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Enhancing the Urea-N Use Efficiency in Maize (*Zea mays*) Cultivation on Acid Soils using Urea Amended with Zeolite and TSP

[1]Osumanu Haruna Ahmed, [2]Aminuddin Hussin, [2]Husni Mohd Hanif Ahmad, [3]Mohamadu Boyie Jalloh, [2]Anuar Abd Rahim and [1]Nik Muhamad Ab. Majid
[1]Department of Crop Science, Faculty of Agriculture and Food Science, University Putra Malaysia Bintulu Campus, Sarawak, 97008 Bintulu, Sarawak, Malaysia
[2]Department of Land Management, Faculty of Agriculture, University Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[3]School of Sustainable Agriculture, University Malaysia Sabah, Locked Bag 2073, 88999 Kota Kinabalu, Sabah, Malaysia

Abstract: Problem Statement: Ammonia loss significantly reduces urea-N use efficiency in crop production. Efforts to reduce ammonia loss are laboratory oriented, as such limited in reflecting actual field conditions. This paper reports the effects of urea amended with triple superphosphate (TSP) and zeolite (Clinoptilolite) on soil pH, soil nitrate, soil exchangeable ammonium, dry matter production, N uptake, fresh cob production and urea-N uptake efficiency in maize (*Zea mays*) cultivation on an acid soil in actual field conditions. **Approach:** The treatments evaluated were: (i) Normal N, P, K application (74.34 g urea, 27.36 g TSP, 24.12 g KCl) (T1), (ii) Urea-TSP mixture (74.34 g urea+27.36 g TSP)+24.12 g KCl (T2), (iii) 74.34 g urea+27.36 g TSP+9.0 g zeolite (T3), (iv) 74.34 g urea+27.36 g TSP+13.5 g zeolite (T4) and (v) No fertilization (T5). Note, the same amount of 24.12 g KCl was used in T3 and T4 plots. Standard procedures were used to determine the selected chemical properties of zeolite, soil, TSP and urea. The pH of the urea, zeolite, soil and TSP were determined in a 1:2.5 soil: distilled water suspension and/or 0.01 N $CaCl_2$ using a glass electrode. The CEC of the zeolite was determined by the CsCl method. Soil CEC was determined by leaching with 1 N ammonium acetate buffer adjusted to pH 7.0 followed by steam distillation. Soil samples at harvest were analyzed for pH using the method previously outlined. Exchangeable ammonium and nitrate at harvest were extracted from the soil samples by the method of Keeney and Nelson and the amount determined using a LACHAT Autoanalyzer. Total N of the plant tissues (stem and leaf) was determined by the Micro-Kjeldhal method. **Results:** Urea amended with TSP and zeolite treatments and Urea only (urea without additives) did not have long term effect on soil pH and accumulation of soil exchangeable ammonium and nitrate. Treatments with higher amounts of TSP and zeolite significantly increased the dry matter (stem and leaf) production of Swan (test crop). All the treatments had no significant effect on urea-N concentration in the leaf and stem of the test crop. In terms of urea-N uptake in the leaf and stem tissues of Swan, only the treatment with the highest amount of TSP and zeolite significantly increased urea-N uptake in the leaf of the test crop. Irrespective of treatment, fresh cob production was statistically not different. However, all the treatments with additives improved Urea-N uptake efficiency compared to urea without additives or amendment. **Conclusion:** Urea amended with TSP and zeolite has a potential of reducing ammonia loss from surface-applied urea.

Key words: Ammonia volatilization, zeolite, triple superphosphate, urea, urea-N uptake efficiency, soil exchangeable ammonium, nitrate, acid soils, maize cultivation

INTRODUCTION

Ammonia loss significantly reduces urea-N use efficiency in crop production[1,2]. Efforts to reduce ammonia loss are laboratory oriented, as such limited in reflecting actual field conditions. Reduction in urea-N use efficiency in agriculture particularly when urea is surface-applied to soils has been generally associated

Corresponding Author: Osumanu Haruna Ahmed, Department of Crop Science, Faculty of Agriculture and Food Sciences, University Putra Malaysia Bintulu Campus, Sarawak, Malaysia Tel: +6086855406 Fax: +608685415

with ammonia volatilization and it is thought to be the major pathway for urea-N loss from surface-applied urea[1,2].

Ammonia volatilization in acid soils is generally thought to occur because of high pH and exchangeable ammonium concentrations in the microsite immediately around the fertilizer[3]. In acid soils, triple superphosphate (TSP) has been used to reduce ammonia loss[3] because it makes the microsite immediately around the fertilizer acidic[3]. The high Cation Exchange Capacity (CEC) and great affinity for ammonium ions of humic acids and zeolite have enabled the use of these materials to reduce ammonia volatilization[3-7]. The small internal tunnels of clinoptilolite zeolite as an example have been found to physically protect ammonium ions from too much nitrification by microorganisms[8]. This process does not only reduce ammonia loss but it also helps in releasing ammonium ions slowly into the soil[9,10]. However, it must be stressed that these studies were carried out under laboratory conditions as such the results may not reflect actual field conditions. In view of this, a field study was carried out to evaluate the effects of urea amended with TSP and zeolite on soil pH, soil nitrate, soil exchangeable ammonium, dry matter production (leaf and stem), N uptake, fresh cob production and urea-N uptake efficiency in maize cultivation in actual field conditions on an acid soil. Positive effects on these variables should lead to reduction in ammonia loss and should in turn improve urea-N use efficiency from surface-applied urea.

MATERIALS AND METHODS

The study was conducted on a sandy clay loam Typic Kanduidult (Bungor Series) of University Putra Malaysia Agricultural Farm at Puchong. The experimental area has annual precipitation of about 2,200 mm. This area also has a mean monthly maximum and minimum temperature of 32 and 24°C, respectively and a relative humidity of 70-90%. The Study was carried out between November 2006 and March 2007. The experimental field of the study was a cultivated field that had received little fertilization. The experimental design was a randomized complete block design with three replications (blocks). The plot size within each block was 1.5 m (length) ×1.5 m (breadth). The distance between plots was 1 m and that between blocks was 1.5 m. The planting distance was 0.75 m between rows and 0.25 m within plants. The pH, Cation Exchange Capacity (CEC), nitrate and exchangeable ammonium of the experimental plots prior to the application of treatments were not different. The treatments evaluated were: (i) Normal N, P, K application (74.34 g urea, 27.36 g TSP, 24.12 g KCl) (T1), (ii) Urea-TSP mixture (74.34 g urea+27.36 g TSP)+24.12 g KCl (T2), (iii) 74.34 g urea+27.36 g TSP+9.0 g zeolite (T3), (iv) 74.34 g urea+27.36 g TSP+13.5 g zeolite (T4) and (v) No fertilization (T5). Note, the same amount of 24.12 g KCl was used in T3 and T4 plots. The amounts of urea, TSP and KCl used were based on the standard recommendation for the test crop (Swan). The zeolite rates were adopted because based on several laboratory trials, they gave better mixtures[5]. It must be noted that the rates used in this study were a scale up of our previous laboratory trials. Treatments 3 and 4 were prepared by first weighing the 3 materials (for each treatment) separately into plastic vials. The materials were then transferred into a set of plastic vials, tightly closed and shaken on a reciprocal shaker at 150 rpm for 30 min. to ensure they were uniformly mixed.

Ten Days after Planting (DAP) treatments were applied to the test plants in the plots. At 28 DAP, the treatments were again applied. The plants were monitored and harvested (excluding guard rows) at 90 DAP. The weight of the harvested cobs was taken *in situ* using a weighing balance. Harvested stems and leaves were oven dried at 60°C until constant weight was attained. Afterwards, their weights were also taken by using a weighing balance. Before planting and a day before harvesting, composite soil samples (bulk of 3 samples) were taken at 0-20 cm in each of the experimental plots using an auger. The soil samples were air dried and ground to pass a 2-mm sieve.

Standard procedures were used to determine the selected chemical properties of zeolite, soil, TSP and urea. The pH of the urea, zeolite, soil and TSP were determined in a 1:2.5 soil: distilled water suspension and/or 0.01 N $CaCl_2$ using a glass electrode. The CEC of the zeolite was determined by the CsCl method[11]. Soil CEC was determined by leaching with 1 N ammonium acetate buffer adjusted to pH 7.0 followed by steam distillation. Soil samples at harvest were analyzed for pH using the method previously outlined. Exchangeable ammonium and nitrate at harvest were extracted from the soil samples by the method of Keeney and Nelson[12] and the amount determined using a LACHAT Autoanalyzer (LACHAT Instruments, Milwaukee, WI, USA). Total N of the plant tissues (stem and leaf) was determined by the Micro-Kjeldhal method. Analysis of variance was conducted to test for treatment effect while means of treatments were compared using Tukey's test. Urea-N use efficiency was calculated according to the formula[13]:

$$\% \text{ fertilizer nutrient recovery} = \frac{(\text{TNF})-(\text{TNU})}{\text{R}} \times 100$$

Where:

TNF = Total nutrient uptake from fertilized plots
TNU = Total nutrient uptake from unfertilized plots
R = Rate of fertilizer nutrient applied

RESULTS

The soil pH (water; 1:2.5 soil: Distilled water suspension), pH (0.01 N $CaCl_2$) and CEC before planting were 4.50, 4.00 and 6.40 cmol kg^{-1}, respectively. These results were consistent with those reported in the literature. The pH (water), pH (0.01 N $CaCl_2$) and CEC of zeolite were 6.10, 5.30 and 105 cmol kg^{-1}, respectively and they were also comparable with those reported by Ahmed et al.[14] who also provided other properties of this zeolite. Irrespective of treatment, the soil pH (water), pH (0.01 N $CaCl_2$), exchangeable ammonium and nitrate at harvest were not significantly different at p = 0.05 (Table 1). This observation is consistent with the finding of a study that evaluated these treatments on Bungor Series cultivated with a maize variety called Putra J-56[15], suggesting that T_2, T_3 and T_4 have no long term effect in controlling the release of these nutrients under field conditions.

Compared to T_5, T_3 and T_4 (treatments with higher amounts of TSP and zeolite) significantly increased the dry matter production (stem and leaf) of the test crop (Table 2). In a related field study, urea with the highest amount of additives significantly increased the stem and leaf dry weight of Putra J-56 maize variety[15]. All the treatments had no significant effect on the urea-N concentration in the leaf and stem of the test crop while in terms of urea-N uptake in these parts, only T_4 significantly increased urea-N uptake in the leaf of the crop (Table 3 and 4).

Irrespective of treatment, fresh cob production was statistically not different (Table 5) but in terms of efficiency, T_2, T_3 and T_4 improved urea-N uptake efficiency (Table 6).

Table 1: Soil pH, soil nitrate and soil exchangeable ammonium at 90 Days after planting (DAP)

Treatment	pH $_{(1\ NKCl)}$	pH $_{(water)}$	NO_3 (ppm)	NH_4 (ppm)
T_1	3.86	5.09	7.97	609
T_2	3.79	5.18	7.77	563
T_3	3.83	5.09	7.77	653
T_4	3.88	5.30	7.93	544
T_5	3.93	5.50	5.80	470

Table 2: Dry weight of stem and leaf of Swan at 90 DAP

Treatment	Stem g $plant^{-1}$	Leaf g $plant^{-1}$
T1	156.60^{bc}	58.27^{abc}
T2	127.45^{bc}	49.89^{bc}
T3	164.74^{ab}	93.27^{a}
T4	203.51^{a}	85.89^{ab}
T5	123.01^{c}	36.32^{c}

Note: Different alphabets within column indicate significant difference between means using Tukey's test at p = 0.05

Table 3: Urea-N concentrations in stem and leaf of Swan at 90 DAP

Treatment	Stem (%)	Leaf (%)
T1	0.83	0.24
T2	1.37	0.27
T3	1.13	0.21
T4	1.35	0.25
T5	1.13	0.19

Table 4: Urea-uptake in leaf and stem of Swan at 90 DAP

Treatment	Leaf g $plant^{-1}$	Stem g $plant^{-1}$
T_1	0.14^{ab}	1.30
T_2	0.13^{ab}	2.38
T_3	0.19^{ab}	2.03
T_4	0.24^{a}	2.34
T_5	0.08^{b}	1.29

Note: Different alphabets within column indicate significant difference between means using Tukey's test at p = 0.05

Table 5: Fresh cob yields of Swan at 90 DAP

Treatment	kg ten $plant^{-1}$
T_1	3.38
T_2	3.37
T_3	3.48
T_4	3.42
T_5	3.00

Table 5: Fresh cob yields of Swan at 90 DAP

Treatment	kg ten $plant^{-1}$
T_1	3.38
T_2	3.37
T_3	3.48
T_4	3.42
T_5	3.00

Table 6: Urea-N uptake Efficiency at 90 DAP

Treatment	Leaf (%)	Stem (%)	Total (%)
T_1	0.79	0.18	0.97
T_2	0.67	13.50	14.17
T_3	0.79	9.00	9.79
T_4	1.79	13.00	14.79
T_5	na	na	na

Na: not applicable

DISCUSSION

In one of our laboratory studies on the effect urea amended with TSP and zeolite, we found significant accumulation of ammonium at only 0-3 cm only after 15 days of incubation[7]. We found no significant accumulation of ammonium at 3-7.5 cm while for nitrate, regardless of soil depth, there was no significant accumulation irrespective of treatment[7]. In the case of pH, our laboratory study results also indicated no significant effect regardless of treatment and soil depth after 15 days of incubation[7]. The pH of the TSP was 2.50 and was considered low. This may be partly attributed to the acceptable amounts of K, Ca and Mg in the TSP[5]. The pH of the urea was 8.00 and it was also considered high.

Contrary to our study, urea with the highest amount of additives significantly increased the stem and leaf dry weight of Putra J-56 maize variety[15]. This could be attributed to varietal difference.

It is interesting to note that the under T_1 (urea without additives) the overall urea-N use efficiency only 1% only while those under T_2, T_3 and T_4 (urea with additives) were approximately 14, 10 and 15%, respectively. Based on the climatic information provided, perhaps the additives of these treatments may have caused a temporary reduction in ammonia loss at the initial stages of the application of the treatments compared to T_1.

CONCLUSION

Compared to T_5, T_3 and T_4 significantly increased the dry matter production Swan. In terms of urea-N uptake in the leaf and stem tissues, only T_4 had significant effect on urea-N uptake in the leaf of the test crop. Irrespective of treatment, fresh cob production was statistically not different. However, all the treatments with additives improved urea-N efficiency compared to urea without additives or amendment. This suggests that urea amended with TSP and zeolite has the potential of reducing ammonia loss from surface-applied urea. Hence could contribute to reduction of environmental pollution particularly in relation to urea use in agriculture.

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