

GRAIN SORGHUM IRRIGATION IN THE US EASTERN COASTAL PLAIN USING VARIABLE RATE IRRIGATION

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ABSTRACT. Grain sorghum is one of the top five cereal crops and an important grain crop throughout the world. It is generally considered more drought tolerant compared to other grain crops such as maize. Recently, in the US eastern Coastal Plain region, there was an emphasis on increasing regional grain production in which grain sorghum played an important role. The region's soils have low water holding capacities that combined with high rainfall variability cause crops frequently to be exposed to water stress. In this research, an experiment was conducted to evaluate the yield response of two grain sorghum varieties at different supplemental irrigation levels and three nitrogen levels. During our 3-year study, seasonal rainfall was adequate to produce acceptable grain sorghum yields and ranged from 421, 365, and 357 mm in 2012, 2013, and 2014, respectively. These rainfall amounts were greater than the seasonal calculated crop evapotranspiration requirement, but supplemental irrigation was required to maintain soil water potential above -30 kPa. However, irrigation did not increase grain sorghum yields. Additionally, no significant differences were found in grain yield between the two sorghum varieties or for increasing nitrogen applications. Results from this study suggest that there would be little benefit for supplemental irrigation for sorghum production in the US eastern Coastal Plain.

Keyword: Irrigation, grain sorghum, irrigation management

Grain sorghum (*Sorghum bicolor* L.) is an important grain crop that is considered drought tolerant and suitable to be grown in regions drier than those for corn (Swick, 2011). In some areas of the country with low rainfall such as the Southern High Plains, sorghum has to some extent replaced corn (Bordovsky and Lyle, 1996). In many of these areas, irrigation is used to supplement rainfall in grain sorghum fields. In 2013, the average irrigation water applied to grain sorghum was approximately 1100 mm in Arizona, 365 mm in Texas, and 60 mm in North Carolina (USDA-NASS 2017, Quick Stats). In 2012, the US Census of Agriculture reported grain sorghum production at approximately 2.1 million hectares with 0.25 million hectares irrigated (~12%). In much of the Southern High Plains, grain sorghum is deficit irrigated at rates below that of a well-watered crop. In western Kansas, Klocke et al. (2012) studied the impact of deficit irrigation on grain sorghum yields. In their study, grain sorghum yields increased linearly with increased

irrigation amounts. Similarly, in northern Texas, O'Shaughnessy et al. (2012) reported on deficit irrigation levels in grain sorghum using automatic and manual irrigation scheduling. They found that optimum deficit irrigated yields and water use efficiencies were obtained when irrigation was from 55 to 80% of well watered crop evapotranspiration rates.

Only limited data are available on irrigating grain sorghum in humid regions. Recently in Mississippi, Bruns (2015) found no significant impact of irrigation on sorghum grain yield and concluded that supplemental irrigation would not be necessary in the Mid-south under normal seasonal conditions.

Grain sorghum yields are also influenced by fertilization. Hibberd and Hall (1990) studied the response of grain sorghum hybrids to nitrogen fertilizer. In a 3-year furrow irrigation study, they reported significant increases in sorghum grain yields by increasing nitrogen applications. In 2 of the 3 years, they observed differences among the evaluated hybrids. They determined the optimum rate of nitrogen application to be approximately 120 to 180 kg N ha⁻¹. They also observed a leveling off of grain yields at higher nitrogen concentrations. Assefa and Staggenborg (2010) investigated the impact of grain sorghum yield and hybrid advancement from 1957 through 2008. In the 52 years of data analyzed, they found hybrid yields increasing nearly 50 kg ha⁻¹ per year in dryland sites with nitrogen fertilizer explaining 34% of the yield increases while the remaining yield increase was due to improved hybrids. However, irrigated grain sorghum yields remained unchanged over the same time period. They concluded that hybrid improvement programs had selected hybrids with better drought tolerance characteristics for dryland rather than for irrigated production.

In 2012, Murphy-Brown, Inc. (a division of Smithfield Grain, Rose Hill, NC) initiated a grain sorghum production program in the Carolinas and Virginia to increase local grain supplies for the swine industry (Murphy-Brown, 2012). Even though grain sorghum is generally drought tolerant, supplemental irrigation during drought conditions could impact grain sorghum yield potentials because the agricultural soils of the US south eastern Coastal Plain Region are generally coarse-textured with low water holding capacities (Camp and Sadler, 2002). Additionally, rainfall during the growing season can be highly variable. Sheridan et al. (1979) documented that there was a 50% chance of a 20-day drought during the annual growing season in the southeastern Coastal Plain. In this research, our objective was to evaluate the yield response of two grain sorghum varieties at different supplemental irrigation depths and three nitrogen levels. Results from this study will provide the regions sorghum growers information to make informed irrigation management decisions.

MATERIALS AND METHODS

FIELD EXPERIMENT

A sorghum experiment was conducted from 2012 through 2014 under a 6-ha variable-rate center-pivot irrigation system (Camp et al., 1998) on a Norfolk loamy sand (Typic Kandiuult) near Florence, South Carolina (34°14'36.94" N, 79 48'34.14" W, elevation 42 m). The site is located in the humid U. S. Eastern Coastal Plain region and has an annual mean rainfall of 1089 mm and mean temperature of 18°C. In 2012, there were four irrigation treatments (0%, 33%, 66%, and 100% irrigation) and two nitrogen fertilization treatments (85 and 170 kg N ha⁻¹) with one cultivar (Dekalb A571). In 2013 and 2014, there were three irrigation treatments ((0%, 50%, and 100% irrigation), three nitrogen fertilization treatments (0, 85 and 170 kg N ha⁻¹), and 2 varieties (Dekalb A571 and Pioneer 84P80, both mid to late maturity varieties, i.e. greater than 70 days to mid-bloom). In all years there were 4 replications. Grain sorghum was planted at the rate of 272,000 seeds per hectare. The planting dates for each year are shown in Table 1.

Table 1. Seasonal rainfall, irrigation for the 100% treatment, crop evapotranspiration (ET_c), planting and harvest dates for the 2012 to 2014 sorghum growing seasons.

	Seasonal Rainfall (mm)	Irrigation (mm)	ET _c (mm)	Planting Date	N application dates	Harvest Date
2012	421.8	50.8	335.7	6/20/12	7/11, 7/19	10/22-23/12
2013	364.8	38.1	291.7	7/10/13	7/26, 8/26	11/18-19/13
2014	357.3	12.7	313.3	6/18/14	6/30, 8/7	10/1-3/14

The Norfolk loamy sand has a water holding capacity of approximately 24.3 mm in the surface 0.30 m (Peele et al., 1970) (field capacity 8%, 12 kPa; wilting point 2.3%, 1500 kPa; sand/silt/clay 86%,10%, 4%; bulk density 1.3 g/cm³). A soil water potential (SWP) value of -30 kPa corresponds to approximately 50% depletion of the plant available water holding capacity. A 12.5 mm irrigation was initiated when SWP at the 0.30 m depth was below -30 kPa in the 100% irrigation plot with high N. Irrigations were applied on the following dates: 7/20/12, 7/27/12, 8/2/12, 8/6/12, 9/12/13, 9/16/13, 9/20/13, and 8/27/14. Soil water potentials were measured in all irrigation treatments for the high N rate using tensiometers at two depths (0.30 and 0.60 m). Measurements were recorded at least two times each week. The other irrigation treatments (0%, 33%, and 66%) received an application proportional to the 100% 12.5 mm

application. The seasonal evapotranspiration for the sorghum crop was found by calculating the daily reference evapotranspiration from an adjacent weather station using the ASCE standard for grass (Walter et al., 2000) and the dual-crop-coefficient method of Allen et al. (1998) (table 1).

The experimental design in 2012 was a split-plot with irrigation rate as main plots and N levels as subplots. The experimental design in 2013 and 2014 was a split-split-plot with irrigation rate as the main plots and N levels as subplots and cultivars as the sub-subplots. The plot size was approximately 9.1 m wide by 45° of travel for the 137 m center pivot with four replicates (32 plots in 2012 and 72 plots in 2013 and 2014).

FERTILIZER APPLICATIONS

All nitrogen fertilizer was applied via fertigation through the center-pivot system annually in two split applications. The first N application each year was to all plots at the rate of 85 kg N ha⁻¹. A second N application was applied at this rate to only the high N plots. Nitrogen was applied using the center-pivot irrigation system and injecting urea and ammonium nitrate (UAN) 30% into the incoming center pivot water stream. Nitrogen applications were applied with the minimal water application depths in order to minimize irrigation water applications to non-irrigated plots. For this experiment, all nitrogen was delivered with 1.8 mm irrigation depth operating at 100% duty cycle. At the end of the nitrogen application, the system was again run in non-plot area to purge the system of nitrogen. Phosphorus and K were uniformly applied in granular form across all plots each spring based on soil testing and recommendations of the Clemson University Extension Agricultural Service Laboratory. Fertilizer applied was 30 kg ha⁻¹ P₂O₅ and 50 kg ha⁻¹ K₂O in 2012, 30 kg ha⁻¹ P₂O₅ and 80 kg ha⁻¹ K₂O in 2013, and 25 kg ha⁻¹ P₂O₅ and 60 kg ha⁻¹ K₂O in 2014.

HARVEST

The grain sorghum was harvested when the grain moisture was below 20%. Grain sorghum yields were determined by weighing the grain harvested from a 6.1-m length of two rows near the center of each plot using an Almaco plot combine (Almaco, Nevada, Iowa). Whole plot samples were weighed and a sub-sample from each plot was collected and dried at 60° C for three days to determine grain moisture concentration. Grain sorghum yields were reported as dry grain yields. After yields and total water applied to each treatment were determined, the water use efficiency (WUE) was calculated by dividing the mean plot yield by the total water applied (irrigation + rainfall). The WUE values were reported in units of kg grain ha⁻¹ mm⁻¹ of water applied.

STATISTICAL ANALYSES

Yield and WUE data were statistically analyzed for the treatment effects and year using analysis of variance (ANOVA). Means were separated by calculating the least significant difference (LSD) (SAS version 9.4, Proc GLM, Statistical Analysis System, SAS Institute, Cary, N.C.). All significant differences were evaluated at the 0.05 level.

RESULTS AND DISCUSSION

The growing season rainfall totals for each year were lower than the long term average total of approximately 430 mm. However, in each year, the rainfall totals exceeded the calculated crop evapotranspiration (table 1). In 2012, irrigations were required to maintain SWP's greater than -30 kPa (at the 30 cm depth) during the early part of the growing season 30 to 50 DAP (growth stage 3, 8-leaf to stage 5, boot) and rainfall was adequate throughout the remainder of the growing season. In both 2013 and 2014, rainfall was generally adequate to maintain adequate SWP's except during the midpoint of the season from approximately 60 to 70 days after planting (stage 6, mid-bloom to stage 7, soft dough). During this time period, 3 irrigations in 2013 and one irrigation in 2014 were needed to maintain the SWP's above -30 kPa. The reduced rate irrigation during these time periods did have SWP values that were below -30 kPa levels, but after subsequent rainfalls, their SWP values increased and typically were above the -30 kPa threshold. Soil water potentials for the 60-cm depth followed similar trends to those of the 30-cm depth.

SORGHUM YIELD

In 2012, the overall mean grain sorghum yield was 2.8 Mg ha⁻¹. The mean treatment yields for the four irrigation and two nitrogen application rates are shown in table 2. An analysis of variance for the 2012 year indicated no significant differences in grain yield for irrigation application, nitrogen application rates, or the interactions between the irrigation and nitrogen rates. In 2013, the individual mean grain sorghum yield was 3.3 Mg ha⁻¹ while in 2014, the mean yield was 3.1 Mg ha⁻¹ (Table 3). In both 2013 and 2014, there were no significant differences in sorghum grain yields for the three irrigation or three nitrogen application rates. Additionally, we combined data from 2012-2014 for the Dekalb variety, fertilized at 85 and 170 kg N ha⁻¹ for the fully irrigated (100%) and non-irrigated treatments and reanalyzed the data for the entire 3-year study (Table 7). No significant differences among the irrigation or nitrogen treatments for the sorghum grain yields occurred.

Table 2. The 2012 mean sorghum grain yields and water use efficiencies for the four irrigation and two nitrogen treatments.

	Nitrogen Rate			Nitrogen Rate		
	85	170	Mean	85	170	Mean
	Yield (Mg ha ⁻¹)			Water Use Efficiency (kg ha ⁻¹ mm ⁻¹)		
Water						
0	3.0	2.8	2.9	6.4	6.0	6.1
33	2.8	2.9	2.9	6.0	6.1	6.0
66	2.4	2.6	2.5	5.0	5.6	5.2
100	3.3	2.8	3.1	7.0	6.0	6.5
Mean	2.9	2.8	2.8	6.1	5.9	6.0

Overall, our sorghum grain yields were below those reported in the literature for Kansas (~7 Mg ha⁻¹, Klocke et al., 2012) and for Texas (5 to 7 Mg ha⁻¹, O’Shaughnessy et al., 2012) where supplemental irrigation is often necessary for production. A study in a more humid region by Bruns (2015) in Mississippi reported grain sorghum yields of 5.2 to 5.3 Mg ha⁻¹. Yang et al. (2001), in south Texas, reported sorghum grain yields similar to ours with yields ranging from 2.3 to 4.7 Mg ha⁻¹. Our study yields may have been impacted due to late season bird damage and delayed harvest until the crop was dry enough to harvest with a plot combine.

Unlike other reported studies, we observed no increase in yield response due to increasing nitrogen applications. Abunyewa et al. (2017) reported a quadratic relationship of increasing grain sorghum yields with nitrogen fertilizer applications. Our study site had been in a 4-year highly fertilized bermudagrass production study (Stone et al., 2012) and a 1-year flax study in the previous 5 years, and the soil in this experiment may have had adequate holdover nitrogen to produce an adequate sorghum crop.

WATER USE EFFICIENCY

In 2012, the overall WUE was 6.0 kg ha⁻¹ mm⁻¹ of water received (rainfall + irrigation) and varied among the treatments from 5 to 7 kg ha⁻¹ mm⁻¹ (table 2). In 2013 and 2014, the overall WUE was 8.7 kg ha⁻¹ mm⁻¹ and varied from 7.1 to 10.8 kg ha⁻¹ mm⁻¹ (table 4). In both the 2012 and 2013-2014 studies, there were no significant differences in WUE between irrigation or nitrogen treatments. However, in the combined 2012-2014 dataset, there was a significant WUE difference for the year of the study, with the 2012 year having significantly lower WUE of 6.7 kg ha⁻¹ mm⁻¹ compared to the 2013 and 2014 WUE’s of 8.2 and 7.7 kg ha⁻¹/mm⁻¹, respectively (table 5). The 2012 WUE values were lower because of higher total seasonal rainfall. Our calculated WUE values for the grain sorghum were intermediate between

those published by O'Shaughnessy et al. (2012) which ranged from 4.5 for non-irrigated to 17 kg ha⁻¹ mm⁻¹ for an 80% irrigated study in Texas.

Table 3. Mean sorghum grain yields for the 2013 and 2014 variety, irrigation, and nitrogen treatments.

year	Variety	Nitrogen	Water			Overall Mean
			0	50	100	
			Yield (Mg ha ⁻¹)			
			Mean	Mean	Mean	Mean
2013	DeKalb	0	3.3	3.0	3.5	3.3
		85	2.8	3.3	3.3	3.1
		170	3.3	3.0	3.2	3.2
		Mean	3.1	3.1	3.4	3.2
	Pioneer	Nitrogen				
		0	3.2	3.5	3.4	3.4
		85	4.0	3.8	3.5	3.8
		170	3.4	3.1	3.5	3.3
		Mean	3.5	3.5	3.5	3.5
	2014	DeKalb	Nitrogen			
0			3.5	2.6	2.8	3.0
85			3.4	3.0	3.2	3.2
170			3.1	2.9	2.8	2.9
		Mean	3.3	2.8	2.9	3.0
Pioneer		Nitrogen				
		0	3.0	3.1	2.8	3.0
		85	3.5	3.1	3.6	3.4
		170	3.1	3.5	3.1	3.2
		Mean	3.2	3.2	3.2	3.2
	Overall Mean	3.3	3.2	3.2	3.2	

Table 4. Mean water use efficiencies for the 2013 and 2014 variety, irrigation, and nitrogen treatments.

year	Variety	Nitrogen	Water			Overall Mean		
			0	50	100			
			Water Use Efficiency (kg ha ⁻¹ mm ⁻¹)					
2013	DeKalb	0	9.1	7.9	8.8	8.6		
		85	7.6	8.6	8.3	8.2		
		170	9.0	7.9	8.0	8.3		
		Mean	8.6	8.1	8.4	8.3		
	Pioneer	Nitrogen	0	8.8	9.1	8.4	8.8	
		85	10.8	9.9	8.7	9.8		
		170	9.3	8.0	8.7	8.7		
		Mean	9.7	9.0	8.6	9.1		
	2014	DeKalb	Nitrogen	0	9.8	7.1	7.5	8.1
			85	9.6	8.2	8.5	8.8	
			170	8.7	7.9	7.7	8.1	
			Mean	9.4	7.7	7.9	8.3	
Pioneer		Nitrogen	0	8.5	8.5	7.6	8.2	
		85	9.8	8.5	9.8	9.4		
		170	8.8	9.6	8.3	8.9		
		Mean	9.0	8.9	2.6	2.3		
Overall Mean			9.2	8.4	8.4	8.7		

Table 5. Mean sorghum grain yields and water use efficiencies for the 2012-2014 common variety, irrigation, and nitrogen treatments.

year	Variety	Nitrogen	Yield (Mg ha ⁻¹)			Water Use Efficiency (kg ha ⁻¹ mm ⁻¹)			
			0	100	Mean	0	100	Mean	
2012	DeKalb	85	3.0	3.3	3.2	7.1	7.0	7.1	
		170	2.8	2.8	2.8	6.7	6.0	6.3	
		Mean	2.9	3.1	3.0	6.9	6.5	6.7	
		Nitrogen	85	2.8	3.3	3.1	7.6	8.3	7.9
2013	DeKalb	170	3.3	3.2	3.2	9.0	8.0	8.5	
		Mean	3.0	3.3	3.1	8.3	8.1	8.2	
		Nitrogen	85	3.4	3.2	3.3	9.6	8.5	9.0
		170	3.1	2.8	3.0	8.7	7.7	8.2	
2014	DeKalb	Mean	3.3	3.0	3.1	9.1	8.1	8.6	
		Overall Mean	3.0	3.1	3.1	8.0	7.5	7.7	

SUMMARY AND CONCLUSIONS

Grain sorghum was grown in 2012, 2013, and 2014 to investigate the potential for irrigation to increase yields in the humid SE US. Supplemental irrigation was required for 4, 3, and 1 irrigation events in 2012, 2013, and 2014 respectively, to maintain soil water potential above -30 kPa in the 100% treatments. However, these water applications did not increase grain sorghum yields. Additionally, we found no significant difference in grain yield for increasing nitrogen application. This lack of response to nitrogen applications may have been related to adequate supplies in the soil from previous crops. Our results are similar to previous work from the mid-South USA in that irrigation did not increase sorghum grain yields above those of rainfed and suggest that there would be little benefit for supplemental irrigation for sorghum production in the US eastern Coastal Plain.

REFERENCES

- Abunyewa, A.A., Ferguson, R.B., Wortmann, C.S., Mason, S. C. 2017. Grain sorghum nitrogen use as affected by planting practice and nitrogen rate. *Journal of Soil Science and Plant Nutrition* 17(1):155-166.
- Allen, R. G., Pereira, L.S., Smith, M., and Raes, D. 1998. Crop evapotranspiration. FAO Irrigation and Drainage Paper No. 56. Rome, Italy: Food and Agriculture Organization of the United Nations
- Assefa, Y. and Staggenborg, S. A. 2010. Grain Sorghum Yield with Hybrid advancement and Changes in Agronomic Practices from 1957 through 2008. *Agronomy Journal* 102(2):703-706.
- Bruns, H. A. 2015. Irrigation, seeding rates, and row type effects on grain sorghum in the midsouth. *Agronomy Journal*, 107(1), 9-12.
- Bordovsky, J. P., and Lyle, W. M. 1996. LEPA irrigation of grain sorghum with varying water supplies. *Transactions of the ASAE*, 39(6), 2033-2038
- Camp, C. R., Sadler, E. J., Evans, D. E., Usrey, L. J., and Omary, M. (1998). Modified center-pivot system for precision management of water and nutrients. *Appl. Eng. Agric.*, 14(1), 23-31. <http://dx.doi.org/10.13031/2013.19362>
- Camp, C.R., and Sadler, E. J. 2002. Irrigation, deep tillage, and nitrogen management for a corn-soybean rotation. *Transactions of the ASAE* 45(3):601-608.
- Hibberd, D. D. and Hall, B. D. 1990. The responses of maize and grain sorghum hybrids to nitrogen fertilizer in South East Queensland. *Australian Journal of Experimental Agriculture* 30:825-31.
- Klocke, N. L., Currie, R. S., Tomsicek, D. J., and Koehn, J. W. 2012. Sorghum yield response to deficit irrigation. *Transactions of the ASABE*, 55(3), 947-955.
- Murphy-Brown. 2012. 2012 Sorghum Program. http://mbgrain.com/wp-content/uploads/2012/03/MurphyBrown_SorghumProgram_Draftv3.pdf. Accessed 8/8/2017.
- Peele, T. C., Beale, O. W., and Lesesne, F. F. 1970. The physical properties of some South Carolina soils. Technical Bulletin 1037. South Carolina Agricultural Experiment Station, Clemson University, Clemson, SC.
- O'Shaughnessy, S. A., Evett, S. R., Colaizzi, P. D., & Howell, T. A. 2012. Grain sorghum response to irrigation scheduling with the time-temperature threshold method and deficit irrigation levels. *Transactions of the ASABE*, 55(2), 451-461.
- Rhodes, J. D. 1996. Salinity: Electrical conductivity and total dissolved solids. In: D. Sparks, editor, *Methods of soil analysis*. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI. P. 417-435.
- Sheridan, J. M., Knisel, W. G., Woody, T. K., & Asmussen, L. E. 1979. Seasonal variation in rainfall and rainfall-deficit periods in

- the southern coastal plain and flatwoods regions of Georgia. Bulletin 243. Athens, Ga.: University Georgia Agricultural Experiment Station.
- Stone, K.C., Bauer, P.J., Andrae, J., Busscher, W.J., Millen, J.A., Strickland E.E., and Evans, D.E. 2012. Irrigation and nitrogen impact on bermudagrass yield response in the southeastern Coastal Plain. *Transactions of the ASABE* 55(3):969-978.
- Swick, R.A. 2011. Global feed supply and demand. Recent Advances in Animal Nutrition Australia, University of New England, Armidale, Australia 18:1-8.
- USDA-NASS. 2017. USDA Quick Stats. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, DC. (<https://quickstats.nass.usda.gov/>) Accessed 8/8/2017.
- Walter, I. A., Allen, R. G., Elliott, R., Jensen, M. E., Itenfisu, D., Howell, T. A., Snyder, R., Brown, P., Echings, S., Spofford, T., Hattendorf, M., Cuenca, R. H., Wright, J. L., and Martin, D. 2000. ASCE's standardized reference evapotranspiration equation. In *Proc. 4th National Irrigation Symposium*, 209-215. R. G. Evans, B. L. Benham, and T. P. Trooien, eds. St. Joseph, Mich.: ASAE.
- Yang, C., Everitt, J. H., and Bradford, J. M. 2001. Comparisons of uniform and variable rate nitrogen and phosphorus fertilizer applications for grain sorghum. *Transactions of ASAE* 44(2):201-209.