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# $^{15}N$-Aided Studies on Effects on Maize and Balance Sheets of Different Forms of N Fertilizer

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## ABSTRACT

A field experiment using the $^{15}N$ technique was conducted on a Reddish Brown Lateritic soil to compare the effects of N fertilizer in the forms of ammonium, nitrate and urea on growth, yields and absorption of some nutrient elements of maize (*Zea mays*, L) as well as to compare the balance sheets of these forms of fertilizer.

Ammonium sulfate [$(NH_4)_2SO_4$], potassium nitrate [$KNO_3$] and urea were comparable in promotion on growth, yield production, and absorption of N, P, K, Ca, and Mg of maize and distribution of N, K and Mg in different parts of plant but were different in distribution of P, Ca and Mg in some parts of plant. The accumulation of N from ammonium, nitrate and urea in some plant parts were different.

The recoveries of N from ammonium, nitrate and urea by maize were comparable (25.0-25.95%). The total amounts of fertilizer N remaining in the soil from ammonium (69.7%) and nitrate (68.7%) fertilizers were comparable but larger than that from urea (51.1%). The amounts of N remaining in the 0-15 cm soil layer were in the order: from ammonium > from nitrate > from urea. The amount of N remaining in the 15-30 cm soil layer were: from $NO_3$ > from $NH_4$ = from urea. The amounts of N remaining in the 30-60 cm soil layer from the three forms of N fertilizer were comparable. Leaching losses of the three forms of N fertilizer were also comparable. Gaseous loss of N from urea was higher than those from ammonium and nitrate. Considering the immediate effects on maize yield and the recovery of the fertilizer N, it would be apropriate to say that $(NH_4)_2SO_4$, $KNO_3$ and urea were equally recommendable. However, the comparative residual effects of these fertilizers and improvement in the efficiency of urea when applied by deep placement remained to be seen.


**Key words:** balance sheet, ion absorption, nutrient distribution, maize, N fertilizer, recovery

## INTRODUCTION

Nitrogen has been the most common nutrient that limits the yield of maize and nitrogen fertilizer is accordingly needed for most soils in Thailand in maize production. Mineral nitrogen fertilizers may contain their nitrogen in the forms of ammonium, nitrate, ammonium plus nitrate, or amide. In Thailand $(NH_4)_2SO_4$ and urea have been more common than other N fertilizers. Though early work in Thailand showed that different forms of N fertilizer were comparable in their effects on maize

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grown in a soil of pH 4.6 (Saiyao, 1962), results of some of studies conducted elsewhere not only did not support this result but also have been inconsistent. 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 of ammonium nitrate > the mixed solution of urea and ammonium nitrate > urea. This discrepancy was presumably due to difference in factors affecting losses of N from the fertilizers, including soil properties, application practices and climatic factors. Therefore, it is worthwhile examining efficiencies of different forms of N fertilizer applied for maize to soils that have been widely used for maize production in order that more suitable recommendation may be given regarding form of N fertilizer.

This paper presents results of a field experiment conducted on a Reddish Brown Lateritic soil which has been one of the soils widely used for maize production in Thailand to compare effects of nitrogen fertilizer in the forms of ammonium, nitrate and urea on growth, yields and absorption of some nutrient elements of maize as well as to compare the balance N sheets of these forms of fertilizer.

## MATERIALS AND METHODS

### Site and soil

A field experiment was conducted on a Pakchong soil series (Reddish Brown Lateritic group or Oxic Paleustult) in D4-Block at the National Corn and Sorghum Research Center, Pakchong, Nakhon Ratchasima Province, Thailand. The 0-15 cm layer of the soil prior to the experiment had pH 5.1 (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 15-30 cm 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.

### Design and treatments

A randomized complete block design with 8 treatments and 6 replications was employed. The treatments were as follows:

$N_0$ = no application of N fertilizer;

$N_a$ = application of 20 kg N/ha as $(NH_4)_2SO_4$ and 20 kg N/ha as $KNO_3$, using $^{15}N$-labeled $(NH_4)_2SO_4$ (5.051 atom % $^{15}N$) for the isotope subplots;

$N_n$ = application of 20 kg N/ha as $(NH_4)_2SO_4$ and 20 kg N/ha as $KNO_3$, using $^{15}N$-labeled $KNO_3$ (4.354 atom % $^{15}N$) for the isotope subplots;

$N_u$ = application of 40 kg N/ha as urea, using $^{15}N$-labeled urea (5.321 atom % $^{15}N$) for the isotope subplots;

$N_{oa}$ = application of 40 kg N/ha as $(NH_4)_2SO_4$ (no isotope application);

$N_{on}$ = application of 40 kg N/ha as $KNO_3$ (no isotope application);

$N_{8an}$ = application of 40 kg N/ha as $(NH_4)_2SO_4$ and 40 kg N/ha as $KNO_3$(no isotope application); and

$N_{8u}$ = application of 80 kg N/ha as urea $KNO_3$ (no isotope application).

Application of the $^{15}N$ fertilizers was done only in three of the six replications of $N_a$, $N_n$ and $N_u$

treatments. For the $^{15}N$-labeled treatments, the plot, measuring 7.50 m × 3.75 m, was divided into two subplots, i.e. one yield subplot of 6.00 m × 3.75 m and one isotope subplot of 1.50 m × 3.75 m. Within the isotope subplot, $^{15}N$ fertilizer was applied over the area of 1.5 m × 3.0 m by the same manners as those for the non-$^{15}N$-labeled fertilizer. For the non-$^{15}N$-labeled treatments, no division into subplots was made.

**Planting and fertilizer application**

The experiment was conducted in the late rainy season of 1990. Tillage was performed before planting. Planting was done in August, 1990. In each plot, 5 rows of maize plants (*Zea mays*, L), cultivar Suwan 3, were grown with 75 cm and 25 cm row and hill spacing, respectively. One plant was grown per hill. Triple superphosphate at the rate 120 kg available $P_2O_5$/ha, muriate of potash at the rate 60 kg $K_2O$/ha and 80 kg $ZnSO_4$/ha were applied as basal fertilizers at planting by broadcasting over the entire plots followed by incorporating into the soil. The nitrogen fertilizers were applied at planting by banding 5-10 cm from seed rows at the depth of 5-10 cm.

**Weed control, irrigation and harvest**

Weeds were controlled by pre-emergence application with Alachlor and application with 2,4-D spraying at 1 month after planting. Supplemental irrigation by sprinklers was applied so that the plots received a minimum of 40mm within each 7-day interval. The crop eventually received about 40-46mm water within each 7-day interval from planting to 60 days of age and 40-53 mm within each 7-day interval during 64 days of age to harvest. There was only one heavy rain (130mm) at 63 days of age. The water supply therefore did not favor leaching of the soil. Harvest was done at the physiological maturity, 109 days after planting. Only the three central rows were harvested, discarding two plants at each end of the rows.

**Root, weed and soil sampling**

Maize roots, weed and soil were taken from the central area of 1.5m (across the plant rows) x 0.5m (along the plant rows) of each isotope subplot and from one the unfertilized plots as a control. All of the obtained weed was washed free of soil, oven dried, weighed and ground for chemical analysis. The soil was dug up in three separate layers, namely 0-15 cm, 15-30 cm and 30-60 cm. The obtained soil from each layer was crushed and thoroughly mixed and then one quarter of the soil was taken. The obtained soil was then re-mixed and a quarter of the soil was taken. These procedures were repeated until approximately 5 kg soil was obtained for total N and $^{15}N$ determination. The maize roots were separated as much as possible from each layer of the soil and then washed free of soil before oven-drying for dry weight determination and grinding for chemical analysis.

**Analyses of total contents of nutrients in plant samples**

Plant samples from the yield subplots were digested with a mixed acid solution (1,000 ml: 100g:1g, $H_2SO_4$:$Na_2SO_4$:Se) and N and P in the digest were determined with a Technicon Auto Analyzer II according to Anonymous (1976). K, Ca and Mg in plant samples were determined by digesting with acid mixture of nitric acid, sulfuric acid and perchloric acid (5:1:2 by volume) according to Jackson (1973). Ca and Mg in the digest were then determined in a 0.5% $SrCl_2$ using Shimazu Model AA-946 atomic absorption spectro-photometer and K was determined by a Hitachi Model 170-30 flame photometer.

**Analysis of $^{15}N$ and calculation of fertilizer recovery**

The total N in plant samples from the isotope

subplots were 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.

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]/ (% $^{15}N$ in fertilizer).

Fertilizer-N yield = [% NdfF x (total-N yield)]/100

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

## RESULTS AND DISCUSSION

### Plant height and yields of maize

Height of maize plants (Figure 1) showed that N fertilizer at the rates 40 and 80 kg N/ha as well as the three forms of fertilizer were comparable in increasing height of maize plants at 30, 60 and 90 days of age.

N fertilizer at the rate 40 kg N/ha increased cob, grain, stubble and total (cob + grain + stubble) yields of maize and N fertilizer at the rate 80 kg/ha further increased the yields (Figure 2). The significant difference in the total biomass found between the treatments $N_a$ and $N_n$ was obtained by chance since the two treatments were identical in both form and rate of fertilizer. At the rate 80 kg N/ ha, $(NH_4)_2SO_4$ + $KNO_3$ and urea produced comparable yields. The results also showed that $(NH_4)_2SO_4$, $KNO_3$ and urea were comparable in producing growth and yields of maize. Though these results were not supported by the results of some authors, they were supported by the results of Morris and Giddens (1963) who applied $(NH_4)_2SO_4$ and $NaNO_3$ for maize and Balasupramanian and Singh (1982) who applied urea and $Ca(NO_3)_2$ for maize and wheat.

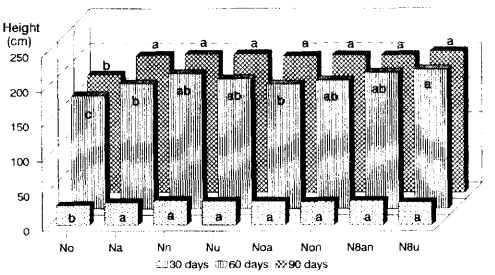



**Figure 1** Heights of maize plants at 30, 60 and 90 days of age as affected by rate and form of N fertilizer. Along the x-axis, bars with a common letter are not different by $DMRT_{.05}$. %CV: 10.1 for 30 days of age; 7.4 for 60 days of age; and 7.3 for 90 days of age.

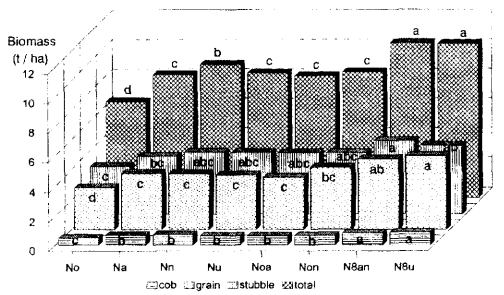



**Figure 2** Biomass of dry cob, dry stubble, grain at 15% moisture and total shoot (grain + cob + stubble) of maize plants as affected by rate and form of N fertilizer. %CV: 14.7 for cob; 13.8 for grain ;17.5 for stubble; and 7.3 for total shoot. See Figure 1 for captions.

**N yield**

N yields from different parts of maize plants increased with the rates of N fertilizers (Figure 3). However, at the rate of 40 kg N/ha, $KNO_3$, $(NH_4)_2SO_4$ and urea produced comparable N yields and at the rate 80 kg N/ha $(NH_4)_2SO_4 + KNO_3$ and urea produced comparable N yields showing no difference in the effects of the three forms of N fertilizer.

**Uptake of P, K, Ca and Mg and distribution in plants**

The mounts of P in grain showed no significant difference in the effects of the three forms N fertilizer, though they showed the clearest positive response to N fertilizer as compared to the amounts of P in the other parts of maize plants, (Figure 4). However, nitrate gave a significantly higher amount of P in cob and a trend of higher amount of P in stubble than the other two forms of N fertilizer. The results showed that the three forms of fertilizer were comparable in their effects on P absorption but different in their effects on the distribution of the absorbed P in the plants. Nitrate produced higher accumulation of P in cob and showed a trend to produce higher accumulation of P in stubble than the other forms of fertilizer

The amounts of K in the shoot and those in grain showed clearer responses to rate of N fertilizer than the amounts in cob and stubble. However, the three forms of fertilizer showed comparable effects on the mounts of K in different parts of the plant (Figure 5).

The amounts of Ca in stubble, in cob and in the shoot (total Ca) showed no significant difference in the effect of the three forms of fertilizer (Figure 6). At the rate 40 kg N/ha, the three forms of fertilizer did not showed significant difference in the amount of Ca in grain whereas, at the rate 80 kg N/ha, urea gave larger amount of Ca in grain than $(NH_4)_2SO_4 + KNO_3$. These results suggested that the three forms of N fertilizer were comparable in

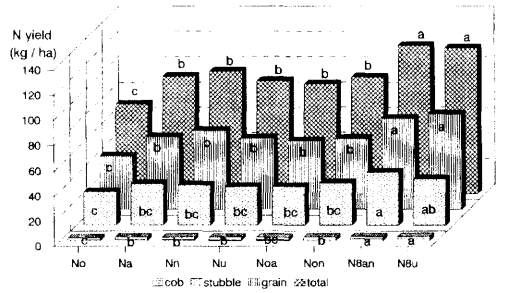



**Figure 3** N yields from cob, stubble, grain and total shoot (grain + cob + stubble) of maize plants as affected by rate and form of N fertilizer. %CV: 11.9 for cob; 13.0 for grain ; 18.5 for stubble; and 11.9 for total shoot. See Figure 1 for captions.

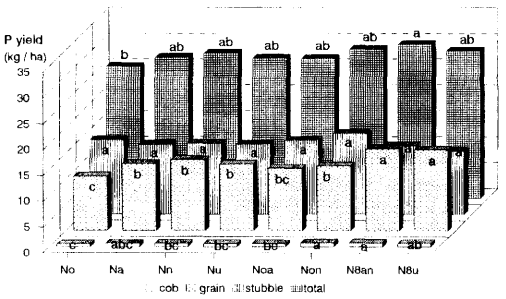



**Figure 4** P yields from cob, stubble, grain and total shoot (grain + cob + stubble) of maize plants as affected by rate and form of N fertilizer. %CV: 13.5 for cob; 11.7 for grain ; 20.5 stubble; and 10.5 for total shoot. See Figure 1 for captions.

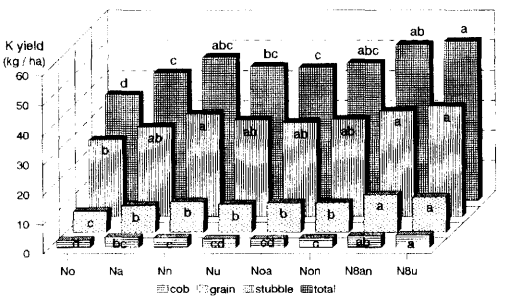



**Figure 5** K yields from cob, stubble, grain and total shoot (grain + cob + stubble) of maize plants as affected by rate and form of N fertilizer. %CV: 13.5 for cob; 11.1 for grain ; 17.0 for stubble; and 12.5 for total shoot. See Figure 1 for captions.

their effects on Ca absorption by maize plants but urea gave higher accumulation of Ca in grain than combination of the other two forms of fertilizer when they were applied at high rates.

The total amount of Mg in plants and the amounts of Mg in different parts of maize plants were generally increased by application of N fertilizer (Figure 7). However, there were no significant differences in effects of the three forms of fertilizer.

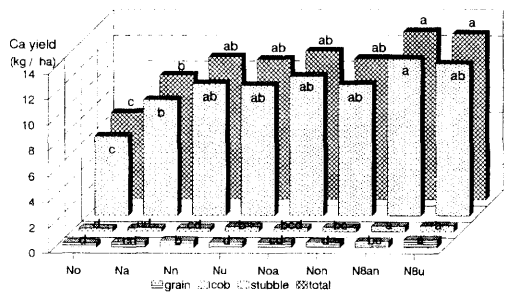



**Figure 6** Ca yields from cob, stubble, grain and total shoot (grain + cob + stubble) of maize plants as affected by rate and form of N fertilizer. %CV: 14.3 for cob; 12.4 for grain ; 21.6 for stubble; and 16.8 for total shoot. See Figure 1 for captions.

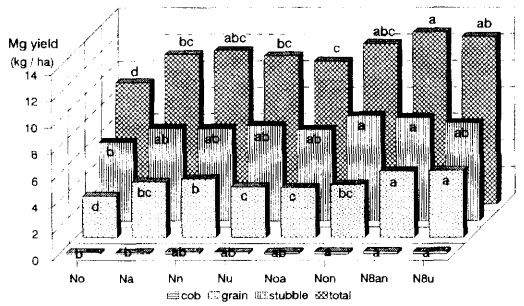



**Figure 7** Mg yields from cob, stubble, grain and total shoot (grain + cob + stubble) of maize plants as affected by rate and form of N fertilizer. %CV: 27.5 for cob; 10.5 for grain ; 16.8 for stubble; and 10.3 for total shoot. See Figure 1 for captions.

The present results on the comparative effects on absorption of the above mentioned nutrients were not in agreement with results of many authors (Dokic, 1981; and Murtadha *et al.*, 1988) who found that plant treated with ammonium-N absorbed less Ca, Mg and K but more P when compared to plant treated with nitrate-N and/or urea-N. However, these authors found differences in the effects on crop yields from different forms of N fertilizer.

**Recovery of N fertilizer in different plant parts**

The percent fertilizer N recovered (% FR) in different parts of maize plants showed some differences in the effects of different forms of N fertilizer in the cases of root, cob and stubble but no difference in the case of grain (Figure 8). In the cases of root and stubble, urea gave significantly lower % FR than ammonium and showed only a trend to give lower % FR than nitrate. In the case of cob, nitrate gave significantly lower % FR than urea and showed only a trend to give lower % FR than ammonium.

**Amounts of fertilizer N remaining in different soil layers**

The percent N fertilizer remaining, %FR, (Figure 9) in the soil showed that the amounts of fertilizer N remaining in the 0-15 cm layer were in the order: from ammonium > from nitrate > from urea. In the 15-30 cm layer, nitrate gave larger residue than ammonium and urea whereas the latter two fertilizers gave comparable amounts of residue. In the 30-60 cm layer, the three forms of fertilizer gave comparable amounts of residue. These results showed that though more nitrate fertilizer was leached down the soil profile than ammonium and urea fertilizers, the leached nitrate was still in the root zone.

**Balance sheets of the N fertilizers**

The balance sheets of the N fertilizers are

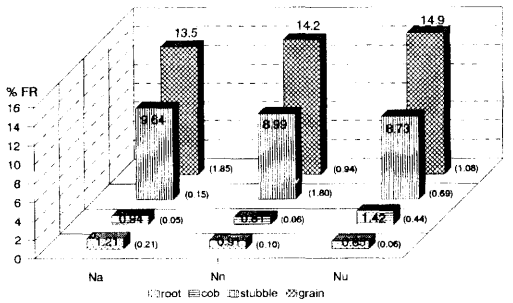



**Figure 8** Percent N-fertilizer recovery (% FR) in root, cob, stubble, and grain as affected by form of N fertilizer. The standard errors are in parentheses. $N_a$, $N_n$ and $N_u$ represent ammonium form, nitrate form and urea, respectively.

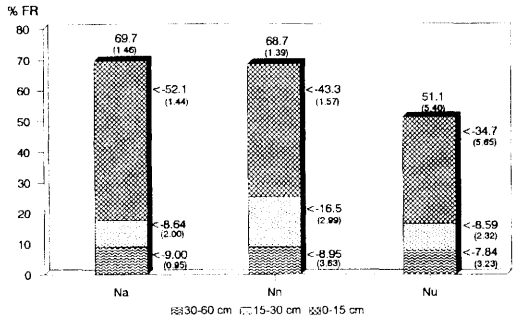



**Figure 9** Percent N-fertilizer recovery (% FR) in the soil at different depths as affected by form of N fertilizer. See Figure 8 for captions.

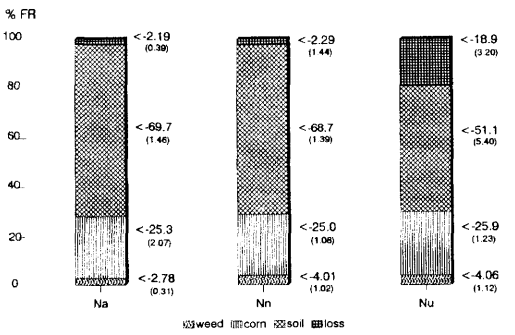



**Figure 10** Balance sheets of the three forms of N fertilizer. See Figure 8 for captions.

shown in Figure 10. %FR showed that the amounts of N taken up by maize plants and by weeds from the three forms of fertilizer were comparable. The total amounts of N remaining in the three soil layers from ammonium and nitrate fertilizers were comparable but were 17.6-18.6 % larger than that from urea fertilizer. Assuming that the amounts of N fertilizer that were not recovered in plants and in the soil within the 60 cm depth were the amounts of fertilizer N that were lost by leaching and transformation to gaseous forms, the amount of N lost from ammonium and that from nitrate were comparable but were smaller than that from urea.

The lack of difference in the amounts of fertilizer in the bottom layer of the soil indicated that leaching losses from the three forms of fertilizer were comparable. This lack of difference in leaching loss and the lack of difference in the N recovery by plants suggested that the higher total loss of N from urea was primarily due to gaseous losses. The lack of difference in amounts of N recovered in plants even with higher loss of urea than ammonium and nitrate further suggested that the gaseous loss of N from urea was primarily from the top soil layer in which very few roots, if any, were present and absorbed the fertilizer N. This is supported by the results of Matocha (1976) Pobedov and Lebedev (1980). Matocha (1976) found that with surface application, loss of N through ammonia volatilization from urea was about 17% more than ammonium sulfate and ammonium nitrate. Pobedov and Lebedev (1980) found that ammonia losses from urea during 30 days after application was more than loss from ammonium nitrate. Deep application may therefore be an effective measure to prevent gaseous loss of N from urea fertilizer.

## CONCLUSIONS AND RECOMMENDATIONS

From the present results, conclusions can be drawn and recommendation can be made as follows: (1) $(NH_4)_2SO_4$, $KNO_3$ and urea were comparable in promotion on growth, production of maize yield, recovery of fertilizer N in plant and absorption of P, K, Ca, and Mg from soil of maize; (2) $(NH_4)_2SO_4$, $KNO_3$ and urea gave comparable distribution of N, K and Mg in different parts of maize plant but were different in distribution of P, Ca and Mg in some parts of maize plant; (3) Potassium nitrate gave higher accumulation of P in cob than $(NH_4)_2SO_4$ and urea. However, the three forms of fertilizer gave comparable amounts of P in grain and stubble; (4) $(NH_4)_2SO_4$ and $KNO_3$ gave higher accumulation of Ca in grain than urea. The three forms of fertilizer were however comparable in accumulation of Ca in cob and stubble; (5) The amounts of N fertilizer remaining in the soil from ammonium and nitrate fertilizers were comparable but larger than that from urea. The amounts of N remaining in the 0-15cm soil layer were in the order: from ammonium > from nitrate > from urea. The amount of N remaining in the 15-30 cm soil layer from nitrate was larger than those from ammonium and urea, with the latter two being comparable; The amounts of N remaining in the 30-60 cm soil layer from the three forms of N fertilizer were comparable; (6) Leaching losses of the three forms of N fertilizer were comparable; (7) Gaseous loss of N from urea was higher than those from ammonium and nitrate fertilizers; and (8) Considering with the immediate effects on maize yield and recovery the fertilizer N, $(NH_4)_2SO_4$, $KNO_3$ and urea were equally recommendable. However, it remained to see the comparative residual effects of these fertilizers and improvement of the effects of urea when applied by deep placement.

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