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UREA TRANSFORMATION IN SOME TROPICAL SOILS

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Summary—The effects of incubation at 20°, 30° and 40°C and urea concentrations of 0, 50, 100 and 200 μg N/g soil on urea hydrolysis and nitrification were investigated in three Nigerian soils. At constant temperature urea hydrolysis and rate of NO_3^- accumulation increased with increasing rate of urea addition. Urea was rapidly hydrolyzed within 1 week of incubation. Nitrification in Apomu soil increased with increasing incubation temperature. Nitrification was slow in acid Nkpologu soil (pH 4·7). Texture, cation exchange capacity and C:N ratios of the soils were not related to urea hydrolysis or nitrification. Nitrite accumulation in these soils was insignificant. Soil pH was decreased by nitrification of hydrolyzed urea-N.

INTRODUCTION

Ammonium sulfate is a widely used fertilizer for crop production in West Africa. It has an acidifying effect on the soil, which may, with continuous use or if applied at high rates, have undesirable effects on crops (Bache and Heathcote, 1969). Because acid soils already occur in the region practices that lead to increased acidification should be minimized.

Urea, with its less acidifying properties and higher N content, is a preferred N source under these conditions. Field data by Enyi (1965) and from the International Institute of Tropical Agriculture (1973) indicate that urea is as effective as ammonium sulfate in increasing maize yields.

The rate of urea hydrolysis in soil is dependent on rate of urea application (Overrein and Moe, 1967), temperature (Fisher and Parks, 1958) and soil biochemical status (Chin and Kroontje, 1963). Microbes and plants compete for NH_4^+ formed by urea hydrolysis. The extent and rate of microbial transformation of NH_4^+ to NO_2^- and NO_3^- depends upon this competition and on soil type, pH, moisture, temperature, and the initial population of nitrifiers (Alexander, 1965; Sabey, Frederick and Bartholomew, 1959).

Little is known about transformation of urea in tropical soils. Because of the increasing use of urea as an N fertilizer in many parts of the tropics, it is desirable to understand the factors that may affect its hydrolysis and nitrification of the hydrolysis product. Such an understanding will permit more efficient use of fertilizer urea.

We report work on the effect of soil type, incubation temperature, and rate of urea addition on urea hydrolysis and subsequent nitrification of the product in three Nigerian soils.

MATERIALS AND METHODS

The soils used (Table 1) were surface (0–15 cm) samples.

To study the effects of rate of urea and incubation temperature on urea hydrolysis and nitrification, samples (100 g) of air-dry and sieved (≤ 2 mm) Apomu series soil were placed in 500 ml bottles. Urea solutions (2 ml/bottle) were added to batches of 32 bottles to give 50, 100 and 200 μg N/g soil (low, medium and high rates). Six bottles received only distilled water. To study the effects of rate of urea and soil series on urea hydrolysis and nitrification, samples (100 g) of air-dry Ngala and Nkpologu series soils were placed in 500 ml bottles. To sets of 5 bottles for each soil was then added 2 ml distilled water or urea solutions to give 0, 50, 100 or 200 μg N/g of soil. The soil and urea solutions were thoroughly mixed, distilled water added to each bottle to bring the soil to 60% of its water holding capacity, and mixed again. The bottles were capped loosely. Ten bottles of Apomu soil of each N rate were incubated at 20, 30 and 40 ± 0·5°C. All other bottles were incubated at 30°C. The relative humidity in the incubators was maintained between 70 and 80%. Bottles were weighed weekly and weight losses compensated for by additions of distilled water.

Initially and after 1, 2, 3, 4 and 5 weeks, one bottle of untreated and duplicate bottles of treated Apomu soil were removed from the incubators. Duplicate bottles of Ngala and Nkpologu soils were removed initially and after 1, 2, 3 and 4 weeks. The soil in each bottle was thoroughly mixed. Three 10-g (air-dry basis) sub-samples were taken from each bottle to determine pH, extractable $NH_4^+ + NO_2^-$ and extractable NO_3^-. Soil pH was measured with the glass electrode using a 1:1 soil: water paste; $NH_4^+ + NO_2^-$ was extracted with 2·0 *N* KCl, and NO_3^- was extracted with water (Bremner, 1965). NH_4^+ was determined by nesslerization (Wilson and Knight, 1952), NO_2^- by diazotization (Montgomery and Dymock, 1961) and

Table 1. Properties of soils used

Soil series	Mechanical analysis Sand (%)	Silt (%)	Clay (%)	pH	Organic C(%)	Total N(%)	CEC (meq/100g)
Apomu	87	5	8	6.2	0.78	0.06	2.98
Ngala	18	18	64	6.5	0.86	0.06	38.84
Nkpologu	78	17	5	4.7	0.84	0.06	3.65

NO_3^- by the phenol-disulfonic acid method (Bremner, 1965).

Rates of NO_3^- accumulation were calculated from NO_3^- curves as the maximum slopes of the linear portions of the maximum rate phase (Sabey *et al.*, 1959) and expressed as μg NO_3^--N/g of soil/week.

RESULTS

In the experiment on the effect of rate of urea and incubation temperature, hydrolysis of urea in the Apomu soil, as indicated by NH_4^+ accumulation, was rapid and increased with urea addition. Accumulation of NH_4^+ was maximum within 1 week of amendment (Fig. 1). Urea conversion to NH_4^+, as a percentage of urea added at the low, medium and high rates were respectively 58, 50 and 54% at 20°C, 22, 30 and 39% at 30°C, and 24, 36 and 50% at 40°C.

NO_3^- accumulation at 20°C was constant at the three rates of urea applied but at 30° and 40°C nitrification increased with increasing amounts of added urea. Small amounts of NO_2^- were found in soils receiving medium and high rates of urea and incubated at 20°C and soil receiving the high rate of urea and incubated at 30°C.

Soil pH increased initially when soils heavily fertilized with urea were incubated (Table 2). The pH rise was temporary. It reached a maximum 1 week after incubation and eventually fell below the initial value, regardless of urea concentration and incubation temperature.

In the experiment on the effect of rate of urea and soil series, NH_4^+ accumulation in Ngala soil increased as added urea was increased. Maximum values were observed after 1 week (Fig. 2). NH_4^+ recovered was 12, 40 and 62% on the basis of added urea for low, medium and high rates, respectively. Significant quantities of NH_4^+ remained in urea-amended soil after 4 weeks of incubation.

Addition of urea to the Nkpologu soil led to accumulations of large amounts of NH_4^+ (Fig. 2). Within 1 week almost all of the added N was in the form of NH_4^+. No NO_2^- accumulated and little NO_3^- was observed in this soil.

The pH changes observed when urea was added to Ngala and Nkpologu soils are shown in Table 2. Although the pH was not measured immediately after urea addition, it is suggested that NH_4^+ production accounted for the differences in initial pH values in the Nkpologu soil. We have no explanation for the initial decrease in the pH of the treated Ngala soil. In the Ngala soil, nitrification led to decreases in soil pH. Amounts of urea added had little effect on the pH. There was only a slight change in pH in the Nkpologu soil.

DISCUSSION

Court *et al.* (1964a) suggest that if urea of low biuret content is applied to certain soils, free NH_3 or NO_2^- are likely to be phytotoxic, especially at pH values above 7. This investigation suggests that only NH_4^+ accumulates to concentrations that are likely to be phytotoxic in these soils because essentially no NO_2^- was found. Results from glasshouse work with an acid sand showed that NH_4^+ could be toxic to maize in the later stages of growth (Court *et al.*, 1964b). Phytotoxicity by NH_4^+ will most likely be observed in the Nkpologu soil, particularly if urea is added close to seedlings. It would result in a localized pH increase and formation of free NH_3. However, at high rates of urea addition NH_4^+ can also accumulate to toxic amounts in the other two soils.

Soil acidity appeared more closely related to NH_4^+ accumulation than was clay content because the highly acid Nkpologu soil accumulated more NH_4^+ than the clay textured Ngala soil. This does not agree with the results of Court *et al.* (1963). In our work, NH_4^+ accumulation was not related to cation exchange capacity, soil texture or C:N ratio.

Volatilization of NH_3 could be significant at high temperatures. Therefore, in assessing the efficacy of

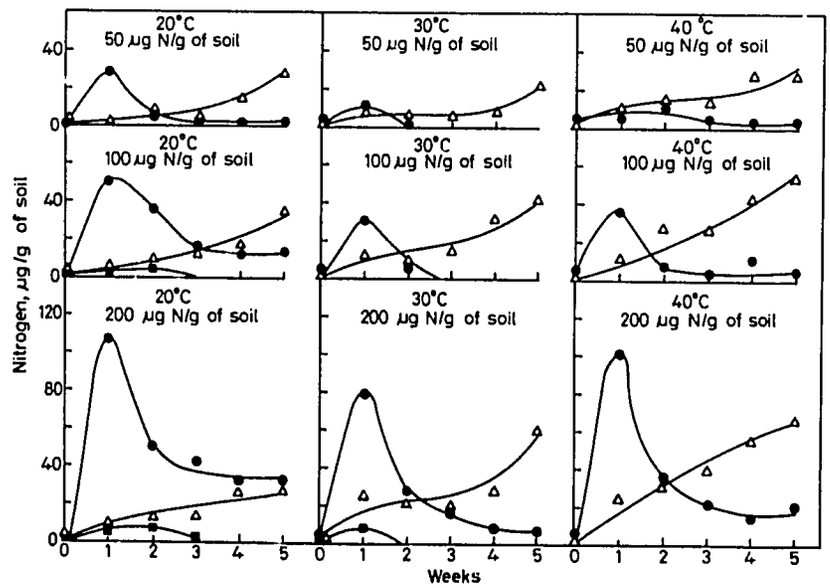

Fig. 1. Formation of NH_4^+ (●), NO_2^- (■), and NO_3^- (△) in Apomu soil incubated at 20°, 30°, or 40°C with 50, 100 and 200 μg urea-N/g of soil.

Table 2. Effects of incubation temperature and urea concentration on pH of Apomu, Ngala and Nkpologu soils

Soil series	Incubation temperature (°C)	Urea added (µg N/g of soil)	pH of soil at incubation time (weeks) specified 0	1	2	3	4	5
			pH					
Apomu	20	50	6.2	6.6	5.7	5.8	5.3	5.3
		100	6.1	7.4	6.0	5.9	5.5	5.2
		200	6.2	8.5	6.8	6.2	5.8	5.6
	30	50	6.1	5.9	5.4	5.4	5.3	5.4
		100	6.1	6.1	5.6	5.2	4.8	4.8
		200	6.1	7.3	5.8	5.4	4.9	4.7
	40	50	6.2	5.7	5.3	5.3	5.1	5.2
		100	6.1	6.0	5.7	5.1	4.8	4.8
		200	6.1	8.0	6.0	5.2	4.9	4.8
Ngala	30	50	6.4	6.9	6.4	ND*	6.7	ND
		100	6.3	7.0	6.2	ND	6.5	ND
		200	6.3	7.2	6.3	ND	6.2	ND
Nkpologu	30	50	4.7	5.2	5.0	ND	4.8	ND
		100	4.8	5.7	5.4	ND	5.1	ND
		200	5.0	6.6	6.1	ND	5.6	ND

*Not determined.

urea fertilizers temperatures selected for study must reflect the high soil temperatures that can occur in the region. Thus incubation temperatures of 20°, 30 and 40°C were examined in contrast to studies in temperate regions where maximum temperatures frequently used are between 28 and 30°C (Fisher and Parks, 1958; Overrein and Moe, 1967). Although the temperatures used in this investigation were higher than those used by others, the results agree with observations made by Fisher and Parks (1958), and Overrein and Moe (1967) that at constant temperature the rate of urea hydrolysis is directly proportional to the amount of urea in the soil. Because soil is not a sterile medium, immobilization, volatilization and nitrification may proceed simultaneously during urea hydrolysis. For this reason the amount of NH_4^+-N found at any time is the net outcome of these reactions. It was also observed that if the concentration of urea remained constant an increase in temperature did not necessarily result in increased NH_4^+ accumulation. This may result from NH_3 volatilization and nitrification.

The effects of temperature on the rate of NO_3^- accumulation (Table 3) were not consistent, probably because the 40°C temperature exceeded the optimum temperature of 30–35°C for nitrification (Alexander, 1965). Amounts of urea added significantly affected the rate of NO_3^- accumulation at 30°C. As amount of urea increased the rate of NO_3^- accumulation also increased. Addition of high amounts of urea to the sandy Apomu soil is likely to lead to considerable leaching of NO_3^- during the rainy season.

Delay rate constants, which are a measure of the lag period in NO_3^- production and, among other things, indicate the level of the initial population of nitrifiers in a soil (Sabey *et al.*, 1959) were calculated as 1–2 weeks for the Apomu soil and 2–3 weeks for the Nkpologu soil, both incubated at 30°C. Ngala soil incubated at 30°C or Apomu soil incubated at 20° or 40°C either showed no measurable lag periods

Table 3. Effects of incubation temperature and urea concentration on the maximum rate of NO_3^- accumulation in three soils

Soil series	Incubation temperature (°C)	NO_3^--N found at urea-N treatment (µg/g of soil) specified 50	100	200
		µg NO_3^--N/g of soil/week*		
Apomu	20	10.0	9.0	4.0
	30	12.0	14.0	25.0
	40	12.0	14.0	14.0
Ngala	30	3.0	6.0	16.0
Nkpologu	30	0.0	0.0	6.0

*Calculated from NO_3^--N data in Figs. 1 and 2 from the maximum slope of the linear portion of the maximum rate phase (Sabey *et al.*, 1959).

or accumulated no NO_3^-. Lag periods of from less than 1 day to more than 32 weeks were reported for soils that differed in initial numbers of nitrifiers, if the incubation temperature was decreased from 25 to 0°C (Sabey *et al.*, 1959). High soil acidity also increases the lag period (Dancer *et al.*, 1973).

Slow nitrification in the Nkpologu soil may be due to three factors: (a) toxicity of NH_3 to *Nitrosomonas* (Alexander, 1965); (b) inhibition of nitrification by extreme acidity (Alexander, 1965; Dancer *et al.*, 1973) or soil factors related to low pH or (c) absence of nitrifiers (Ishaque and Cornfield, 1974). Ayanaba and Omayuli (1975) report that Nkpologu sandy loam and Nkpologu sandy clay loam soils contain few nitrifiers. Thus, any one or combination of these three factors may have led to the slow nitrification in

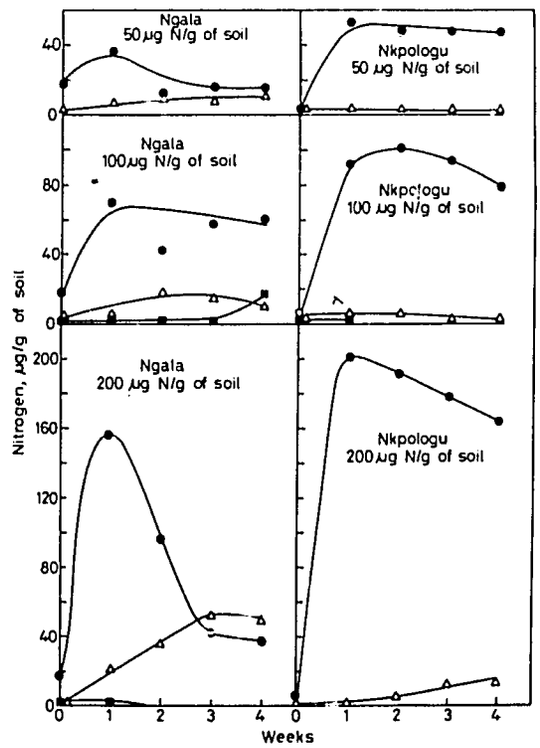

Fig. 2. Formation of NH_4^+ (●), NO_2^- (■), and NO_3^- (△) in Ngala and Nkpologu soils incubated at 30°C with 50, 100 and 200 µg urea-N/g of soil.

Nkpologu soil. We think the third factor is the most significant.

The addition of high rates of urea close to seedlings growing in acid tropical soils may cause NH_4^+ toxicity to the seedlings. In soils in which nitrification of NH_4^+ proceeds at an appreciable rate phytotoxicity would not be a problem. The results of this work suggest that slow nitrification could be a widespread problem. There is a need for more extensive investigations to help optimize the use of urea in acid tropical soils.

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