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Isotopic Lysimeter Studies on Effects of Soil pH on the Behavior of Different Forms of N Fertilizer for Maize

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ABSTRACT

A lysimeter experiment, using the ^{15}N technique, was conducted with a Reddish Brown Lateritic (Oxic Paleustult) soil adjusted to different pH's to compare the effects of N fertilizer in the forms of ammonium, nitrate and urea on the yields and N uptake of maize (*Zea mays*, L) and on the balance sheets of the applied N at different pH's. In strongly acid to neutral soils, ammonium, nitrate and urea were comparable in their fertilizer use efficiencies whereas in moderately alkali soils, nitrate was comparable to urea but superior to ammonium. Leaching losses of the fertilizer N increased with soil pH but was not affected by different forms of fertilizer. Gaseous loss of fertilizer N (3.7-38.2%) was much higher than leaching loss (0.2-3.8%) and was generally highest in alkali soils and lowest in neutral soils. In strongly acid soils, gaseous loss of N from urea was higher than those from ammonium and nitrate. In neutral to moderately alkali soils, the gaseous losses from ammonium and urea were comparable but higher than the loss from nitrate, with the difference being greater at higher pH. After the harvest, the amounts of fertilizer N remaining in neutral soils were not affected by the forms of fertilizer. In strongly acid soils, the amount of fertilizer N remaining in the soil from nitrate was greater than those from ammonium and urea. In moderately alkali soils, the amount of fertilizer N remaining in the soil from nitrate was comparable to that from urea but greater than that from ammonium. The figures obtained from the lysimeters on fertilizer-N recovery by maize were over-estimating whereas those on the amounts of N remaining in the soil were under-estimating compared to those obtained in the field. The total amounts of N loss from fertilizer obtained from the lysimeters were comparable to those obtained in the field.

Considering the comparative effects on fertilizer recovery by plant and losses of the fertilizer, the three forms of N fertilizer are equally recommended for neutral soils. For strongly acid soils, ammonium and nitrate forms are recommended. For moderately alkali soils, nitrate form is highly recommended.

Key words: balance sheet, form, N fertilizer, losses, lysimeter, maize, recovery, soil pH

INTRODUCTION

Though early work in Thailand showed that different forms of N fertilizer were comparable in their effects on maize grown in a soil of pH 4.6 (Saiyao, 1962), results of some studies conducted elsewhere not only did not support this result but were also inconsistent. Spratt and Gasser (1970)

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and Bundy *et al.* (1986), for example, reported that $(NH_4)_2SO_4$ was superior to $Ca(NO_3)_2$ and urea regarding their effects on biomass yields and N yield of maize. On the other hand, Rennie and Rennie (1973) and Dev and Rennie (1979) obtained the highest uptake of N by plant from nitrate form of fertilizer followed by ammonium form and urea, respectively. Obi *et al.* (1986) found that dry matter yield of wheat was greater when calcium nitrate was used than when urea was used in Pine Ridge, Wellwood and Granvelle soils. From field experiments for 3 years, Touchton and Hargrove (1982) obtained maize grain yields from different forms of N in the order: ammonium nitrate > the mixed solution of urea and ammonium nitrate > urea. This discrepancy was presumably due to differences in factors affecting losses of N from the fertilizers, including soil properties, application practices and climatic factors. Results of studies have shown that the comparative results on gaseous loss of N from different forms of N fertilizer varied with soil pH (Matocha, 1976). Loss of N by NH_3 volatilization from ammonium and urea may be expected to be pH dependent while loss of N by leaching from nitrate fertilizer may be expected to be higher than from ammonium and urea since nitrate is not adsorbed by clay particles whereas the latter two contain or produce NH_4 ions which are adsorbed by clay particles. It is therefore worthwhile examining effect on crop, recovery and the balance sheets of N from different forms of N fertilizer at different levels of soil pH so that most suitable recommendation may be made.

This paper presents results of a lysimeter experiment conducted to compare effects of nitrogen fertilizer in the forms of ammonium, nitrate and urea on the yields of maize, recoveries and the balance sheets of the fertilizers at different levels of soil pH.

MATERIALS AND METHODS

Design and treatments

A 4×3 factorial in randomized complete block design with 2 replications was employed. The experimental factors were as the following:

Factor A: N fertilizer application

0 = no application of N fertilizer

A = application of 0.375 g/lysimeter (equivalent to 20 kg N/ha) as ^{15}N-labeled $(NH_4)_2SO_4$ (5.051 atom % ^{15}N) and 0.375 g/lysimeter as KNO_3

N = application of 0.375 g/lysimeter as $(NH_4)_2SO_4$ and 0.375 g/lysimeter as ^{15}N-labeled KNO_3 (4.354 atom % ^{15}N)

U = application of 0.75 g/lysimeter as ^{15}N-labeled urea (5.321 atom % ^{15}N)

Factor B: Soil pH

a) soil pH 5.0

b) soil pH 6.5

c) soil pH 8.5

Each experimental observation consisted of one out door lysimeter in which one maize plant was grown. One border row of maize plants (each plant being grown in pot containing 12 kg soil) was set up around the lysimeters. The lysimeters were arranged so that plant spacing was the recommended one, 85cm between rows and 35cm between plants in the row.

Lysimeter setting and soil

The experiment was conducted at the Department of Soil Science, Kasetsart University, Bangkok, using 24 outdoor lysimeters arranged in two rows. The lysimeters, measuring 75cm (length) × 25cm (width) × 100cm (height), were constructed from concrete blocks lined with cement to protect air penetrating through the wall into the lysimeters. The bottom of each lysimeter was V-shaped and connected to a cylinder containing mixture of 80g cation exchange resin (Lewatit S 100) and 80g anion exchange resin (Lewatit M 504). The cation resin was strongly acidic with an exchange capacity of 2.2 eq/l whereas the anion resin was strongly basic with an exchange capacity of 1.3 eq/l. The outlet at the bottom of the cylinder was connected to a plastic drainage tube. The other end of the drainage tube was kept under water throughout the experiment to prevent air exchange between the soil and the atmosphere.

The soil used was a Reddish Brown Lateritic soil collected from the National Corn and Sorghum Research Center, Nakhon Ratchasima, Thailand. The soil of two plots, measuring 1.5m × 1.5m each was dug up at three different layers, namely 0-15cm, 15-30cm and 30-60cm from the surface. All of the soil from each layer was thoroughly mixed and divided into 24 portions. Since the initial soil pH was approximately 5.0, slaked lime (basing on the lime requirement of the soil from each layer) was added to some of the soil to adjust the pH to 6.5 or 8.0, as required. The soil was thoroughly mixed with the desired amount of slaked lime and then incubated at the field capacity moisture content until the desired pH was attained. The 0-15cm layer of the soil prior to the liming had pH 5.0 (1:1, H_2O:soil), 2.48% organic matter (by Walkley and Black's titration method), 88 ppm P (Bray-II method), 193 ppm exchangeable K (by NH_4OAc), 13.8 me/100g soil CEC and a sandy clay loam texture whereas the 15-30cm layer had pH 4.7 (1:1, H_2O:soil), 1.71% organic matter (by Walkley and Black's titration method), 44 ppm P (Bray-II method), 68 ppm exchangeable K (by NH_4OAc), 10.0 me/100g soil CEC and a sandy clay loam texture.

After 10kg cleaned sand had been filled in each lysimeter, the soil of each layer was packed into the lysimeter, layer by layer, so that the soil of each layer was placed within the 15cm thickness. The packed soil was then regularly watered for 3 months before planting.

Planting, fertilization, watering and harvest

Five maize (*Zea mays*, L., cv. Suwan 3) seeds were placed in the soil at the middle of each lysimeter. The seedling were then thinned to two plants and one plant per lysimeter at one and two weeks after planting, respectively. The unwanted seedlings were left to decayed on the soil surface.

Triple superphosphate at the rate of 120 kg P_2O_5/ha, muriate of potash at the rate of 60 kg K_2O/ha and 80 kg $ZnSO_4$/ha were applied as basal fertilizers by mixing with the soil to about 12cm depth. The nitrogen fertilizers were applied at planting by banding 5cm from seed rows at the depth of 5-8cm.

Weeds were removed manually and the removed weeds were left to decay on the soil surface. Each lysimeter received water twice a week so that 40mm water was applied per week. In case of raining, the amount of water to be given was adjusted so that each lysimeter received 40mm water during each 7-day interval. The individual rainfalls during the growing period eventually did not exceed 35cm. Harvest was done at 90 days after planting, about 15 days before the physiological maturity. The harvested plants were separated into grain, stubble and cob for chemical analysis.

Root and soil sampling

Shortly after the harvest, soil of each layer, sand and resin in the lysimeters were taken out. Each of them was then mixed well, weighed and sampled for total N and ^{15}N determination. Maize roots were separated from the soil as much as possible, washed, oven-dried, weighed, sampled and ground for total N and ^{15}N determination.

Analysis of total N and ^{15}N in samples

The total N in plant samples was measured by digesting with a semimicro Kjeldahl procedure (McKenzie and Wallace, 1954) followed by measurement of N by a phenol-hypochlorite method (Smith, 1980). The total N in soil samples was determined using salicylic acid thiosulfate modification of the Kjeldahl method to include nitrate and nitrite (Bremner and Mulvaney, 1982). The determination of ^{15}N contents in the plant and soil samples was done by the freeze layer method (Volk and Jackson, 1979) with a CEC 21-620 mass spectrometer.

Calculation of fertilizer recovery

Percent N derived from fertilizer (% NdfF) and percent fertilizer-N recovery (% FR) were calculated according to IAEA (1983) as follows:

% ^{15}N a.e. in sample = a - b,

where: a is total atom % ^{15}N in the isotope fertilized sample; b is total atom % ^{15}N in non-isotope fertilized sample.

% NdfF = [(% ^{15}N a.e. in sample) x 100]/(% ^{15}N a.e. in fertilizer)

Fertilizer-N yield = % NdfF × (total-N yield)/ 100 % FR = [(Fertilizer-N yield) × 100)]/(Amount of N added)

RESULTS AND DISCUSSION

Maize yields and N uptake

Grain yields, stubble yields and total dry matter of maize as affected by rate and form of N fertilizer at different soil pH's are given in Figure 1. In most cases, non-significant responses to the applied N were obtained. The lack of clear response to the N fertilizers was presumably caused by too low rate of N application. It was thus expected that the application of $(NH_4)_2SO_4$ + KNO_3 and urea showed no significant difference in the yields and in the amount of N taken up by maize plants (Figure 2).

Amounts of fertilizer N remaining in different soil layers

Percent N fertilizer remaining in the soil (Figure 3) showed that the amounts of fertilizer N remaining in the 0-15cm and 30-60 layers from the three forms of fertilizer were comparable. However, the amounts of N fertilizer remaining in the 15-30cm layer from nitrate were higher than those from ammonium and urea at soil pH 5.0 and 8.0 but

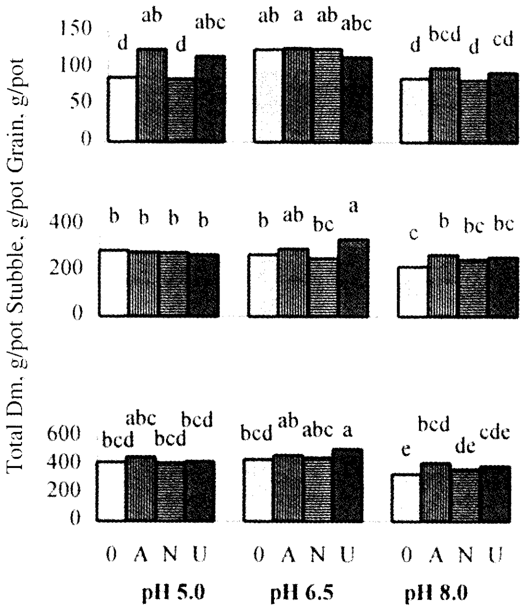

Figure 1 Total dry matter (grain + cob + stubble + roots, total DM), dry stubble and dry grain of maize as affected by rate and form of N fertilizer and soil pH . %CV: 6.5 for total DM; 7.1 for stubble; and 16.4 for grain. Bars with a common letter are not different by $DMRT_{.05}$.

0, no N fertilizer ; A, 20 kg N/ha as ^{15}N-labeled $(NH_4)_2SO_4$ and 20 kg N/ha as KNO_3; N, 20 kg N/ha as $(NH_4)_2SO_4$ and 20 kg N/ha as ^{15}N-labeled KNO_3; U, 40 kg N/ha as ^{15}N-labeled urea.

were comparable to those from ammonium and urea at soil pH 6.5. The present results were supported by that of Suwanarit *et al.* (1996) who worked with the same soil in the field and found that the amount of fertilizer N remaining in the 15-30cm layer from nitrate was greater than those from ammonium and urea.

Leaching and gaseous losses of fertilizer N

Percent fertilizer N lost by leaching and by transformation to gaseous forms are shown in Figure 4. The amounts of fertilizer N lost by leaching were obtained by assuming that the fertilizer N recovered in the sand (at the bottom of the lysimeter) and in the resin were the amounts lost by leaching. The amounts of fertilizer N lost in gaseous forms were obtained by subtracting the amounts of applied N with the amounts of fertilizer N recovered by plant, fertilizer N recovered in the three soil layers and fertilizer N lost by leaching.

The amounts of fertilizer N lost in gaseous forms were much greater than those lost by leaching. The former were 3.7-38.2% whereas latter were 0.21-3.8%. The leaching losses increased with soil pH. The gaseous losses were in the order: from soil with pH 8.0 > from soil with pH 5.0 > from soil with pH 6.5. The form of N fertilizer did not show significant effects on the leaching loss but showed significant effects on the gaseous loss. At soil pH 5.0, the gaseous loss from urea was higher than those from ammonium and nitrate, with the latter two being comparable. At soil pH 6.5 to 8.0, the

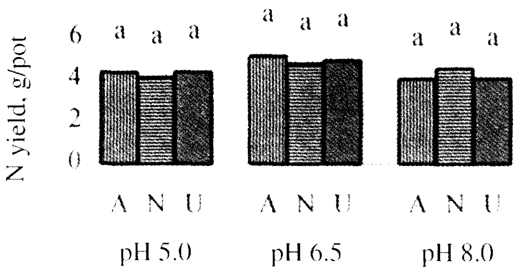

Figure 2 Total N yields of maize as affected by form of N fertilizer and soil pH. %CV: 12.1. See Figure 1 for captions.

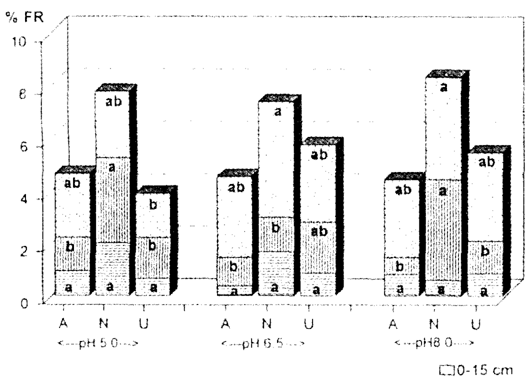

Figure 3 Percent N-fertilizer recovered (% FR) from the soil at different depths as affected by form of N fertilizer and soil pH. % CV: 26.1 for 0-15cm; 44.4 for 15-30cm and 74.9 for for 30-60cm. Along the x-axis, bars with a common letter are not different by $DMRT_{.05}$.

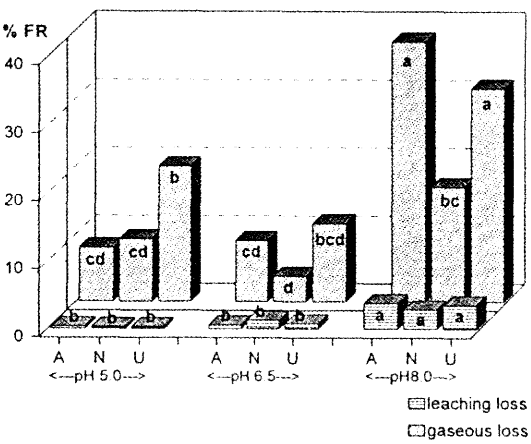

Figure 4 Percent fertilizer N lost by leaching and that lost in gaseous forms as affected by form of fertilizer and soil pH. % CV: 36.5 for leaching loss; and 25.8 for gaseous loss. See Figure 3 for captions.

gaseous losses from ammonium and urea were comparable but higher than that from nitrate. The comparative results on leaching and gaseous losses from the soil with pH 5.0 were in good agreement with the results of Suwanarit *et al.* (1996) who worked in the field on a similar soil with pH 5.1.

Balance sheets of the fertilizers

The balance sheets of the fertilizers are shown in Figure 5. The amounts of N taken up by maize plants from the three forms of fertilizer were comparable at soil pH's 5.0 and 6.5. However, at soil pH 8.0, the amount of fertilizer taken up by maize from nitrate was greater than that taken up from ammonium and tended to be greater than that from urea. The %FR by maize obtained in this experiment (54.6-87.1%) were much higher than those obtained from a similar soil in field experiment

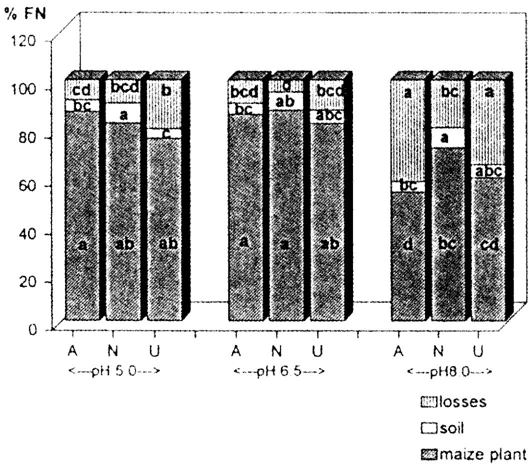

Figure 5 Percent fertilizer N (%FN) recovered by maize (fertilizer N in root, stubble, grain and cob), remaining in the three soil layers and lost by leaching and in gaseous forms of the three forms of N fertilizer at different levels of soil pH. % CV: 6.7 for % FR by maize plant; 21.8 for % FR from soil; and 25.9 for losses. See Figure 3 for captions.

by Suwanarit *et al.* (1996) (25.0-25.9 %). This discrepancy was presumably due to difference in root intensity. Root growth of each maize plant grown in the lysimeter was limited within the area of 75cm × 25cm whereas that of each maize plant grown in the field was not. This resulted in higher root intensity near the plant, and also near the site of fertilizer application in the former case than in the latter. The figures from lysimeters were therefore over-estimating. However, the comparative results on fertilizer recovery by maize were agreeable with those of Suwanarit *et al.* (1996).

The total losses of fertilizer N (leaching loss + gaseous losses) were generally in the order: from the soil with pH 8.0 > from the soil with pH 6.5 > from the soil with pH 5.0. The three forms of fertilizer gave some differences in the total loss in the case of soils with pH's 5.0 and 8.0 but not in the case of soil with pH 6.5. For the soil with pH 5.0, urea gave higher loss than ammonium and nitrate with the two latter giving comparable losses. For the soil with pH 8.0, ammonium and urea gave comparable losses that were higher than the loss from nitrate. The maximum figure for total amount of fertilizer N lost obtained from the soil with pH 5.0 in this experiment (20.1%) was very comparable to that from the field experiment on a similar soil by Suwanarit *et al.* (1996) (18.9%). This suggested that the total amounts of fertilizer obtained from this lysimeter experiment were comparable to those obtained in the field.

At soil pH 5.0, the amount of fertilizer N remaining in the soil from nitrate was greater than those from ammonium and urea, with the latter two being comparable. These comparative results were in good agreement with those of the field experiment by Suwanarit *et al.* (1996) on a similar soil with pH 5.1. At soil pH 6.5, the amounts of fertilizer N remaining in the soil were comparable. At soil pH 8.0, the amount of fertilizer N remaining in the soil from nitrate was comparable to that from urea but larger than that from ammonium. Since the figures on the amounts of fertilizer N taken up by plant were over-estimating as deduced above, the figures on the amounts of fertilizer N remaining in the soil in this experiment were under-estimating.

CONCLUSIONS

From the present results, conclusions can be drawn and recommendation can be made as the following: (1) In strongly acid to neutral soils, ammonium, nitrate and urea were comparable in their fertilizer use efficiencies whereas in moderately alkali soils, nitrate was comparable to urea but superior to ammonium; (2) Leaching losses of the N fertilizer increased with soil pH but was not affected by forms of fertilizer; (3) Gaseous loss of fertilizer N (3.7-38.2%) was much higher than leaching loss (0.2-3.8%) and was generally highest in alkali soils and lowest in neutral soils. In strongly acid soils, gaseous loss of N from urea was higher than those from ammonium and nitrate. In neutral to moderately alkali soils, the gaseous losses from ammonium and urea were comparable but higher than the loss from nitrate with the difference being greater at higher pH's; (4) After the harvest, the amounts of N fertilizer remaining in neutrals soil were not affected by form of fertilizer. In strongly acid soils, the amount of fertilizer N remaining in the soil from nitrate was greater than those ammonium and urea. In moderately alkali soil, the amount of fertilizer N remaining in the soil from nitrate was comparable to that from urea but larger than that from ammonium; (5) The figures obtained from the lysimeters on fertilizer-N recovery by maize were over-estimating whereas those on the amounts of N remaining in the soil were under-estimating compared to those obtained in the field. The total amounts of N loss from fertilizer obtained from the lysimeters were comparable to those obtained in the field; and (6) Considering with the comparative effects on fertilizer recovery by plant and losses of the fertilizer, the three forms of N fertilizer are equally recommended for neutral soils. For strongly acid soils, ammonium and nitrate forms are recommended. For moderately alkali soils, nitrate form is most recommendable.

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