EFFECTS OF VARIABLE NITROGEN FERTILIZER RATES ON CORN GRAIN YIELD, PROFITABILITY, AND NITROGEN LOSSES IN SOUTHWESTERN MINNESOTA

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ABSTRACT

Global corn (*Zea mays L.)* production heavily relies on the application of nitrogen (N) fertilizers, which unfortunately comes with environmental concerns. The primary pathways N is lost to the environment are through nitrate leaching into groundwater, ammonia volatilization, and nitrous oxide emissions to the atmosphere. This ongoing study started in 2021 at the University of Minnesota Southwest Research and Outreach Center in Lamberton, MN, to comprehensively assess the effects of varying N fertilizer rates (0 to 320 lbs N ac^{-1} in 80 lbs N ac^{-1} increments) on corn grain yield, profitability, and N loss (nitrate, nitrous oxide, and ammonia). The N rates were split applied with 80 lbs N ac^{-1} as ESN pre-plant and the rest of the N was applied as Agrotain (urea + N-(n-Butyl) thiophosphoric triamide) at V6 development stage. The economic optimum N rate (EONR) was calculated at a fertilizer to corn price ratio of 0.1 US\$0.5 lb^{-1} N and \$5 $bushel^{-1}$ of corn. The EONR in 2021 was 116 lb N $acre^{-1}$ and the grain yield at the EONR was 106 bu $acre^{-1}$ while in 2022, the EONR was 158 lb N $acre^{-1}$ and the grain yield at the EONR was 111 bu $acre^{-1}$. The low yield and EONR reflected drought conditions in 2021 since there was minimal nitrate leaching (1.6 lbs NO_3-N ac^{-1}), minimal nitrous oxide emissions (0.48 lbs N_2O-N ac^{-1}) with the only significant emissions occurring after rainfall events, and ammonia volatilization was relatively low (1.4 lbs NH_3-N ac^{-1}) and similar between treatments. Compared to 2021, in 2022, early-season precipitation caused three times more N loss as nitrate leaching and two times more nitrous oxide emissions on average but slightly less ammonia volatilization and likely contributed to a higher EONR. However, dry conditions for the remainder of the growing season along with corn rootworm damage resulted in low grain yield. The 2023 season contrasted the previous seasons with more rainfall and ammonia volatilization being five times less on average than 2022 but preliminary analysis showed greater NO_3-N and N_2O-N emissions, indicating weather has a profound influence on N management.

INTRODUCTION

Minnesota plays a major role in corn production, being one of the largest corn producers in the US. Corn production relies on N fertilizer, but excessive use harms farmers profits and the environment. Nitrate leaching impacts surface and groundwater quality and nitrogenous gas losses to the atmosphere result in climate change and ecosystem degradation. All these environmental impacts also cause human health concerns, loss of diversity to ecosystems, and economic costs.

Studies that concurrently evaluate the various N loss processes are limited, especially studies that evaluate various loss pathways at the same location and time due to infrastructure and cost limitations. In addition, older studies are outdated due to changes in agriculture, technology, and climate. There is an imperative need to research systematically the effects of N rate on corn grain production and N losses via nitrate leaching from drain tiles, and nitrogenous gas losses as ammonia and nitrous oxide emissions. This research, conducted with an adequate number of N rates, allows us to define the point of intersection (optimum N rate) between profitable corn production and N loss to the environment. Having this information can allow us to generate data-driven scenarios to better determine the possible environmental and agronomic outcomes when the N rate departs from the optimum.

MATERIALS AND METHODS

Field experiments were conducted at the Southwest Research and Outreach Center (SWROC) in Lamberton, Minnesota in existing tile-drain plots that were established in 1994. Each of the 15 individual drainage plots has a tile line and is isolated by a plastic barrier to prevent lateral water flow from adjacent plots. Before this project, the site was under continuous corn production since 2014 with an annual application of 180 lb N ac^{-1}.

Starting in the 2021 growing season, five N rates in 80 lb N ac^{-1} increments (0, 80, 160, 240, 320 lb N ac-1) were applied in a randomized complete block design with three replications in a continuous corn cropping system. The N rates were applied as 80 lb N ac^{-1} at pre-plant using the polymer coated urea ESN (44-0-0, N-P-K), which was broadcast and incorporated with tillage. The remainder N was applied at the V6 corn growth development stage using urea (46-0-0, N-P-K) with the urease inhibitor Agrotain: N-(n-Butyl) thiophosphoric triamide (NBPT) to minimize volatilization losses, as the fertilizer was broadcast and left on the soil surface.

The site received primary tillage in the fall. Before planting every season samples were collected to determine general soil fertility parameters and to determine if adjustments were necessary. In the spring pre-plant N treatments were applied, incorporated with secondary tillage for seedbed preparation, planted with DKC 49-44 at 35,000 seeds ac^{-1}, and ammonia traps, nitrous oxide chamber emission bases, and moisture and temperature sensors were installed. The split nitrogen application was done at V6 development stage as well as the final plant population.

Agronomic responses were measured in several ways. Soil N (NH_4^+-N and NO_3-N) samples were collected from the 0-12-, 12-24-, and 24–36-inch depth increments before planting and after grain harvest and from the first two depth increments only at the V10 development stage. Canopy sensing data (NDVI and NDRE) was collected with a RapidScan at V8, V10, and V12 development stages. Plant biomass and nitrogen content was measured at V10 and R6 development stage. Lower stalk samples for nitrate-N analysis were also collected at R6 development stage. Grain yield and grain N content were measured at harvest. Plant N content and biomass were used to calculate crop N use efficiency parameters.

Nitrate leaching was measured continuously from each plot with automated sampling equipment. The sampling began each field season as soon as the frost was off the soil profile. Flow-proportionate water samples were collected and analyzed for nitrate concentrations and along with flow data, were used to calculate total nitrate loads and flow-weighted concentrations of nitrate. Nitrous oxide emissions were collected approximately two to three times per week from April through July, two times per week during August and September, and weekly thereafter until grain harvest. Measurements were done with a novel portable high-accuracy nitrous oxide and carbon monoxide gas analyzer and flux calculations were done using R studio. Ammonia emissions were measured with semi-static chambers following an acid trap methodology. Ammonia emissions were captured in traps that were sampled 1, 4, 7, 14, 21, and 28 days after each fertilizer application.

Regression analysis was used to develop response curves to N rate. This analysis was used to determine the EONR and grain yield at the EONR and to calculate the points of intersection between the EONR curve and the curves for the nitrogen loss parameters in the study. This analysis allowed us to evaluate the relationship that exists between agronomic and environmental parameters at different N rates and to determine the cost benefit relationship between these variables.

RESULTS AND DISCUSSION

Preliminary results indicate a positive response to N rate. This finding suggests that manipulating N levels can potentially enhance crop performance. However, it is essential to note that grain yields were consistently low for 2021 and 2022. Despite 2022 being drier overall compared to 2021, the observation of a greater EONR in 2022 (158 lbs N ac^{-1}) in comparison to 2021 (116 lbs N ac^{-1}) is intriguing. This shift in EONR is likely a result of increased NO_3-N leaching and N_2O-N losses, triggered by episodic rain events during 2022. Low yields and EONRs highlight that moisture was the most limiting factor rather than N for the 2021 and 2022 growing seasons (Fig. 1 and 2, Table 1).

Throughout the growing season, N_2O fluxes remained relatively low, except for the higher N rates following precipitation events (Fig. 3 and 4). This suggests that N_2O emissions are particularly sensitive to N application timing and rates. Precipitation, particularly in relation to the timing of fertilizer application, had a substantial and contrasting impact on N losses. Precipitation increased N_2O and NO_3 losses, whereas NH_3 losses decreased under similar conditions. Notably, NH_3 emissions surged shortly after fertilization, regardless of timing or rate of fertilization, with drier conditions post-fertilization intensifying these emissions. These variations in emission levels were evident when comparing 2021, the driest year, with 2023, the wettest year (Fig. 5).

A general trend of increased N losses with higher N application rates was apparent, although the differences were relatively small. At the highest N rates, grain yields also decreased. This is unusual in corn but could be attributed to larger biomass development early in the season that might have resulted in more evapotranspiration, and ultimately resulting in water stress during the dry growing seasons. This further reinforces the importance of managing N rates and timing to optimize yields. In conclusion, these findings shed light on the complex interplay of N management, moisture availability, and precipitation patterns in shaping crop performance and environmental outcomes. Managing N effectively, considering both rate and timing in the context of local weather conditions, is crucial for optimizing yields while minimizing environmental impacts.

Table 1. Cumulative NO_3-N load, flow weighted NO_3-N concentration, cumulative N_2O-N emissions, cumulative NH_3 emissions, and grain yield for 2021 and 2022. Within column and year, means followed by the same letter are not significantly different from one another (P<0.10)

Treatment	Cumulative NO_3 Load	Average Flow Weighted NO_3	Cumulative N_2O Emissions	Cumulative 56 day NH_3 Emissions	Grain Yield
lbs ac^{-1}	lbs ac^{-1}	mg L^{-1}	lbs ac^{-1}	lbs ac^{-1}	bu ac^{-1}
			2021		
0	0.8A	5.2B	0.05A	1.40A	82B
80	1.5A	7.1AB	0.16A	1.31A	100AB
160	2.3A	7.0AB	0.52A	1.45A	113A
240	1.2A	8.5A	0.73A	1.39A	100AB
320	2.0A	7.9AB	0.96A	1.32A	91AB
			2022		
0	0.7B	2.8A	0.08C	1.11A	67B
80	3.1AB	3.9A	0.12C	1.25A	99AB
160	11.3A	9.8A	0.54BC	1.20A	110A
240	5.9AB	7.8A	2.06AB	1.04A	111A
320	6.3AB	11.6A	3.23A	1.12A	100AB

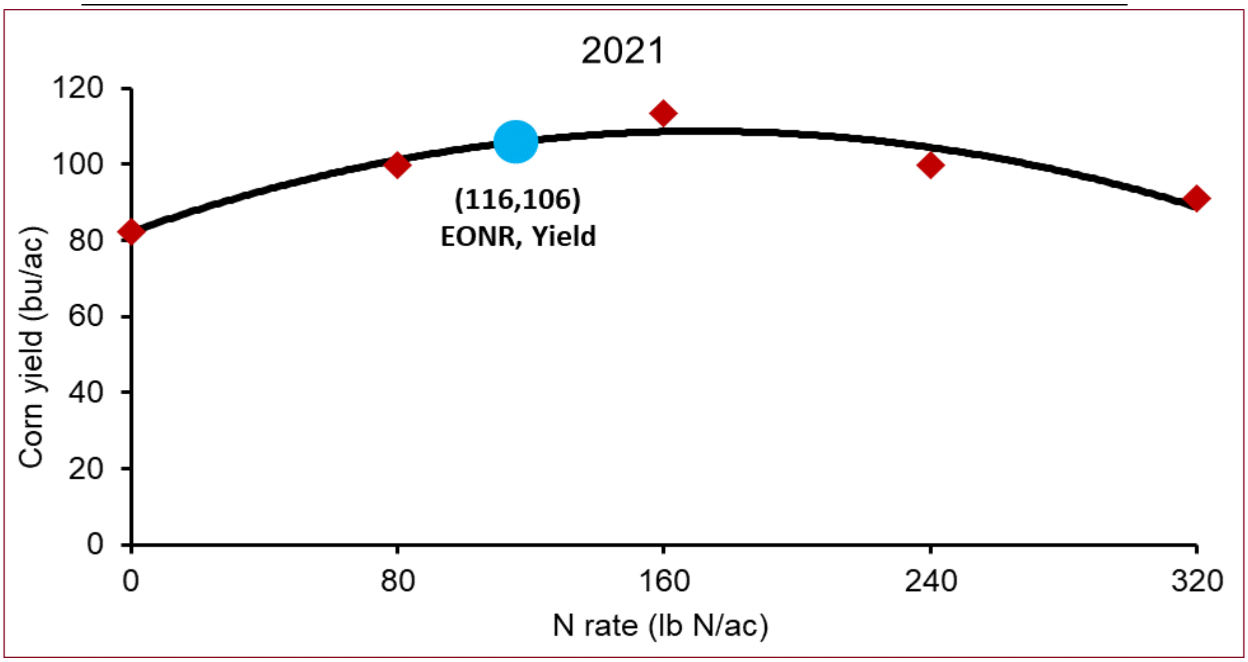

Figure 1. Agronomic trends in 2021 corn yields: quadratic regression analysis and EONR

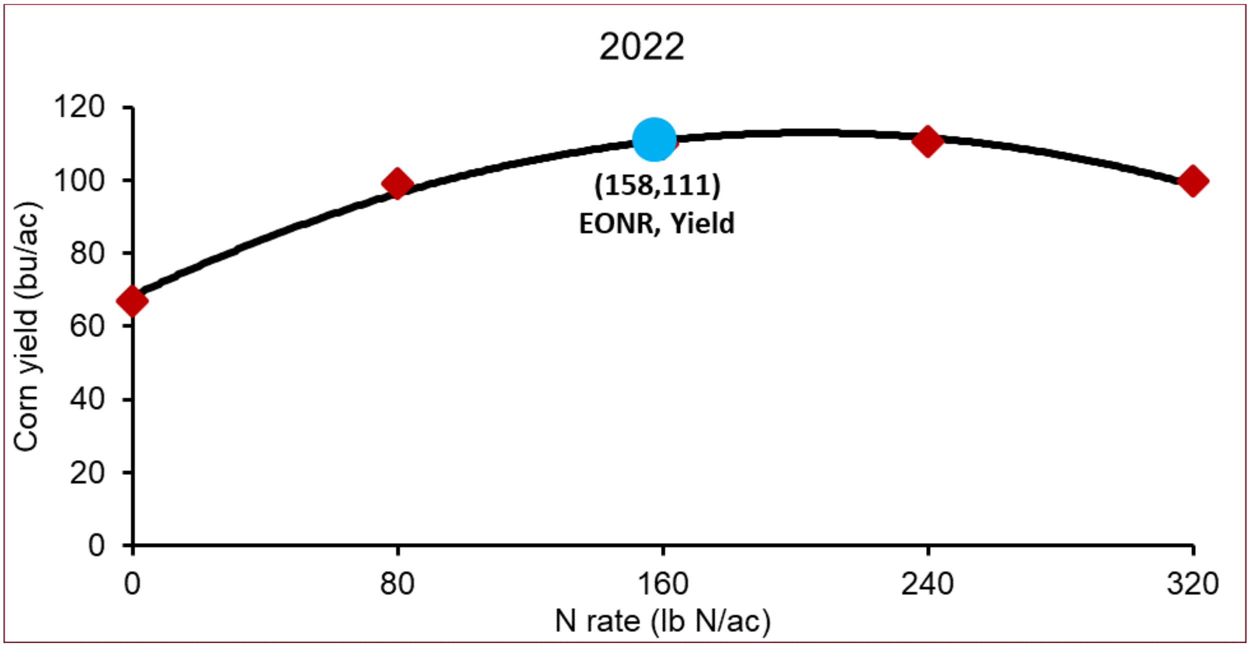

Figure 2. Agronomic trends in 2022 corn yields: quadratic regression analysis and EONR

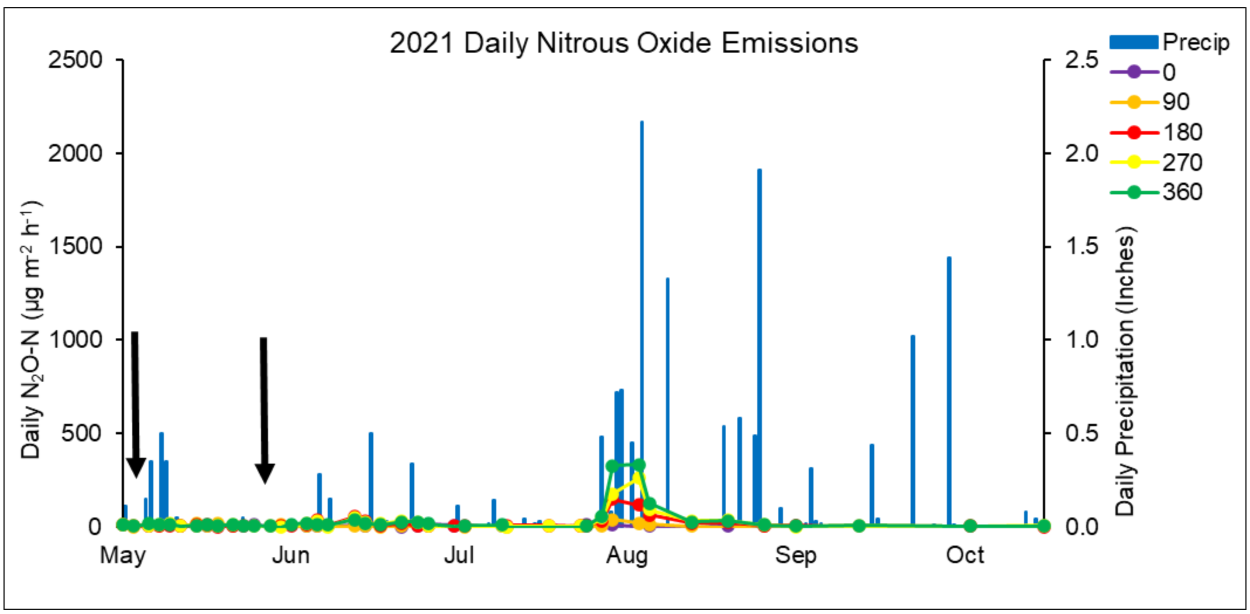

Figure 3. Daily N_2O-N emissions in response to N rate (lbs/ac) and daily precipitation in 2021. Downward pointing arrows indicate pre-plant and split fertilizer application dates.

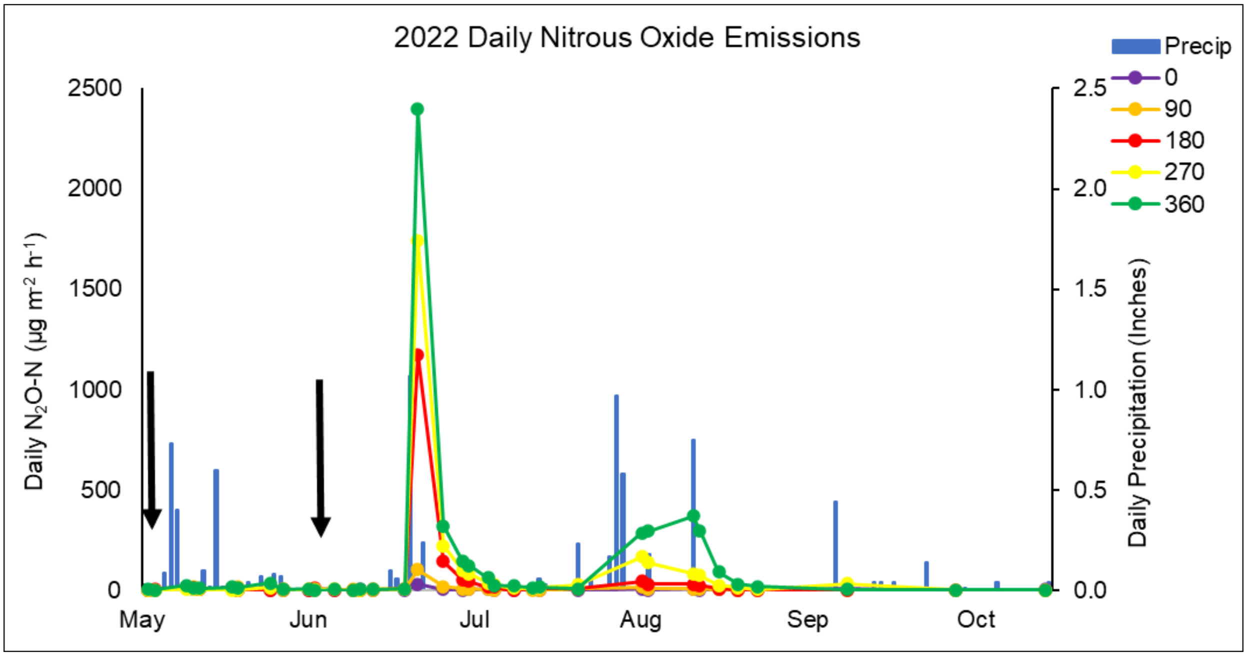

Figure 4. Daily N_2O-N emissions in response to N rate (lbs/ac) and daily precipitation in 2022. Downward pointing arrows indicate pre-plant and split fertilizer application dates.

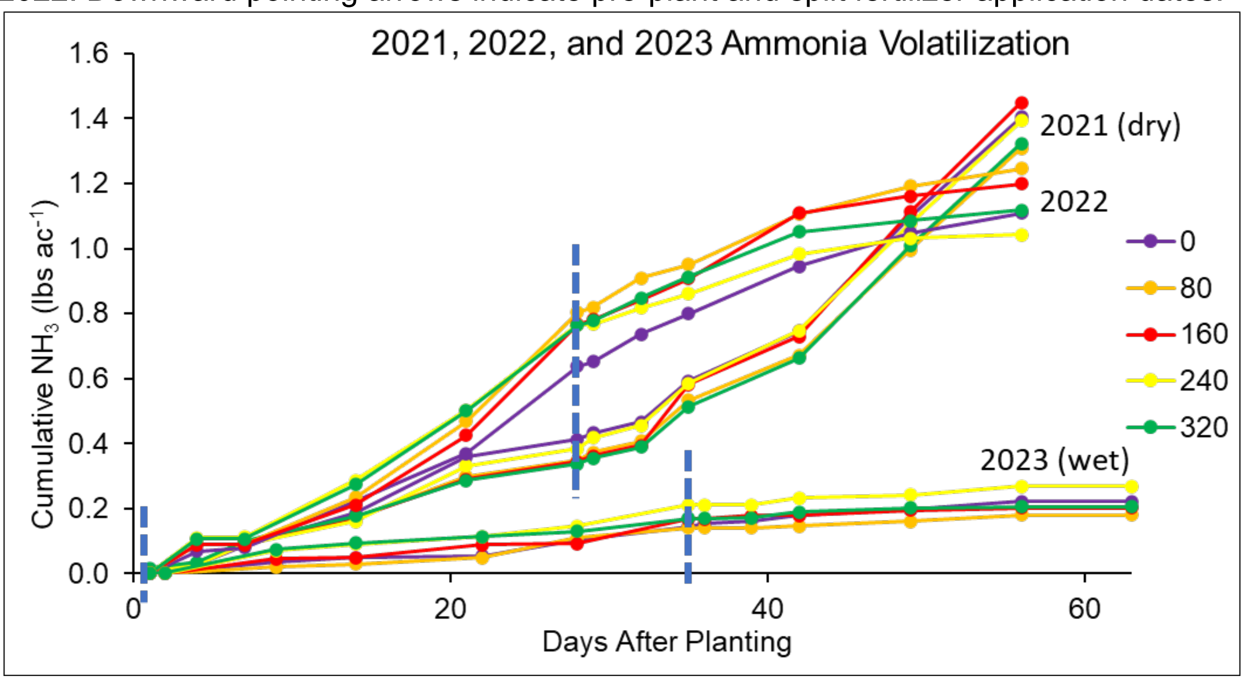

Figure 5. Cumulative NH_3-N volatilization loss as influenced by treatment over a 56-day period for 2021 and 2022 and a 63-day period for 2023 starting at pre-plant fertilizer application. Dashed blue lines indicate the split fertilizer application.