EVALUATING GRAIN SORGHUM RESPONSE TO NITROGEN FERTILIZER MANAGEMENT STRATEGIES ACROSS KANSAS ENVIRONMENTS

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ABSTRACT

Grain sorghum (*Sorghum bicolor* L. Moench) is an important crop in Kansas, yet nitrogen (N) management recommendations remain uncertain because yield response to N fertilizer is highly variable among environments. The objectives of this research were to (i) quantify grain yield and N uptake responsiveness to N rate, (ii) evaluate whether pre-plant soil tests and plant measurements can identify responsive sites, and (iii) compare the performance of enhanced-efficiency N practices against a pre-plant broadcast urea baseline. Field experiments were conducted in Kansas: N rate study and an N source, placement, and timing studies were placed across thirteen site-years for grain yield. In the N rate study, grain yield and N uptake generally increased quadratically with N rate, but responses varied widely. Initial response slopes ranged from 4 to 55 kg grain ha^{-1} per kg N ha^{-1}, and the agronomic optimum N rate ranged from 73 to 336 kg N ha^{-1}, with most site-years between 105 and 156 kg N ha^{-1}. At a 6:1 fertilizer-to-grain price ratio, the economic optimum N rate was 0 kg N ha^{-1} at three site-years and reached 165 kg N ha^{-1} at another. Pre-plant soil tests (NO_3^--N, soil organic matter, and inorganic N) were negatively but not significantly related to yield gain per unit N (R2 ≤ 0.19. In the efficiency study, no N source, placement, or timing consistently increased yield relative to 67 kg N ha^{-1} applied as pre-plant broadcast urea. Of 18 significant yield contrasts, 11 were negative, and gains (+0.12 to +0.55 Mg ha^{-1}) occurred at only five site-years. Enhanced-efficiency sources increased uptake by 11 to 14 kg N ha^{-1} at a few site-years, whereas in-season sidedress and split urea applications reduced yield and uptake at several site-years. Overall, environment, rather than N product or application method, was the dominant source of variation in sorghum N response. These results support site-specific, economically based N management tied to current price ratios, indicate that non-responsive sites can receive reduced N without a yield penalty, and show that enhanced-efficiency products and delayed applications should not be assumed to be beneficial. Future research should develop in-season indicators of N status and expand testing across environments to identify responsive sites before N is applied.

INTRODUCTION

Grain sorghum (*Sorghum bicolor* L. Moench) is a highly versatile cereal crop utilized globally for human nutrition, livestock forage, and biofuel production. Ranked among the top five most important cereal crops worldwide, global annual production reaches approximately 65 million metric tons (FAOSTAT, 2025). The United States is currently the leading producer of grain sorghum, harvesting about 8.73 million metric tons during the 2024–2025 growing season and accounting for approximately 14% of total global yield (Sorghum | USDA Foreign Agricultural Service, 2025).

Nitrogen (N) availability is frequently the primary yield-limiting nutrient in agronomic cropping systems. To maximize yield potential and minimize production risks, agricultural producers often apply high rates of synthetic N fertilizers (Houser, 2022). However, dynamic soil-plant-atmosphere interactions influenced by soil texture, soil organic matter (SOM), pH, ambient temperature, and seasonal precipitation render N management exceptionally complex. (M. Sainju et al., 2020; Shanahan et al., 2008). Consequently, crops typically recover only 40% to 60% of applied N fertilizer (Cassman et al., 2002). To mitigate loss pathways and improve NUE, various advanced management strategies have been developed, including enhanced-efficiency fertilizers (EEFs), specialized placement methods, and split-application timing protocols. Chemical Inhibitors, like additives such as the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) and the nitrification inhibitor dicyandiamide (DCD) temporarily delay urea hydrolysis and ammonium oxidation, respectively. By slowing these microbial processes, inhibitors protect nitrogen during early-season biological windows when crop demand is minimal. Controlled-Release Formulations: Physical barriers, such as polymer-coated urea (ESN), regulate nutrient release via diffusion, aiming to match the temporal nitrogen delivery with crop uptake kinetics over the growing season (Motavalli et al., 2008). Targeted Application and Split Timing, Physical placement techniques including streamed liquid urea ammonium nitrate (UAN) and in-season split or sidedress applications reduce the spatial and temporal exposure of fertilizer to environmental loss mechanisms. Despite the potential of these enhanced technologies and practices, their efficacy and economic viability often vary substantially depending on local soil characteristics, weather patterns, and regional management practices.

Thus, evaluating these integrated N management strategies within specific grain sorghum production systems remains critical to improving overall agricultural sustainability. Two different approaches were evaluated at each location, within the same field to evaluate different N fertilizer rates and different N managements. The first study quantified the response to N rate in grain yield, also the economics to obtain a break-even price ratio of N price to grain prices and lastly evaluated soil test values to predict response to N before planting. The second study evaluated the response to N to stablish a baseline in grain yield to later compare with different management treatments that included UAN placement, EEFs, and different timings of broadcast urea; in this way we can compare if a management practice performs better than a conventional baseline broadcast urea at planting.

MATERIALS AND METHODS

Thirteen grain sorghum site-years were established across Kansas between 2021 and 2025. All study site-years were located at Kansas State University experimental fields; operations, such as planting, weed management, and sorghum hybrid vary depending on the region and each field operation. At all locations, sorghum was planted with a 0.76 m row spacing. Individual plots consisted of 4 rows and measured 12.2 m in length by 3 m in width (36.6 m^2). Grain yield was measured at all ten site-years,

Fourteen N management treatments were evaluated in a randomized complete block design to determine the individual and combined effects of N application rate, placement method, fertilizer source, and application timing. Prior to the establishment of the experiment, composite soil samples were collected from each replicate (block) using a hand probe at a depth of 0-15 cm for baseline soil characterization and 0-60 cm for residual inorganic N determination. Grain was harvested from the two centers of four rows of each plot, representing a total area of 16.3 m^2 (0.76 m row spacing x 10.67 m length x 2 rows). Harvested grain moisture content was recorded, and yields were adjusted to a standard moisture of 140 g kg^{-1}.

Data were analyzed using R (Version 4.5.0) using RStudio (Version 2025.05.0+496), with the function “lmer” (Bates et al., 2015) from the lme4 package in to run a linear mixed model analysis that estimates the effect of N fertilizer rate while accounting for block-to-block variability, and the statistical significance was determined at α = 0.05, with degrees of freedom and p-values calculated via the Kenward-Roger approximation (Kenward & Roger, 1997). Figures and data visualizations were generated using the “ggplot2” package (Wickham & RStudio, 2023).

RESULTS

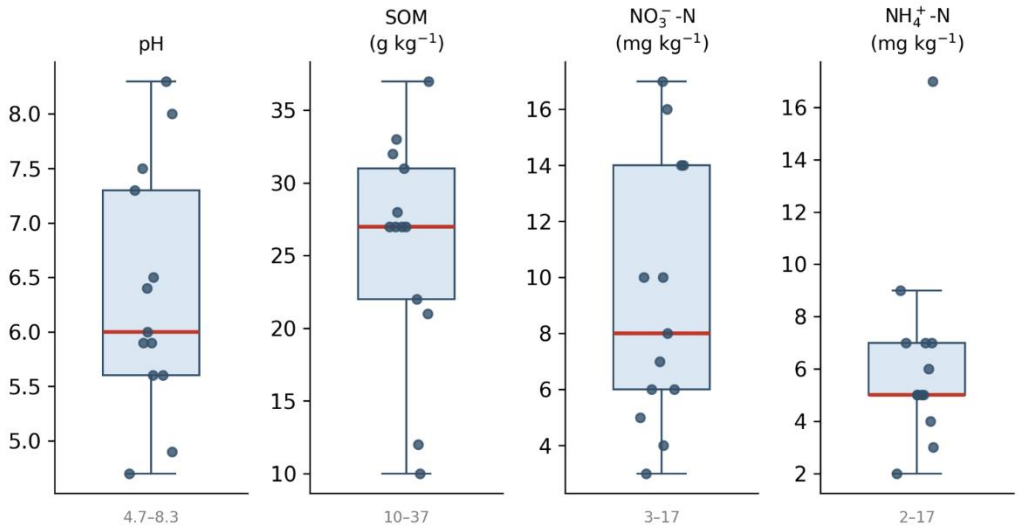


Figure 1. Preplant soil test results. Soil organic matter (SOM), nitrate (NO_3^-N), ammonium (NH_4^+-N), Inorganic N (NO_3^-N + NH_4^+-N).

Table 1. Grain yield response to increasing nitrogen rates

Site	Intercept	Slope	Quadratic	R^2	AONR	EONR
1	6.2	0.026	-1.20E-04	0.89	108	83
2	4.3	0.011	-4.52E-05	0.64	122	55
3	5.1	0.011	-4.49E-05	0.39	122	56
4	5.9	0.015	-5.51E-05	0.97	136	82
5	6.6	0.004	-2.73E-05	0.09	73	0
6	5.8	0.026	-8.33E-05	0.82	156	120
7	4.8	0.017	-5.54E-05	0.66	105	99
8	3.9	0.055	-1.82E-04	0.85	151	135
9	7.8	0.015	-4.89E-05	0.82	153	92
10	6.5	0.006	-8.93E-06	0.48	336	0
11	6.3	0.024	-5.46E-05	0.82	220	165
12	4.3	0.009	-3.57E-05	0.48	126	42
13	6.8	0.001	-8.89E-03	0.43	133	0

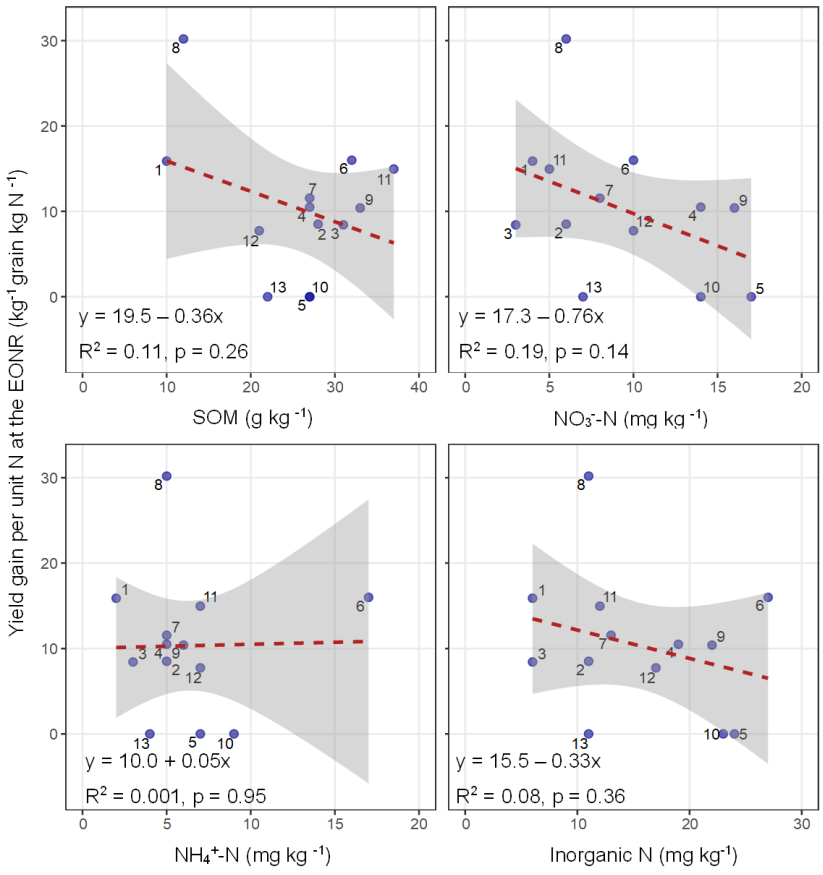


Figure 2. Yield gain per unit nitrogen at the economic optimum nitrogen rate response to soil variables. Agronomic optimum nitrogen rate (EONR), soil organic matter (SOM), nitrate (NON), ammonium (NH-N), Inorganic N (NON + NH-N).

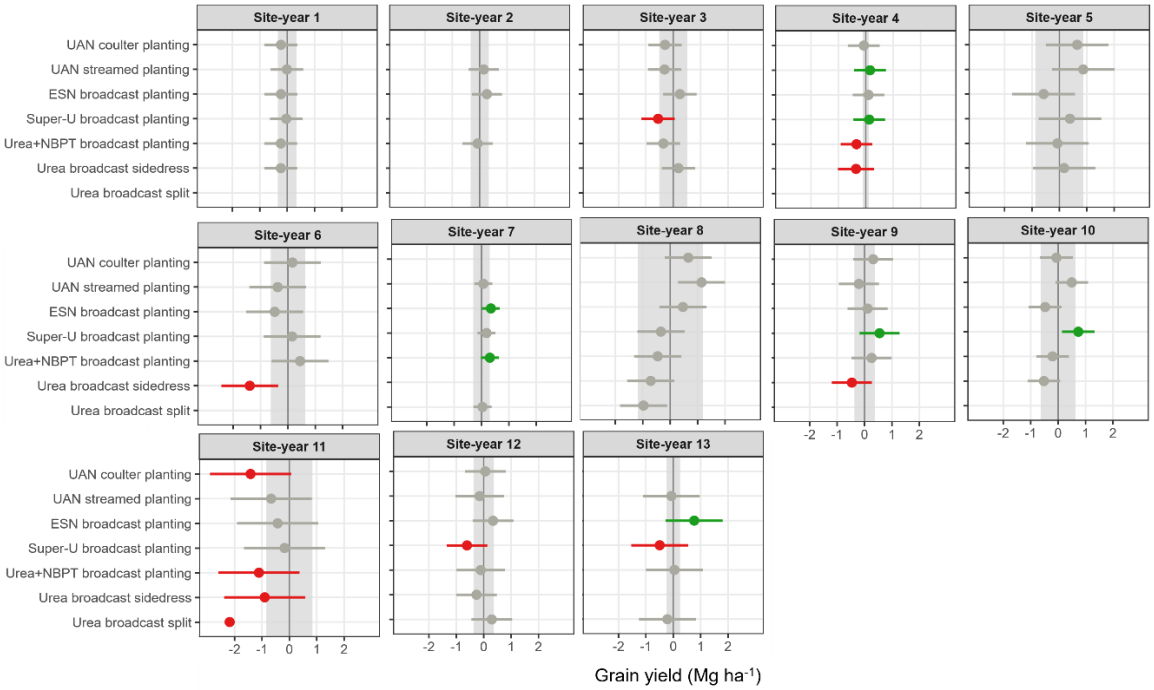


Figure 3. Grain yield response difference from baseline for each site-year evaluated at 67 kg N ha^{-1}.

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