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Could the Use of Nitrification Inhibitor Optimize the Nitrogen Use Efficiency of Corn Production?

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Summary

Nitrogen (N) is an essential nutrient for corn production, higher grain yields are dependent on N fertilizer application. Substances like the nitrification inhibitors (NI) were created to increase yields, promote nitrogen use efficiency (NUE), and reduce N losses. The study was carried out in ten site-years in Kansas from 2017 to 2021, with the objective of evaluating the nitrogen agronomic efficiency (NAE) in corn with and without the use of NI and comparing corn grain yield, grain N uptake, and soil mineral nitrogen content with the use of the NI. Nitrogen fertilizer at the rates of 100, 150, and 200 lb of N/a using anhydrous ammonia (AA) as source was applied to the soil with and without the combination of NI (nitrapyrin) in the spring, also a treatment with 0 lb of N/a without NI was used as control. Soil ammonium average content in V8 growth stage was higher with the use of the NI at the rate of 150 lb of N/a, AONR and EONR values were lower with the use of NI. Higher N grain uptake and NAE were obtained when 150 lb of N/a was applied with NI combination.

Introduction

Nitrogen (N) fertilizer application to the soil system is necessary to maximize corn yield; however, it is difficult to precisely supply enough N to meet crop physiological requirements and also control the risk of N losses to the environment (Sweeney et al., 2018). While N rates lower than optimum will increase risk of lower yields, N rates above optimum will cost more, may not offer additional yield, and could be lost to the groundwater (Kranz, 2015). The agronomic optimum N rate (AONR) represents the total amount of fertilizer N required to maximize yield, but not necessarily profit (Camberato et al., 2021), and the economic optimum N rate (EONR) is defined as the N rate that makes the most effective use of N on a monetary basis, being dependent to the economic environment (Oglesby et al., 2022). Both AONR and EONR are terms used to develop N rate recommendations based on data-driven field trials, aiming to increase nitrogen use efficiency.

Nitrogen use efficiency (NUE) is defined as the ratio of the crop nitrogen uptake to the total input of N fertilizer. Increasing N rates are often associated with progressively lower corn NUE values. A management practice option to reduce N losses during crop production and increase the NUE, is the use of nitrification inhibitors (Omonode and Vyn, 2013). Nitrification inhibitors are substances developed to reduce the process of nitrification and keep N available for plant uptake for longer time, especially during the highest crop demands (Corrochano-Monsalve et al., 2021). The objectives of this study were to evaluate the nitrogen agronomic efficiency (NAE) in corn with and without the use of NI, compare corn grain yield, grain N uptake and soil mineral nitrogen content with the use of the NI under field conditions in Kansas.

Procedures

Field studies were conducted from 2017 to 2021 during crop growing seasons in 10 site-years in Kansas (Table 1). Nitrogen fertilizer at the rates of 100, 150, and 200 lb of N/a using anhydrous ammonia (AA) was applied to the soil with and without the combination of a nitrification inhibitor (nitrapyrin) in the spring. A control treatment was included with no N application. The experimental design was a randomized complete block with four replications. Soil composites samples were collected using hand probes by block at 0- to 6-in. and 0- to 24-in. depths before planting, and by plot during the crop development at the V2, V4, V6, V8, V12, R1, and R6 growth stages at two soil depths, 0- to 12-in. and 12- to 24-in. depths. Soil NO_3^- and NH_4^+ concentrations were determined using 1M potassium chloride (KCl) extraction. Nitrate concentrations were determined by the cadmium reduction method, while NH_4^+ concentrations were determined by colorimetric reaction.

Plant and grain samples were collected from six plants from middle rows when corn reached the R6 maturity growth stage; samples were dried at 140°F (60°C) and ground to 2 mm. N content in the plant and grain were determined through dry combustion. Yields were determined by harvesting the two middle rows from each plot and correcting grain moisture to 15.5%. Nitrogen agronomic efficiency (NAE) was calculated as:

$$NAE = \frac{(Y_N - Y_{0N})}{F}$$

Where Y_N represents the grain yield (lb/a) obtained from the N fertilized plots, Y_{0N} represents grain yield (lb/a) obtained from the plots with 0 lb of N/a, and F represents the amount of N fertilizer applied (lb of N/a).

Analysis of variance (ANOVA) using function lmer from lme4 package and pairwise comparisons using function cld from multcomp package at $\alpha < 0.1$ were performed using the RStudio 2022.12.0+353 software version.

Results

Corn Grain Yield

Corn grain yield was affected by the nitrogen rates, obtaining higher yields with the higher rates.

The AONR value obtained with the use of the inhibitor (153 lb of N/a) was lower than the value obtained without the use of the inhibitor (167 lb of N/a). Also, EONR value with the inhibitor (130.38 lb of N/a) was lower than that obtained without using the inhibitor (140.73 lb of N/a). Results indicate that by using the nitrification inhibitor corn grain yield could reach an agronomic and economic maximum using less nitrogen fertilizer.

Nitrogen Agronomic Efficiency and Corn Nitrogen Uptake

Grain nitrogen uptake shows similar results to those obtained with the grain yield. At the rate of 150 lb of N/a uptake increases significantly with the use of the inhibitor (Figure 2A). The nitrogen agronomic efficiency decreases with higher N rates. At the rate of 150 lb of N/a the inhibitor increases N agronomic efficiency (Figure 2B).

Soil Mineral Nitrogen

Soil NO_3^- increased early in the growing season (peaking at V6 in the 0- to 12-in. depth). This was likely result of the nitrification process in early spring (Figure 3A). Soil NO_3^- at the 12- to 24-in. depth, without the use of an inhibitor, reached a peak later, around the V8 growth stage. This result suggested a leaching process to the lower soil layer (Figure 3B). The use of nitrification inhibitor (nitrapyrin) resulted in average lower soil NO_3^- early in the season.

Soil NH_4^+ was higher early, but quickly decreased to background levels by the V12-R1 growth stage. At the V8 growth stage the NH_4^+ content was significantly higher with the use of the nitrification inhibitor at the 0- to 12-in. depth (Figure 3A). No difference was detected for soil NH_4^+ at the 12- to 24-in. depth (Figure 3B).

Soil mineral N measured in-season with soil sampling was highly variable, making individual sampling events unreliable and a poor indicator of current plant available N.

Acknowledgments

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Table 1. Experimental locations, soil type, pH, organic matter, and mineral nitrogen before planting and treatment application

Site-year	County	Soil	Texture	Planting date	0–6 in. pH	0–6 in. OM	0–24 in. NO_3^-	0–24 in. NH_4^+
						%	------ lb/a ------	
1	Riley	Smolan	Silt loam	4/24/17	7.3	1.8	22.6	55.8
2	Republic	Hastings	Silty clay loam	4/25/17	5.8	3.3	31.3	50.2
3	Riley	Smolan	Silt loam	4/28/18	8.0	1.9	105.2	44.0
4	Shawnee	Eudora	Silt loam	5/07/18	6.9	1.4	16.8	-
5	Riley	Smolan	Silt loam	5/25/19	5.7	1.6	43.0	12.0
6	Shawnee	Eudora	Silt loam	4/25/19	6.6	1.5	13.2	11.6
7	Riley	Belvue	Silt loam	4/30/20	6.5	2.2	15.5	28.0
8	Shawnee	Eudora	Silt loam	4/23/20	6.4	1.3	30.4	29.6
9	Riley	Belvue	Silt loam	4/28/21	5.9	1.7	29.5	35.9
10	Shawnee	Eudora	Silt loam	4/29/21	7.5	2.1	29.3	36.2

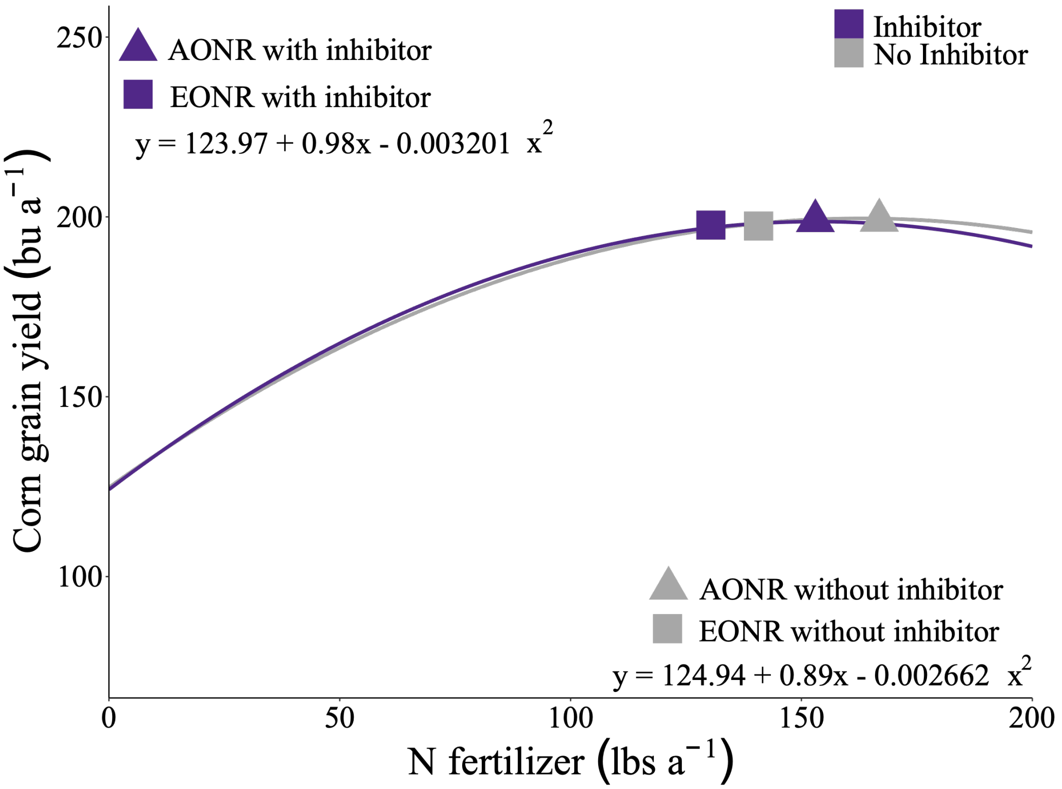

Figure 1. Corn grain yield (bu/a) as affected by nitrogen (N) fertilizer rates (lb/a) and nitrification inhibitor across site-years. Agronomic optimum N rate (AONR) and Economic optimum N rate (EONR) were calculated using quadratic equation. The results were EONR at 7.19 corn:N price ratio (\$6.58 bu^{-1} corn: \$0.915 lb^{-1} N) without inhibitor, and at 6.9 corn:N price ratio (\$6.58 bu^{-1} corn: \$0.915 lb^{-1} N + \$0.038 lb^{-1} NI) with inhibitor.

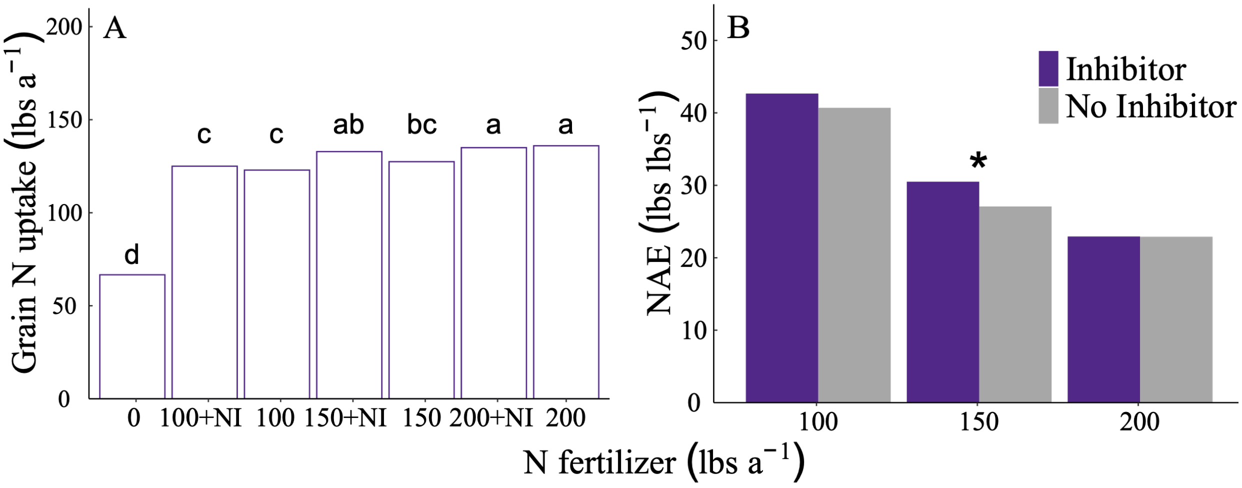

Figure 2. (A) Grain nitrogen (N) uptake (lb/a) as affected by N fertilizer rates (lb/a) and nitrification inhibitor across site-years. Means followed by different lowercase letters indicate significant differences at $P < 0.1$. (B) Nitrogen agronomic efficiency (NAE) in lbs lbs^{-1} of corn as affected by N fertilizer rates (lb/a) and nitrification inhibitor across site-years. Symbol (*) indicates significant differences at $P < 0.1$.

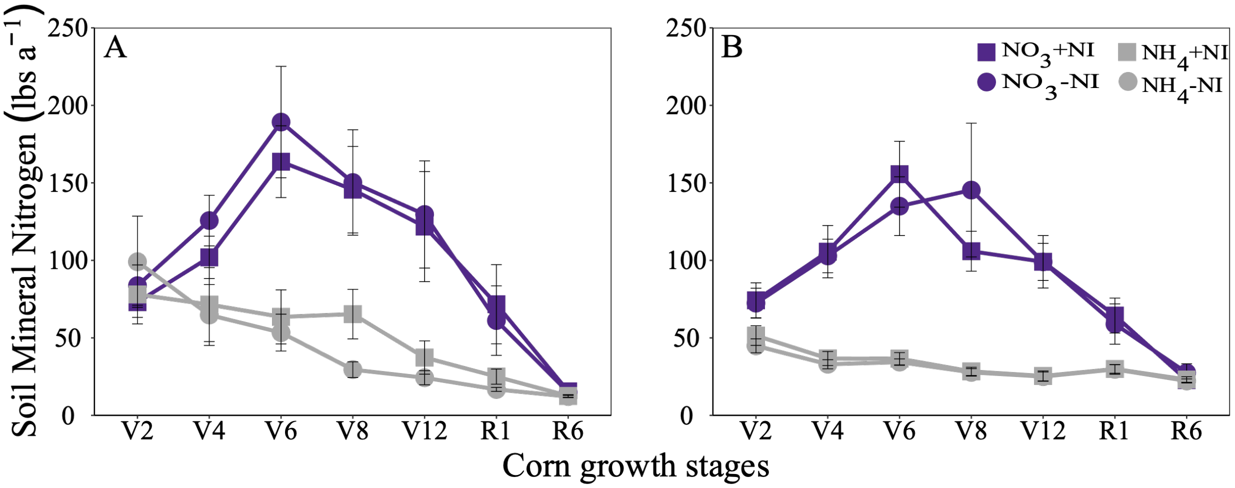

Figure 3. Average soil mineral nitrogen content throughout the corn growing season as affected by the use of nitrification inhibitor at the rate of 150 lb of N/a across site-years. Soil nitrate (NO_3^-) and ammonium (NH_4^+) at the 0- to 12-in. depth (A), and at the 12- to 24-in. depth (B).