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PATTERNS OF N LOSS IN A NIGERIAN SOIL

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ABSTRACT

An experiment was conducted on a bare well drained soil of the Apomu Series, classified as a Quartzipsamment (USDA). The loss patterns of 100kg N ha^{-1} of ammonium sulphate, sulphur coated urea (SCU) and urea were compared during ten weeks in the rainy season. After approximately 25mm of rainfall the soil was sampled at 15cm intervals down to 90cm. Measurements of the inorganic N (NH_4–N and NO_3–N) showed: a) SCU had no advantage over the other forms of N used, b) there was little evidence of leaching, c) volatile losses were possible during the first seven days after addition and could have been 29% and 71% for ammonium sulphate and urea respectively; and d) all the added N was lost by 40 days after addition.

RESUMEN

Se realizó una experiencia en un suelo raso bien drenado de la serie Apomu, con clasificación de Quartzipsamment (USDA). Se compararon los patrones de pérdida de 100 kg Nha^{-1} de sulfato de amonio, de urea revestida de sulfato (SCU) y de urea por diez semanas dudante la estación lluviosa. Tras aproximadamente 25mm de precipitación, se tomó muestras del suelo a intervalos de 15cm de profundidad hasta 90cm. Las mediciones del N inorgánico (NH_4 – N y NO_3 – N) demostraron que: (a) la SCU no ofrecía ninguna ventaja comparada a las otras formas de N que se utilizaron; (b) había poca evidencia de desalación; (c) había una posibilidad de pérdidas por evaporación durante los primeros siete días posteriores a la añadidura. Estas pudieron haber sido del 29% en el caso del sulfato de amonio y del 71% en el caso de la urea; y (d) la totalidad del N añadido se perdió dentro de los 40 días posteriores a la añadidura.

Keywords: Fertilizer–N loss; Nigerian soil

With continuous cropping in the humid zone of Western Nigeria maintenance of adequate nitrogen in the soil appears to be a major problem (Vine, 1953; Kang, Donkoh and Moddy, unpublished data). This may be attributed in part to leaching losses of the native and fertilizer N with continuous cropping.

There is some evidence to support this: Chesney (1967) showed that applied NO_3–N was rapidly leached to below the 45–60cm depth within 4–6 weeks of application, similarly Hardy (1946) found that 1000mm of continuous rainfall caused rapid leaching.

It is assumed that after rapid nitrification added fertilizer–N would be rapidly leached. However, there is little direct evidence to support this. Two experiments were conducted to examine the loss pattern of added N. Three sources of N (ammonium sulphate, urea and sulphur-coated urea) were used in a field experiment. In a second laboratory experiment changes in the form of mineral N from ammonium sulphate and urea added to the same soil were followed over a 28-day period.

Materials and methods

Field experiment

The experiment was conducted at the International Institute of Tropical Agriculture (IITA) at Ibadan (7° 23'N, 3° 56'E) located in the humid zone of western Nigeria, during the 1973 rainy season from June to August.

The land had been under secondary forest until two years earlier, and in the previous year was used for a sulphur response trial. The soil is mapped as Apomu series (Psammentic Ustorthent, USDA classification). It is very well drained with a loamy sand texture containing a uniform 7.6 per cent clay to 90cm depth and underlain with a laterite gravel layer. Some of the characteristics of the soil at various sampling depths are given in Table 1.

Table 1 . Some characteristics of the Apomu soil at the site of the field experiment, IITA, Nigeria.

Depth (cm)	pH in H_2O	Organic C (%)	Total N (%)	CEC (me/100g)	Bulk density (g/ml)	Moisture content (at 0.1 bar g/100ml)
0-15	5.9	0.64	0.064	3.0	1.42	8.76
15-30	6.3	0.38	0.041	2.5	1.43	6.79
30-45	6.4	0.02	0.027	3.0	1.32	4.87
45-60	6.3	0.11	0.022	2.3	1.39	5.33
60-75	6.5	0.07	0.018	2.1	1.31	4.68
75-90	6.7	0.10	0.011	2.2	1.30	5.12

Three N sources; ammonium sulphate (21 per cent N, 24 per cent S), urea (46 per cent N) and sulphur-coated urea (34.1 per cent N, 20.8 per cent S) were compared in a randomized complete block design with four replications. Control plots had no added N. The sulphur-coated urea (SCU) used was obtained from TVA, Muscle Shoals, Alabama, USA, and has a

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dissolution rate of 15 per cent in the first 7 days. The fertilizers were compared with bare fallow. Each fertilizer was uniformly broadcast in a single application at a rate of 100 kg N ha^{-1}. Ammonium sulphate and urea as crystals, and the SCU as granules, were raked into the top 1cm of soil. Plot size, was 5.0m x 4.5m. The plots were kept free of weeds.

Field samples were taken using a 10cm diameter bucket auger to a depth of 90cm at 15cm intervals. Five samples, taken at each depth from each plot, were combined for storage at 20°C and subsequent analysis. In order to keep the SCU granules intact the samples were not crushed.

Laboratory experiment

Changes in the form of the mineral N from ammonium sulphate and urea were followed in the laboratory using surface Apomu soil (0-15cm). The N source was added to 100g samples of air-dry soil in polythene bags at a rate of 100 ppm N, and water was added to 70 per cent field capacity. The bags were sealed and incubated at 20°C, 30°C and at field temperature. Samples were taken for analysis at four-day intervals up to 28 days. The temperature of the field was measured twice daily; the average was 26°C.

NH_4–N and NO_3–N concentrations were measured in KCl extracts of the soil samples (Bremner and Keeney, 1966). Urea–N was measured by the method of Douglas and Bremner (1970), but it could not be detected later than 24 hours after being added to the soil. Soil pH was measured using a water to soil ratio of 2.5:1.

Climatic observations

Some of the climatic data recorded during the course of the experiment are shown in Table 2. Evaporation values were obtained from open pan evaporation. Drainage values were estimated from rainfall and evaporation.

Results and discussion

Samples of the soils to 90cm depth immediately prior to application of the fertilizers showed average contents of 67, 84, 94 and 103 kg ha^{-1} of mineral N in the ammonium sulphate, urea, SCU and control plots respectively. These high amounts and the variability between plots caused the subsequent changes to be less clear than expected.

The calculated drainage (Table 2) gives an indication of the periods during which loss by leaching could be expected. These were at 26,40 and 60 days. Statistical analysis of the data showed no significant changes in mineral N below a soil depth of 30cm. For each treatment all the added N seemed to have been lost by 40 days, following a period of intense rain.

Leaching losses

The mineral-N changes during the first 40 days (Fig. 1) shows that there was little loss of N by leaching. The SCU treated plots showed only slight changes in mineral N before 26 days. This would be expected since the granules would only slowly release the urea. However, under conditions of heavy and prolonged rainfall, when it would have been expected that SCU would reduce losses, the granules burst releasing all the remaining urea. This accounts for the increase at 40 days which was mainly due to an exceptionally high N content of one of the replicates.

The evidence against loss by leaching comes mainly from considering the ammonium sulphate and urea treatments. Loss from the 0–15cm depth is not accompanied by significant accumulation in the 15–30cm depth. Furthermore there does not seem to have been appreciable nitrification of the added N to NO_3. The largest increases in the NO_3–N content of the 0–15cm depth were 7.3 (at 18 days) and 10.1kg N ha^{-1} (at 7 days) for ammonium sulphate and urea respectively. Therefore the losses which occurred by 7, 18, 26 and 40 days were due mainly to loss of NH_4–N.

Nitrogen leaching in the humid tropics has mainly been measured indirectly. Vine (1953) reported some evidence of NO_3 leaching in the humid zone of Western Nigeria. Fayemi (1966) ascribed the advantage for maize of split N applications over a single application to the smaller leaching loss. It is only work done subsequently, in the Caribbean, which supports the above findings (Gabriel, 1983; Nkrumah, 1983).

Table 2. Rainfall and evaporation during the period of the field experiment

Time after fertilizer application (days)	Rainfall (R)* (mm)	Evaporation (E) (mm)	Calculated drainage (R-E) (mm)
0	0	0	0
7	15.5	20.1	-4.6
18	42.4	39.4	3.1
26	42.4	14.6	27.8
40	235.5	35.6	199.9
45	9.3	13.4	-4.1
50	52.9	51.4	1.5
60	99.1	27.2	71.9

* A total of 234.8 mm of rain was recorded from June 1973 to start of the trial on 6 July 1973; 14.5 mm were recorded one day prior to fertilizer application.

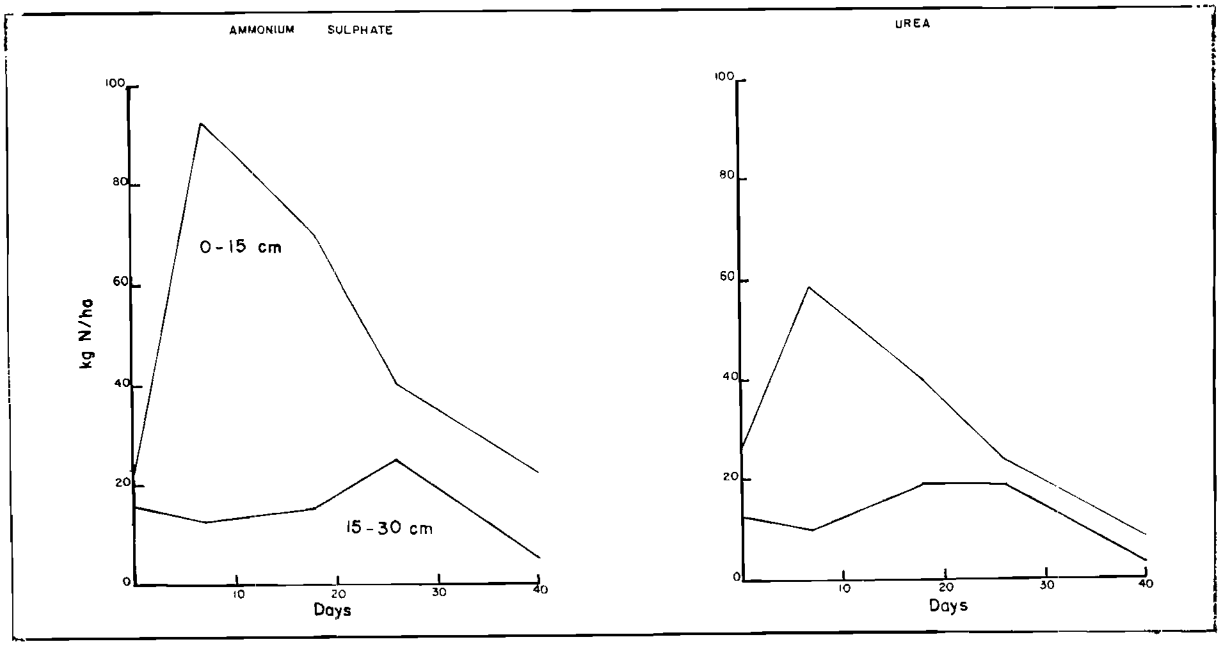

Fig. 1a. Changes in total inorganic N (NH_4–N + NO_3–N) in the 0 - 15 and 15 - 30cm depths of Apomu soil during 40 days.

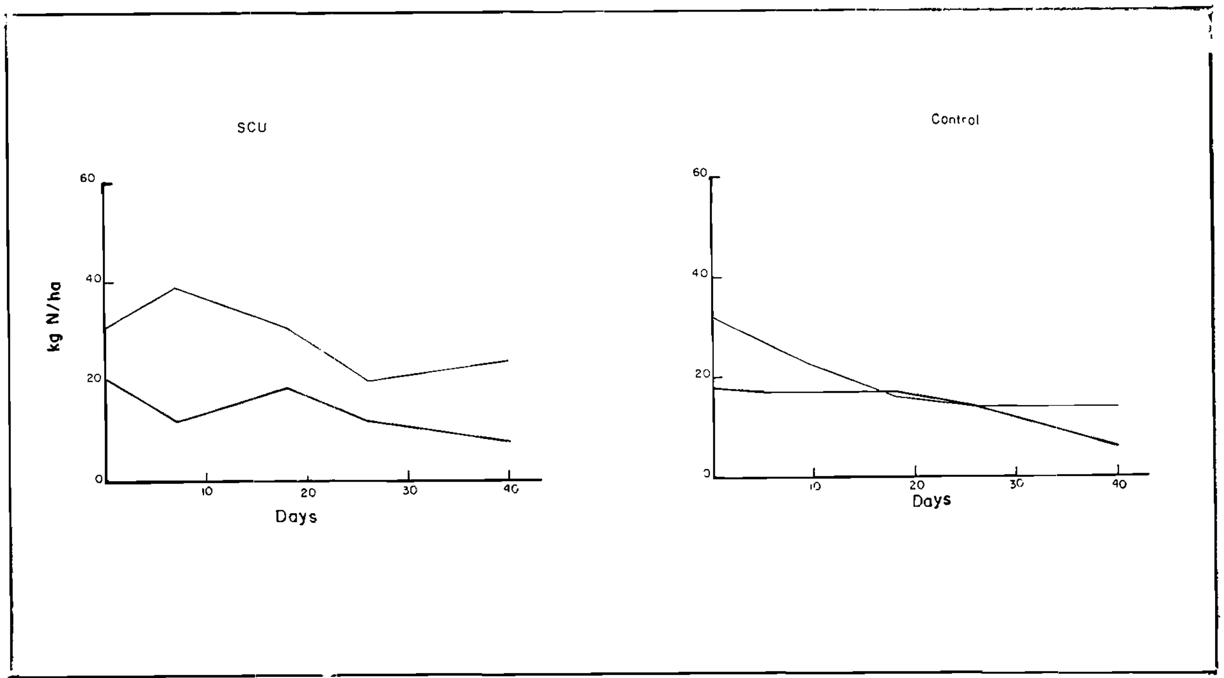

Fig. 1b. Changes in total inorganic N (NH_4–N + NO_3–N) in the 0 - 15 and 15 - 30cm depths during 40 days.

NH_4-N losses

Table 3 shows the losses of NH_4-N during the first 40 days of the experiment:

Table 3. Loss of NH_4–N (kg N ha^{-1}) from the 0–15cm depth of the plots treated with ammonium sulphate or urea and control plots during 40 days.

Period (days)	Ammonium sulphate	Urea	Control
0 – 7	34.29	78.23	4.63
7 – 18	26.04	8.24	0.00
18 – 26	26.68	11.07	7.02
26 – 40	15.76	9.74	4.47

NH_4–N was lost more rapidly from urea than ammonium sulphate, all the added N being lost by 26 and 40 days respectively. The loss of NH_4–N from ammonium sulphate was fairly evenly spread throughout the 40 days, ranging from 34.3kg N ha^{-1} to 15.8 kg N ha^{-1} in the 0–7 and 26–40 day periods. NH_4–N loss from urea was much more dramatic, the largest loss being 78.2 and the smallest 9.7 kg N ha^{-1} for the 0–7 and 26–40 day periods respectively.

It is possible that NH_4–N can be lost from the mineral N fraction by denitrification. Allison (1963) suggested that the decomposition of ammonium nitrate could be the cause of gaseous loss of N. Also it is possible that anaerobic zones could be present in a supposed aerobic soil. Both these mechanisms of loss would not seem to account for the large losses which occurred in the present trial.

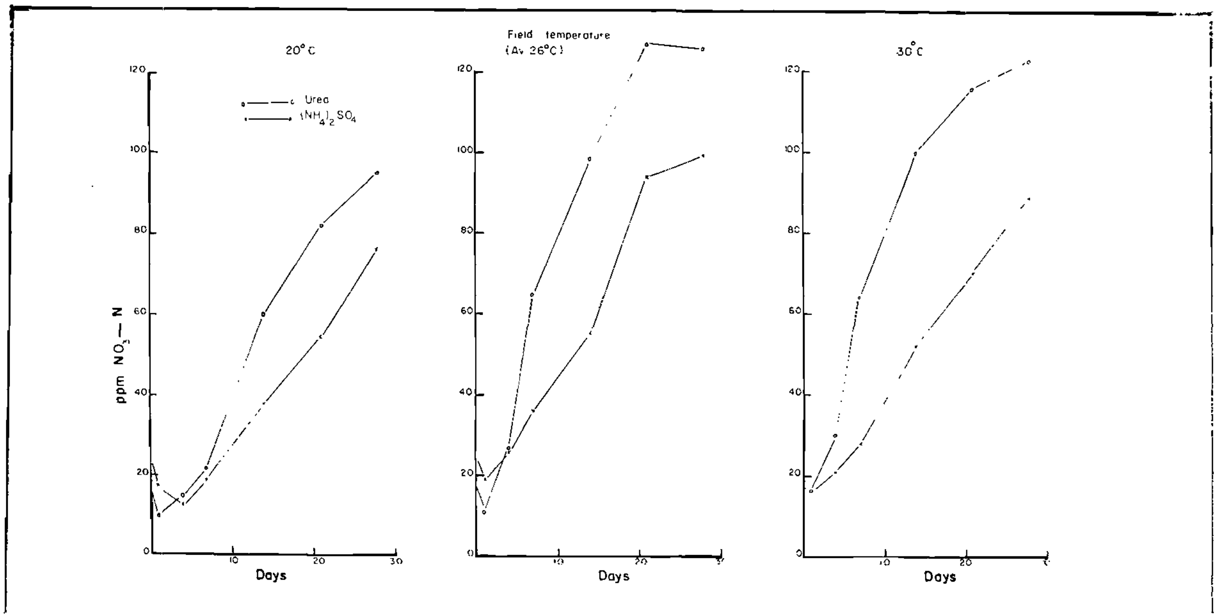

Fig. 2 Mean NO_3 – N content of Apomu soil treated with $(NH_4)_2$ SO_4 and urea incubated at 20°C, field temperature and 30°C for 28 days.

The more rapid loss from urea than ammonium sulphate suggests loss by volatilisation, which occurs because of the pH rise when urea hydrolizes (Gasser, 1964). Acquaye and Cunningham (1965) also reported substantial losses of urea as compared to ammonium sulphate with shallow incorporation into soil. Measurements of the soil pH in the field experiment missed the rise due to urea hydrolysis but this was noticed in the incubation experiment to be discussed later.

The loss from ammonium sulphate is unexpected. Possible explanations are: (a) that there was immobilization and (b) that the exchange of SO_4^{--} for OH^- produced locally high pH values which induced volatilization.

Laboratory experiment

Incubation at 20°C, 30°C and field temperature (FT) showed clearly that nitrification in Apomu soil is rapid (Fig. 2). The rate of nitrification was temperature dependent: 30°C $\triangleq$ FT > 20°C. Little or no moisture loss occurred with incubation at these temperatures. At 40°C (results not presented), however, there was significant moisture loss. This is in agreement with work done by Eno (1960).

The rate of nitrification was also dependent on source of N. The urea treated soil had a faster rate at each temperature; nitrification had started by 7 days at 20°C and by 4 days 30°C and field temperature. The respective times for ammonium sulphate were 14 and 7 days. By 28 days nitrification of the NH_4–N derived from urea was essentially complete whilst that from ammonium sulphate was not.

There was no loss of NH_4–N from the mineral fraction (Table 4).

In fact it would seem that there was release from the organic or clay fraction during incubation. The fluctuation in the field temperature did not significantly affect either the rate of nitrification or the recovery of the added N.

During the first four days of incubation the pH of the urea treated soil was 1.2 units higher (pH 7.3) than initially. By the end of the experiment the pH was essentially the same as that of the ammonium sulphate treated soil, i.e. 5.4. The pH of the ammonium sulphate treated soil had dropped 0.6 units from an initial value of 6.0. Therefore urea hydrolysis causes an initial increase of pH which can be easily missed in measuring the pH of a field sample. This increase could be responsible for the much faster initial rate of nitrification.

Table 4: Percentage recovery of urea and ammonium sulphate after 28 days incubation at 20°C, 30 °C and field temperature (FT)

Fertilizer	Percentage recovery		
(100 ppm)	20 °C	30 °C	FT
Urea	104	110	115
$(NH_4)_2SO_4$	115	126	127

It would seem that it is the wetting and drying cycles in the field which are the critical factor in the removal of NH_4–N from the mineral fraction. Whether the NH_4–N is lost by volatilisation or immobilised requires further work.

Conclusions

i. Under the conditions of the field trial added N can be considered completely removed from the mineral fraction by 40 days.

ii. There was little or no leaching of added N.

iii. It is NH_4–N and not NO_3–N which is removed. This could be either by volatilisation and/or immobilisation.

iv Since this removal occurred only under field conditions and not in the laboratory, the wetting and drying conditions in the field seem to be critical.

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