Tea Q. 50 (3), 105—116, 1981. Printed in Sri Lanka

EFFECT OF NITROGEN FERTILIZATION ON SOIL SOLUTION COMPOSITION ACIDITY AND NUTRIENT LEACHING IN ACID RED-YELLOW PODZOLIC SOILS

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The effect of N-fertilization of soils under the tea crop (*Camellia sinensis L.*) was studied using selected plots from two long term experiments.

Where in (1) A factorial combination of 3 levels of N, 3 levels of K and 3 levels of P were used with ammonium sulphate as the only source of N and in

(2) The different N-sources urea and ammonium sulphate were compared at three levels. A laboratory incubation was also conducted in order to supplement the field data.

All the theoretical changes expected of urea hydrolysis and subsequent nitrification were observed in the incubated soils. A faster initial nitrification was observed in urea treated soils over that of ammonium sulphate treated ones. Soil-solution pH at 20, 40, 60, 80 and 100 cm depths were not sensitive to the surface applied fertilizer transformations under field conditions. A considerable release of cations into the soil solution was observed with the onset of nitrification where as the acidity did not move down even to 20 cm depth. The cation release could be explained by the Donnan equilibrium and the pH-dependent CEC. The nitrate formed did not reach depths lower than 60 cm in either of the experiments. This is determined by the soil texture, plant uptake and also to a certain extent by the gradient of the tea growing hill slope. Though the laboratory incubation showed a large initial nitrification rate of urea N over that of ammonium sulphate the field data did not follow the same trend.

Nitrification markedly affected the soil nutrient concentration by virtue of the H-ion release. The observed trends are in accordance with the changes in the pH-dependent CEC and Donnan equilibrium between the multiionic soil solution and the constant potential clay colloid surface.

INTRODUCTION

Fertilization of the tea crop (*Camellia sinensis L.*) with nitrogen fertilizers such as urea and ammonium sulphate has become important due to the nature of the harvested portion (two leaves and a bud), which removes a substantial portion of the added N from the soil-plant system by virtue of its composition (3-4% N). The use of such fertilizers may have more nutritional effect than merely supplying N, partly because of the fertilizers effect on the behaviour of other nutrients in the soil, changes in adsorption, changes in leaching losses and the implications of the pH effects accompanying the transformations of the fertilizers.

The purspose of this study was to determine the effects of applied fertilizer mixtures containing urea and ammonium sulphate on the soil solution composition and its leaching characteristics.

MATERIALS AND METHODS

Field Experiment (1) Plots were selected from a field experiment in its 13th year designed to study the effect on yield of N (applied as ammonium sulphate) 3 levels of P (applied as rock phosphate) and 3 levels of K (applied as commercial potassium chloride) in all combinations. The soil in the experimental site belong to the Red Yellow Podzolic great soil group and Coombe series (De Alwis *et al*, 1981) plots with the following N K treatments at the highest level of P were used.

N_1K_0 — 112 kg N/ ha/year without K
N_2K_0 — 224 ,, ,,
N_3K_0 — 336 ,, ,,
N_1K_2 — 112 Kg N/ha/year with 116 K Kg/ha/year
N_2K_2 — 224 ,, ,,
N_3K_2 — 336 ,, ,,
N_0K_0 — Control without fertilizer

Since the fertilizer had been given in four equal doses the plots had received one fourth the quantity indicated. The soil solution composition was monitored by using suction soil solution samplers in duplicate at depths 20, 40, 60, 80 and 100 cm respectively, and field soil moisture content was measured using a nutron moisture meter. Measurements were taken over a two month period after a surface broadcast of fertilizer. The extracted soil solutions were analysed NH_4-N, NO_3-N,Ca, Mg and K, and pH. Total nitrate nitrogen content in the profile was calculated by $(NO_3-N)_0^{100} = \sum_0^{100} \theta_z C_z \blacktriangle_z$. where θ_z is the volumetric moisture content at a layzer z cm deep, C_z the concentration of NO_3-N, and $\blacktriangle_z$ the thickness of the layer.

Field Experiment (2) The plots were selected from a two year old field experiment designed to study the effect of two sources of nitrogen, ammonium sulphate and urea at 3 levels each, along with K as commercial potassium chloride at the rate of 135 Kg K/ha/year and rock phosphate 34 Kg P/ha/year. Nitrogen was tested at 3 levels in a rectangular lattice design. The two treatments, 100 Kg N/ha/year and 300 Kg N/ha/year were selected for both N-sources. Soil solution samples were drawn from five depths, 20, 40, 60, 80 and 100 cm and moisture measurements were done as in the experiment (1). The soil in the experimental site belongs to Red Yellow Podzolic great soil group and Waltrim series (deep phase) (De Alwis *et al.* 1980). The soil solution was analysed for NH_4+-N, NO_3- N, Ca, Na, K, and pH.

Laboratory Incubation Experiment

Field moist samples of soils from a clay loam 0–15 cm (Coombe series) were collected (initial moisture 35% w/w) and weighed 1 Kg each into seven polythene bags. Urea and ammonium sulphate were added in solution form to give 409 ppm in N (w/w) more water was added to bring the moisture content to 40% and the soils were homogeneously mixed. The bags were tied loosely and kept at room temperature, samples were drawn at prescribed time intervals, initially, once in 4 days and later, once a week, for chemical analysis. Samples were drawn daily for pH measurements.

pH measurements were done using 0.02 N (1:2.5) KCI and H_2O (1:1) and the samples for chemical analysis were extracted with 2N KCl or H_2O (1:5). No adjustment was done for moisture loss during incubation.

Water extracts and KCl extracts were analysed for NH_4-N, NO_3-N and Ca. Ca and Mg were determined by atomic absorption spectrometry, K and Na by flame photometry NH_4—N (Titlow and Wilson, 1964), NO_3-N (Middleton, 1959) and urea (Douglas and Bremner, 1970) by colourimetry.

Results and Discussion

In the field experiment (1) where nitrogen was added in the form of ammonium sulphate, nitrification took place rather rapidly as indicated by the total nitrate build up in the soil profile 0-100 cm depth as calculated from the moisture content and nitrate concentration data.

TABLE 1 — *Total nitrate content* in the 0-100 cm profile of the treated plots µg N/ cm²*

Treatments	*Days after treatments*							
	3	*10*	*17*	*24*	*31*	*38*	*45*	*52*
N_0K_0	—	—	103	29	125	74	76	65
N_1K_0	357	340	756	710	730	680	863	490
N_2K_0	607	685	854	934	1168	1501	1781	1427
N_3K_0	684	739	1281	1471	2461	2242	2773	2363
N_1K_2	108	109	184	149	179	103	133	214
N_2K_2	140	205	406	337	484	404	349	300
N_3K_2	788	748	1215	1320	1334	1080	1556	1536

* Values are averages of 3 determinations.

At K_0 level of Potash, addition of more nitrogen lead to larger nitrate production, reaching a maximum concentration of about 2800µg N/cm² in a 1-meter soil profile. At the K_2 level lower nitrate production took place due to inhibitoryµ effects of commercial potassium chloride (Golden *et al*, 1981). A similar trend was observed in the soil solution calcium in the soil profile.

TABLE 2 — *Soil solution Calcium ion content in a 1 cm² soil profile, 1 meter deep µg Ca)*

Treatments	*Days after treatments*							
	3	*10*	*17*	*24*	*31*	*38*	*45*	*52*
N_0K_0 (control)	—	—	69	154	123	28	87	42
N_1K_0	419	380	378	384	324	188	183	225
N_2K_0	600	609	913	1167	1389	1488	1916	1877
N_3K_0	819	1123	1106	1479	1641	1669	2755	2390
N_1K_2	401	402	441	547	526	397	479	434
N_2K_2	642	494	432	436	421	164	367	294
N_3K_2	1210	1117	1104	805	1047	680	1055	1369

Calcium concentration shows the same trend as nitrate increase for the K_0 treatments, giving the highest value for Ca ion content in solution on 45th day for N_3K_0 treatment (Table 2) which correspond to the largest amount of nitrate production (Table 1). Same trend was observed with Mg ions (data not shown), but in this case the largest Mg content was observed in the N_3K_2 treatment. The

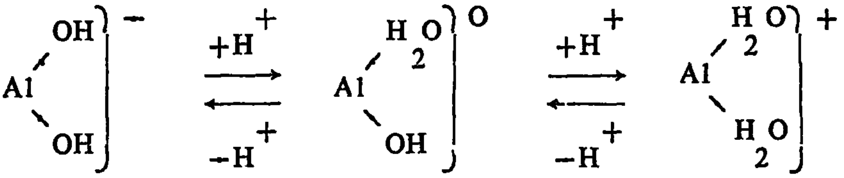
Nitrification produces H ions which can cause a temporary decrease in the pH dependant negative charge on these soils. The H ions released during nitrification according to the following reactions (1) and (2),

$$(1)\quad (NH_4)_2SO_4 + 3O_2 \xrightarrow[\text{(Nitrosomonas)}]{\text{Bacteria}} 2HNO_2 + H_2SO_4 + 2H_2O$$

$$(2)\quad 2\,HNO_2 + O_2 \xrightarrow[\text{(Nitrobactor)}]{\text{Bacteria}} 2\,HNO_3$$

can affect the pH dependant negative charge on these soils.

This effect is quite prominent as the soils are rich in 1:1 clay minerals and iron and aluminium oxides (Golden, D.C., *et al*, 1981). The surface charge and H-ion interaction could be given by (Parks, 1965),



Lowering of CEC by such a pH change can cause a preferential release of divalent cations (Ochtere, Boteng and Ballard, 1980). The Ca-ion is the most prominent cation to diffuse into the soil solution as a result of such perturbations in CEC in a multiionic Donnan system.

Ca and Mg show similar increasing trend with increase in N rates. K follows the same trend (at K_0 level) with increase in NO_3-N. At the K_2 level K does not increase with the increase in N levels of the treatments (data not shown). At the Zero K level increase in N, and therefore the larger nitrification has caused soil acidity to increase (pH 4 to 3.45). The Ca, Mg, and K concentrations in soil solution increased with increase in N. Nitrate N production under the treatment N_1K_2 and N_2K_2 were rather low yet the Ca and Mg increased from N_1K_2 to N_3K_2.

The exchangeable cations Ca, Mg and K in the soil show a consistent decrease with the increase in N-levels at K_0 level. The same trend could be seen at K_2 level (Table 4) except for K ions. This could be attributed to the higher N rates. At the K_0 the leaching effect is due to effect of NH_4 ions and acidity, but at the K_2 level the high electrolyte concentration imparted by the addition of higher rates of N and K must have played a prominent role in the leaching of Ca and Mg ions. Though the 2N-KCl extractable cation content (Ca, Mg and K ions) has decreased with increasing N level at K_0 level. The soil solution concentration has increased in the same direction (Table 3), thus making these ions more vulnerable to leaching.

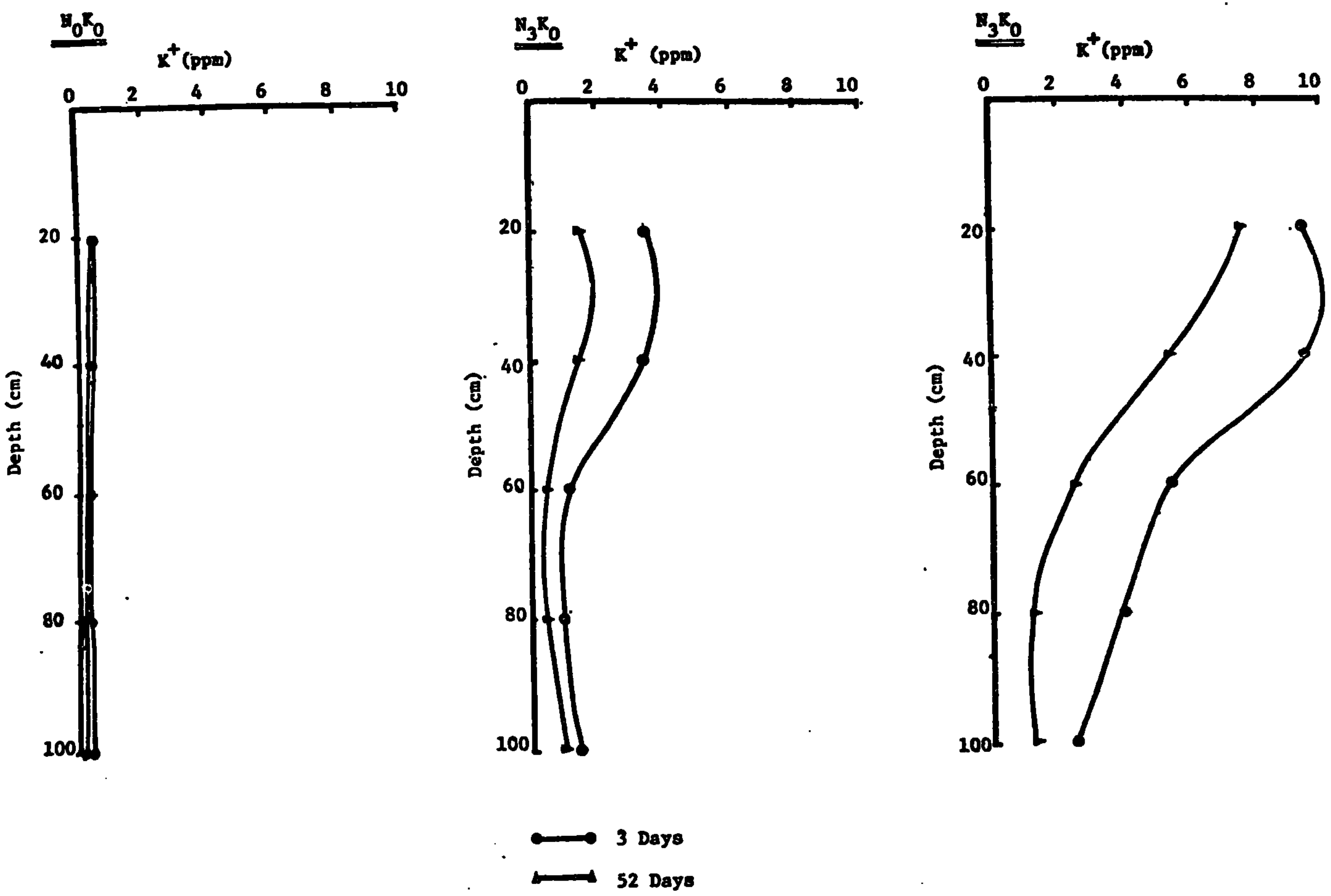


Fig. 1.—Potassium concentration in the soil solution (µg/g soil) in the treated plots.

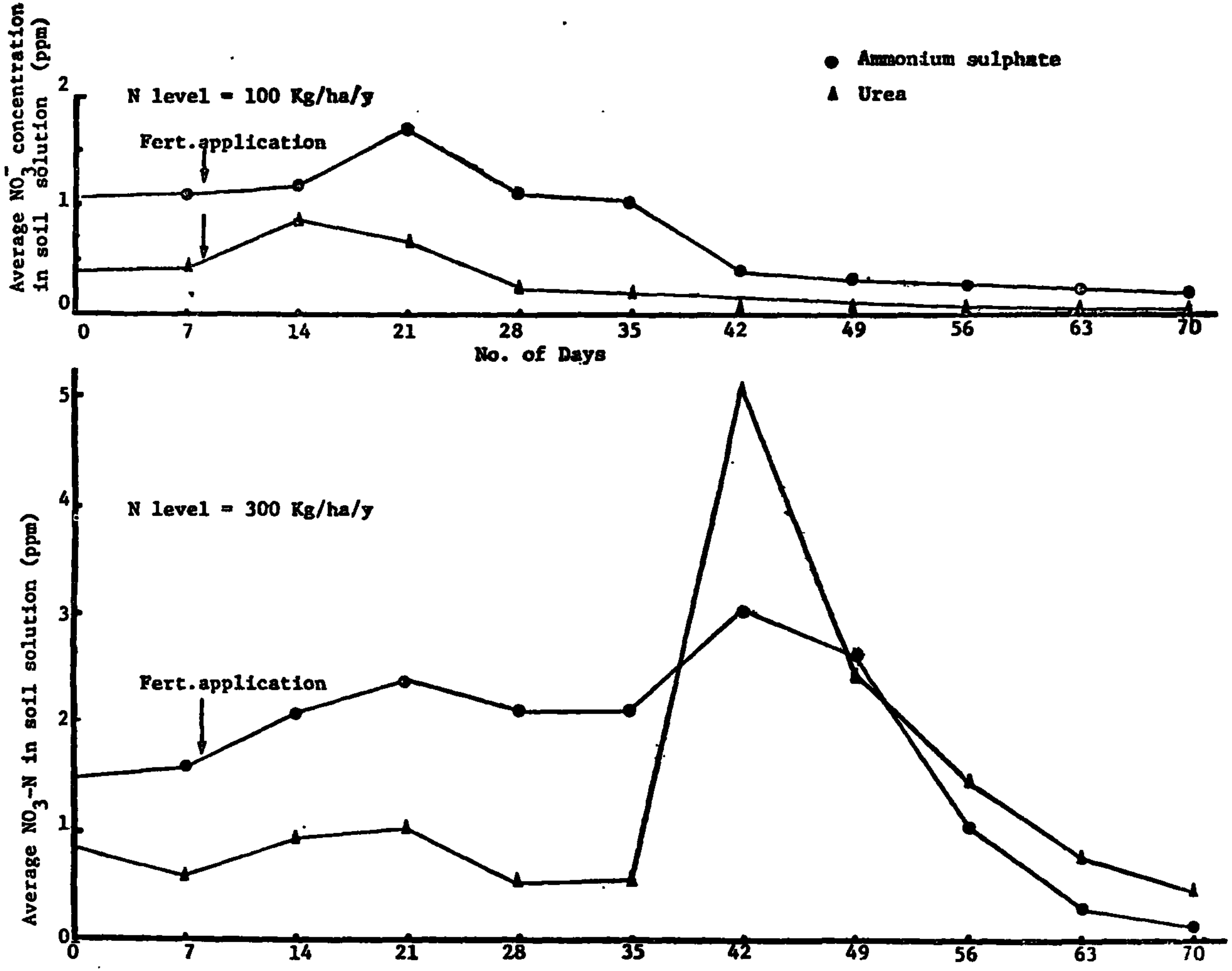


Fig. 2. — Nitrate-N concentration (ppm) in the soil solution after application of fertilizers, urea and ammonium sulphate (Field expt. 2).

TABLE 3 — *The total ions K, Ca, Mg and NH_4 (µg/cm²) and NO_3 in soil solution after 45 days of fertilization in top meter of the soil profile (at K_0 level)*

Treatment	*NO_3-N*	*Ca*	*Mg*	*K*	*Top soil pH in KCl*
N_0K_0	76	87	484	24	4.00
N_1K_1	863	183	989	40	3.75
N_2K_0	1785	1916	1111	61	3.50
N_3K_0	2773	2755	1336	73	3.45

Profile Distribution of the Nutrients

Potassium in soil solution profile is shown in Fig. 1. In the N_3K_0 plot there is more K approximately 10 ppm in soil solution than K_0N_0 (control). This is due to displacement of native exchangeable K into the soil solution by added NH_4 and also due to any movement of the acidity down the profile. The distribution of soil solution K down the soil profile shows that the added K has moved considerably down the profile. As 90% of the feeder roots of tea are found in the 0-30 cm layer all what is below this zone may be unavailable to the plants. This loss is rather important as K being a very important nutrient to the tea plant. Ca though not as important shows a similar trend.

Field experiment (2) to compare urea vs. ammonium sulphate

The variation of the nitrate ion concentration in the soil profile (Fig. 2) with time indicates that in the ammonium sulphate treated plots and the urea treated plots at the lower rate of application (100 Kg N/ha), the nitrate concentrations are quite low, though a peak is observed in about 1 to 2 weeks. However a prominent peak with a sharp increase in NO_3-N was observed for the urea treated plot at the higher rate of application. Ammonium treated plot showed a relatively lower increase in NO_3-N. In general the nitrate concentration in ammonium sulphate treated plots were above that of urea treated plots except at the peak concentration. The sharp increase in NO_3-N in the urea treated plot is in conformity with the results of the incubation experiment. The nitrification and the associated changes are not very prominent in this field experiment probably due to high level of commercial potassium chloride included with the treatment. The inhibitory effect on nitrification of commercial potassium chloride in these soils are discussed elsewhere (Golden *et al*, 1981). The Ca mobilized in the soil profile (Fig. 3) shows that ammonium sulphate releases more Ca ions into the soil solution than does urea at both rates of application. This clearly indicates the greater removal of lime from soil by the acidifying effect of ammonium sulphate.

However there is a time lag of about one week, between the nitrate concentration peak (Fig. 2) due to 300 Kg/ha rate of application of both urea and ammonium sulphate and the appearance of Ca ion concentration peak (Fig. 3). There is a bigger lag ($\simeq$ 4 weeks) in the case of 100 Kg/ha rate. Probably the lag is a measure of the rate of leaching as the diffusion coefficient of NO_3 is greater than that of Ca^{++}. The lower rates of N application has given rise to a lower rate of cation leaching, whereas higher doses stimulated a faster leaching. The Ca ion content in the soil solution profile has shown the expected changes corresponding to the N fertilizer transformations. K and Mg ions seem to be comparatively less sensitive (Table 4) to these changes unlike in the previous experiment, with Coombs series soil.

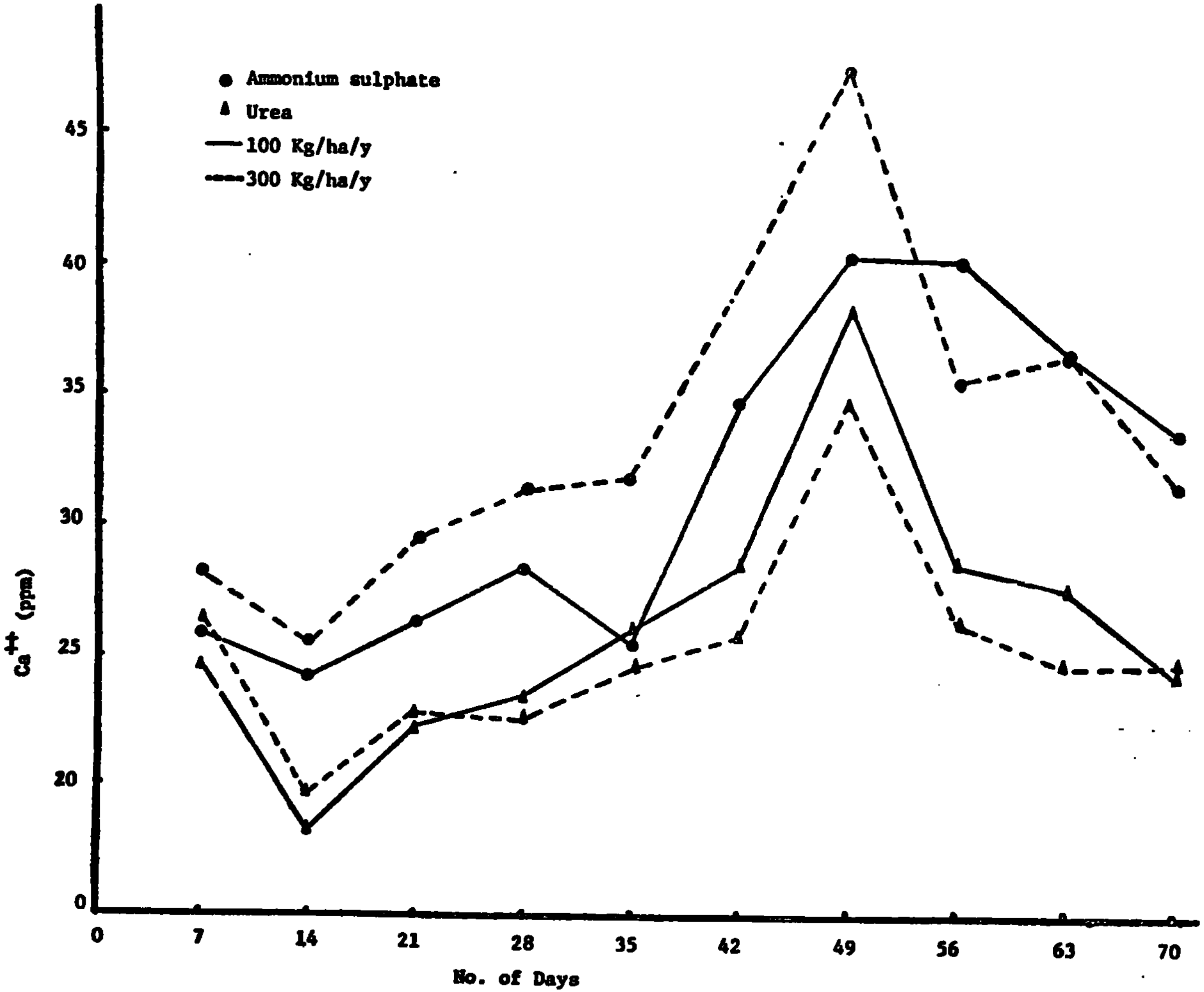


Fig. 3. — *Calcium ion concentration (ppm) in soil solution after the application of fertilizer-N (Field expt. 2).*

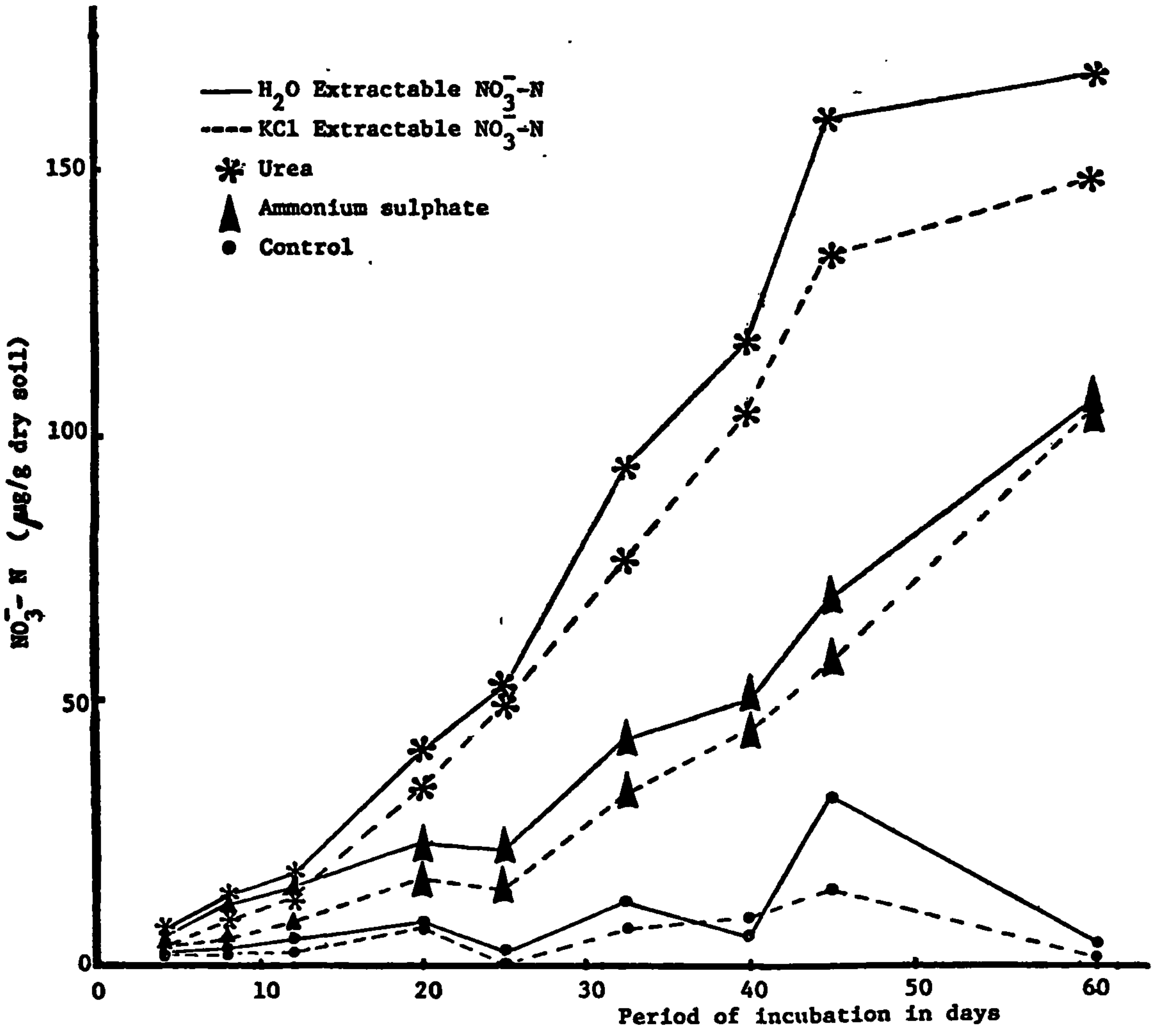


Fig. 4. — Nitrate-N concentration in the incubated soils.

TABLE 4 — *The exchangeable ions (2N.KCl) in 0-15 cm layer of the treated plots*

Treatment	*Exchangeable ions (ppm)*				
	NO_3-N	*NH_4-N*	*Ca*	*Mg*	*K*
N_0K_0 (Control)	4.0	5.8	28.8	26.9	57.2
N_1K_0	9.6	3.9	300.8	28.0	103.7
N_2K_0	12.3	5.0	18.1	8.8	95.2
N_3K_0	18.0	27.6	15.8	6.4	33.9
N_1K_2	8.2	5.9	214.4	14.5	255.1
N_2K_2	20.9	96.0	26.5	8.1	201.4
N_3K_2	24.4	166.8	10.4	5.1	181.8

Incubation Trial

A soil (Red Yellow Podzolic, Coombe series 0-15 cm depth) was incubated with fertilizer N to study these transformations and to confirm the field observations. The pH (H_2O 1:1) of the urea treated soil increased to 5.4 within a day (Table 5) and then gradually decreased over a period of 40 days to come to the level of the control. The nitrification rate in the urea added soil was higher than that of ammonium sulphate treated soil (Fig. 4) confirming the earlier observations (Krishnapillai, 1981).

TABLE 5 — *pH variation with time in the treated soils (Incubation experiment)*

Extractant	*Treatment*	*Number of days*									
		1	*6*	*8*	*12*	*19*	*26*	*33*	*40*	*47*	*62*
KCl (0.2N)	Urea	4.25	4.33	4.30	4.27	4.24	4.03	4.17	3.83	4.05	3.92
	Amm. sulphate	3.95	3.95	3.94	3.95	4.00	3.90	4.06	3.87	0.04	3.95
	Control	3.85	3.77	3.78	3.76	3.80	3.75	3.90	3.82	3.96	3.96
H_2O	Urea	5.20	5.18	5.10	5.05	4.90	4.67	4.54	4.37	4.23	4.00
	Amm. sulphate	4.15	4.24	4.20	4.22	4.26	4.17	4.28	4.33	4.27	5.15
	Control	4.35	4.39	4.31	4.33	4.36	4.27	4.40	4.31	4.42	4.35

The effect of ureolytic pH increases and subsequent nitrification pH drop could be clearly seen from the Ca concentration (Table 5) in the water extract of the urea treated sample, which shows negligible water extractable Ca (Table 6) up to the 40th day and an increase thereafter, whereas in the ammonium treated samples the water extractable was much more than the KCl extractable Ca. In this case, the controlling factor for the Ca concentration in the extract being probably the solubility of $CaSO_4$ rather than the CEC of the soil. In this incubation study the behaviour of the other cations were not studied.

TABLE 6 — *Change in Calcium ion concentration* (µg/g dry soil) in treated soils with time*

Extractant	*Treatment*	*Number of days*								
		0	*8*	*12*	*19*	*26*	*33*	*40*	*47*	*62*
KCl	Urea	6	13	54	27	7	10	10	5	24
	Amm. sulphate	6	6	30	30	4	6	7	4	4
	Control	6	6	31	10	4	5	7	4	4
H_2O	Urea	12	0	9	0	9	3	21	29	74
	Amm. sulphate	12	27	37	32	29	9	41	57	65
	Control	12	12	25	11	13	17	23	18	26

* Each value is an average of triplicate determinations.

To summarise the results, the application of urea and ammonium sulphate in the field caused

1. Ureolytic pH increase
2. pH decrease during nitrification
3. Change in cation exchange capacity due to pH change

The result being a large fluctuation in the concentration of ions Ca and Mg and pH depending on the type of transformation involved at a given time, whereas the monovalent cations were affected to a lesser degree than divalent ions in accordance with the predictions from the Donnan equillibrium. The implication of this being a larger leaching of Ca and Mg ions, with the application of ammonium sulphate. In the case of urea, the temporary high pH phase due to ureolysis caused less cations go into the soil solution, but subsequent rapid nitrification liberates them again into the soil solution. The pH rise was apparent in the soil incubation, but measureable changes in the pH was not observed in the solution even at the depth of 20 cm under field conditions. The release of Ca was an indicator of the nitrogen transformation occurring in the surface soil at a given time.

ACKNOWLEDGEMENTS

The authors express their gratitude to Mr. S. Selvanathan for his assistance in doing the incubation trial, and Mr. M. A. Wijedasa for his help in the analytical work.

REFERENCES

De Alwis, K. A., Jayasooriya, S. G. and Perera, M. B. A. Soils of St Coombs Estate. *Tea. Q.* 49 (1), 5-24.

1 — Environmental and Morphological Characteristics. *Tea. Q.* 49, (1980).

Douglas, L. A. and Bremner, J. M. (1970). Extraction and Colorimetric Determination of Urea in Soils. *Soils. Sci. Soc. Am. Proc.* 34, 859-862.

Golden, D. C., Sivasubramaniam S. and Wijedasa, M. A. (1981). Inhibitory Effect of Commercial Potassium Chloride on the Nitrification Rate of added Ammonium Sulphate in an Acid Red Yellow Podzolic Soil. *Plant and Soil.* 59, 147-151.

Golden, D. C., Weed, S. B., Sivasubramaniam, S. and Nalliah, P. (1981). Studies on the Performance of Two Phosphatic Fertilizer on Tea Soils with respect to the P-Adsorption, Mineralogy and Plant Species using ^{32}P labelled Fertilizer. *Tea. Q.* 50 (2), 50-60.

Krishnapillai, S. and Pethiyagoda, U. (1980). Factors affecting Nitrification in Tea soil and in stored solution. *Tea. Q.* 49, 142-157.

Ochtere-Boateng, J. and Ballard, T. M. (1978). Urea fertilizer effects on dissolved nutrient concentration in some forest soils. *Soil. Sci. Soc. Am. J.* 42, 503-508.

Titlow, J. A. and Wilson, A. L. (1964). An absorptiometric method of determining ammonia in boiler feed water. *Analyst.* 89, 453-465.