EVALUATING THE EFFECTS OF NITROGEN SOURCE, PLACEMENT, AND TIING ON CORN YIELD AND NITROGEN LOSSES IN THE SANDY SOILS OF NORTHEAST NEBRASKA

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ABSTRACT

The impact of nitrogen sources, placement, enhanced efficiency fertilizers (EEFs), and application timing on improving groundwater quality in groundwater management areas remains unclear. This study assessed the effects of various N fertilizer sources, EEFs, application timing, and placement on corn yield and nitrogen losses via nitrate (NO_3^-) leaching and ammonia (NH_3) volatilization. The experiment was conducted in 2023, a notably dry year, at a farmer's site in Concord, Nebraska. The experimental design included 11 treatments with four nitrogen fertilizer sources: anhydrous ammonia (AA), urea ammonium nitrate (UAN), ESN (environmentally smart N), and urea. Each source was applied using both preplant and split application. Anhydrous ammonia was injected into the soil, while urea and ESN were broadcast. UAN was applied both by broadcast and injection.

The results showed that nitrogen fertilizer sources significantly affected corn grain yield, while placement and application timing did not influence yield. In contrast, nitrogen sources, timing and placement significantly affected both NO_3^- leaching and NH_3 volatilization. Split application increased NH_3 volatilization compared to pre-plant application but it reduced NO_3^- leaching losses ($p<0.001$). Furthermore, injected UAN reduced NH_3 volatilization and NO_3^- leaching by 75% and 18%, respectively, compared to broadcast urea. ESN applied pre-plant significantly reduced NO_3^- -N leaching compared to pre-plant anhydrous ammonia, UAN broadcast, and urea broadcast, with leaching levels like those from the split application of other nitrogen sources. Additionally, ESN pre-plant substantially reduced NH_3 volatilization compared to all other nitrogen sources, regardless of application timing, except injected UAN. Overall, the findings suggest that nitrogen sources, EEFs, placement, and timing of application significantly influence both crop yield and nitrogen losses, even in dry years.

INTRODUCTION

Over time, fertilizer consumption in Nebraska has grown significantly, rising from 47,000 tons of nitrogen (N) in 1955 to a peak of over 960,000 tons in 2019. Much of this nitrogen comes from Urea Ammonium Nitrate (UAN) solutions (57%), followed by anhydrous ammonia (23%) and urea (14%). However, despite increased fertilizer use, Nitrogen Use Efficiency (NUE) has stagnated since 2000, with farmers applying 0.8 to 0.9 pounds of nitrogen per bushel of grain (Ferguson et al., 2024). This plateau suggests that traditional fertilization practices have reached their efficiency limits, highlighting the need for innovative strategies to sustain productivity while reducing nitrogen losses.

A promising approach to address these challenges is the 4Rs nutrient stewardship, which emphasizes the right source, right rate, right time, and right place for nutrient application. This framework seeks to enhance NUE while minimizing environmental impacts such as nitrate leaching and ammonia volatilization. However, despite its potential benefits, few studies have explored the simultaneous impact of all 4R practices on both grain yield and nitrogen losses, particularly in the Midwest. Currently, N-recommendation tool from the University of Nebraska-Lincoln (UNL) focus primarily on right rate of fertilizer, with limited guidance on right fertilizer sources and placement. Given the dominance of UAN, anhydrous ammonia, and urea in Nebraska’s fertilizer practices, the integration of Enhanced Efficiency Fertilizers (EEFs)—such as Environmentally Smart Nitrogen (ESN)—offers a promising scientific alternative.

The source, placement, and timing of nitrogen fertilizer significantly influence both crop yield and nitrogen losses. It is hypothesized that selecting the appropriate fertilizer source, combined with strategic placement and application timing, will (1) improve grain yield, and (2) reduce environmental nitrogen losses by minimizing nitrate leaching and ammonia volatilization. So, the objectives of the study were to: 1) Quantify the effect of nitrogen fertilizer source, placement, and timing on crop yield, and 2) measure the reduction in nitrate leaching and ammonia volatilization under different nitrogen management practices. This study aims to fill critical knowledge gaps by evaluating the environmental and agronomic impacts of 4Rs practices, providing actionable insights for sustainable nitrogen management in corn production systems.

MATERIAL AND METHODS

In 2023, a field experiment was established near the Haskell Agricultural Laboratory (HAL) on a farm site in Concord, NE (42° 23.613' N, 96° 56.673' W). The study employed a randomized complete block design (RCBD) with 11 treatments, each replicated four times, during the corn phase of a corn-soybean rotation. Treatments included four fertilizer sources: anhydrous ammonia (82% N), urea ammonium nitrate (UAN, 32% N), environmentally smart nitrogen (ESN, 44% N), and urea (46% N), applied either pre-plant or as a split application. Anhydrous ammonia was injected, ESN and urea were broadcast, while UAN was applied using both broadcast and injection methods (see Table 1 for details).

To assess total dry matter production, six corn plants were harvested at the R6 stage, with ears shelled and stover processed to measure moisture and calculate dry weight. Nitrogen content in the stover and grain was analyzed and multiplied by yield to determine total nitrogen uptake. Grain yield was calculated by harvesting from a specified area, shelling the ears, adjusting for moisture, and combining it with stover yield for total biomass. Ammonia volatilization losses were measured using acid traps placed on the soil surface in spring 2023, covered with plastic buckets to prevent air mixing, with samples collected and analyzed periodically over 30 days. Nitrate leaching losses were quantified using two suction cup lysimeters installed at a 1.2 m depth in each plot, following protocols by Singh et al. (2024) and Maharjan et al. (2014).

Table 1. Fertilizer-N treatments at farmer's site located at Concord, NE in 2023

Treatments			[&]Stage of fertilizer application	N rate (% of [#]RRF)	4Rs Treatments
[§] N-source	Placement	Time			
AA	Injected	Preplant	PP	100% at PP	S/T
	Injected	Split[±]	PP + SD at V6	40% at PP + 60% at SD	S/T
UAN	Broadcast	Preplant	PP	100% at PP	S/T/P
	Broadcast	Split[±]	PP + SD at V6	40% at PP + 60% at SD	S/T/P
	Injected	Preplant	PP	100% at PP	S/T/P
	Injected	Split[⊥]	PP + SD at V6	40% at PP + 60% at SD	S/T/P
ESN	Broadcast	Preplant	PP	100% at PP	S/T
	Broadcast	Split[⊥]	PP + SD at V6	40% at PP + 60% at SD	S/T
Urea	Broadcast	Preplant	PP	100% at PP	S/T
	Broadcast	Split[⊥]	PP + SD at V6	40% at PP + 60% at SD	S/T
Control	-	-	-	-	-

[§] AA = Anhydrous Ammonia, UAN-B = Urea Ammonia Nitrate, [&]PP = pre-plant; SD = side dress; [#] RRF= recommended rate of fertilizer (140 lbs N/ha^{-1}) was calculated using UNL-N Algorithm.

RESULTS AND DISCUSSION

Crop Yield

This study examined the impact of various nitrogen fertilizer sources, application timing, and placement on corn grain yield. Corn yield response to N-fertilizer treatments was significantly higher than the control (Figure 1). Among fertilizer treatments, there were no statistically significant differences in yield except for the split-applied UAN broadcast treatment. Timing of application (pre-plant vs. split) did not significantly affect yield, as pre-plant applications across all fertilizer types produced similar yields to split treatments. When averaged across both pre-plant and split applications, anhydrous ammonia resulted in a significantly lower yield compared to other fertilizer sources (p = 0.057).

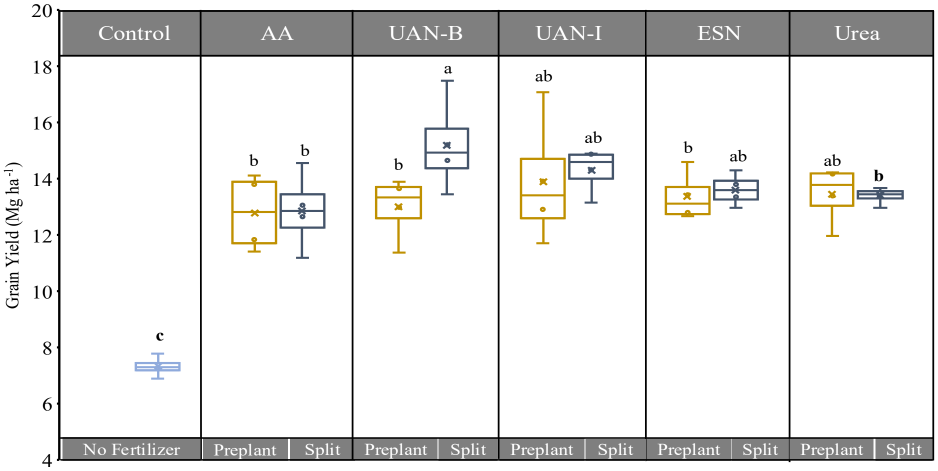

Figure 1. Effect of different nitrogen fertilizer sources and their application timing on corn grain yield at Farmer's site, Concord, NE. Treatments followed by the same letter are not significantly different at p = 0.05

Ammonia Volatilization

The temporal variation in NH_3 emissions following pre-plant and split applications of N-fertilizer is illustrated in Figure 2a and Figure 2b, respectively. N-fertilizer treatments significantly affected cumulative NH_3 losses ($p < 0.001$), with the highest losses observed in split-applied urea, comparable to split-applied UAN broadcast. UAN, whether applied as a pre-plant or split treatment, resulted in significantly lower NH_3 losses, comparable to the no-fertilizer control, with reductions of 84.7% and 83.8%, respectively, compared to split-applied urea. Overall, contrast analysis indicated that pre-plant treatments generally led to lower NH_3 losses than split treatments. ESN application reduced NH_3 losses by 30.1% compared to urea, regardless of application timing ($p = 0.028$). Additionally, UAN placement had a significant impact, with injected UAN reducing NH_3 loss by 76.1% compared to broadcast applications ($p < 0.0001$).

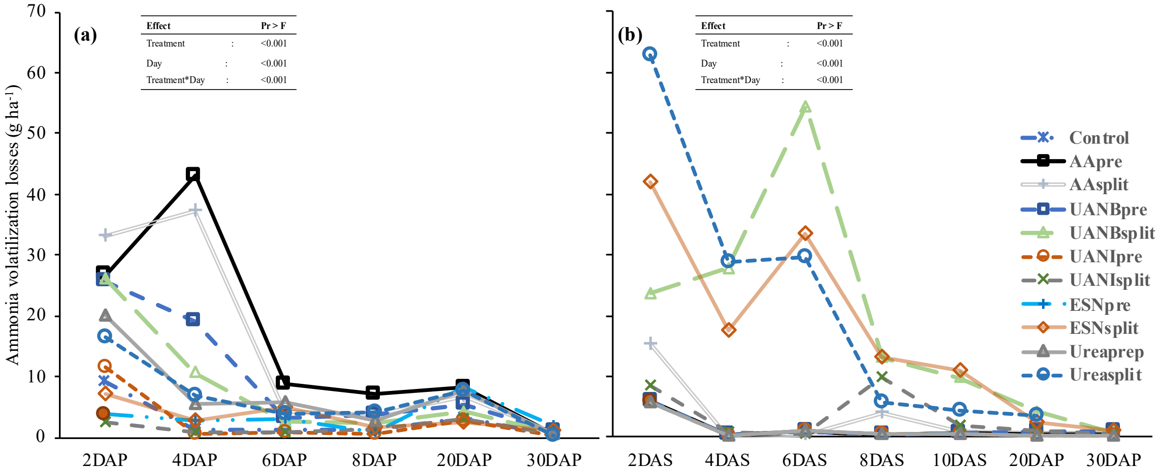

Figure 2. Ammonia volatilization losses (a) after preplant application of N-fertilizer (b) after split application of N-fertilizer at the farmer's site, Concord, NE. Note: DAP=Days after Preplant application, DAS=Days after Split application.

Nitrate Leaching

Figure 3 shows pore water NO_3^--N concentrations from samples collected throughout the season at a 4-foot depth using a lysimeter, with 19 samples taken after precipitation or irrigation events. Sampling date significantly influenced NO_3^--N concentrations ($p < 0.001$), which ranged from <1 to 82.9 mg kg^{-1} over the corn growing season. Following the pre-plant nitrogen application, NO_3^--N levels were between 12.7 and 66.4 mg kg^{-1}, then increased to 24.3–82.9 mg kg^{-1} after a split application in mid-June. Most treatments showed a gradual decline in NO_3^--N levels as the season progressed, except for the anhydrous ammonia (AA) pre-plant treatment, where delayed nitrification kept NH_4^+ stable longer, sustaining higher NO_3^--N levels later. The urea pre-plant treatment showed higher pore water NO_3^--N concentrations from early on through mid-July, resulting in the highest average NO_3^--N levels throughout the season, comparable to those in the anhydrous ammonia pre-plant treatment.

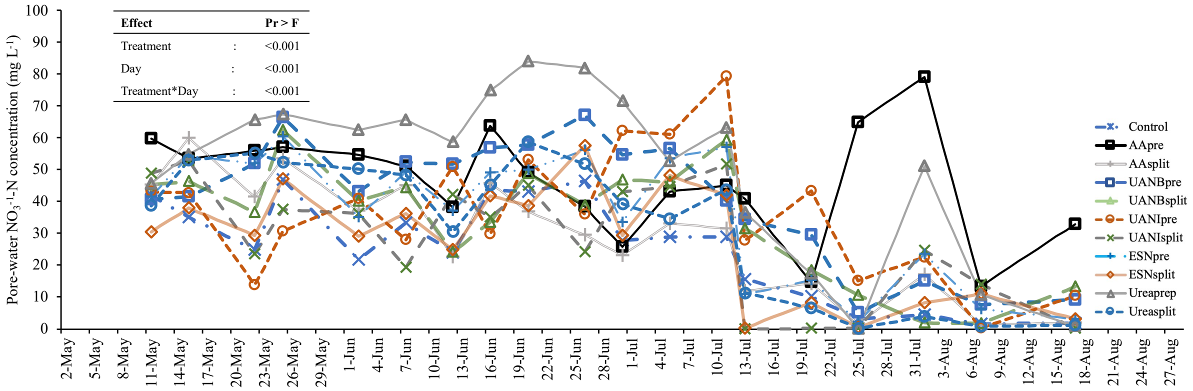

Figure 3. The pore-water NO^{-}_{3}-N concentration (mg L^{-1}) of water samples collected from 4 feet depth throughout the corn growing season at the farmer's site, Concord, NE.

The contrast estimate for fertilizer-N treatments (Figure 4) shows that split applications significantly reduced porewater NO_3^--N concentrations compared to pre-plant applications ($p < 0.0001$). UAN injection also resulted in lower NO_3^--N levels than UAN broadcast applications, regardless of application timing ($p < 0.018$). Among the sources, split-applied ESN was the most effective in minimizing porewater NO_3^--N, followed by split-applied UAN injection, with ESN maintaining NO_3^--N concentrations comparable to the control (no fertilizer) due to its controlled-release properties. ESN's gradual nitrogen release aligns with crop demand, reducing nitrogen losses and limiting nitrate accumulation in the soil. Enhanced efficiency fertilizers like ESN are valuable for mitigating nitrate leaching into groundwater while providing adequate nitrogen for crop growth.

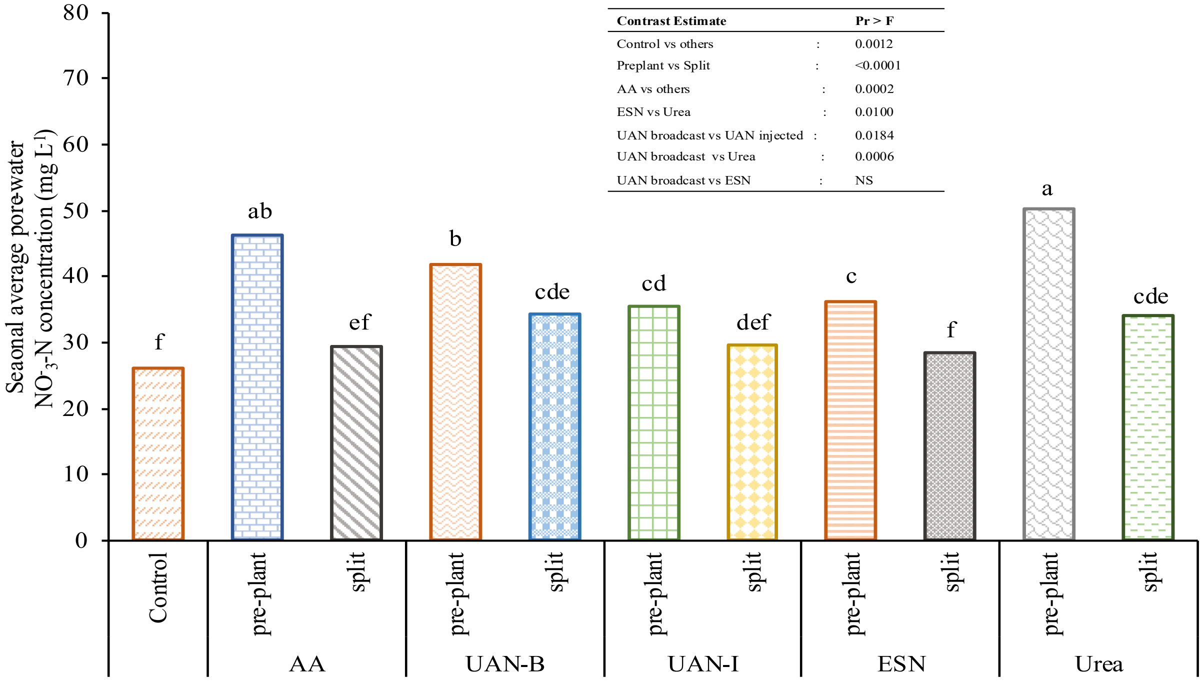

Figure 4. Seasonal average pore-water NO_3^--N concentration (mg L^{-1}) at the farmer's site, Concord, NE. Treatments followed by the same letter are not significantly different at $p = 0.05$

CONCLUSIONS

Ammonia losses were generally higher with split-applied treatments, with the lowest levels observed in UAN-I. Split applications proved effective in reducing NO_3^--N leaching, with split-applied ESN and UAN-I treatments showing the least leaching losses. In terms of nitrogen efficiency and corn yield, split-applied UAN injection performed best, resulting in minimal nitrogen losses and high yields, second only to split-applied UAN-B. While different nitrogen sources did not significantly influence corn grain yield, they did notably affect nitrogen losses, even in dry conditions. Collecting additional data from various locations and under different weather conditions would help refine statewide recommendations.

REFERENCES

Ferguson, R. B., Maharjan, B., & Iqbal, J. (2024). Nitrogen fertilizer trends in Nebraska, 1955-2023. Crop Watch. Retrieved October 27, 2024, from https://cropwatch.unl.edu/2024/nitrogen-fertilizer-trends-nebraska-1955-2023

Maharjan, B., Venterea, R. T., & Rosen, C. (2014). Fertilizer and irrigation management effects on nitrous oxide emissions and nitrate leaching. Agronomy Journal, 106(2), 703–714. https://doi.org/10.2134/agronj2013.0179

Singh, A., Rudnick, D., Snow, D. D., Proctor, C., Puntel, L., & Iqbal, J. (2024). Impact of split nitrogen applications on nitrate leaching and maize yield in irrigated loamy sand soils of Northeast Nebraska. Agrosystems, Geosciences & Environment, 7(3), e20554. https://doi.org/10.1002/agg2.20554