Nitrate in Tile-Drain Water Relative to Time and Source of Nitrogen Application 2019

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Summary: Why this work is important

Sound nitrogen (N) management is a key component to minimizing environmental degradation and improving farmer's profitability. Nitrogen fertilization in agricultural lands in much of the Midwest has been linked to water quality issues related to the hypoxia zone in the Gulf of Mexico. Currently, Minnesota and other Midwestern states have or are developing Nutrient Reduction Strategies to reduce nitrate loads. While we have learned much about some of the practices that can help us achieve reductions in nitrate loads to the Mississippi river, still there are many uncertainties on how well some N management practices work. Further, other practices, such as in-season applications, split pre-plant plus sidedress applications, or the use of controlled release fertilizers, have not been evaluated to truly determine their value for agronomic and water quality goals. It is clear that substantial research efforts are needed in order to provide meaningful and reliable guidance to enhance agricultural productivity in Minnesota while protecting the environment.

Introduction

Nitrogen is extremely important for optimizing corn yield as this crop has a large requirement for this nutrient. At the same time, N is important from an environmental standpoint as this nutrient can have profound negative impacts on environmental quality when introduced into surface- and ground-water or the atmosphere in the form of nitrous oxide. Nitrogen fertilization in agricultural lands in much of the Midwest has been linked to water quality issues related to the hypoxia zone in the Gulf of Mexico. Currently, Minnesota and other Midwestern states are developing Nutrient Reduction Strategies to reduce nitrate loads by 45% by the year 2045. In order to achieve this lofty goal, much needs to be done with research to determine how effective various traditional and new N-management practices are.

Although during the early development stages corn does not grow vigorously and does not require large amounts of N, this nutrient is typically applied before planting to ensure season-long N availability for the crop. Early spring is also the time when normally there is greater potential for N loss through tile-drainage as the soils tend to be saturated with water and precipitation exceeds crop needs. Several projects in the past have studied the impact of fertilizer rate and fall and spring fertilizer timing on nitrate leaching. Relatively little effort has been devoted to quantifying the effect of time of application on water quality when nitrogen is applied at sidedress (typically when corn is at the 2- to 4-leaf stage) or split-applied between a pre-plant and a sidedress application. Further, less is known about the potential of polymer coated urea (or controlled-release fertilizers) to improve N availability for the crop while minimizing the risk of environmental degradation. Delaying the application of fertilizer to sidedress time, splitting the application between pre-plant and sidedress, or applying a polymer coated urea product could reduce potential losses in early spring when N loss potential is typically highest. However, delaying the application or using controlled-release fertilizers can have similar negative effects if the crop does not have the N that it needs to optimize productivity. When this occurs, not only yield and profitability are diminished, but the N that was not used to make yield can potentially be lost to the environment later. It is clear that while we have learned much about some of the practices that can help us achieve reductions in nitrate loss to the environment, still there are many uncertainties on how well some N management practices work. Further, other practices have not been evaluated to truly determine their value for agronomic and water quality goals. This illustrates that substantial research efforts are needed in order to provide meaningful and reliable guidance to enhance agricultural productivity while protecting the environment.

Goals and Objectives

The goal of this project is to characterize the potential benefits of utilizing current technologies in innovative ways to improve water quality and crop yield. The objectives of this study are to 1) quantify the effect of timing of N application and N sources on nitrate concentration and load in tile-drain water, and 2) quantify nitrogen use efficiency in terms of corn N uptake and yield based on fertilization management.

Materials and Methods

The field was in soybeans during 2013 and had not been used for research purposes for approximately 7 years. This project started in spring 2014—and is ongoing— at the Southwest Research and Outreach Center at Lamberton (SWROC) on a Webster clay loam soil (fine loamy, mixed, mesic Typic Haplaquoll) that is a common series in the Minnesota River basin. The plow layer has a clay loam texture (36% sand, 35% silt and 25% clay). The study is using existing tile-drain plots established in 1994. The study site consists of 16 plots, each 30 feet wide (12 crop rows wit 30-inch spacing) by 60 feet long. Each plot is individually drained with 4-inch tile line 4 feet below the surface and 5 feet from the plot width edge to simulate a 110 feet tile spacing. To prevent lateral water movement each plot is isolated by a 6 feet deep plastic (0.03 mm thickness) barrier.

Starting in 2014 a continuous corn cropping system was established. Four treatments of 180 lb N acre^{-1} were arranged in a randomized complete block design with four replications: pre-plant urea, pre-plant ESN, and split-applied with N rate at one-third pre-plant/two-third sidedress at V4 (2014-2016) and V6 (2017-2019) of urea/urea and ESN/urea.

Pre-treatment soil conditions (0-12, 12-24, and 24-36 inch) were assessed with samples collected on 23 May 2014, 8 May 2015, 29 Mar 2016, 24 April 2017, 15 May 2018, and 16 May 2019. Pre-plant treatments were applied on 23 May 2014, 9 May 2015, 6 May 2016, 24 April 2017, 31-May 2018, and 10 June 2019 and incorporated by tillage within 24 hrs. Corn hybrid (DeKalb DKC49-29 RIB) was planted on 25 May 2014 and 9 May 2015 and thinned to 32,000 plants/acre; corn hybrid (Pioneer P0157 AMX) was planted on 16 May 2016 and 6 May 2017 and thinned to 34,000 plants/acre; corn hybrid (DKC 39-27 RIB) was planted on 31 May 2018 at 35,000 seeds/acre; and corn hybrid (DKC 40-77 RIB) was planted on 10 June 2019 at 35,000 seeds/acre. Sidedress treatments were applied on 16 June 2014, 18 June 2015, 16 June 2016, 22 June 2017, 21 June 2018, and 8 July 2019 at the V4 development stage in all years except 2017, 2018, and 2019 where the crop was at the V6 development stage.

In 2014 whole plant samples for total N analysis, soil samples (0-12 and 12-24 inch) for NH_4^+ and NO_3^- analysis, and SPAD meter scans were collected at V8, V12, and R1 development stage on 8 July, 28 July, and 7 August, respectively. The same sampling was done in 2015 to 2017 at V4, V8, V12, and R1 on 18 June 2015, 2 July 2015, 15 July 2015, and 29 July 2015, respectively; on 16 June 2016, 5 July 2016, 20 July 2016, and 1 August 2016 respectively; and on 9 June 2017, 29 June 2017, 11 July 2017, and 26 July 2017 respectively. In 2018 and 2019 the soil, plant, and canopy sensing with SPAD measurements were collected at V6, V10, and R1 on 27 June 2018, 16 July 2018, and 31 July, respectively; on 8 July 2019, 28 July 2019, and 6 August 2019, respectively. Whole plant samples at R6 development stage for total N analysis were collected on 9 October 2014, 28 September 2015, 4 October 2016, 19 September 2017, 24 September 2018, and 16 October 2019. Grain harvest was done on 24 October 2014, 16 October 2015, 19 October 2016, 20 October 2017, 22 October 2018, and 31

October 2019. Each year the center four rows of each plot were harvested except in 2017 where only the center two rows were harvested. Post-harvest soil samples for NH_4^+ and NO_3^- analysis were collected 7 November 2014, 3 November 2015, 7 November 2016, 13 November 2017, 22 October 2018, and 15 November 2019.

During 2014, we installed the tile drain water sampling equipment and no drainage occurred the rest of that growing season or in the fall. In 2015, there was limited (inconsistent) amount of drainage, as substantial amount of precipitation was needed to recharge the soil profile, which was dry from the previous year, before drainage occurred. In fall 2015, we were able, for the first time, to measure drainage. The samples were analyzed for nitrate concentration and those data along with water flow rates were used to calculate total nitrate loads. In 2018 and 2019 water samples started to be analyzed for phosphorus concentration. While there was variability in the amount of monthly flow, in 2016 we measured flow every month from March to November, in 2017 from April to December, in 2018 from April to November, and in 2019 from April to November. In addition, in 2018, we changed the way water samples are collected. From 2014 to 2017, samples were collected with ISCO samplers and data loggers. This system had too many problems, often leading to missing data. The drainage flow from each plot is now continually measured at monitoring wells with pumps and flow meters. A flow-proportionate sample is collected every time there is flow with a sideline fitted to an orifice in one end and a collection container in the other end.

Data were analyzed using the GLIMMIX procedure of SAS and software R.

Results and Discussion

Overall, the 2019 season was wetter than normal. Precipitation was below normal only in June and August and substantially above normal the rest of the growing season (Table 1). The overall growing season (April-Oct) precipitation was 220 mm (8.7 in) above normal. Temperatures were cooler than normal in April, May and October, near normal for June-August and above normal in September (Table 1).

Mean grain yield across all treatments in order from the 2014 to 2019 growing season have been 153, 164, 169, 212, 163, and 171 bu/ac. In 2019, the wet and cooler conditions at the beginning of the season (April and May) substantially delayed planting (latest of any previous year) and likely lead to lower yields than could have been achieved otherwise. Overall treatments produced grain yields that were not significantly different from each other (Fig. 1). The grain yield data had substantial variability, which resulted in this lack of difference. That said, the pre-plant urea (163 bu/ac) and ESN (167 bu/ac) had numerically lower yields than the side-dress urea/urea+ (176 bu/ac) and ESN/urea+ (177 bu/ac) treatments. As in previous years, ESN pre-plant showed a trend for greater yield than the pre-plant urea treatment likely because ESN helped protect the fertilizer from loss and released it in time for the crop to use it during the high uptake period. Averaged across all years urea pre-plant produced 165 bu/ac compared with 174 bu/ac for pre-plant ESN. Also, for the split application treatments ESN/urea+ produced 178 bu/ac (8 bu/ac more than urea/urea+). While the these results were only a trend, they illustrate that ESN applied at pre-plant can be a good alternative to improve grain yield and improve economic return as long as the yield increase is sufficient to cover the price difference compared to urea.

In most years, water deficit is an important limiting factor for corn production in Lamberton. During critical corm development stages, such as August, there was inadequate amounts of precipitation (Table 1). Plant N uptake increased from V6 to R1 development stage (Table 2). The pre-plant treatments had more N accumulated than the split application treatments at V6, likely because there was more N available with the pre-plant treatments where the full rate (180 lb N/ac) was already applied. However, by V10 and R1 the difference disappeared. By harvest time, the total N accumulated (tissue at R6) and removal in grain was lower for the pre-plant urea treatment relative to the other treatments. Correlation of SPAD measurements to grain yield was poor (Data not shown).

Another important aspect of this project is linking N management to water quality. This year we had very wet conditions in April, May, July, September, and October (Table 1). Nitrate concentrations were relatively typical (Table 3). Overall, treatments were not significantly different likely due to high variability. However, the mean cumulative load followed closely the pattern we have seen over the last few years, especially 2018, where ESN pre-plant that had substantially lower season-long cumulative nitrate loads compared to the other three treatments. That said, these results should be considered preliminary at this time, as the data are still been analyzed and scrutinized for errors and adjustments that are often needed when highly variable flow and concentration values are continuously collected. Nonetheless, it is clear that ESN seems to reduce N loss by leaching in years with substantial precipitation (Table 3 and Fig. 2). Most of the nitrate loss happened in early spring before treatment application, and at two events after treatments application. In early July and in September when the crop was no longer growing (Fig. 2). As in previous years, the loss is driven by precipitation amount and frequency when the crop has little capacity to use water or nitrogen and the soil is near field capacity. When the crop is actively growing and using large amounts of N and water (mostly in July and August) even though there were a few large rain events and periods with substantial precipitation, we observed little or no nitrate leaching (Figure 2).

Residual soil N (ammonium and nitrate) was low at the end of the previous growing season with ammonium-N in the top 12 inches being highest in general (Fig. 3). In previous years, we also observed that ammonium-N was generally greater. This is likely because of mineralization happening in the fall after crop uptake is finished but soil temperatures and moisture allow mineralization of soil organic N to continue. Unfortunately, as observed in figure 2, a substantial part of the N that is mineralized in the fall and the spring becomes nitrified and is leached in wet springs like the ones experienced in April and May during 2019. This loss of N and possibly some immobilization, resulted in very low residual soil N before treatment applications (Fig. 4). At pre-plant both ammonium and nitrate levels were similar throughout the profile and the highest amounts were present in the top 12 inches of the soil. At V6 development stage the pre-plant treatments show high levels of nitrate-N in the top 24 inches of the soil indicating that the fertilizer had been largely nitrified (ammonium-N levels are similar to the split application treatments) (Fig. 4). It was surprising to see the pre-plant ESN treatment with similar ammonium and nitrate as the pre-plant urea. Release of N across the polymer coating by diffusion might have happened faster this year when the application was done so late (June 10) and soil temperatures are higher and moisture was abundant. The low soil N levels at V6 for the split application treatments are a reflection of the fact that these treatments had only received a small portion of the total N at this point. After sampling, the sidedress treatments were applied. By V10, development stage there was more soil N for the split application treatments than the pre-plant treatments (Fig. 4). This is likely because the split application had been done closer to the time of sampling than for the pre-plant treatments. In addition, as described earlier, N uptake for the pre-plant treatments was greater than for the split application treatments up to the V10 development stage. The soil data at V10 also shows a substantial amount of nitrified N from the recent split application. By R1, there was very low soil N and nitrate-N in the top 12 inches of the soil was the most important form of N for all treatments. By fall, the post-harvest soil data (Fig. 3) show higher levels of ammonium-N regardless of treatment, similar to fall 2018 post-harvest data.

Finally, in 2018 as part of a large Midwest regional study, we included nitrous oxide and in 2019, we included ammonia volatilization measurements in this study. The nitrous oxide results showed that urea pre-plant had significantly greater cumulative flux compared to the other three treatments (Fig. 5). ESN pre-plant, urea/urea+ and ESN/urea+ were not significant different from each other. These data show the disadvantage of using urea as a single source of fertilizer at pre plant. It also shows the benefits gather from using ESN during wet years. It was clear that pre-plant urea suffered substantial N loss as nitrous oxide soon after the application while pre-plant ESN and the split applications were very low. Differently from 2018 (Fig. 6), we did not receive high amounts of precipitation after the split application were done. This likely explains the low emissions from the side-dress treatments as opposed to 2018.

Ammonia volatilization was collected at two different times, after pre-plant and side-dress fertilizer application. After pre-plant fertilizer, urea pre-plant was the treatment that had the highest emissions, being significant differently than the ESN pre-plant treatment (Fig.7). Split application treatments had the lowest emissions after pre-plant fertilizer, likely because of the low amount of fertilizer applied at this time. After side-dress fertilizer application, split applied treatments had significantly greater volatilization loss than the pre-plant treatments. Side-dress treatments were not significantly different from each other. One of the reasons that might explain the high amount of emissions seen after side-dress in the urea/urea+ and ESN/urea+ treatments is the lack of fertilizer incorporation, which is known to be an important factor in increasing ammonia volatilization. This happened even with the application of urea with a urease inhibitor, and highlights that incorporation of N fertilizers should be done whenever possible. These data along with the nitrate leaching and nitrous oxide emission data highlight that ESN may be a beneficial source for pre-plant spring applications during wet springs. Nitrous oxide and ammonia volatilization emissions in conjunction with the measurements we were already collecting make this a unique and valuable study as scant data are available where both measurements are done at the same time.

Table **1**. Mean monthly air temperature and mean monthly cumulative precipitation for the 30-yr normal and the 2019 growing season at Lamberton, MN.

Year	Apr	May	Jun	Jul	Aug.	Sep	Oct.	Apr-Oct Cumm.
					Precipitation (mm)			
30-yr normal	76	87	105	99	102	77	51	597
2019	150	122	60	174	56	153	102	817
					Temperature (˚C)			
	Apr	May	Jun	Jul	Aug.	Sep	Oct.	Apr-Oct Cumm. Ave.
30-yr normal	7.5	14.4	20.3	22.5	20.6	16.1	9.2	15.8
2019	6.7	11.8	20.6	22.6	19.7	17.9	6.8	15.2

Table **2**. Total plant nitrogen uptake in vegetative tissues (no ear) at different development stages and grain at harvest for different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage) for the 2019 growing season.

Treatment	V6	V10	R1	R6	Grain
			lb N/ac		
Urea	53	102	91	32	65
ESN	48	112	94	40	106
Urea/Urea+	28	94	102	41	106
ESN/Urea+	31	94	106	38	114

Table **3**. Treatment minimum, maximum, and mean nitrate-N concentrations measured during flow events and mean season-long cumulative load for 2015 to 2019 growing seasons.

Treatment	**Min**					**Max**					**Mean**						
	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016
	mg/L																
Urea	1.6	6.9	1.4	1.4	1.9	18.9	19.6	149.2	17.6	19.6	9.8	13.0	23.5	7.7	7.8	6b	23a
ESN	1.7	7.3	0.7	2.0	2.7	19.1	23.6	129.5	18.5	12.4	7.3	13.5	17.4	6.4	7.8	4b	17a
Urea/Urea+	1.6	6.5	1.7	3.2	2.6	31.0	20.5	150.8	16.4	16.6	10.3	11.8	27.1	8.0	9.2	10a	22a
ESN/Urea+	0.9	7.4	1.2	0.9	3.9	17.7	18.3	129.5	17.2	18.8	10.1	11.5	31.9	7.0	8.5	5b	15a

Values followed by the same letter within year are not significantly different at *P*= 0.1.

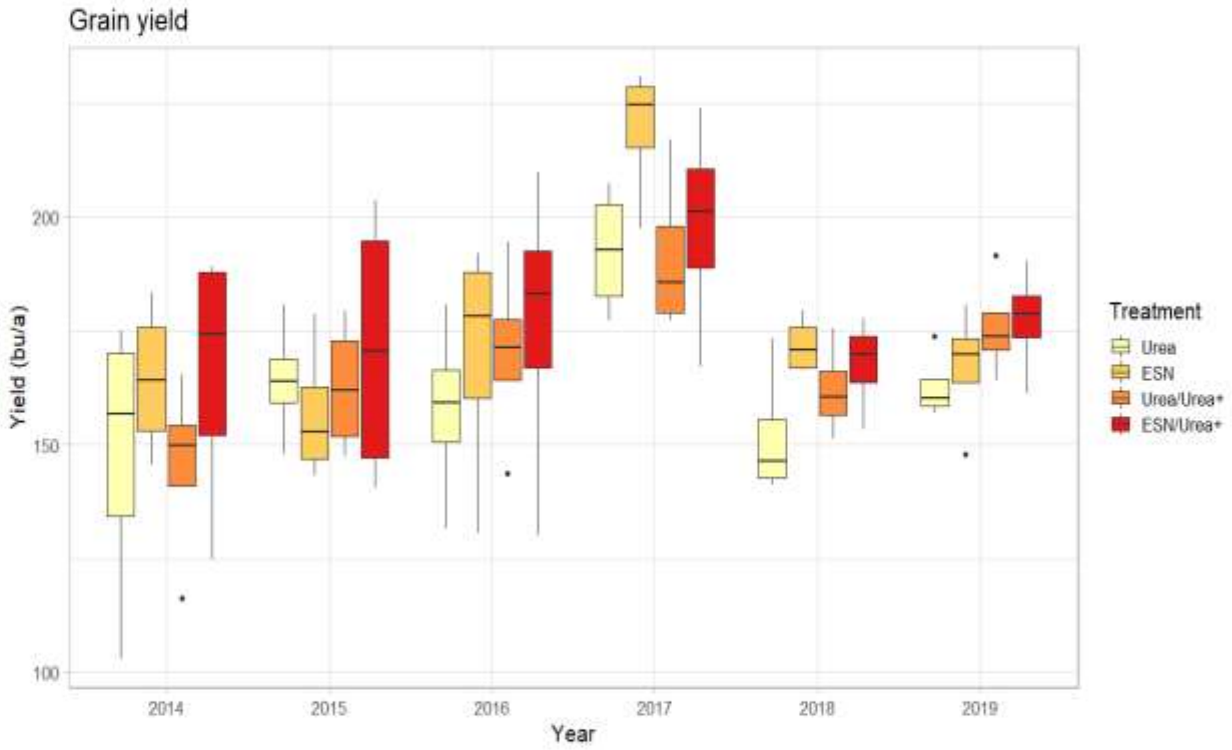

Figure **1.** Grain yield for different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage) for 2014 to 2019 growing seasons.

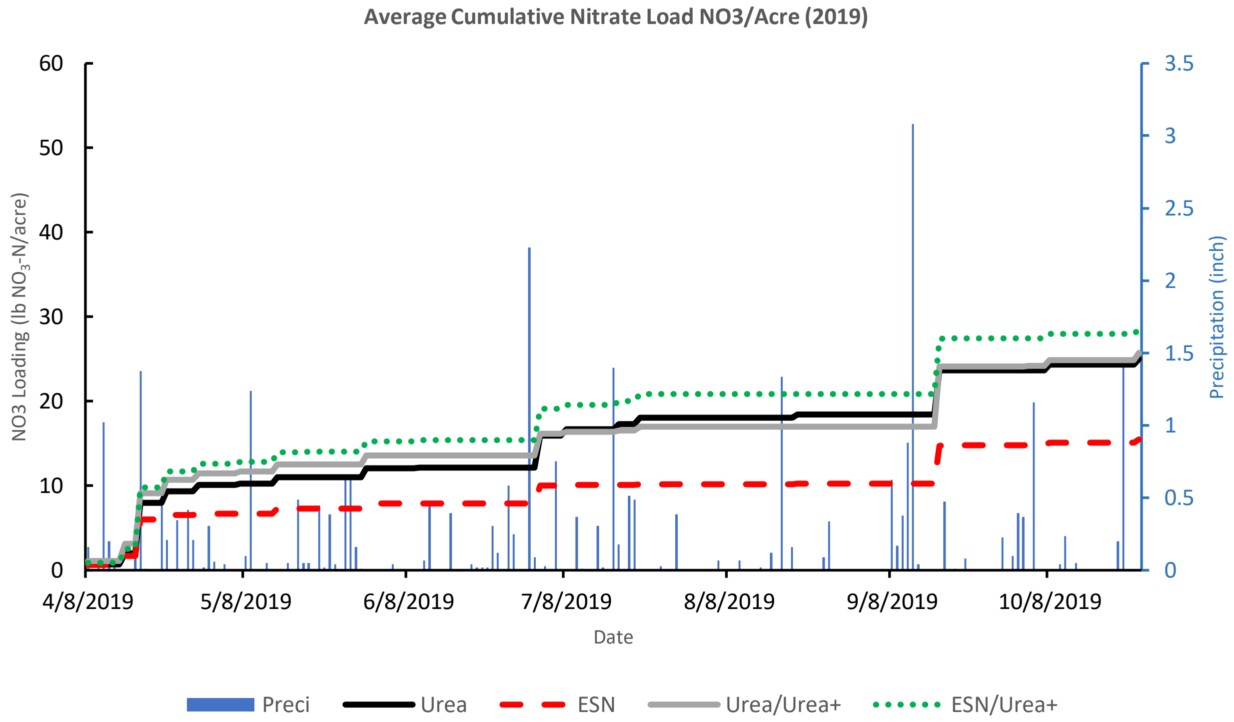

Figure **2.** Cumulative nitrate loading across the 2019 growing season as affected by treatment: different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage.

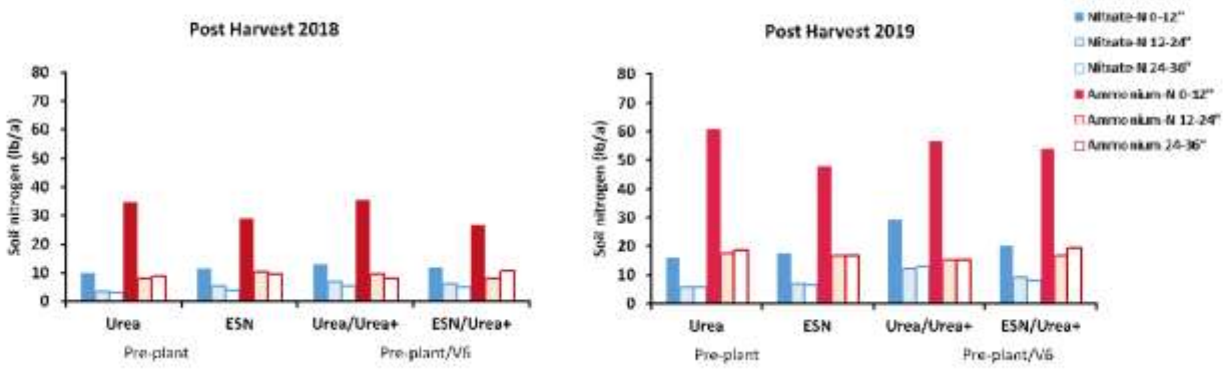

Figure **3**. Residual soil nitrogen for various soil depths at the end of the 2018 and 2019 growing seasons for the various treatments: different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage

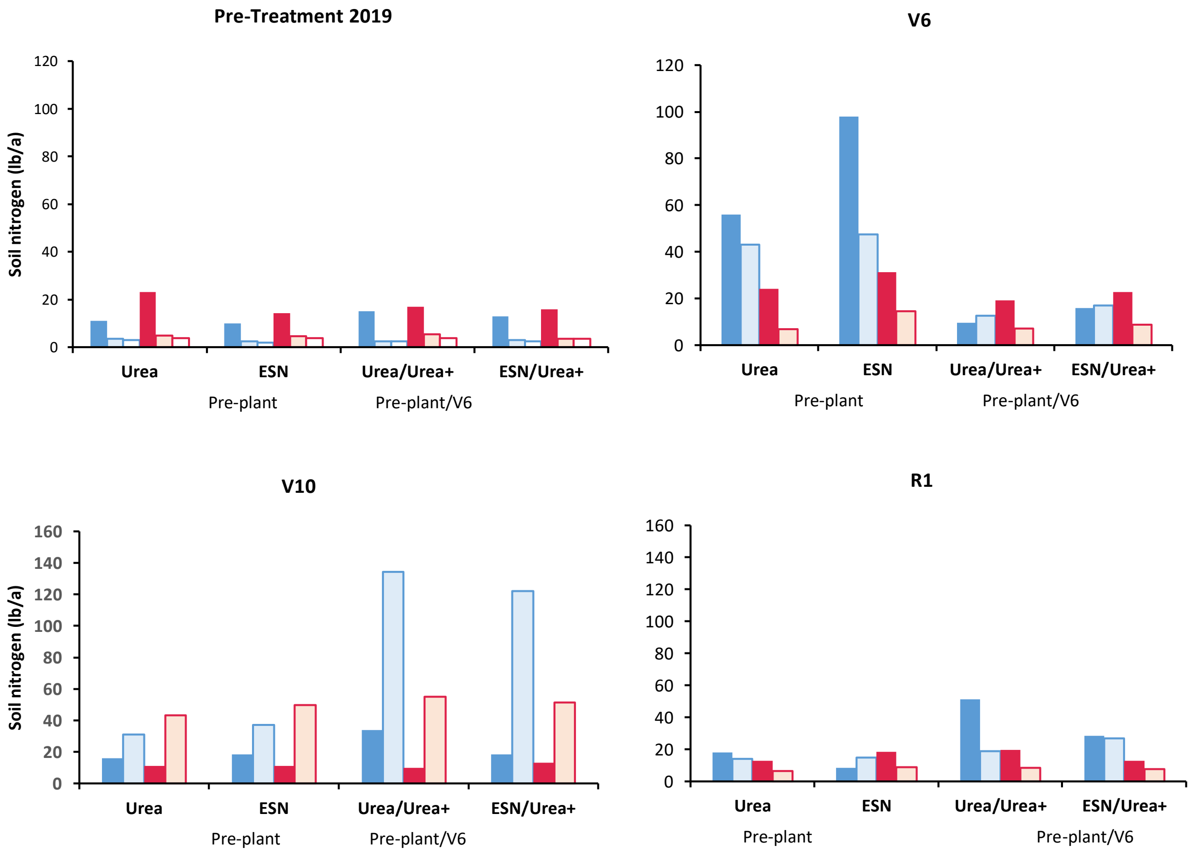

Figure **4**. Soil nitrogen for various soil depths across the 2019 growing season as affected by treatment: different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage. Columns from left to right: nitrate 0-12 inches, nitrate 12-24 inches, ammonium 0-12 inches, and ammonium 12-24 inches.

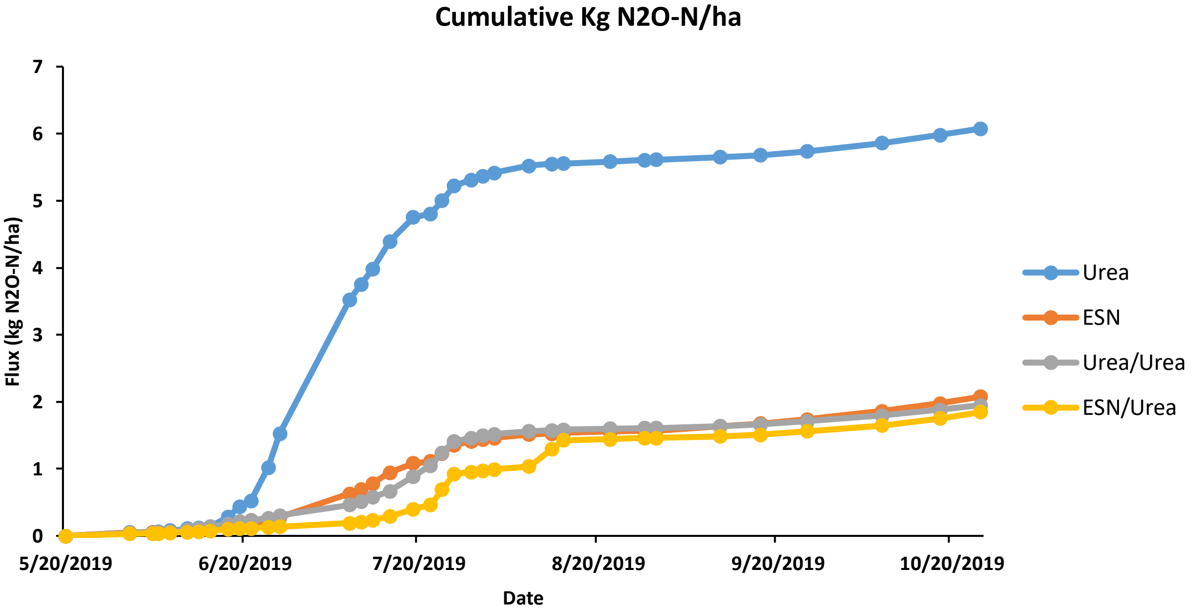

Figure **5**. Cumulative nitrous oxide emissions across the 2019 growing season as affected by treatment: different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage.

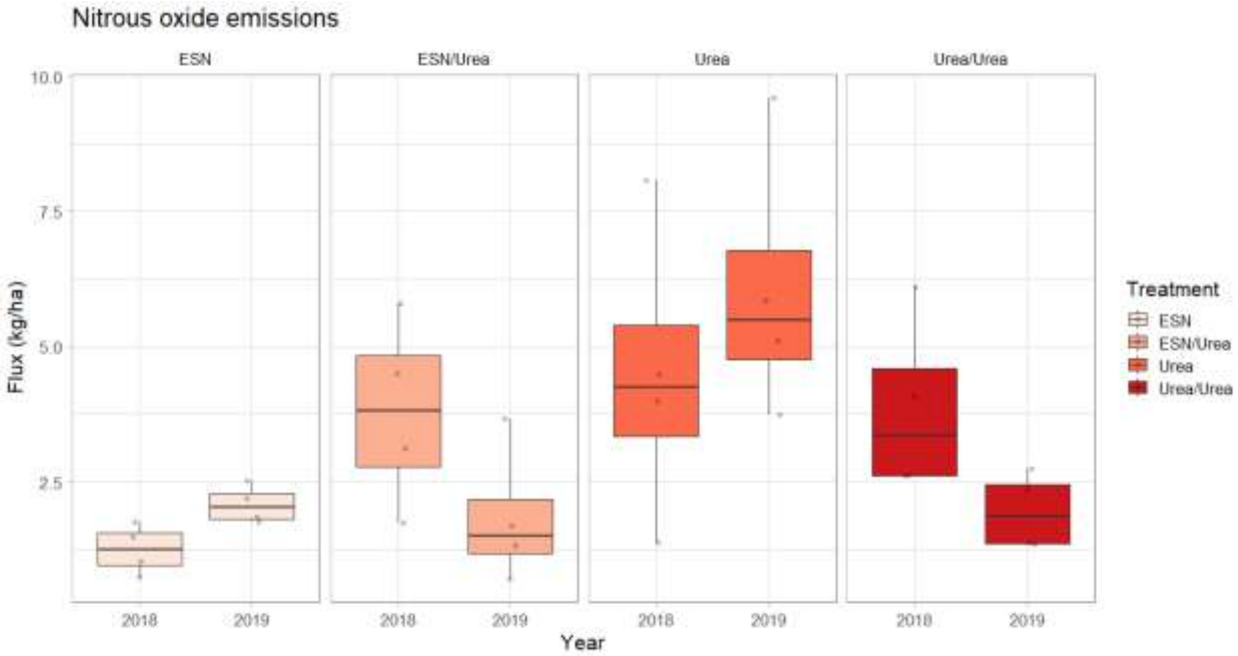

Figure **6**. End-of-season cumulative nitrous oxide emissions for 2018 and 2019 growing seasons as affected by treatment: different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage.

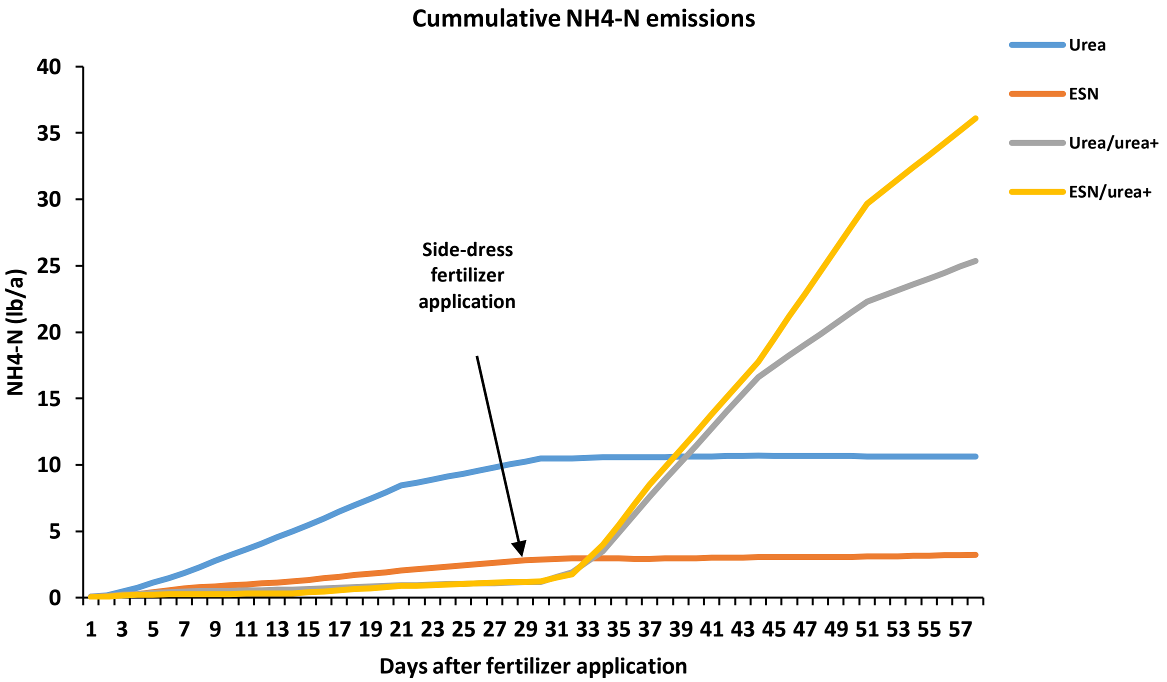

Figure **7**. Cumulative NH4-N emissions across days after fertilizer application as affected by treatment: different N sources (urea and ESN) and different times of application (180 lb N/ac pre-plant or 60 lb N/ac pre-plant and 120 lb N/ac applied at V6 development stage.