

USE OF ENHANCED EFFICIENCY NITROGEN FERTILIZERS TO REDUCE LEACHING AND VOLATILIZATION LOSS

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Abstract

A laboratory study was conducted to explore interactions of N source and treatment with precipitation events on a coarse-textured soil. Nitrogen sources included urea-ammonium nitrate solution (UAN), UAN with additives of either nitrpyrin (Instinct[®]) or a carboxylated polymer (Nutrisphere-N[®]), or a polymer-coated dry urea (PCU) (ESN[®]). These products were applied to soil chambers which allowed measurement of ammonia (NH₃-N) volatilization or nitrate leaching over 31 days. Precipitation events simulated rainfall frequency and amount which occurred in field studies in 2009 (dry conditions) and 2011 (wet conditions). Ammonia volatilization was far lower in wet than dry conditions. Total NH₃-N loss for the dry precipitation regime ranged from 11-18% of applied fertilizer N, except for the PCU treatment. In contrast, wet conditions kept NH₃-N loss extremely low (<1% of applied N), as urea moved deep enough into the soil to protect from most volatile loss. However, substantial NO₃-N leaching occurred with wet conditions, on the order of 50-60% of applied N for most treatments. Leaching loss was greatest for UAN, followed by UAN with additives. For both dry and wet environments, loss of N from polymer-coated urea to either NH₃ volatilization or NO₃-N leaching was negligible.

Introduction

A concern with urea-based fertilizers is the risk of N loss via ammonia volatilization, and there is concern for the risk of NO₃-N leaching with coarse-textured soils and subsequent contamination of groundwater from highly soluble fertilizers containing urea or nitrate-N. Inhibitors are available which can be added to urea fertilizers to reduce the risk of N loss to the environment. Urease and nitrification inhibitors can prevent the conversion of urea to NH₄⁺ and NH₄⁺ to NO₃⁻, respectively. The activity and effectiveness of inhibitors will be influenced by complex interactions among crop management, soil, and environmental factors (Keeney, 1980; Murphy and Ferguson, 1997). Consequently, performance of inhibitors, and particularly impact on grain yield, can vary substantially. Polymer coated, or controlled release N fertilizers are designed to release N into the soil solution at a rate that approximately matches crop N demand, thus maximizing N use efficiency by decreasing N losses (Malthi et al., 2001; Golden et al., 2011). Studies have found that controlled release N fertilizers can reduce N leaching on sandy soils, as well as reduce atmospheric N losses (Allen, 1984; Wang and Alva, 1996). The benefits of slow release N fertilizer in increasing crop yield and N use efficiency have varied substantially

depending on soil and climatic conditions. Historically, controlled release N fertilizers have been used primarily for turf and high value crop applications due to their cost. A laboratory study was conducted to replicate weather patterns observed in 2009 and 2011 field studies evaluating various N treatment effects on N use efficiency of irrigated corn. The lab study was conducted in a controlled environment to directly measure $\text{NH}_3\text{-N}$ and $\text{NO}_3\text{-N}$ loss, in order to better understand the mechanisms impacting yield and N use efficiency in the field.

Procedures

The soil used in this study was an Ipage loamy fine sand (mixed, mesic Oxyaquic Ustipsamments). Soil properties in the surface 20 cm were: pH 7.6, organic matter 1.1%, Mehlich-3-P 8.5 mg kg^{-1} , ammonium acetate-K 103 mg kg^{-1} , DTPA-Zn 3.8 mg kg^{-1} , CEC 6.9 cmol kg^{-1} . Soil was collected in depth increments of 0-10 (top soil) and 10-20 cm (subsoil). Soil was brought to the lab and sieved through a 2-mm screen. Soil was leached with distilled water three times to remove any excess $\text{NO}_3\text{-N}$ accumulated while in storage, then air-dried to 10% water content, followed by storage at $4 \text{ }^\circ\text{C}$. Acrylic chambers used in the experiment had a diameter of 50 mm, and height of 300 mm. Porous ceramic plates (one bar) were inserted at the bottom of the chamber central body, and Whatman 42 filter paper was placed on top of the ceramic plate prior to soil packing to prevent soil entry into the plate. Soil, comprised of 1/3 topsoil and 2/3 subsoil, was packed to a bulk density of 1.3 Mg m^{-3} and a depth of 24 cm on top of the ceramic plate. An airspace of approximately 4 cm was left between the soil surface and the lid of the chamber. The lid and base of the chamber assembly were also made from acrylic. Two sponges (one 5.5 cm dia, one 6.0 cm dia), 1.5 cm thick were placed in the lid to trap volatilized $\text{NH}_3\text{-N}$. Each sponge was saturated with 5 ml of H_3PO_4 -glycerol solution (40 ml glycerol, 50 ml conc. H_3PO_4 acid, 910 ml deionized water). The lower sponge served as the primary trap for NH_3 emitted from soil, while the upper sponge served as a buffer for ambient $\text{NH}_3\text{-N}$. On selected dates following rainfall events, a vacuum was introduced into the chamber base for two minutes to facilitate soil water entry into and through the ceramic plate. Leached soil solution was removed from the lower chamber for urea, ammonium and nitrate-N analysis. The lower chamber was rinsed 3X with 2M KCl solution containing phenylmercuric acetate (PMA) to block urea hydrolysis. Leachate was brought to a constant volume for urea, ammonium and nitrate-N analysis. Leachate urea content was analyzed colorimetrically. Ammonium and nitrate-N concentration in leachate were determined with a continuous flow analytical system.

Fertilizers were 32% N UAN solution (UAN), UAN with Instinct[®] (UAN-IN), UAN with Nutrisphere-N[®] (UAN-NS) and polymer-coated urea (ESN[®]) (PCU). All fertilizers were applied at the rate of 150 kg N ha^{-1} . A fifth treatment was an unfertilized check. Two water application regimes were used, to replicate times and amounts of rainfall observed in field studies in 2009 (dry regime) and 2011 (wet regime). Water application times and amounts are shown in Figure 1. Water was applied with a syringe at a rate to avoid ponding of water on the soil surface. Fertilizers were incorporated into the top 20 mm of soil to replicate field conditions. After fertilization, chambers were placed in an incubator which maintained a daytime (8 AM – 8 PM) temperature of $25 \text{ }^\circ\text{C}$, and a night temperature of $18 \text{ }^\circ\text{C}$. Ammonia trap sponges were replaced on days 2, 4, 7, 10, 14, 21 and 31. Removed sponges were shaken in 50 ml 2 M KCl-PMA for one hour, with the extract analyzed for $\text{NH}_4\text{-N}$. There were four replications of each precipitation

regime/N source treatment combination, which were placed in the incubator in a completely randomized design.

After 31 days, the study was terminated. The ceramic plate was removed from each chamber assembly, allowing soil to be pushed out the top of the central chamber. Soil was extracted in 4 cm increments. Soil from each layer was thoroughly mixed, then two 10.5 g samples were collected – one for soil moisture determination and pH measurement, the other for urea, ammonium and nitrate-N determination. Samples were shaken for one hr with 100 ml KCL-PMA, filtered, and analyzed as described above. Fertilizer N recovery as volatilized ammonia, leached urea, ammonium or nitrate-N, or soil residual urea, ammonium or nitrate-N was calculated by subtracting corresponding values of ammonia, urea, ammonium or nitrate-N in the check treatment. Analysis of variance was conducted using PROC GLM (SAS Institute, Carry, NC) to test for N source, moisture regime, and interaction effects on dependent variables. Treatments were compared based on Duncan’s multiple range test at the 0.05 ($P<0.05$) or 0.01 ($P<0.01$) probability levels.

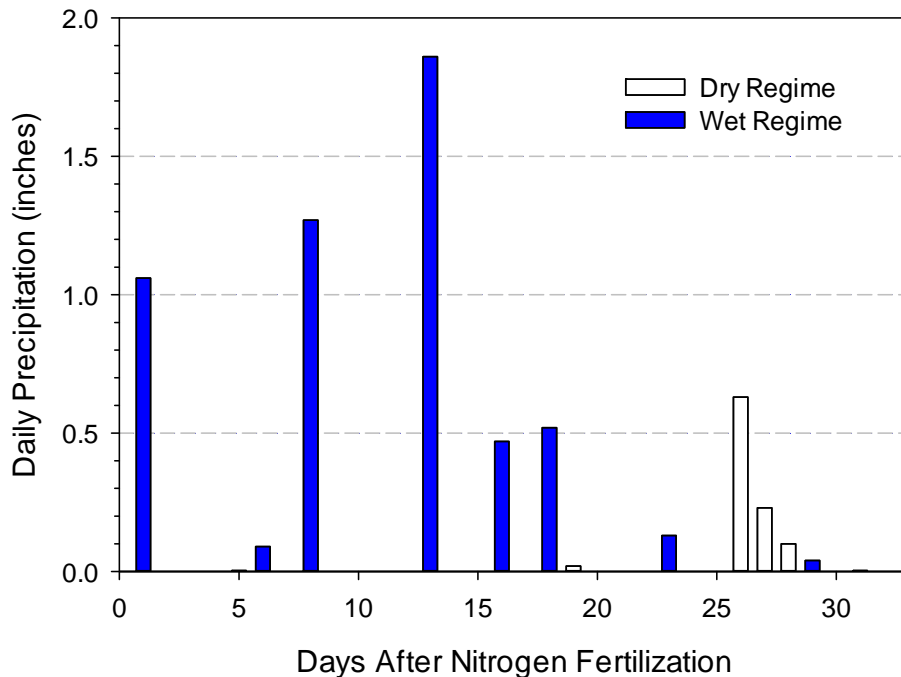


Figure 1. Precipitation days and amounts.

Results and Discussion

Ammonia Volatilization

Ammonia volatilization occurred mainly in the first ten days after fertilization (Figure 2). Cumulative $\text{NH}_3\text{-N}$ loss ranged from a low of 0.2% with UAN in the wet precipitation regime to a high of 18.7% for the dry precipitation regime from the UAN-IN treatment. There were

significant interactions between precipitation regime and N source through the course of the study on NH₃-N loss (Table 1).

Table 1. Analysis of variance, cumulative NH₃-N loss.

Source	DF	Pr>F						
		Day 2	Day 4	Day 7	Day 10	Day 14	Day 21	Day 31
Replication	3	0.111	0.382	0.372	0.344	0.378	0.372	0.331
Precip. (A)	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N Source (B)	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A*B	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Total ammonia volatilization amounts were much higher with the dry precipitation regime compared to the wet regime (Figure 2) – ammonia loss with the wet regime was negligible from all fertilizer sources. The PCU treatment also had negligible NH₃-N loss with the dry precipitation regime, while other fertilizer sources experienced significant volatile N loss. For the dry regime, the UAN treatment had the highest level of volatile loss early in the study, but the UAN-IN treatment loss was greater from 14 days on. This may be due to the nitrification inhibitor in this treatment causing ammonium concentrations to increase as urea hydrolysis occurred, driving more NH₄ to convert to NH₃. Others have also found that nitrification inhibitors increased NH₃-N loss due to the prolonged presence of NH₄-N (Gioacchini et al., 2002; Zaman et al., 2008). For the dry regime, the UAN-NS treatment also significantly reduced NH₃ loss compared to UAN and UAN-IN treatments. Though fertilizers were lightly incorporated, to a depth of 2 cm, this was inadequate to protect against NH₃ volatilization with this poorly buffered, low CEC soil. The large precipitation event on Day 1 with the wet regime (1 inch) likely moved most or all urea and nitrate-N from UAN, UAN-IN and UAN-NS treatments well into the soil profile, effectively eliminating the risk of NH₃ volatilization (Harper et al., 1983; Bouwmeester et al., 1985; Ferguson and Kissel, 1986).

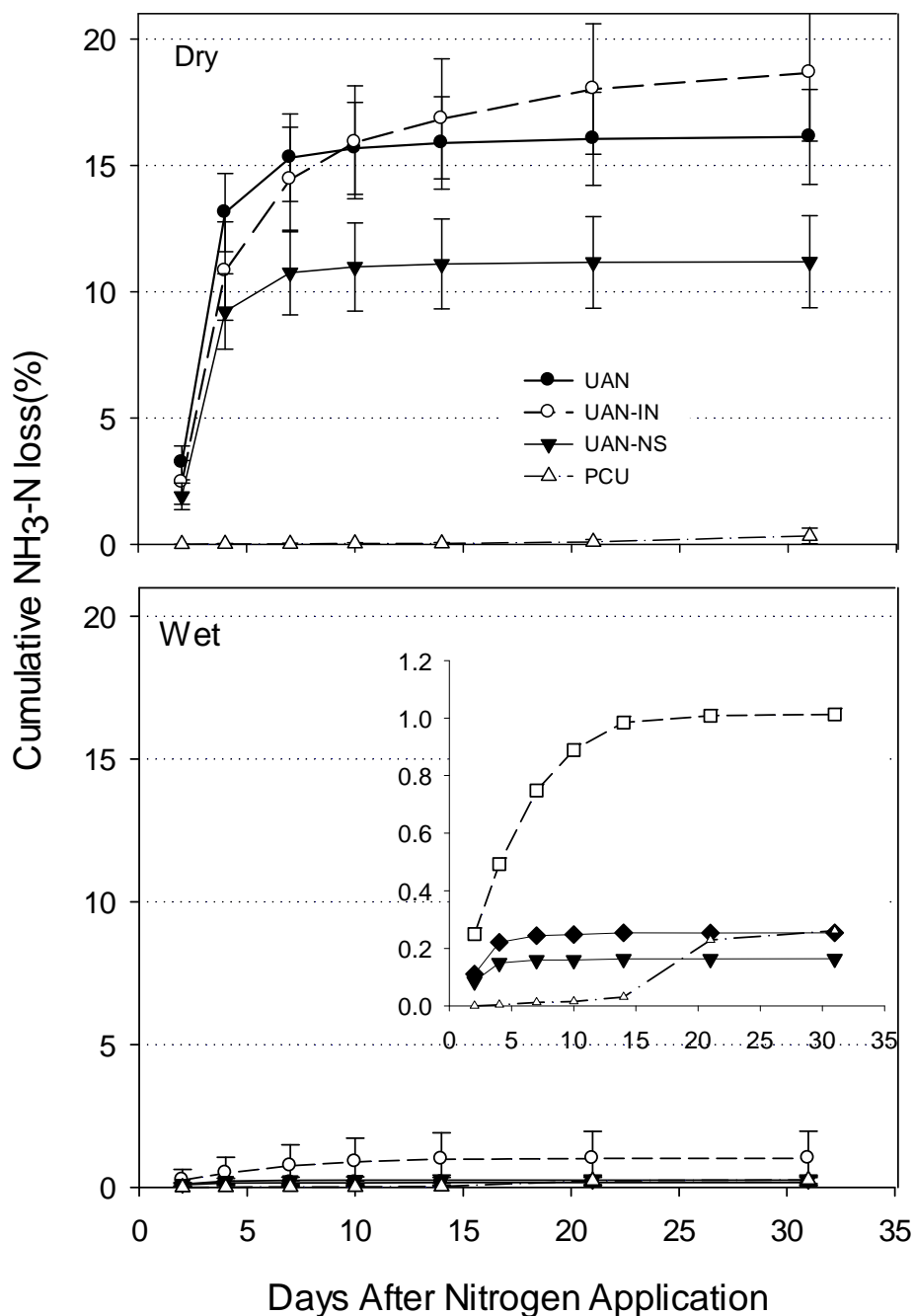


Figure 2. Cumulative ammonia volatilization loss, dry and wet moisture regimes. UAN=urea ammonium nitrate solution; UAN-IN=UAN with Instinct[®]; UAN-NS=UAN with Nutrisphere-N[®]; PCU=polymer-coated urea (ESN[®]). Error bars are standard error.

Nitrate-N Leaching

Significant leachate from soil columns was not recorded until Day 9 (Figure 3), and then only from the wet precipitation regime treatments. Leaching never occurred from the dry regime

treatments – consequently statistical analysis and presentation of leaching data is from the wet regime only. Through the course of the study, the PCU treatment resulted in much lower nitrate-N leaching than other treatments, with a total of 6.2% of fertilizer N leached, compared to total leaching loss ranging from 48 to 65% of fertilizer N applied for other sources. Total N leached was not different between UAN-IN and UAN-NS treatments, and both had trends for lower total N leached than the UAN treatment.

Table 2. Analysis of variance, leached NO₃-N (wet precipitation regime only).

Source	DF	Pr>F			
		Day 9	Day 13	Day 16	Day 18
Replication	3	0.9515	0.1934	0.2148	0.2246
N Source	4	<0.001	<0.001	<0.001	<0.001

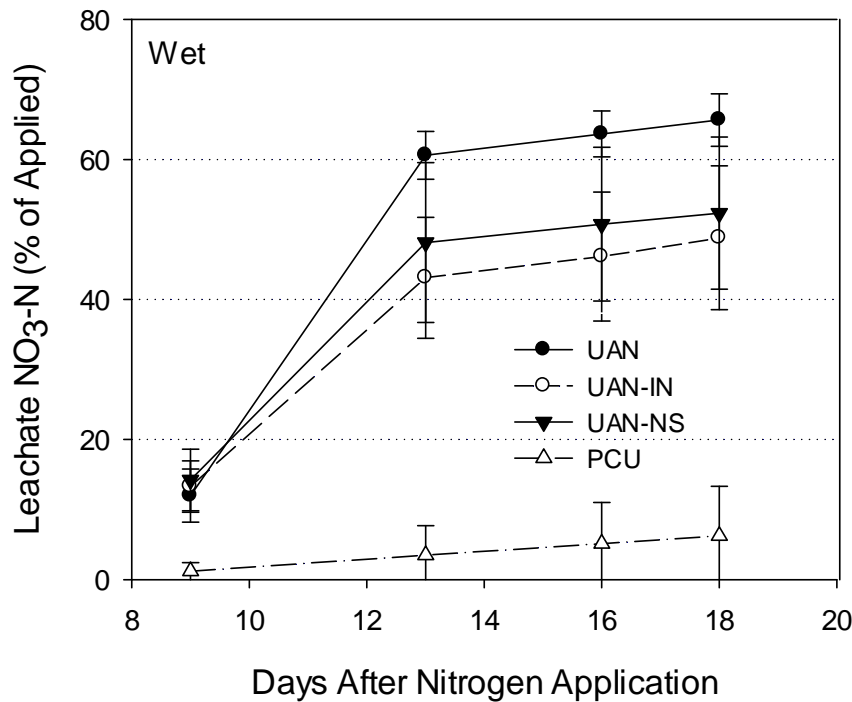


Figure 3. Cumulative nitrate-N leached. Error bars are standard error.

Fertilizer N Recovery

Total fertilizer N recovery is shown in Figure 4. Total N recovery ranged from 80 to 97%, with the remainder unaccounted for. It is likely that some un-recovered fertilizer N was converted to organic forms in soil, which were not measured in this study. There were substantial differences in the fraction of N recovered among precipitation regime and N source treatments. Volatilized NH₃-N loss was negligible for the wet regime, but was as high as 18% of applied N for the dry regime. No leaching occurred with the dry regime, and thus no loss of nitrate or other forms of N

in leachate. However, leached nitrate-N was as high as 65% of applied N with UAN for the wet precipitation regime. The only recovery of urea-N, either as soil residual or leached N, occurred with the PCU treatment. In this case, the residual coated granules were recovered from the surface soil layer, crushed, and extracted with 2M KCl-PMA separately from the surrounding soil. No urea-N was recovered with any treatment other than PCU, and then urea-N was only found in the surface 0-4 cm layer. Residual urea-N with the PCU treatment ranged from 47 – 69% of applied N. With the intensity of precipitation early in the study with the wet regime, it is likely that urea from UAN, UAN-IN and UAN-NS treatments leached into lower depths of the column. However, by the time the study was terminated and soil extracted in layers, all urea had hydrolyzed to ammonium.

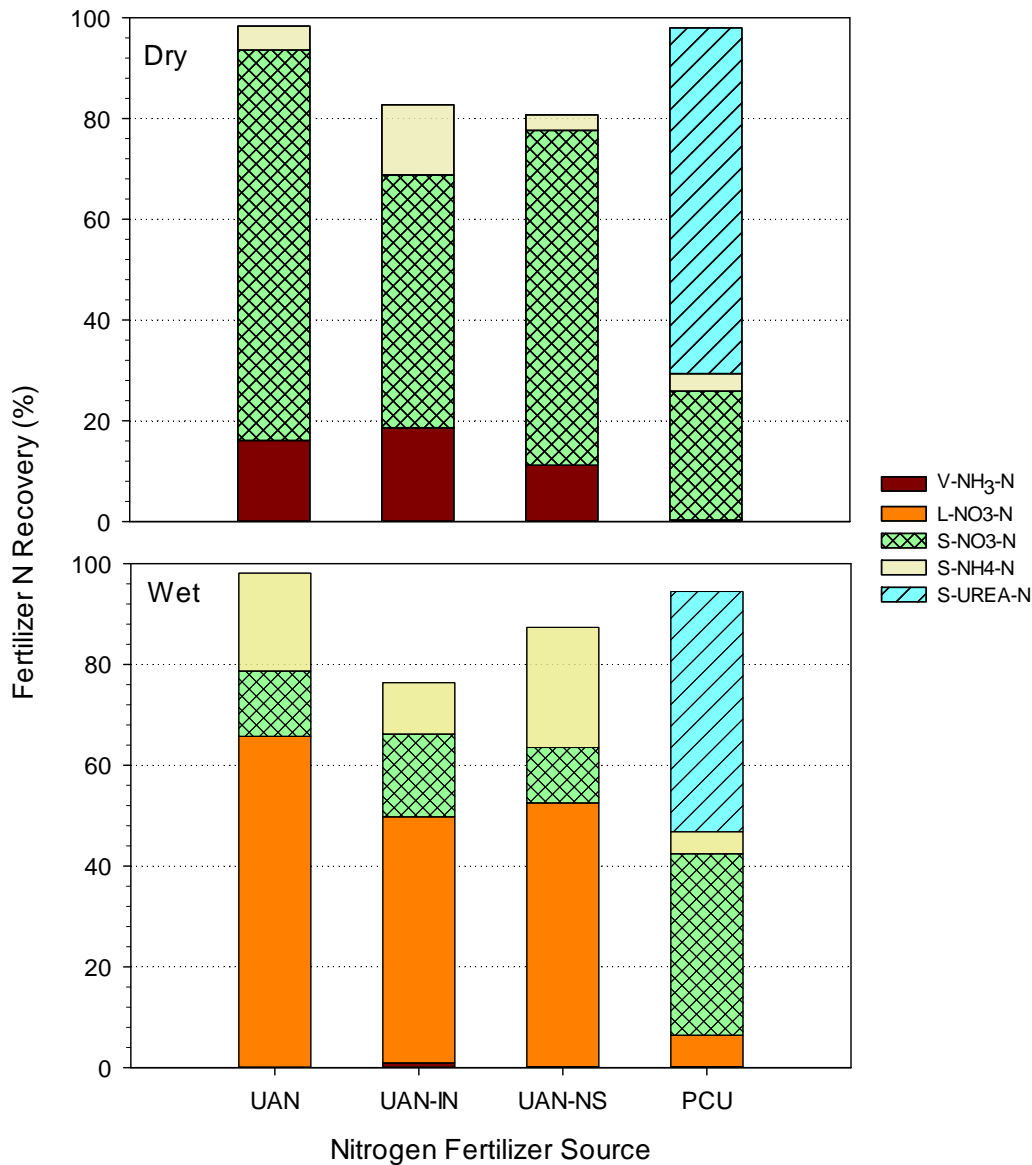


Figure 4. Cumulative fertilizer nitrogen recovery. V= volatilized ammonia-N; L=leached nitrate-N; S=soil residual nitrate, ammonium, or urea-N.

Summary

Conditions in this study represent extremes for weather risk of N loss. However, such events should not be considered rare, as they occurred over three successive growing seasons in one location in Nebraska. Most growers recognize the risk of applying all fertilizer N at one time on coarse-textured soils and split their N fertilization into multiple events during the growing season. However, applying the majority, or sometimes all, of the N fertilizer for a crop to coarse-textured soils is not uncommon either. In such cases, there can be multiple risks of N loss, as documented in this study. If urea-based N fertilizers are left on or near the soil surface, the risk of significant NH₃ volatilization is high on poorly buffered, coarse-textured soils without rainfall or irrigation to move urea into the soil. If heavy rainfall occurs soon after fertilization on such soils, the risk of NH₃ loss disappears. However, leaching of both urea and nitrate-N can occur with these conditions. We did not measure any urea-N in leachate, or at depth within soil columns at the end of the study. However, since no leachate was collected until Day 9 with the wet precipitation regime, it is likely that any urea which leached from the surface had hydrolyzed to ammonium by the time sampling occurred. Polymer-coated urea effectively protected against either NH₃ volatilization or NO₃-N leaching, depending on the precipitation regime. The UAN-IN and UAN-NS treatments generally reduced loss compared to UAN alone. However, they were less effective than PCU when heavy precipitation occurred very soon after fertilization and urea leaching into the profile was likely significant.

References

- Allen, S.E. 1984. Slow-release nitrogen fertilizer. *In* Nitrogen in Crop Production, ed. R.D. Hauck. pp. 195-206. Madison, Wisc.: ASA, CSSA, SSSA.
- Bouwmeester, R.J.B., P.L.G. Vlek, and J.M. Stumpe. 1985. Effect of environmental factors on ammonia volatilization from a urea-fertilized soil. *Soil Sci. Soc. Am. J.* 49:376-381.
- Ferguson, R.B., and D.E. Kissel. 1986. Effect of soil drying on ammonia volatilization from surface-applied urea. *Soil Sci. Soc. Am. J.* 50: 485-490.
- Gioacchini, P., A. Nistri, and C. Marzadori. 2002. Influence of urease and nitrification inhibitors on N losses from soils fertilized with urea. *Biol. Fertil. Soils.* 36: 129-135.
- Golden, B., N. Slaton, and R. Norman. 2011. Nitrogen release from Environmentally Smart Nitrogen fertilizer as influenced by soil series, temperature, moisture, and incubation method. *Commun. Soil. Sci. Plant Anal.* 42: 1809-1824.
- Harper, L.A., V.R. Catchpole, and R. Davis. 1983. Ammonia volatilization: Soil, plant and microclimate effects on diurnal and seasonal fluctuations. *Agron. J.* 75: 212-218.
- Kenney, D.R. 1980. Factors affecting the persistence and bioactivity of nitrification inhibitors. *In*: Meisinger, J.J., G.W. Randall and M.I. Vitosh (eds). *Nitrification Inhibitors - Potential and Limitations*. ASA Special Publication 38, American Society of Agronomy. Madison, WI, Chapter 3, pp. 33-46.
- Malthi, S.S., C.A. Grant, and A.M. Johnston. 2001. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. *Soil Till. Res.* 60:101-122.
- Murphy, T.L., and R.B. Ferguson. 1997. Ridge-till corn and urea hydrolysis response to NBPT. *J. Prod. Agric.* 10:271-282.
- SAS Institute. 2010. SAS Inst., Cary, NC.

- Wang, F.L., and A.K. Alva. 1996. Leaching of nitrogen from slow-release urea sources in sandy soils. *Soil Sci. Soc. Am. J.* 60:1454-1458.
- Zaman, M. M. L. Nguyen and J. D. Blennerhassett. 2008. Reducing NH_3 , N_2O and NO_3^- -N losses from a pasture soil with urease or nitrification inhibitors and elemental S-amended nitrogenous fertilizers. *Biol. Fertil. Soils.* 44:693–705.

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