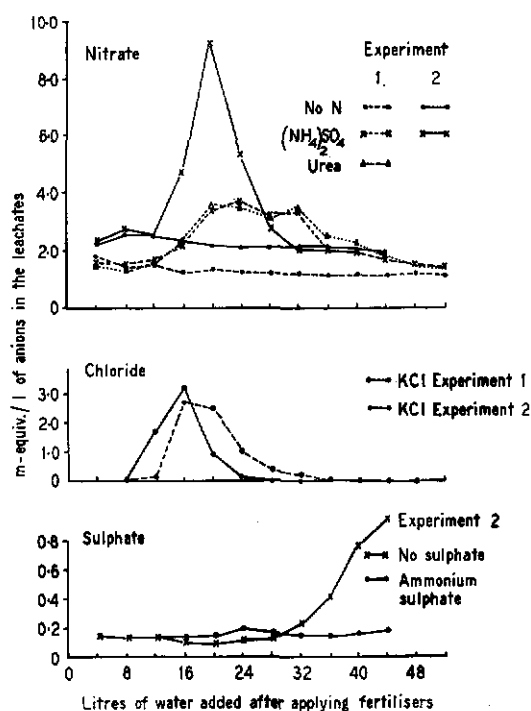


Figure 1. Rate of anion removal in leachates.

approximate 'normal error curve'. BERG AND THOMAS (1959) showed that a curve of this form denotes no anion adsorption whereas the skewed form of the graph shown in the first experiment is caused by anion adsorption. These results show that some chloride was adsorbed at pH 4.8 but not at pH 5.2.

At the next collection after fertiliser chloride appeared, nitrate concentrations in the leachates increased where ammonium sulphate had been given. The difference in leaching rates for chloride and nitrate was probably caused by the time required for nitrification of the ammonium cation. WETSELAAR (1960) showed that nitrate and chloride move at similar rates in many soils, including latosols. *Figure 1* shows that the applied nitrogen was recovered in the leachates sooner in Experiment 2 (with the less acid soil). Nitrate concentrations in the first experiment were slightly larger in N-treated lysimeter leachates even after leaching with 52 litres of water (when 88% of the applied N had been recovered); but, in the second experiment, 95% of the applied N was recovered in leachates from 32 litres of added water. Differences in nitrification rates explain this. All nitrate concentrations were larger in the second experiment, even without added N-fertiliser, probably because of the higher pH and exchangeable calcium. GUHA AND WATSON (1958) showed that applying calcium carbonate to similar soils in pots increases the rate of mineralisation and nitrification of organic nitrogen. Total N was the same in both soils before leaching.

The quantity of N removed in leachates from untreated lysimeters was large—equivalent to 3.7 cwt/acre of ammonium sulphate in the first experiment and 4.7 cwt/acre in the second. Only 3 cwt/acre of this fertiliser was applied in the treatments.

Similar amounts of nitrates were leached from ammonium sulphate and urea (applied at equal rates of N) showing that urea hydrolysed rapidly and there were no detectable losses from ammonia volatilisation under these conditions (*Figure 1*).

Increased amounts of sulphate in leachates from the fertilisers were measured only during

the last few weeks of the second experiment (*Figure 1*). No sulphate was leached from the more acid soil. Therefore considerable adsorption of this ion must have occurred. In Experiment 2, an average of 15% of added sulphate was recovered in the leachates but the amounts depended also on the other fertilisers. Using third and fourth order interactions to estimate experimental errors, the main effects of superphosphate, potassium chloride and limestone on sulphate leaching were significant ($P=0.05$). The interaction tables showed that sulphate recovered in the leachates from ammonium sulphate was increased by these other fertilisers. A negative interaction between superphosphate and limestone on leached sulphate was also significant.

Phosphate was not detected in the leachates from any treatment. The method of analysis used was not sensitive enough to measure the small amounts of phosphate (0.001 p.p.m.) likely to be present in soil solutions from such latosols.

Leaching of Cations

Concentrations of cations in the leachates were related to concentrations of anions especially nitrate and chloride. *Table 3* summarises the main effects of the fertilisers (averaged over all treatments) on total cations and anions in the leachates. In both experiments, calcium was the major cation leached. Ca : Mg and Ca : K ratios were larger in the second experiment because the soil contained more exchangeable calcium. Fewer basic cations (Ca+Mg+K) than anions ($\text{NO}_3^- + \text{Cl}^- + \text{SO}_4^{--}$) were leached. The average ratio of cations to anions was 0.56 in the first, and 0.91 in the second experiment. This deficit of cations is probably because the leachates were acid and contained Al^{3+} and Fe^{3+} , (pH of the leachates was not measured). Obviously more of these ions would be leached from the more acid soil. The larger amounts of calcium leached from the less acid soil caused less potassium and magnesium to be leached, although both soils initially contained the same amounts of exchangeable potassium and magnesium.

TABLE 3. TOTAL* CATIONS AND ANIONS IN THE LEACHATES

Mean of eight lysimeters	Experiment 1					Experiment 2				
	NO ₃ -N	SO ₄ -S	K	Mg	Ca	NO ₃ -N	SO ₄ -S	K	Mg	Ca
Without N	51.0	0.32	6.27	6.95	20.7	66.4	4.78	3.51	2.42	66.3
Ammonium sulphate	86.9	0.46	8.91	11.60	28.1	101.3	9.40	4.01	3.82	101.3
Without P	67.5	0.33	7.40	9.07	23.9	83.7	6.49	3.62	3.11	83.7
Rock phosphate	70.4	0.46	7.79	9.47	24.9	—	—	—	—	—
Superphosphate	—	—	—	—	—	83.9	7.68	3.90	3.14	83.9
Without K	69.1	0.41	5.72	8.71	23.2	74.5	6.38	3.41	2.76	74.5
Potassium chloride	68.9	0.38	9.46	9.84	25.6	93.2	7.79	4.11	3.49	93.2
Without Mg or Ca	67.6	0.43	7.50	6.77	24.9	82.3	6.38	3.64	3.10	82.2
Magnesium sulphate	70.4	0.36	7.69	11.78	23.9	—	—	—	—	—
Calcium carbonate	—	—	—	—	—	85.4	7.80	3.89	3.15	85.4

* M-equiv./lysimeter

In individual leachates from lysimeters treated and untreated with ammonium sulphate, the concentration of K and the square root of concentrations of (Ca+Mg) were correlated as expected, if the Ratio Law (SCHOFIELD, 1947) applies. Ca : Mg ratios were also constant in individual leachates from these treatments in both experiments. This shows that cations in these leachates were in equilibrium with the original soils by the time they reached the bottom of the profiles.

The Ratio Law may be used to show when potassium from the fertilisers appeared in the leachates. Figure 2 shows that $K/\sqrt{(Ca+Mg)}$ ratios were similar in all individual leachates from lysimeters not given potassium (Experiment 1). Where potassium was given, this ratio greatly increased after 24 litres of water was added. Therefore, in this soil fertiliser potassium was leached less rapidly than the chloride co-ion (recovered in leachates 8-24) but the delay in K leaching was only six weeks during which time the equivalent of about 100 mm of rainfall passed through the 56 cm profile. In the second experiment using soil containing more exchangeable calcium, $K/\sqrt{(Ca+Mg)}$ ratios in all leachates from lysimeters

treated and untreated with potassium chloride were similar. This suggests that all the added fertiliser K remained in the lysimeters; a result confirmed by the soil analyses made after leaching.

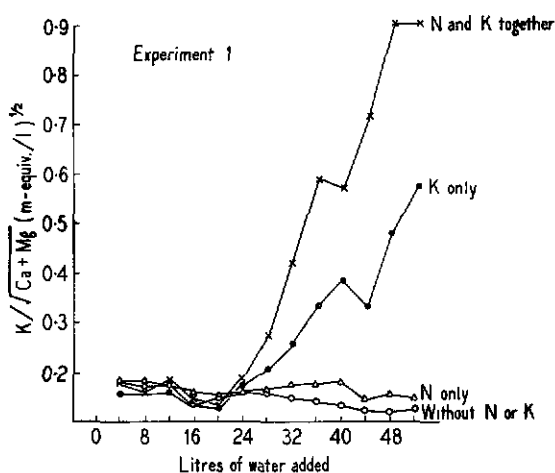


Figure 2. Potassium activity ratios in leachates from lysimeters treated and untreated with ammonium sulphate (N) and potassium chloride (K). Each value is the mean of four lysimeters.

Magnesium fertiliser was only applied in the first experiment (with the more acid soil) $Mg/(Ca+Mg)$ ratios in the leachates were similar for all lysimeters without any magnesium additions. Magnesium sulphate by itself slightly increased $Mg/(Ca+Mg)$ ratios in the leachates but, when applied together with ammonium sulphate, this ratio was considerably increased after 16 litres of water had been added (Figure 3). This shows that fertiliser Mg

leached nearly as rapidly through the soil profile as nitrate derived from ammonium sulphate.

Soil Analyses after Leaching

After leaching, the lysimeter profiles were dissected into six horizons and the air-dried soil in each horizon weighed. Sub-samples were then analysed for pH, exchangeable cations, nitrate, sulphate and 'available' phosphate.

Soil analyses confirmed the effects of fertilisers on nutrient leaching deduced from analyses of the leachates *i.e.*, nutrients not leached were recovered from the soils. However, for most cations and anions, the distribution of fertiliser residues was not uniform down the soil profiles; phosphate and calcium remained in the surface layers of soil, nitrate was recovered mainly from the bottom layers of soil in the lysimeters.

Figure 5 shows the distribution of nitrate in the soil profiles. Differences between treatments were not found in individual horizons. Nitrate-N concentrations increased with depth from 1 p.p.m. in the top to 4 p.p.m. in the bottom of the profiles.

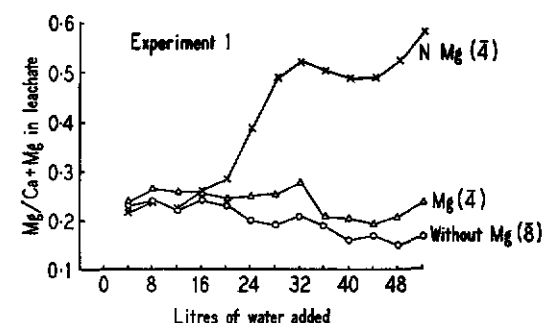


Figure 3. Ratios of magnesium/calcium plus magnesium in leachates from lysimeters treated and untreated with magnesium sulphate (Mg) and ammonium sulphate (N). Figures in parentheses show the number of lysimeters used.

TABLE 4. EFFECTS OF ROCK PHOSPHATE AND SUPERPHOSPHATE ON NH_4F/HCl SOLUBLE P* AT DIFFERENT DEPTHS AFTER LEACHING

Depth (cm)	Experiment 1			Experiment 2		
	Without P	Rock phosphate Without N	With N	Without P	Superphosphate Without N	With N
2.5	2.8	103.1	129.4	4.2	123.2	135.3
10.0	2.8	3.7	4.0	7.3	15.8	14.3
18.0	2.7	2.5	2.7	7.9	8.8	8.0
25.0	2.6	2.5	3.0	8.1	8.4	7.7
40.0	2.7	2.5	2.8	8.7	8.0	8.4
60.0	2.9	2.6	2.7	8.2	8.3	7.9
Before leaching		3.9			8.5	

* p.p.m. in soil

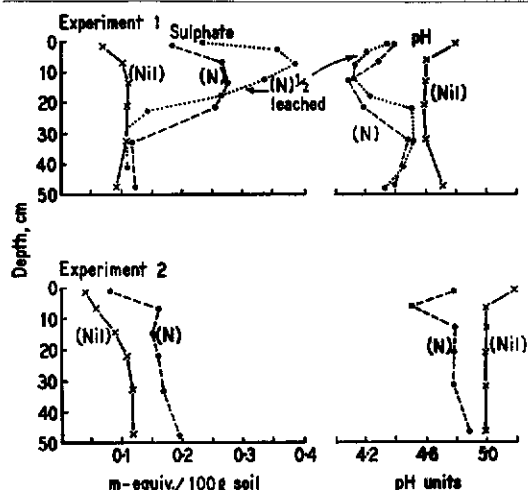


Figure 4. Values of pH and amounts of sulphate at different depths in the lysimeters after leaching. Treatments in parentheses.

The amounts of phosphate in the soils that were soluble in a $\text{HCl}/\text{NH}_4\text{F}$ extract (Table 4) show that rock and superphosphate P mostly

remained in the surface 2.5 cm. There was a slight increase in soluble P at 2.5–10 cm from rock phosphate and a larger increase in this horizon from superphosphate. Below 10 cm, soluble P was similar to values determined before leaching.

The distribution of sulphate down the profile after leaching was different in the two experiments. In the more acid soil, the applied sulphate was mostly recovered from the 0–30 cm depth; but, in the less acid soil (from which more sulphate was leached), sulphate was increased similarly in all horizons where ammonium sulphate was given (Figure 4). Sulphate measurements down the profile of an extra lysimeter removed from the first experiment after half the added N had leached are also shown in Figure 4. Most sulphate was recovered from the top 20 cm of soil and larger amounts were adsorbed than when all the N had leached.

Sulphate adsorption lowered the measured pH especially of the more acid soil (Figure 4). This interesting result will be discussed in

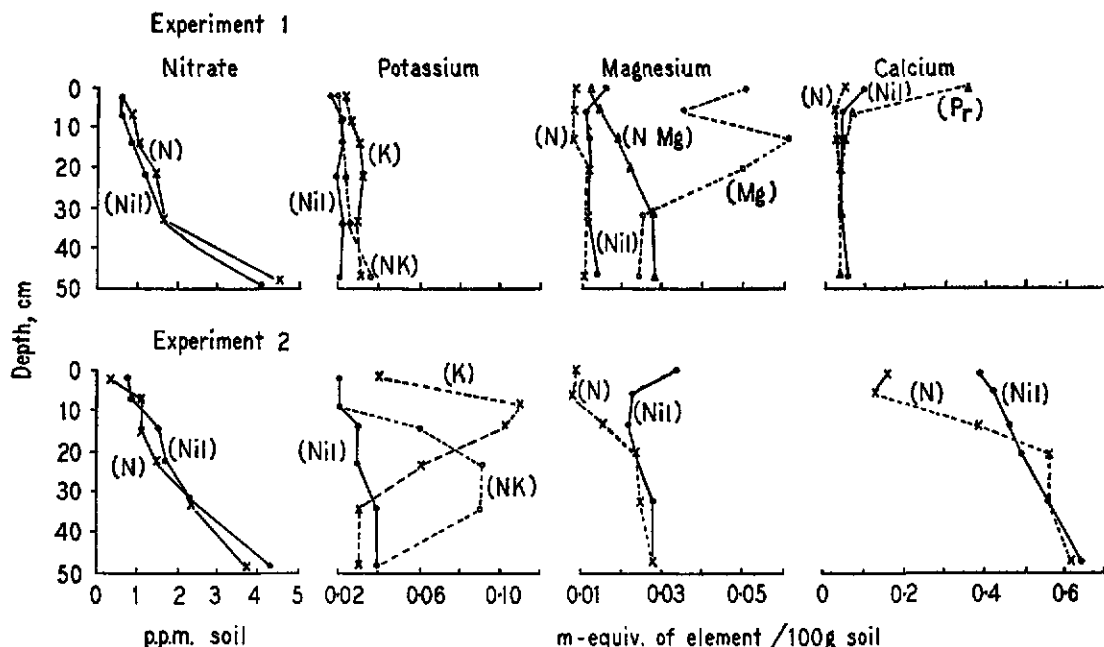


Figure 5. Amounts of nitrate and exchangeable cations in the soils at different depths after leaching. Treatments in parentheses.

more detail elsewhere. The brief description of the results of soil analyses confirms the deductions from leachate analyses that sulphate was adsorbed more strongly at pH 4.8 than at pH 5.2 in this soil.

The distribution of exchangeable potassium in the profiles after leaching was also different in the two soils. It has already been shown that fertiliser K leached rapidly through the profile of the more acid soil. Exchangeable K in this soil was larger where potassium had been given in all horizons below 10 cm depth. In the other soil (pH 5.2), a 'chromatographic' pattern had developed down the profile. Exchangeable K was similar for all treatments at the bottom of the lysimeters. The main zone of fertiliser K accumulation was at 10 cm depth in lysimeters with KCl only added, and

at 25–35 cm in lysimeters with KCl and ammonium sulphate added together (*Figure 5*).

Magnesium sulphate when applied alone increased exchangeable Mg throughout the profile of the acid soil but most in the surface 20 cm. Where this fertiliser was applied together with ammonium sulphate, more magnesium was lost and the largest increases in exchangeable Mg were at the bottom of the lysimeters. In the upper horizons, most of the added magnesium had leached and exchangeable Mg was only slightly more than in untreated lysimeters (*Figure 5*). In the second experiment, which did not include magnesium treatments, the analyses showed that ammonium sulphate had decreased exchangeable Mg only in the upper soil horizons (*Figure 5*).

Table 5 gives exchangeable Ca analyses in

TABLE 5. EFFECTS OF AMMONIUM SULPHATE (N), ROCK PHOSPHATE (P_r) AND SUPERPHOSPHATE (P_s) ON EXCHANGEABLE CALCIUM AND pH OF THE SOILS AT DIFFERENT DEPTHS AFTER LEACHING

Depth (cm)	Experiment 1				Experiment 2							
	Nil	N	P _r	NP _r	Nil	N	P _s	NP _s	Ca	NCa	P _s Ca	NP _s Ca
	Exchangeable calcium (m-equiv./100 g soil)											
2.5	0.10	0.06	0.36	0.35	0.39	0.16	0.81	0.59	4.84	4.86	4.96	5.02
10.0	0.05	0.03	0.07	0.06	0.42	0.12	0.52	0.16	0.50	0.20	0.56	0.42
18.0	0.04	0.03	0.05	0.04	0.46	0.38	0.54	0.38	0.54	0.50	0.55	0.28
25.0	0.04	0.04	0.05	0.04	0.49	0.56	0.55	0.58	0.58	0.64	0.56	0.47
40.0	0.04	0.04	0.05	0.05	0.57	0.56	0.61	0.58	0.62	0.66	0.62	0.62
60.0	0.05	0.04	0.04	0.05	0.61	0.64	0.66	0.72	0.65	0.74	0.69	0.72
Before leaching	0.11				1.10							
	pH											
2.5	4.9	4.6	5.0	5.0	5.2	5.2	5.4	5.0	7.4	7.3	7.1	7.2
10.0	4.6	4.3	4.6	4.4	5.1	4.6	5.1	4.6	5.2	4.8	5.1	4.7
18.0	4.6	4.2	4.6	4.2	5.0	4.8	5.0	4.8	5.2	4.8	5.0	4.6
25.0	4.6	4.4	4.6	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.8
40.0	4.6	4.5	4.6	4.4	5.0	4.8	5.0	4.9	5.0	5.0	4.8	4.9
60.0	4.5	4.5	4.5	4.5	5.0	4.9	5.0	4.9	5.0	4.9	4.8	4.8
Before leaching	4.8				5.2							

the profiles of lysimeters treated and untreated with ammonium sulphate and rock phosphate (Experiment 1) averaged over all K and Mg treatments. Rock phosphate increased exchangeable Ca mostly in the surface 2.5 cm of soil, slightly in the 2.5–10 cm horizons but not below 10 cm. Ammonium sulphate lessened exchangeable Ca only in the top 18 cm of soil. In the second experiment also, ammonium sulphate lessened exchangeable Ca in the top 18 cm of soil but not below. The losses of calcium were larger from the soil that initially contained larger amounts of exchangeable Ca. Superphosphate and limestone increased exchangeable Ca only in the surface soil. The results for limestone were surprising since relatively large amounts of calcium were added—amounts sufficient to saturate the exchange complex in the surface 2.5 cm of soil where the pH was increased to 7.2. Even when ammonium sulphate was applied with the limestone, exchangeable Ca and pH were hardly affected below 2.5 cm depth (Table 5).

Recovery of Anions and Cations from Soil and Fertilisers

Losses of some cations in the leachates were large in relation to total amounts initially present. Forty per cent of the exchangeable K in the more acid soil was leached from lysimeters untreated with fertilisers. Fifty-one per cent was lost from lysimeters treated with ammonium sulphate. In the second experiment, more calcium but less potassium was leached; 17% of exchangeable K initially present was leached from untreated soil and 20% from soils, given ammonium sulphate. Of the potassium added as potassium chloride, 14% was leached from the more acid soil without added N and 28% in its presence. In the less acid soil, less than 5% of the added potassium was removed in the leachates both with and without N. Overall recovery of fertiliser potassium from the residual soils and leachates was only 66% in the first experiment and 90% in the second. No satisfactory explanation can be given for the small recovery in the first experiment. Potassium fixation would not be expected in soils with mainly kaolinite clay fractions; NG (1965) found that Serdang series

soil fixed less than 5% of added K in laboratory experiments.

There was a'so much leaching of both native and added magnesium. In the untreated lysimeters of the first experiment, 35% of exchangeable Mg initially present was leached and this was increased to 45% by adding N. Less than 4% of the added Mg was leached when magnesium sulphate alone was applied, but 59% was leached when this fertiliser and ammonium sulphate were applied together. Less than 2% of the exchangeable magnesium originally present in the less acid soil was leached, even when ammonium sulphate was given.

A larger proportion of the exchangeable calcium initially present in the more acid soil was leached (40% without and 58% with ammonium sulphate). In the second experiment, 11% of the exchangeable Ca was leached from untreated lysimeters, and 16% from lysimeters treated with ammonium sulphate. No calcium was leached from the added limestone and superphosphate.

DISCUSSION

A common method of replanting old rubber areas in Malaya involves felling and removal or burning of the old stand, ploughing, then planting a cover crop (mainly *Pueraria phaseoloides*) and the new rubber seedlings. The soil is therefore free of vegetation for several months and conditions resemble those in the lysimeters. The planting rows (about a quarter of the ground area) are kept free of weeds for at least eighteen months during which time tree roots develop until they explore the whole area of cleared ground. Clearly, large amounts of nitrate from mineralised organic matter leach through the soil profile during this period. These lysimeter studies show that this will cause considerable losses of exchangeable cations from the top soil. However, losses of calcium are not of major importance because *Hevea* requires less of this nutrient for normal growth than most other crops (BOLLE-JONES, 1954) and calcium deficiencies rarely occur in rubber trees in Malaya (SHORROCKS, 1964). Potassium and magnesium are more important and deficiencies of these elements in

trees grown on latosols are widespread. To be used efficiently, fertiliser must be applied at rates and frequencies such that the trees can take up the nutrients before they are leached from the root zone. These experiments show that a significant proportion of potassium and magnesium added with ammonium sulphate are leached below 60 cm depth in six months when the equivalent of about 710 mm of rain is added to the soil surface.

The strong adsorption of sulphate by both soils suggests that potassium sulphate may be a more efficient fertiliser than potassium chloride for crops grown on latosols. The slower leaching of sulphate than chloride would ensure that associated cations remain longer in the top soil and have a greater chance of uptake by plant roots. Experiments are needed to test this, especially with crops such as oil palm (grown on latosols in Malaya) requiring much potassium.

The ratios of potassium, calcium and magnesium in leachates are a function of those adsorbed on the exchange complex and at different anion concentrations, the Ratio Law (SCHOFIELD, 1947) applies. Therefore, losses of potassium and magnesium from surface soil may be lessened by increasing the percentage saturation of the exchange complex with calcium *e.g.*, with limestone. However, the experiments show that this can only be done in reasonable period by mixing limestone mechanically throughout the soil profile. Leaching of calcium from surface applications of limestone was negligible in the experiments. Also, soil pH was increased to neutral in the top 2.5 cm of soil, but hardly changed below. Local high-pH sites, especially at the soil surface, can create problems for 'calciphobes' such as rubber.

Hevea grows badly in soils of pH greater than 6.5 (RUBBER RESEARCH INSTITUTE OF MALAYA, 1960). MIDDLETON AND PUSHARAJAH (1966) suggested that much calcium in the trees is associated with latex instability (pre-coagulation).

Soil calcium may be increased better by ploughing in rock phosphate before planting since phosphate also remains in the surface horizons. Experiments have shown that such

practice gives better growth of leguminous cover plants than surface applications of rock phosphate (RUBBER RESEARCH INSTITUTE OF MALAYA, 1965).

In these highly leached soils, moderate fertiliser applications potentially increase amounts of cations and anions available to plants considerably; 1.5 cwt/acre of potassium chloride (18.4 m-equiv./lysimeter) added more potassium than was already present in the exchangeable form in the whole 60 cm lysimeter profile (12.7 m-equiv.) of the experimental soils. The same amount of magnesium sulphate also potentially increased the soil exchangeable Mg by 50%. Rock phosphate applied at 3 cwt/acre doubled the amount of calcium in the same depth of the more acid soil; it also added much more phosphate (437 mg/lysimeter) than was originally present as 'available' P in the whole profile (166 mg) and was a significant addition to the total P (originally 4250 mg/lysimeter). It is not surprising therefore that fertiliser effects on soil and plant composition are easily measured and that growth of plants can be affected for many years after fertilisers are applied, even in small amounts. WATSON (1964) and SHORROCKS (1965), who related amounts of nutrients in these soils and in normal fertiliser dressings with amounts in rubber trees of different ages, found that fertilisers are essential to satisfy the needs of trees grown on latosols.

These experiments show how cations and anions leach down the profile of a typical soil used to grow *Hevea*. In general, the results support current agronomic practices, especially the importance of minimising anion leaching by early establishment of suitable cover plants and adding frequent small dressings of fertilisers during early growth of the trees when the root range is limited.

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REFERENCES

- BERG, W.A. AND THOMAS, G.W. (1959) Anion elution patterns from soils and soil clays. *Proc. Soil Sci. Soc. Am.*, **23**(5), 348.
- BOLLE-JONES, E.W. (1954) Nutrition of *Hevea brasiliensis* III. The inter-relationships of magnesium, potassium and phosphorus *J. Rubb. Res. Inst. Malaya*, **14**, 231.
- BOLLE-JONES, E.W. (1956) A glasshouse suitable for physiological investigations on plants grown in the tropics. *Emp. J. exp. Agric*, **24**(96), 331.
- BOLTON, J. (1961) The effect of fertilisers on pH and the exchangeable cations of some Malayan soils. *Proc. nat. Rubb. Res. Conf. Kuala Lumpur* 1960, 70.
- BOLTON, J. (1963) A study of the leaching of commonly used fertilisers on Malayan latosols used for the cultivation of *Hevea brasiliensis* Thesis submitted for the degree of Master of Science, University of Leeds.
- BOLTON, J. (1964) The manuring and cultivation of *Hevea brasiliensis*. *J. Sci. Fd Agric.*, **15**, 1
- BRAY, R.H. AND KURTZ, L.T. (1945) Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci*, **59**(1), 39.
- GUHA, M.M. AND WATSON, G.A. (1958) Effects of cover plants on soil nutrient status and on growth of *Hevea* I. Laboratory studies on the mineralisation of nitrogen in different soil mixtures. *J. Rubb. Res. Inst. Malaya*, **15**(4), 175.
- KELLOG, C.E. (1950) Tropical soils *Trans. int Congr. Soil Sci Amsterdam* 1950, Volume I, 266.
- MAINSTONE, B.J. (1963) Manuring of *Hevea* VI. Some long-term manuring effects, with special reference to phosphorus, in one of the Dunlop (Malaya) experiments. *Emp. J. exp. Agric.*, **31**(122), 175.
- MIDDLETON, K.R. AND PUSHPARAJAH, E. (1966) The use of phosphates in the cultivation of *Hevea brasiliensis* in Malaya. *Outl. Agric.*, **5**(2), 69.
- NG, S.K. (1965) The potassium status of some Malayan soils. *Malay agric. J.*, **45**(2), 143.
- NYE, P.H. AND GREENLAND, D.J. (1960) The soil under shifting cultivation. *Tech. Commun. Commonw. Bur Soils No. 51*
- RUBBER RESEARCH INSTITUTE OF MALAYA (1960) Soil reaction and rubber cultivation. *Plrs' Bull. Rubb Res. Inst. Malaya No. 50*, 98.
- RUBBER RESEARCH INSTITUTE OF MALAYA (1965) *Rep. Rubb. Res. Inst. Malaya*, 1964, 25.
- SCHOFIELD, R.K. (1947) A ratio law governing the equilibrium of cations in the soil solution. *Proc. 11th int Congr. pure appl. Chem. London* 1947, Volume III, 257.
- SHORROCKS, V.M. (1964) *Mineral Deficiencies in Hevea and Associated Cover Plants* Kuala Lumpur: Rubber Research Institute of Malaya.
- SHORROCKS, V.M. (1965) Mineral nutrition, growth and nutrient cycle of *Hevea brasiliensis* II. Nutrient cycle and fertiliser requirements *J. Rubb. Res. Inst. Malaya*, **19**(1), 48
- WATSON, G.A. (1964) Maintenance of soil fertility in the permanent cultivation of *Hevea brasiliensis* in Malaya *Outl. Agric.*, **4**(3), 103.
- WETSELAAR, R. (1960) Capillary movement of nitrate towards tropical soil surfaces. *Nature, Lond*, **186**(4724), 572.