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Depth of Moist Soil at Planting Affected Grain Sorghum Response to Nitrogen Fertilizer

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Summary
The depth of moist soil before planting is a critical factor for grain crop production in dryland cropping systems. We investigated depth of moist soil at planting and nitrogen (N) fertilizer application effects on continuous grain sorghum yields on a Crete silt loam soil over 32 years in western Kansas. Treatments were four N rates (0, 20, 40, and 60 lb/a) in a randomized complete block design with four replications and depth of moist soil at planting determined with a Paul Brown moisture probe. Grain sorghum yield response to N fertilizer application was -0.10, 14.4, 29.3, and 36.5 lb of grain/a for every lb of N applied in very low yielding (VLY), low yielding (LY), high yielding (HY), and very high yielding (VHY) environments, respectively. Grain yield increased with depth of moist soil at planting for each N rate, with yield increases of 217 to 461 lb/a per inch increase in depth of moist soil at planting for the unfertilized control through 60 lb N/a. Regardless of yield environment, net returns were negative when depth of moist soil at planting was less than 30 inches. These results suggest that continuous grain sorghum should not be planted when depth of moist soil measured with a Paul Brown probe is < 30 inches. Results of this 32-year study showed the depth of moist soil at planting could be used to fine-tune N application rates for sorghum. Despite greater drought tolerance**,** sorghum N response is dependent on combination of soil water at planting and in-season precipitation. We need to continue this research to identify sorghum hybrids with improved drought tolerance and nitrogen use efficiency to increase probability of dryland sorghum production.

Introduction
The increase in soil water storage due to adoption of conservation tillage has allowed cropping intensification (including continuous grain sorghum) in dryland systems in the central Great Plains. Grain sorghum was produced on more than 5.2 million acres annually from 2016 to 2020 in the United States, more than 50% of which was grown in Kansas (USDA NASS, 2021). Storage of moisture is critical to ensure profitable grain sorghum production in water-limited environments. In addition to moisture stress, soil nutrients—particularly N availability—affect sorghum production. Too much fertilizer could provide good vegetative growth, but, because of limited soil moisture, yield levels could be low. However, too little fertilizer may not use the stored moisture effectively and thus, would not optimize profitable yields. There are limited studies that have attempted to address the effect of available soil water at planting and N fertilizer application on grain sorghum production in the semi-arid Great Plains. In

dryland systems, measuring the depth to moist soil could provide a measure of water stored at crop planting. The depth of moist soil could be determined using the Paul Brown Moisture probe (Brown, 1960). The amount of force required to push the Brown moisture probe into the soil is directly related to soil moisture content, with resistance increasing as the soil moisture content decreases. The objective of the current research was to determine if the depth of moist soil at planting measured with the Paul Brown probe could be used to make fertilizer application decisions.

Experimental Procedures

This study was conducted at the Kansas State University Agricultural Research Center near Hays, KS, between 1970 and 2002 under a dryland reduced tillage operation system with annual cropping of sorghum. Treatments were four N rates (0, 20, 40, and 60 lb/a) arranged in a randomized complete block design with four replications. Individual plot size was 40-ft long × 12-ft wide. Tillage operations were accomplished with a V-blade or sweep plow to about 6-inch depth. Approximately two tillage operations were performed, one in the fall and another in late spring before sorghum planting. Nitrogen as ammonium nitrate fertilizer was broadcast applied in the fall each year just prior to fall tillage to incorporate fertilizer. Soil test levels for available P were medium to high over the study period and exchangeable potassium (K) levels are inherently high in this soil, therefore, N was the only fertilizer applied over the 32-year study period. An objective of this study was to determine the influence of depth of moist soil at planting on grain sorghum response to N fertilizer. The depth of moist soil was determined prior to sorghum planting in each year of the study using the Paul Brown probe (Brown, 1960). Briefly, depth of moist soil was determined by pushing a 0.4 inch diameter rod with a 0.5 inch ball bearing on the end into the soil. The depth to which the rod could be pushed was marked as the depth of moist soil (Brown, 1960). Six probe measurements were taken and averaged per plot and the depth of moist soil were converted to plant available water at planting (ASW) using conversion tables based on soil texture.

Grain sorghum was planted in late May through the second week in June and harvested in October. Grain sorghum was planted in 30-inch row spacing at 35,000 plants/a. Grain sorghum hybrids changed occasionally over the course of the study as the seed companies replaced discontinued hybrids with newer, better-adapted hybrids. Weed control in grain sorghum was done with a pre-mixture of 25.3% of [alachlor, 2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide] and 15.3% of [atrazine, 2-chloro-4-(ethylamino)-6-(isopropylamino) s-triazine]. Grain yields were determined by harvesting 5- × 40-ft long area of each plot with a plot combine harvester (Massey Ferguson, Duluth, GA). The net returns from N fertilizer were computed for each N application rate treatment as the difference between total revenue from grain sales and the cost of production (including planting, harvesting, trucking and fertilizer application costs). The total revenue was calculated as the product of grain yield and grain price. Nitrogen fertilization costs included in the calculations were the price of fertilizer and application costs taken from the Kansas Agricultural Statistics custom rates (*https://www.nass.usda.gov/Statistics_by_State/Kansas/*). The economic analysis was conducted excluding government payments and crop insurance.

Data analyses for grain yield and net returns from N fertilizer for the 32 years were done using the PROC MIXED procedure of SAS (SAS Institute, 2012). Descriptive statistics were conducted and based on the results, the data were grouped into very low yielding environments (VLY), low yielding environments (LY), high yielding environments (HY), and very high yielding environments (VHY). Yield responses to N in these environments were regressed using the PROC REG procedure of SAS. Nitrogen application rate, depth of moist soil, and the effects of their interaction on yield and net return were analyzed with the PROC MIXED procedure. The Tukey's honest significant difference method was used to conduct mean separation for the effects of treatments.

Results and Discussion

Precipitation and Grain Yield

Growing season precipitation (May through September) varied significantly over the study period (data not shown). Total average growing season precipitation over the 32 years of the study was 15.5 inches. In general, the 1993, 1996, and 2001 growing seasons recorded the highest growing season precipitation amounts. The driest growing season was 1983, with total seasonal precipitation amount of 6.8 inches. In 15 years of the 32-year study, the amount of precipitation received was equal to or greater than the 30-year average.

Sorghum grain yield varied significantly over the 32-yr study for each N rate. In five of the 32 years, average yield was less than 1133 lb/a, significantly smaller than the average yield (VLY). Average yields in twelve years of the study were less than the overall average but within the lower portion of the standard deviation (LY). In eleven of the 32 years, annual average yields were greater than the overall average but within the standard deviation (HY). In four of the 32 years, yields were significantly greater than the overall mean (VHY). Sorghum grain yield did not respond to N fertilizer in VLY environments. In the LY, HY, and VHY environments, sorghum yields responded positively to fertilizer application rate (Figure 1a). In the LY environment, grain yield increased by 14 lb/a for each additional lb/a N fertilizer applied. In the HY environment, yield increased by 29 lb/a for each lb increase in N fertilizer. Similarly, in the VHY environment, yield increased by 37 lb/a for a one lb/a increase in N fertilizer (Figure 1a). Available soil water at planting and in-season precipitation amounts differed significantly among yield environments (Figure1b and c).

In-season precipitation was generally weak at explaining grain yield response to N fertilizer application rate. However, sorghum grain yields responded positively to ASW at planting, and ASW explained 86–98 % of the variation in yield within each N application rate (Figure 2). Sorghum grain yield increased by 217 lb/a for an inch increase in ASW for the unfertilized control. Nitrogen fertilizer at 20 lb/a increased grain yield by 318 lb/a for an inch increase in ASW at planting. Likewise, grain yield increased by 317 and 461 lb/a with N application of 40 and 60 lb N/a, respectively, for an inch increase in ASW at planting (Figure 2).

Net Return

Regardless of N fertilizer amount applied, net return for continuous sorghum production was negative for all environments when depth of moist soil at planting was less than 30 inches. Irrespective of in-season precipitation, net return from N fertilizer application increased with the depth of moist soil. For example, when in-season precipitation was < 16 inches, net return averaged $-200 to $-46 when depth of moist soil was ≤ 30 inches compared to net returns of $142 to $355 when depth of moist soil was

48 to 72 inches. In environments with > 16 inches in-season precipitation, net return to fertilizer application increased by $3.40 to $3.60 for each additional inch of increase in depth of moist soil.

Conclusion

Grain sorghum's response to N fertilizer application was highly dependent on yield environment. Available soil water at planting explained 86–98% of the variation in yield within N fertilizer rate. However, in-season precipitation explained only 4–18% of variability in yield with N rate. Net return with fertilizer application was negative for all environments when depth of moist soil at planting was less or equal to 30 inches. We concluded that the depth of moist soil at planting could be used to fine-tune continuous sorghum planting (do not plant sorghum when depth of moist soil < 30 inches) and N fertilizer requirements.

Despite greater drought tolerance, sorghum N response is dependent on a combination of soil water at planting and in-season precipitation. We need to continue this research to identify sorghum hybrids with improved drought tolerance and nitrogen use efficiency to increase probability of dryland sorghum production.

Acknowledgments

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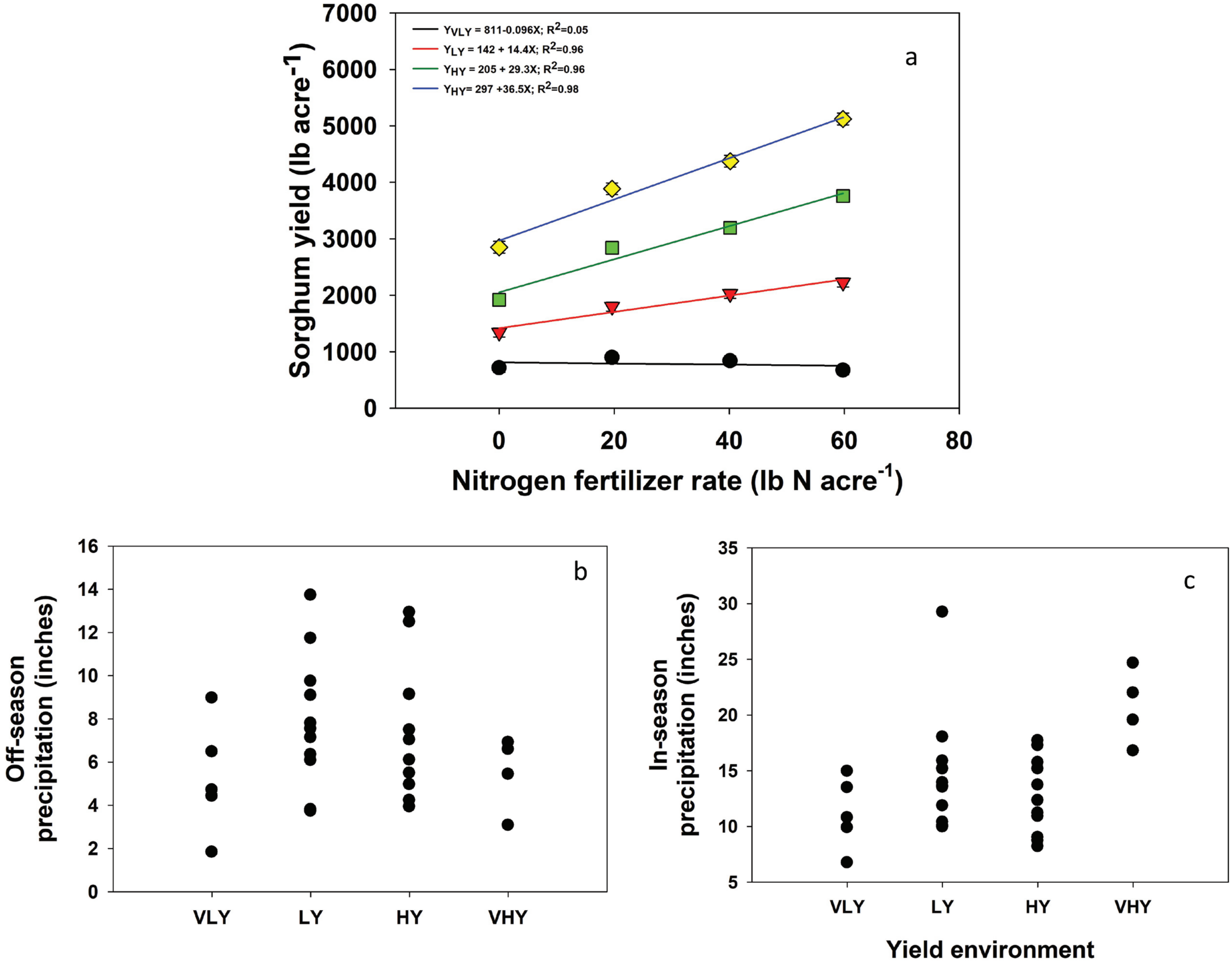

Figure 1. Nitrogen fertilizer rate and sorghum yield relationships at four dryland yield environments [years with very low yielding (VLY), low yielding (LY), high yielding (HY), and very high yielding (VHY)] and (b) off-season (fallow) precipitation, and (c) in-season precipitation amounts by yield environment from 1971–2002 near Hays, KS.

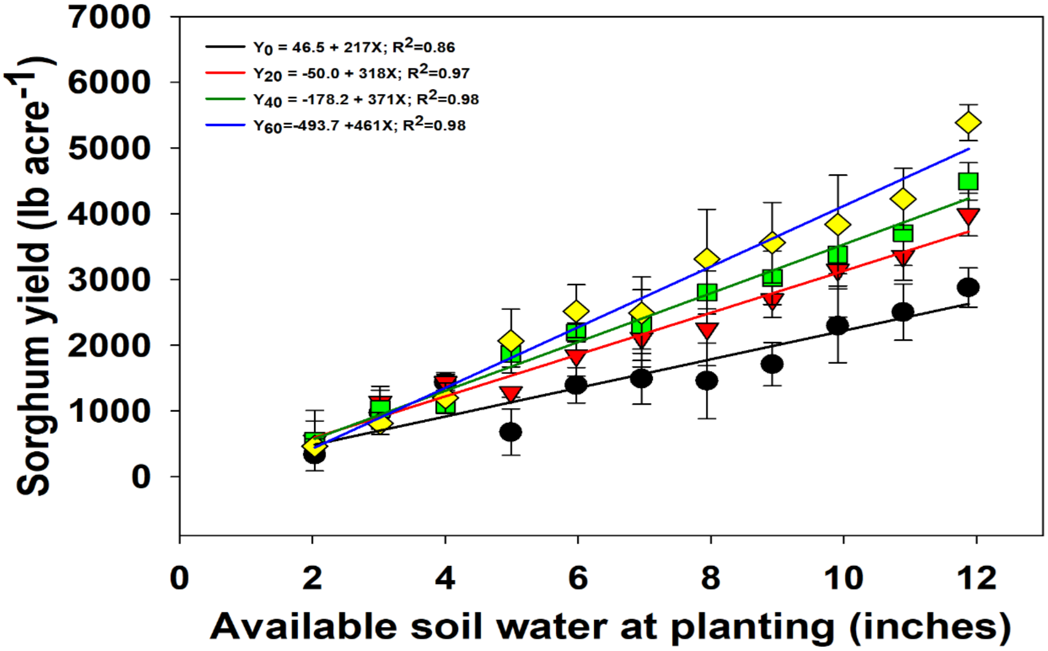

Figure 2. Available soil water and sorghum yield relations in four N fertilizer amounts over the years from 1971–2002.