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Effects of Nitrogenous Fertilisers on Growth of Rubber Seedlings and Leaching Losses of Nutrients

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Large dressings of ammonium sulphate increased the growth of leaves, stems and petioles of Hevea seedlings grown in a sandy soil in lysimeters more than ammonium nitrate and much more than urea. Root growth was suppressed by these fertilisers, especially at double rates. More nitrogen was leached from ammonium nitrate than from ammonium sulphate or urea. Nitrogenous fertilisers significantly increased leaching of K, Ca and Mg, while potassium fertilisers increased the movement of NH_4, Ca and Mg ions in the soil and slowed the growth of the rubber seedlings. The pH of the surface soil (0 – 8 cm) was increased by urea but decreased by the other nitrogenous fertilisers, especially ammonium sulphate; below 8 cm the pH of treated soils always decreased.

Nitrogenous fertilisers comprise almost half of all fertilisers used in rubber cultivation in West Malaysia. Ammonium sulphate, ammonium nitrate and urea are the commonest commercially available forms. Their efficiency in promoting growth of rubber trees depends on the amounts of ammonium- and nitrate-nitrogen supplied to the trees and their overall effect on the cation- and anion-levels in the soil.

Relatively large amounts of fertilisers are applied to rubber trees during the immature period, particularly during the first year. In the manuring schedule given by the RUBBER RESEARCH INSTITUTE OF MALAYA (1963), the amount of nitrogen recommended for one-year-old rubber plants is about 6.9 tonnes per hectare per year, applied in a circle of 30.5 cm radius around the plant. Due to the limited root development of young plants, such high levels of fertilisers result in considerable leaching losses, as the plants are unable to fully utilise the nutrients supplied. Leaching is increased by rainfall, especially if the soil is sandy and highly porous. In the present study, leaching of ammonium- and nitrate-nitrogen from the three nitrogenous fertilisers was investigated with cropped glasshouse lysimeters. The influence of these fertilisers on the growth of rubber seedlings, leaching losses of other cations and the effect of potassium chloride on leaching losses of nitrogen were also studied.

EXPERIMENTAL

Approximately 44 kg air-dried and sieved soil (2 mm mesh), taken from depths of 3 – 15, 15 – 31 and 31 – 61 cm was used in each lysimeter. The top layer of soil was discarded because of the presence of a high proportion of organic debris and feeding roots of plants. Serdang series soil (OWEN, 1951), a fine sandy loam latosol derived from sandstone parent material, was used as it is commonly found in the rubber-growing areas of West Malaysia. The physical and chemical properties of the test soil are shown in *Table 1*.

Two levels of ammonium sulphate, ammonium nitrate, urea and potassium chloride (*Table 2)* were applied in a factorial experi-

COMMUNICATION 570

TABLE 1. PROPERTIES OF SOIL USED IN LYSIMETER

Property	Soil depth (cm)		
	0 - 15	15 - 31	31 - 61
Texture [a]			
Coarse sand (%)	40.7	43.0	40.8
Fine sand (%)	29.5	24.7	25.3
Silt (%)	1.8	2.7	2.1
Clay (%)	22.0	24.7	27.6
Chemical properties			
pH	4.8	4.80	4.80
Organic carbon (%)	1.06	0.61	0.37
Total nitrogen (%)	0.094	0.054	0.046
K (m.e., % acid extractable)	0.26	0.22	0.24
Exchangeable	0.07	0.04	0.04
Ca (m.e., %) Acid extractable	0.26	0.20	0.23
Exchangeable	0.16	0.06	0.15
Acid extractable	0.88	1.00	1.10
Mg (m.e., %) Exchangeable	0.08	0.03	0.04
Clay minerals [b]			
Kaolinite (%)	←— 50 - 65 —→		
Gibbsite (%)	←— 1 - 5 —→		
Chlorite vermiculite (%)	←— 5 - 10 —→		
Illite (%)	←— 35 - 50 —→		

[a] Particle size as in International Textural Classification determined by pipette method.

[b] Data from SINGH, M.M. (1970).

TABLE 2. TOTAL AMOUNTS OF FERTILISERS APPLIED TO LYSIMETERS

Fertiliser	Level	Rate of application per lysimeter (g)	Total amount applied (g)	Equivalent to tonnes/ha
Ammonium sulphate (21% N)	1 (A_1) 2 (A_2)	11.43 22.86	68.58 137.16	9.39 18.78
Ammonium nitrate (26% N)	1 (N_1) 2 (N_2)	9.23 18.46	55.38 110.76	7.58 15.16
Urea (45% N)	1 (U_1) 2 (U_2)	5.33 10.66	31.98 63.96	4.38 8.76
Potassium chloride (60% K_2O)	0 (K_0) 1 (K_1)	– 6.66	– 39.96	– 5.47
C.I.R.P. (36% P_2O_5)	Uniform application	11.40	68.40	9.36
Kieserite (26% MgO)	Uniform application	2.30	13.80	1.89

ment with three replications. Christmas Island rock phosphate and kieserite were given at uniform rates in all the lysimeters, the instruments used being similar to those described by BOLTON (1968).

The lysimeter was packed in stages; soil from the 31 – 61 cm depth was filled first and that from the 3 – 15 cm depth last. At each stage, the soil was 'settled' by slowly adding rain water. Leachate was collected under tension to eliminate the abnormal moisture conditions often obtained in confined lysimeters (COLEMAN, 1946; COLE, 1958). This was achieved by connecting the outlet tube of each lysimeter to a Winchester bottle which in turn was connected to a vacuum pump which gave a negative pressure of about 10 cm mercury.

Three Tjir 1 seedlings were planted in each lysimeter and the weakest of the three removed after two months. Fertilisers, at the rates shown in *Table 2*, were applied one month after planting and thereafter at fortnightly intervals for six months. The rates used were nearly similar to those used in the field during the first six months (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963). The plants were harvested after seven months, and dry weights of leaves, stems and roots were recorded and analysed for nitrogen, phosphorus, potassium, calcium, magnesium and manganese.

Rain water (500 ml, equivalent to 0.69 cm rainfall) was applied daily to each of the lysimeters, and the leachates, collected in black Winchester bottles, were removed at fortnightly intervals and their volumes measured and contents analysed.

The first application of fertilisers scorched some plants. The rate of application was therefore halved and the frequency increased (to fortnightly intervals) from the fourth to the twenty-sixth week, with a break at the

TABLE 3. EFFECT OF NITROGEN AND POTASSIUM FERTILISERS ON THE DRY WEIGHT OF RUBBER SEEDLINGS

Treatment	Dry mattter per pot (g)			
	Leaves	Stem + petiole	Root	Total
Nitrogen effect				
Level 1				
Ammonium nitrate	37.5	103.0	44.8	185.3
Ammonium sulphate	52.5	156.0	59.8	268.3
Urea	25.0	68.2	35.7	128.9
s.e. ±	4.24	5.76	3.57	10.80
Min. sig. diff. (5%)	12.3	16.8	10.4	31.4
Level 2				
Ammonium nitrate	22.2	50.3	22.5	95.0
Ammonium sulphate	20.2	51.5	26.2	97.9
Urea	11.5	40.8	25.2	77.5
s.e. ±	4.24	5.76	3.57	10.80
Min. sig. diff. (5%)	12.3	16.8	10.4	31.4
Control	14.9	58.5	53.0	126.4
Nitrogenous fertilisers	28.2	78.3	35.7	142.2
s.e. of diff. ±	4.58	6.23	3.86	11.67
Min. sig. diff. (5%)	9.4	12.8	7.9	24.0
Potassium effect				
No potassium chloride	30.8	82.1	43.0	155.9
Potassium chloride	21.7	68.9	33.4	124.0
s.e. ±	2.27	3.08	1.91	5.78
Min. sig. diff. (5%)	6.6	9.0	5.6	16.8

twelfth and fourteenth week. Although the pattern of leaching was affected by this method of application, overall leaching losses from the various treatments were still comparable.

At the end of the experiment the lysimeter profiles were sampled with a soil core sampler at 0 – 15, 15 – 31 and 31 – 61 cm depths, and sub-samples from each horizon analysed for pH, ammonium- and nitrate-nitrogen content.

Analytical Methods

Ammonium- and nitrate-nitrogen in leachates were determined by the Nesslerisation (Middleton, 1960) and Orange I (Middleton, 1959) methods respectively. In soil, ammonium- and nitrate-nitrogen were extracted with 2*N* potassium chloride before distillation. The extractant was distilled with magnesium oxide for ammonium-nitrogen and with magnesium oxide and Devarda alloy for nitrate-nitrogen. Ammonia in solution was titrated with 0.005 *N* sulphuric acid. Potassium, calcium and magnesium in leachates were analysed by atomic absorption spectrophotometry. In soil, total cations were extracted with 1:1 hydrochloric acid, whereas neutral *N* ammonium acetate was used to extract the 'exchangeable' forms. The pH was measured in a 1:5 soil-water suspension.

RESULTS

Effect on Growth

The dry weights of leaves, stems and roots of the plants are shown in *Table 3*. At the first level of application, ammonium sulphate gave better growth than ammonium nitrate or urea, the latter giving the poorest growth. The second level of application of all three fertilisers depressed the growth of the seedlings, possibly due to the initial scorching of the plants by ammonium sulphate and ammonium nitrate; no significant difference could be detected in the effects of the three fertilisers. Although plants receiving no nitrogen had the lowest dry weight of leaves, stems and petioles, their root production was significantly higher than in other treatments.

Potassium chloride depressed growth, resulting in reduced weights of leaves, stems, petioles and roots.

Effect on Uptake of Nutrients

The effect of ammonium nitrate, ammonium sulphate and urea on the total uptake of nitrogen, potassium, calcium and magnesium by the seedlings is shown in *Table 4*. More of the nitrogen was taken up by plants when nitrogen was applied as ammonium sulphate, and least from urea. Nitrogen uptake was two to six times greater in plants receiving nitrogen than those not receiving nitrogen.

TABLE 4. TOTAL NUTRIENT UPTAKE BY RUBBER SEEDLINGS FROM VARIOUS NITROGENOUS FERTILISERS

Treatment[a]	Nutrient uptake (g/pot)			
	N	K	Ca	Mg
K_0	0.91	0.88	0.39	0.92
K_1	0.94	1.57	0.17	0.59
N_1K_0	4.12	0.68	0.55	1.33
N_1K_1	2.98	1.91	0.26	0.87
N_2K_0	3.62	0.30	0.35	0.71
N_2K_1	1.90	1.05	0.14	0.33
U_1K_0	2.20	0.54	0.33	0.84
U_1K_1	1.58	1.88	0.20	0.74
U_2K_0	1.52	0.32	0.16	0.47
U_2K_1	1.44	0.97	0.11	0.33
A_1K_0	6.14	0.75	0.68	1.46
A_1K_1	4.36	2.73	0.39	1.08
A_2K_0	2.46	0.25	0.22	0.47
A_2K_1	2.16	0.93	0.15	0.48

[a] See *Table 2*

All values are means of three replications.

Potassium chloride depressed the uptake of nitrogen in all cases where nitrogen was applied, but increased the uptake of potassium. In the absence of potassium chloride, nitrogenous fertilisers depressed the uptake of potassium, particularly at the higher rate of application. However, an increased uptake of potassium was observed when both nitrogen (at the lower level) and potassium were applied, ammonium sulphate giving the highest uptake.

The amounts of calcium and magnesium taken up by the plants were affected by both nitrogen and potassium. While the lower level of nitrogen generally increased the uptake of both these nutrients, potassium chloride depressed it. At the higher rate of nitrogen application, less calcium and magnesium were taken up, but this could be due to a retardation of growth as a result of the plants having been scorched.

Leaching of Plant Nutrients

Volume of leachate. The amount of leachate collected before the rubber seedlings were planted was approximately the same in all lysimeters. However, the subsequent variable growth of the plants (due to the different treatments) resulted in varying amounts of leachate collected from a minimum of 15.4% of the added water in the N_1K_0 treatment to 40.8% in the U_2K_0 treatment *(Table 5)*.

Leaching of ammonium-nitrogen. The total amounts of ammonium-nitrogen leached from the two levels of each of these fertilisers are shown in *Table 6*. Significant differences in the effects of the three types of fertilisers were established, with ammonium sulphate having the greatest loss, and urea the least. Very small quantities of ammonium ions were leached out from the control (non-fertilised) lysimeter. The leaching of ammonium ions at the higher rate of application of nitrogen was three to four times that at the lower level of application.

Potassium chloride (40 g per lysimeter) increased the leaching of ammonium ions

TABLE 5. TOTAL VOLUME OF LEACHATE FROM LYSIMETER

Treatment[a]	Mean volume per pot (litres)	Total water applied (%)
K_0	18.1	16.5
K_1	29.8	27.1
N_1K_0	16.9	15.4
N_1K_1	22.9	20.8
N_2K_0	30.4	27.6
N_2K_2	40.9	37.2
U_1K_0	23.9	21.7
U_1K_1	31.4	28.5
U_2K_0	44.9	40.8
U_2K_1	41.5	37.7
A_1K_0	16.9	15.4
A_1K_1	17.5	15.9
A_2K_0	34.1	31.9
A_2K_1	35.5	32.3

[a] See *Table 2*

from all three fertilisers at both levels of application. This effect was highly significant, and even in the control lysimeter (where no nitrogen was applied) potassium increased the leaching of ammonium ions.

Leaching of nitrate-nitrogen. Nitrate appeared in appreciable amounts in the leachates from all three nitrogenous fertilisers two weeks after application. There was a greater fluctuation in the amount of nitrate in the leachates than in the amount of ammonium ions, particularly in the lysimeters treated with ammonium nitrate. An average of 0.5 g nitrate was leached from the control lysimeter. There was a significant difference in the loss of nitrate from the nitrogenous fertilisers, with ammonium nitrate having the greatest loss and ammonium sulphate the least at both levels of application *(Table 6)*. More nitrate was lost from ammonium nitrate in lysimeters to which potassium chloride had been added. This was not so with ammonium sulphate and urea, particularly at the higher level of application where a decrease in leached nitrate was observed in lysimeters to which potassium chloride had been added.

Total nitrogen. The greatest loss of nitrogen through leaching occurred with ammonium sulphate. Approximately equal amounts of nitrogen were lost from ammonium sulphate and urea at the first level of application, but at higher levels the loss from the former was significantly greater.

Leaching of potassium, calcium and magnesium. Both levels of nitrogen led to a significant increase in the leaching of potassium, calcium and magnesium, although there were no significant differences in the different nitrogenous fertilisers in enhancing such losses *(Table 6)*. Only at the lower level of application was the leaching of potassium from ammonium nitrate significantly greater than from ammonium sulphate.

Application of potassium chloride increased the leaching of calcium and magnesium only where additional nitrogen was not applied.

Effect on Nitrate Content of Soil

Table 7 shows the amount of ammonium- and nitrate-nitrogen (p.p.m.) at each depth of the lysimeter profile. In the control lysimeter the application of potassium chloride decreased the nitrogen content in the first three depths, whereas in the lower horizon (31 – 61 cm) an accumulation of ammonium ions was observed. This suggests that potassium chloride caused a vertical movement of ammonium ions down the profile. Such movement was also evident in lysimeters treated with ammonium sulphate and ammonium nitrate. However, there was no accumulation of ammonium-nitrogen at the lower part of the profile in the urea treatment, even in the presence of potassium chloride.

TABLE 6. LEACHING OF AMMONIUM-NITROGEN, NITRATE-NITROGEN, TOTAL NITROGEN AND CATIONS FROM VARIOUS NITROGENOUS FERTILISERS

Treatment	Leaching of nutrients (g/pot)					
	NH_4 - N	NO_3 - N	Total N	K	Ca	Mg
Nitrogen effect						
Level 1						
Ammonium nitrate	2.30	5.11	7.41	4.58	2.06	0.69
Ammonium sulphate	2.33	2.22	4.55	3.19	1.46	0.52
Urea	1.11	3.84	4.94	4.03	1.85	0.71
s.e. ±	0.368	0.302	0.593	0.359	0.319	0.069
Min. sig. diff. (5%)	1.07	0.88	1.73	1.04	0.93	0.20
Level 2						
Ammonium nitrate	8.22	10.29	18.51	5.80	2.57	0.90
Ammonium sulphate	9.40	3.52	12.92	5.00	2.91	0.89
Urea	3.77	7.22	10.99	5.20	2.52	0.92
s.e. ±	0.368	0.302	0.593	0.359	0.319	0.069
Min. sig. diff. (5%)	1.07	0.88	1.73	1.04	0.93	0.20
Control	0.01	0.52	0.53	2.89	0.80	0.24
Nitrogenous fertilisers	4.52	5.37	9.89	4.63	2.35	0.77
s.e. of diff. ±	0.398	0.326	0.641	0.387	0.345	0.074
Min. sig. diff. (5%)	0.82	0.67	1.32	0.80	0.71	0.15
Potassium effect						
No potassium chloride	3.29	4.56	7.85	0.40	2.07	0.63
Potassium chloride	4.46	4.79	9.25	8.37	2.18	0.77
s.e. ±	0.197	0.161	0.317	0.192	0.171	0.037
Min. sig. diff. (5%)	0.57	0.47	0.92	0.56	0.50	0.11

Nitrate accumulated at the lower part of the profile in lysimeters containing ammonium nitrate and urea, but not in those containing ammonium sulphate *(Table 7)*. In the ammonium sulphate treatment there was a slight increase in nitrate content at the lower depth at the first level of application, but at the higher rate of application the distribution of nitrate was more uniform.

Effect on pH Changes in Soil

The effects of nitrogen and potassium fertilisers on the pH of the soil are shown in *Table 8*. All lysimeters (except the control) showed a depression in pH at increasing depths, especially with ammonium sulphate. Urea, and to a lesser extent ammonium nitrate, increased pH in the 0 – 8 cm soil

TABLE 7. EFFECT OF NITROGENOUS FERTILISERS ON AMMONIUM AND NITRATE NITROGEN CONTENT OF SOIL (P.P.M.)

Treatment[a]	Soil depth (cm)							
	3 – 8		8 – 15		15 – 31		31 – 61	
	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
K_0	7.0	1.7	6.2	0.5	5.9	0.2	1.9	0.6
K_1	6.5	3.1	5.6	2.2	4.7	2.4	3.8	1.7
N_1K_0	16.2	21.9	23.7	19.9	22.5	22.0	51.2	117.2
N_1K_1	9.8	26.3	23.4	35.5	25.9	38.7	56.1	87.2
N_2K_0	92.5	49.0	108.7	49.1	103.5	66.3	156.1	153.5
N_2K_1	44.6	28.1	54.5	36.1	57.4	42.7	114.9	106.9
U_1K_0	19.3	35.6	26.4	33.1	17.3	32.7	16.2	81.9
U_1K_1	9.2	35.4	22.1	33.3	15.2	28.5	16.3	50.0
U_2K_0	142.9	19.7	110.0	34.3	59.9	45.1	45.4	65.6
U_2K_1	72.2	20.3	56.3	45.7	38.4	42.0	48.3	52.4
A_1K_0	55.7	9.2	89.9	4.3	72.6	6.5	74.1	14.5
A_1K_1	44.7	7.5	100.0	7.2	85.6	8.1	85.0	15.4
A_2K_0	115.2	18.7	157.3	16.3	144.8	19.5	237.0	15.5
A_2K_1	77.5	19.5	126.6	20.5	120.2	21.5	219.0	21.5

[a] See *Table 2*

All values are means of three replicates.

depth. The incorporation of potassium chloride also tended to increase the pH at every depth.

DISCUSSION AND CONCLUSIONS

Ammonium sulphate was a better source of nitrogen than ammonium nitrate or urea, giving (at the lower rate of application) the most dry matter, and urea the least. HAINES AND FLINT (1931) have also shown urea to be inferior to ammonium sulphate as a fertiliser for Hevea. Most of the nitrogen, potassium, calcium and magnesium were taken up from ammonium sulphate-treated lysimeters. The higher level of all three fertilisers depressed the yield of dry matter; the addition of potassium chloride accentuated this effect. Initial scorching of the plants and increased leaching of nitrogen and cations by potassium chloride probably caused the poorer growth of the seedlings; this fertiliser must be used carefully on young rubber plants to avoid scorch and the excessive leaching of other cations.

Root production was significantly higher in lysimeters without nitrogen and potassium. This is because greater amounts of roots are produced when the concentration of nutrients in the soil solution is low. Rubber trees have been found to exploit poorer soils in this way much more intensively than soils rich in nutrients (SOONG, 1970).

Nitrate-nitrogen appeared in the leachates much more rapidly than ammonium-nitrogen, but ammonium also leached after the sixth

TABLE 8. EFFECT OF NITROGENOUS FERTILISERS ON pH OF SOIL

Treatment	Soil depth (cm)			
	0 - 8	8 - 15	15 - 31	31 - 61
	pH units			
Nitrogen effect				
Level 1				
Ammonium nitrate	4.9	4.5	4.4	4.2
Ammonium sulphate	4.6	4.5	4.2	4.1
Urea	4.9	4.4	4.4	4.2
s.e. ±	0.05	0.06	0.01	0.01
Min. sig. diff. (5%)	0.10	0.20	0.03	0.03
Level 2				
Ammonium nitrate	5.0	4.7	4.5	4.4
Ammonium sulphate	4.7	4.8	4.4	4.3
Urea	6.0	4.5	4.7	4.3
s.e. ±	0.05	0.06	0.01	0.01
Min. sig. diff. (5%)	0.10	0.20	0.03	0.03
Control	5.5	4.9	4.8	4.7
Nitrogenous fertilisers	5.0	4.6	4.4	4.2
s.e. ±	0.05	0.03	0.06	0.04
Min. sig. diff. (5%)	0.1	0.1	0.1	0.1
Potassium effect				
No potassium chloride	5.0	4.5	4.4	4.3
Potassium chloride	5.2	4.7	4.6	4.4
s.e. ±	0.02	0.02	0.02	0.04
Min. sig. diff. (5%)	0.1	0.1	0.1	0.1

week. BOLTON (1968) showed that nitrogen loss from nitrogenous fertilisers is mainly in the form of nitrate, with very little as ammonium. However, the amounts of fertiliser applied by Bolton per unit area of land were very much lower than the dosages used in this experiment. In the present study, both ammonium and nitrate ions were leached from the lysimeters. COLE *et al.* (1960) showed that in basic soils, nitrogen is predominantly leached as nitrate, while in acidic soils ammonium predominates in the leachate. Since most West Malaysian soils are acidic, it is possible that a great deal of ammonium-nitrogen is leached out in the percolates. GUHA AND WATSON (1958) have shown that ammonification proceeds much more rapidly than nitrification in West Malaysian soils. Ammonium nitrate suffers a greater loss of total nitrogen than either ammonium sulphate or urea, and there was no significant difference between ammonium sulphate and urea in the total amount of nitrogen lost.

The ease with which urea is hydrolysed in soil is indicated by the presence of nitrate in the leachate within two weeks of its application.

Application of potassium chloride increased the movement of ammonium, calcium and magnesium ions in the soil. Nitrogen fertilisation had an even more pronounced effect, and the overall effect of the nitrogen treatments increased the leaching of potassium by 62%, calcium by 400% and magnesium by 300% compared with non-fertilised lysimeters (*Table 4*). Similar results were obtained in the field by COLE *et al.* (1960).

Repeated applications of urea raised the pH of the soil significantly, particularly at the surface, probably because of the ammonia gas which is released in the hydrolysis of urea. However, below 8 cm, all nitrogenous fertilisers were found to depress pH, particularly at the lowest depth.

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