NEBRASKA CORN LONG-TERM PRECISION AGRICULTURE 4R'S AND COVER CROP ASSESSMENT

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ABSTRACT

The 4R's (right rate, timing, placement, source) nutrient stewardship play a key role in precision nitrogen (N) management. Long-term studies evaluating these practices in a precision ag setup (on farm, large plots) are scarce. The Nitrogen Research for Agriculture Transformation and Enhancement (NRATE) project at the University of Nebraska–Lincoln addresses this challenge through a multidisciplinary approach linking N management with N losses, water quality, crop modeling, and economics. The project established two long-term field trials in 2022 at Mead, NE: one irrigated and one rainfed. Treatments combine a range of N rates (50-200 lb. N/ac) with two application timings (planting or planting + split), with or without an enhanced-efficiency fertilizer (EEF), and with or without a cover crop. Experiments were conducted with precision agriculture practices, and plot size was 20 ft by 300 feet. Across 2022–2025, total N rate was the main driver of corn grain yield. Economical optimum nitrogen rate (EONR) ranged from 130 to 160 lb. N/ac over the years. Other practices had smaller, rate-dependent effects. Response to EEF, timing, and cover crops was not consistent. EEF raised yield by about 5.3 bu/ac at 50 lb. N/ac ($p = 0.005$) but made no difference at higher rates. Application timing mattered most at 50 lb. N/ac ($p < 0.001$) and less at 150 and 200 lb. N/ac. Cover crops influenced yield only at 150 and 200 lb. N/ac. This long-term study, which will account for the legacy effect of the treatments, will allow us to quantify the benefits of these practices in combination with seasonal weather.

INTRODUCTION

Corn (*Zea mays* L.) receives most of the N fertilizer applied in the United States, so the profit and the environmental impact of corn production depend on how this N is managed (Morris et al., 2018). In Nebraska, much of the corn is irrigated with groundwater, so N lost through leaching directly affects water quality. A 31-year record from about 11,500 irrigation wells showed that nitrate levels were still increasing in 10 of 17 groundwater management areas in the irrigated corn regions of the state (Exner et al., 2014). For these reasons, better N management is important for both farm income and the environment.

The 4R nutrient stewardship framework (right source, right rate, right time, and right place) is a practical way to improve N use efficiency (Johnston and Bruulsema, 2014). Rate is the main decision, but the economic optimum N rate (EONR) is hard to predict because it depends on rainfall, temperature, and soil properties (Morris et al., 2018). Split applications and enhanced-efficiency fertilizers (EEF) are used to better

match N supply with crop demand (Johnston and Bruulsema, 2014). However, the effects of these practices and of cover crops on yield are not consistent. In a three-year study, applying the last part of the N at V12 instead of V3 increased plant N recovery but not grain yield at moderate to high N rates (Mueller et al., 2017). A meta-analysis of rice, corn, and wheat studies found that nitrification inhibitors increased yield by 7% on average, while controlled-release fertilizers did not change yield (Thapa et al., 2016). Grass cover crops did not change corn yield in US and Canadian experiments (Marcillo and Miguez, 2017).

Study length is also important. Because corn N needs depend on rainfall and temperature (Morris et al., 2018), short-term studies cannot capture the full range of weather conditions. Precision agriculture equipment now makes large-plot and on-farm experiments possible (Bullock et al., 2019), but long-term studies of this kind are still rare. The Nitrogen Research for Agriculture Transformation and Enhancement (NRATE) project at the University of Nebraska–Lincoln was created to address this gap. The project connects N management with N losses, water quality, crop modeling, and economics (Balboa et al., 2025). Our objective was to evaluate how N rate, application timing, EEF, and cover crops affected corn grain yield over the first four seasons (2022–2025) of two long-term trials, one irrigated and one rainfed, and to estimate the EONR across years.

MATERIALS AND METHODS

Site Description and Experimental Design

One long-term irrigated field trial was established in 2022 at the University of Nebraska–Lincoln Eastern Nebraska Research, Extension and Education Center near Mead, NE. The predominant soil series was silt loam. The previous crop was soybean, having a corn/soybean rotation. The trial was arranged as a split-split-split plot design with 4 replications. Plots were 20 ft wide (8 rows spaced 30 in. apart) by 300 ft long, and all field operations were performed with commercial-scale precision agriculture equipment.

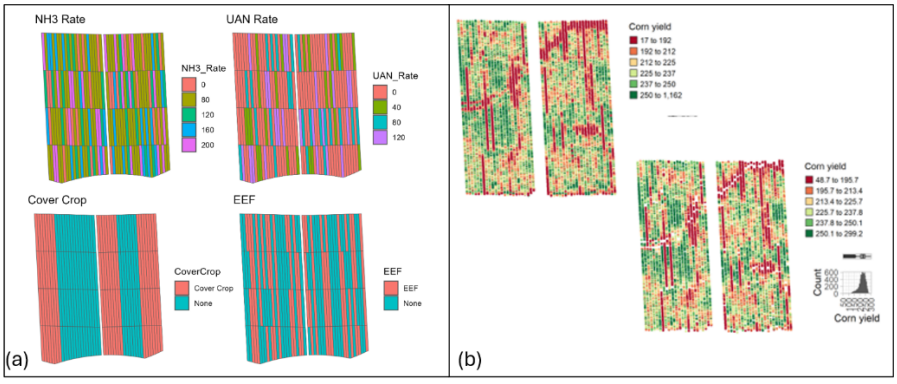


Figure 1. (a) Treatment plot layout. (b) 2023 yield data filtering example

Treatments

Treatments combined N rates ranging from 50 to 200 lb. N/ac with two application timings, with or without an EEF, and with or without a cover crop. In the

single-timing treatment, all N was applied at planting (anhydrous ammonia, AA); in the split treatment, of the total rate was applied at planting (AA) and the remaining at V6–V8 (UAN). The EEF treatment consisted of a nitrification inhibitor. The cover crop consisted of strips with and without cover crop.

Measurements

Roots were sampled in 2023, 2024, and 2025 at R6 in plots without cover crop that received 0 lb. N/ac or 150 lb. N/ac, applied all at planting or split (50 lb. N/ac at planting and 100 lb. N/ac in season), with and without EEF. Soil cores were collected with a hydraulic probe (2-in. diameter) 4 in. from the crop row in the middle of each plot and divided into 1-ft increments to 10 ft in 2023 and 2024 and to 8 ft in 2025; root biomass below 8 ft was minimal in 2023 and 2024. Roots were washed, scanned, and oven-dried to determine root biomass.

Statistical Analysis

Yield data were cleaned by removing non-biological possible values (≤ 0 or > 350 bu/ac), global outliers (mean ± 3 SD), and spatial outliers. Grain yield was analyzed with a factorial linear mixed model in R, with N rate (linear and quadratic), cover crop, EEF, timing, and all their interactions as fixed effects and year as a random intercept.

RESULTS AND DISCUSSION

Root Biomass

From 2023 to 2025 and across treatments, most root biomass (70–92%) was in the top 3 ft of soil. Some trends in root distribution were observed over the years. With the split application, plots with EEF tended to have more root biomass in the second foot than plots without EEF in all three years, and more in the third foot in 2024 and 2025. With all N applied at planting, the EEF trend was not consistent: plots with EEF had more root biomass in the top 3 ft in 2023 and 2025, but not in 2024.

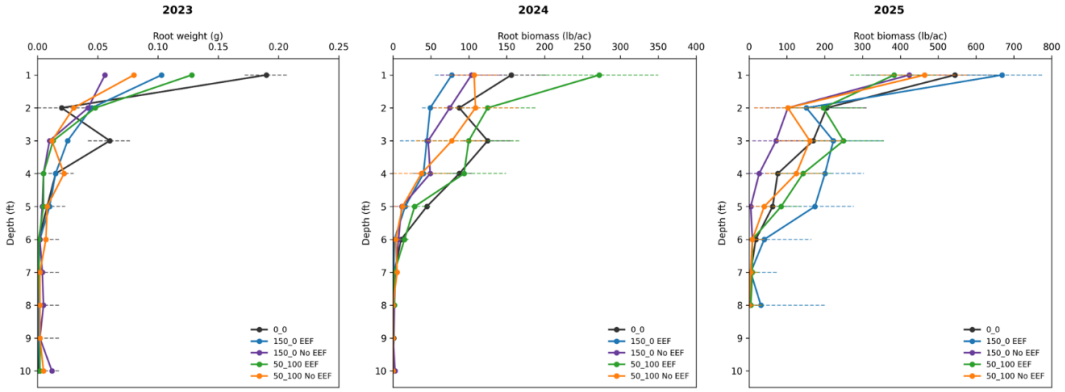


Figure 2. Root distribution by depth in 2023, 2024, and 2025 at Mead, NE, in plots without cover crop. Treatments are N rate at planting. N rate split (lb. N/ac), with or without enhanced-efficiency fertilizer (EEF).

Year-to-Year Yield Variability

Growing season (year) strongly affected corn grain yield (Figure 3). Mean grain yield was highest in 2022 (265 bu/ac), intermediate in 2025 (235 bu/ac) and 2023 (230

bu/ac), and lowest in 2024 (201 bu/ac). Yield in 2024 was 64 bu/ac (24%) lower than in 2022, while 2023 and 2025 were close to the overall mean.

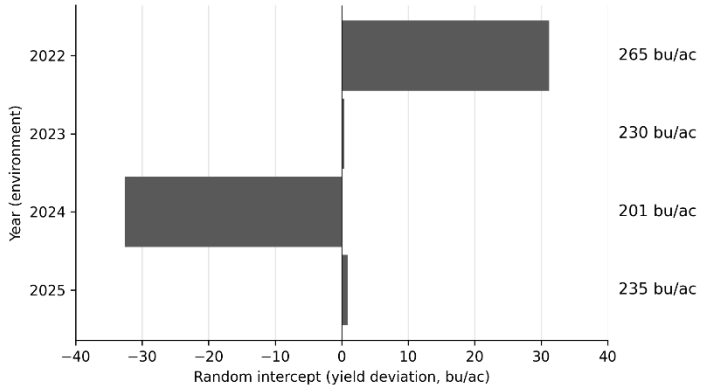


Figure 3. Year (environment) random intercepts for corn grain yield (deviation from the overall mean, bu/ac) at Mead, NE, 2022–2025. Values at right are the mean grain yield of each year.

Corn Yield Response to Nitrogen Rate

Across 2022–2025, total N rate was the main driver of corn grain yield. In all years and management combinations, yield increased with N rate and the response curves flattened between approximately 150 and 200 lb. N/ac (Figure 4). The year effect was consistent across management combinations: the 2022 curves were the highest and the 2024 curves the lowest in all four panels. The EONR ranged from 130 to 160 lb. N/ac across years (Table 1). This range is consistent with the large year-to-year variability in EONR reported across the Corn Belt (Morris et al., 2018; Ransom et al., 2020).

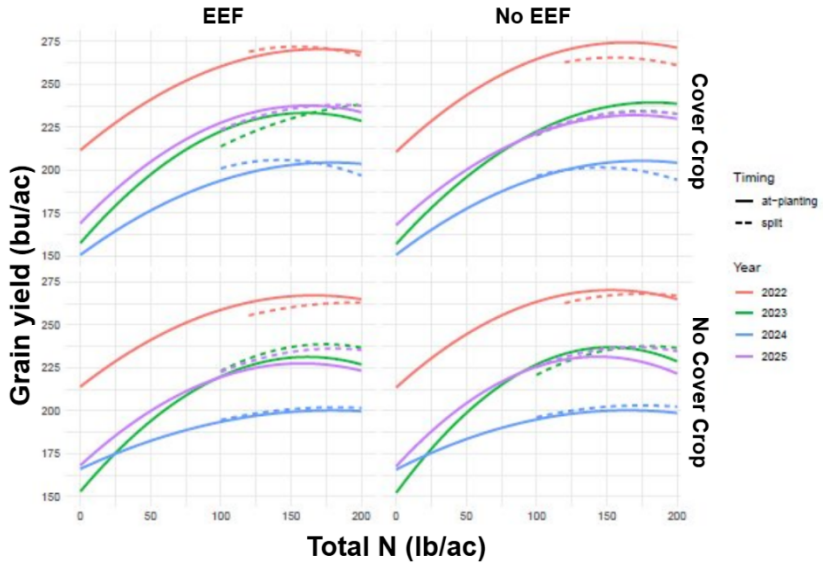


Figure 4. Corn grain yield response to total N rate by year, application timing (solid line, all at planting; dashed line, split), enhanced-efficiency fertilizer (EEF vs. no EEF), and cover crop (cover crop vs. no cover crop) at Mead, NE, 2022–2025.

Table 1. Economic optimum N rate (EONR) for each management combination at Mead, NE, 2022–2025.

Cover crop	EEF	Timing	EONR (lb. N/ac)
Cover crop	EEF	At planting	130.0
Cover crop	EEF	Split	143.2

Cover crop	EEF	Timing	EONR (lb. N/ac)
Cover crop	None	At planting	132.1
Cover crop	None	Split	136.2
None	EEF	At planting	122.9
None	EEF	Split	141.1
None	None	At planting	116.7
None	None	Split	134.7

Enhanced-Efficiency Fertilizer, Application Timing, and Cover Crop

The effects of EEF, timing, and cover crops on grain yield were small compared with the effect of N rate, and they depended on N rate (Table 2). The EEF increased grain yield by 5.3 bu/ac at 50 lb. N/ac ($p = 0.005$), whereas differences at 100, 150, and 200 lb. N/ac were within ±1.1 bu/ac and not significant ($p \geq 0.24$). The yield benefit of EEF was therefore limited to the lowest N rate, when N was most limiting, which agrees with meta-analysis results showing that EEF yield benefits depend on soil and management conditions (Thapa et al., 2016).

The cover crop did not affect yield at 50 or 100 lb. N/ac ($p \geq 0.52$) but increased yield by 2.3 bu/ac at 150 lb. N/ac ($p = 0.08$) and by 3.3 bu/ac at 200 lb. N/ac ($p = 0.038$). These increases correspond to roughly 1% of the mean grain yield. This small positive response agrees with the neutral to positive corn yield response reported in a meta-analysis of US and Canadian studies (Marcillo and Miguez, 2017), and contrasts with the small yield losses observed on commercial fields across the US Corn Belt (Deines et al., 2023). Because cover crop effects on soil N supply develop over several years, continued monitoring of these trials is needed to determine whether this response changes over time.

The timing effect was not consistent in direction. Applying all N at planting yielded 2.3 bu/ac more than the split application at 150 lb. N/ac ($p = 0.03$), whereas the split application yielded 2.3 bu/ac more at 200 lb. N/ac ($p = 0.071$). At 100 lb. N/ac, timing had no significant effect ($p = 0.180$). Inconsistent yield responses to split application at moderate to high N rates have also been reported in the US Midwest (Mueller et al., 2017).

Table 2. Pairwise contrasts of management practices within each total N rate for corn grain yield at Mead, NE, 2022–2025.

Factor	Contrast	N rate (lb. N/ac)	Estimate (bu/ac)	SE	*P*-value
EEF	None – EEF	50	-5.26	1.85	0.005
		100	-0.40	0.95	0.675
		150	1.05	0.90	0.242
		200	-0.91	1.20	0.448
Cover crop	Cover crop – None	50	-1.00	1.54	0.519
		100	0.83	1.36	0.545

		150	2.27	1.29	0.080
		200	3.34	1.60	0.038
Timing	At planting – Split	100	-1.64	1.22	0.180
		150	2.34	1.08	0.030
		200	-2.34	1.29	0.071

Negative estimates indicate higher yield for the second level of the contrast (e.g., EEF, split). Degrees of freedom = 738 for all contrasts.

CONCLUSIONS

During the first four seasons of the NRATE trials, total N rate was the main factor controlling corn grain yield, with an EONR between 130 and 160 lb. N/ac. Enhanced-efficiency fertilizer, application timing, and cover crops had smaller effects that depended on N rate and varied across years. EEF was beneficial only at the lowest N rate, while timing and cover crop effects appeared at selected rates. These results indicate that the value of these practices depends on the level of N supply and seasonal conditions rather than providing a consistent yield advantage. As the trials continue, they will allow the legacy effects of these practices to be quantified in combination with seasonal weather.

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