INFLUENCE OF NITROGEN MANAGEMENT AND PRECIPITATION ON SORGHUM NITROGEN USE EFFICIENCY

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ABSTRACT

Grain sorghum (Sorghum bicolor L. Moench) is a key crop in Kansas which can benefit from optimized nitrogen (N) management that enhances yield while minimizing N losses. Understanding the relationships among physiological efficiency (PE), recovery efficiency (RE), and agronomic efficiency (AE), as well as their interactions with climatic factors such as precipitation, is essential for improving nitrogen use efficiency (NUE).

Experiments were conducted across five rainfed and one irrigated site in Kansas from 2021 to 2024. Nitrogen was applied as broadcast urea at planting at rates of 0, 33, 67, 101, 135, 168, and 201 kg N ha^{-1} to assess rate effects on PE. Additional management treatments evaluated RE and AE at a fixed rate of 67 kg N ha^{-1} under varying N sources (urea, UAN), timings (planting, S6, split) and placements (broadcast, coulter, streamed). Site-specific seasonal precipitation (mm) was obtained from nearby weather stations to determine climatic effects on NUE responses.

Results showed that increasing N rates above 135 kg N ha^{-1} decreased PE across all sites, likely due to nutrient imbalances caused by excessive N. Management treatments showed limited effects on RE and AE, although Split application, Coulter UAN, and the use of Super U seems to have higher RE and AE; however, these trends were not statistically significant ($p < 0.1$). Normal precipitation levels supported optimal conditions across sites, while observed in season precipitation (<468.9 mm) was associated with lower yields but not with RE or AE, emphasizing the role of water availability in sustaining production but other factors involved need to be examined.

INTRODUCTION

Grain sorghum (Sorghum bicolor L. Moench) is a key crop in Kansas cropping systems and ranks among the top five cereal crops globally. The United States is the leading producer, contributing 8.73 million metric tons—14% of world production—in the 2024/2025 season. Sorghum is a drought-tolerant, resource-efficient crop with high water and solar energy use efficiency, making it well-suited for the variable climate of the Central Great Plains. Optimized nitrogen (N) management can enhance grain yield while minimizing N losses to the environment, including nitrate leaching and nitrous oxide emissions. Understanding the relationships among physiological efficiency (PE), recovery efficiency (RE), and agronomic efficiency (AE), as well as their interactions with climatic factors such as precipitation, is essential to improve nitrogen use efficiency (NUE) and support sustainable, profitable sorghum production in Kansas.

MATERIALS AND METHODS

Experiments were conducted from 2021 to 2024 across five rainfed and one irrigated site in Kansas. Prior to fertilizer application, soil samples were collected from 0–15 cm to determine soil pH and organic matter (OM), and from 0–60 cm to quantify profile nitrogen (NO_3^- and NH_4^+). Nitrogen was applied as broadcast urea at planting at rates of 0, 33, 67, 101, 135, 168, and 201 kg N ha^{-1} to evaluate the effect of N rate on physiological efficiency (PE). Additional management treatments were applied at a fixed rate of 67 kg N ha^{-1} to assess recovery efficiency (RE) and agronomic efficiency (AE). These treatments varied by N source (urea, UAN), timing (planting, V6 stage, or split applications), placement (broadcast, coulter, or streamed), and the use of inhibitors (SuperU, ESN, and NBPT). Grain and biomass were collected at stage 9, and samples were processed through Leco N analysis to measure total N uptake. Site-specific seasonal precipitation data (mm) were obtained from nearby Kansas Mesonet weather stations to evaluate the influence of climatic conditions on nitrogen use efficiency (NUE) responses.

Table 1. Treatments description.

Trt	Kg N ha^{-1}	Placement	Source	Timing
1	**0**	Broadcast	Urea	planting
2	**33**	Broadcast	Urea	planting
3	**67**	Broadcast	Urea	planting
4	**101**	Broadcast	Urea	planting
5	**135**	Broadcast	Urea	planting
6	**168**	Broadcast	Urea	planting
7	**201**	Broadcast	Urea	planting
8	**67**	Coulter	UAN	planting
9	**67**	Streamed	UAN	planting
10	**67**	Broadcast	ESN	planting
11	**67**	Broadcast	Super-U	planting
12	**67**	Broadcast	Urea + NBPT	planting
13	**67**	Broadcast	Urea	S6
14	**67**	Broadcast	Urea	Planting/S6

Table 2. Average Soil Texture, pH, OM and N for each location.

	County	Texture	pH	OM%	NO_3^-	NH_4^+
1	Riley	Sandy	5.9	1.0	3.6	2.1
2	Ellis	Silt Loam	4.9	2.7	14.4	5.0
3	Riley	Silt Clay	6.6	2.7	7.7	22.7
4	Reno	Loam	7.5	2.7	17.1	6.6
5	Franklin	Silt Loam	6.0	3.2	9.6	16.8
6	Ellis	Silt Loam	8.3	2.7	7.7	4.9

RESULTS AND DISCUSSION

In season Cumulative Precipitation

Seasonal precipitation played an important role in supporting yield: normal precipitation levels maintained optimal conditions, while below-average in-season rainfall (<468.9 mm) was associated with lower yields. Interestingly, precipitation had minimal effect on RE and AE, highlighting the complex interactions among water availability, N management, and other environmental and physiological factors that influence nitrogen use efficiency.

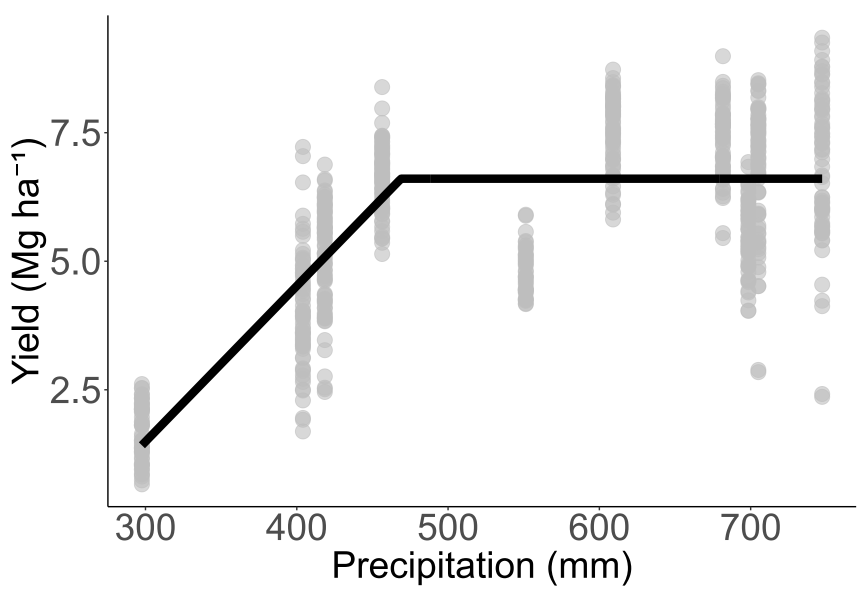

Figure 1. ***Yield response to precipitation.***

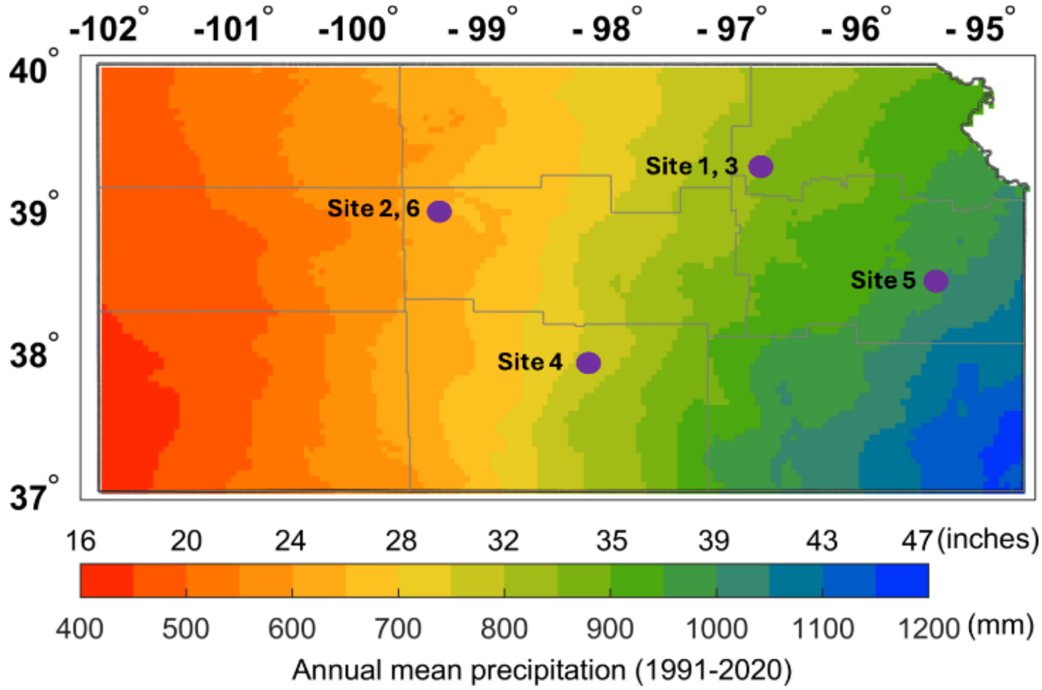

Figure 2. ***Kansas Normal precipitation map*.**

Plant Physiological Efficiency

Increasing N rates above 135 kg N ha⁻¹ consistently reduced physiological efficiency (PE) across all sites, likely due to nutrient imbalances caused by excessive nitrogen. Excessive N can negatively impact both plants and soil health: it increases water demand, can leach into groundwater or run off into surface waters, damages fine root hairs responsible for water and nutrient uptake, and raises susceptibility to pests such as sap-sucking insects. Over-application may also induce deficiencies of other nutrients (e.g., iron, manganese), excess N can promote excessive vegetative growth at the expense of panicle development and grain formation, potentially reducing yield and grain quality. In soils, excess N can disrupt beneficial microbial communities, potentially affecting water movement and overall soil function.

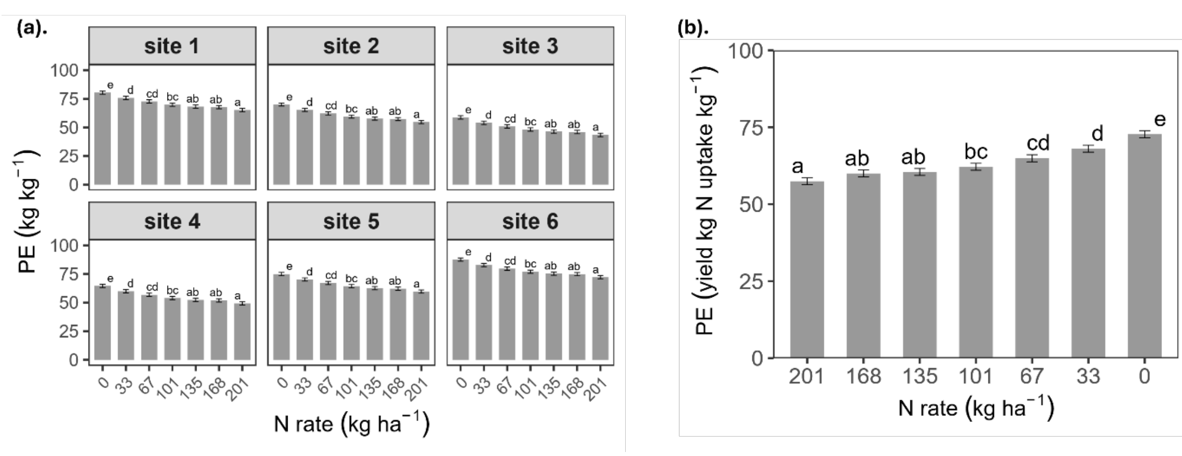

Figure 3. ***Plant PE response to increasing nitrogen rates for each site (a) and across sites (b).*** *Different letters are significantly different at P<0.1.*

Fertilizer Recovery Efficiency and Agronomic Efficiency

Management treatments had limited effects on RE and AE, although Split application, Coulter UAN, and the use of Super U may improve RE and AE, but these differences were not statistically significant (p < 0.1).

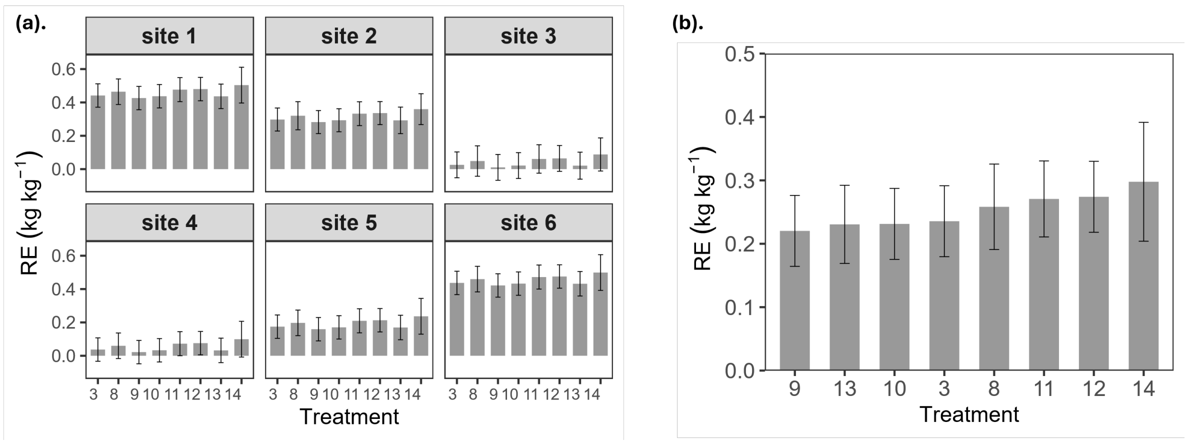

Figure 4. ***Plant RE response to increasing nitrogen rates for each site (a) and across sites (b).*** *Different letters are significantly different at P<0.1.*

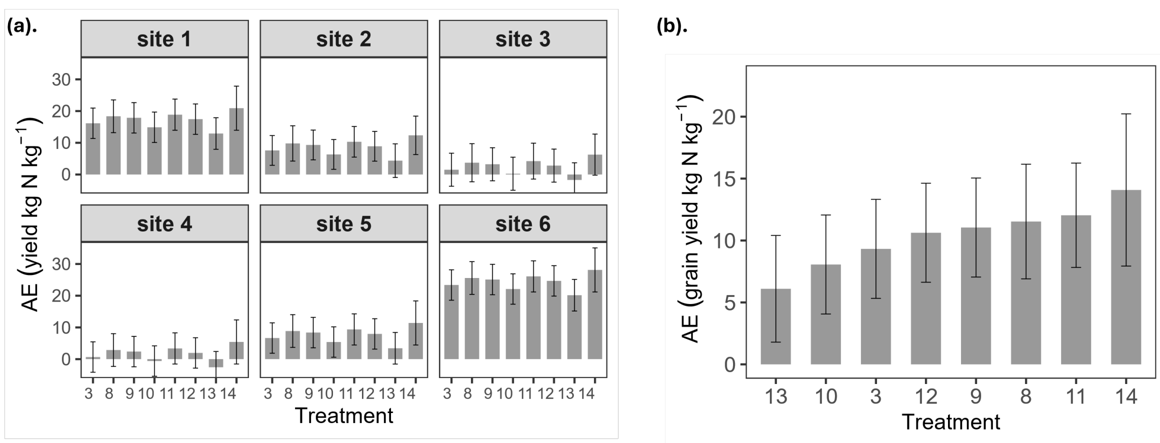

Figure 5. ***Plant AE response to increasing nitrogen rates for each site (a) and across sites (b).*** *Different letters are significantly different at P<0.1.*

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