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Irrigation, Seeding Rates, and Row Type Effects on Grain Sorghum in the Midsouth

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ABSTRACT

Grain sorghum [*Sorghum bicolor* (L.) Moench] is considered more drought tolerant than most other crops and may help reduce depletion of aquifers used by agriculture for irrigation. A study at Stoneville, MS, in 2012 and 2013 examined the effects of seeding rates (98,000, 148,000, 197,600, and 248,000 kernels ha^{-1}), row type (single- vs. twin-row) and furrow irrigation vs. no irrigation on yield and yield components of grain sorghum grown on a clay soil. Irrigation did not affect any of the yield components or grain yield in this experiment. Increased seeding rates did increase heads ha^{-1} (154,274, 181,682, 196,580, and 225,625) but resulted in less grain per head (46.5, 40.0, 37.2, and 33.3 g) and no difference in 1000 kernel weight, thus resulting in no difference in yields. Twin-row seedings produced more heads per ha (199,340) than single-row plantings (179,740) but smaller 1000 kernel weights (26.3 vs.27.4 g) and less grain per head (37.1 vs. 41.7 g) resulting in no difference in yield between row type. Furrow irrigation, twin-row planting, and seeding rates above 98,000 kernels ha^{-1} did not increase grain sorghum yields in this experiment.

Grain sorghum is not a major crop in the lower Mississippi River Valley but was grown on about 133,000 ha in Arkansas, Louisiana, and Mississippi combined in 2013 (USDA-NASS, 2014). A major assumption about the crop is that it is more tolerant of drought stress than other species produced in the area such as cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), rice (*Oryza sativa* L.), and soybean [*Glycine max* (L.) Merr.]. All four of the latter frequently require supplemental irrigation to produce profitable yields. In Mississippi, of the 1.2 million ha of crop land in the Delta nearly 1.0 million ha are irrigated (Buckner, 2013). This intense amount of irrigation, combined with the heavy use of subsurface water by the aquaculture industry in the Mississippi Delta, is unsustainable and will likely deplete the Mississippi Alluvia Aquifer below a useable level within 10 to 20 yr (Pennington, 2009). Rice which is flooded during production, has the highest demand for irrigation of any crop grown in the region with a requirement estimated to be as much as 911.0 ha mm of water. Cotton is estimated to require 176 ha mm, while both soybean and corn are estimated to require 265.0 ha mm (Powers, 2007). Total irrigation costs per hectare for most crops grown in the lower Mississippi River Valley range from U.S.$252.00 to $320.00 ha^{-1} for flood, furrow, or center pivot. Approximately 50 to 66% of those costs are variable, based on fuel prices, labor, supplies, and the number of irrigations applied (Mississippi State University, 2013). A change to alternative crops that consume less water, combined with improved water management practices may reduce or halt the mining of this aquifer and retain the region's crop production potential.

Grain sorghum offers a partial solution to aquifer depletion by generally requiring less water to mature a harvestable crop. Rees and Irmak (2012) reported that under rainfed conditions in Nebraska, grain sorghum produced approximately 30 and 93 kg ha^{-1} more yield per 10 ha mm of water than corn and soybean, respectively. Tacker et al. (2004), reported that grain sorghum in Arkansas required between 400 and 600 ha mm total water through the growing season with peak demand being at Growth Stage 4 as described by Vanderlip and Reeves (1972). They also stated that 250 ha mm of irrigation was needed to assure a good yield.

Most row crop production in the lower Mississippi River Valley is done on raised beds to facilitate furrow irrigation. Planting row crops on raised beds in twin-row configurations has become a popular production technique in the region, especially with corn and soybean. Bruns (2011) reported that by 2010 nearly 80% of soybean land area in the Mississippi Delta was being produced in twin-row configurations. Because the same planters are used to seed corn, soybean, and cotton crops and cotton harvesters are designed for a 102-cm row width, this row spacing has been adopted as the standard for all row crop production in the area.

Research on grain sorghum production systems in the mid-South is limited. Heatherly et al. (1990) compared the effects of irrigation and crop rotation on corn, soybean, and grain sorghum and found grain sorghum had the smallest increase in economic return due to irrigation and the most stable non-irrigated yield of the crops examined. Wesley et al. (2001)

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Table 1. Rainfall, irrigation, and temperature events during the 2012 and 2013 grain sorghum growing seasons at Stoneville, MS.†

2012		2013	
Rainfall	ha mm	Rainfall	ha mm
	mm		mm
15 May‡	**25.4**	10–11 May	46.0
24 May‡	**25.4**	17 May	21.8
31 May	29.5	22 May	26.0
5 June	57.4	30 May–2 June	41.7
10–13 June	104.9	6–7 June	50.0
22 June‡	**25.4**	***18 June‡***	**25.4**
3 July	**25.4**	***24 June‡***	**25.4**
9–16 July	114.6	***1 July‡***	**25.4**
27 July‡	**25.4**	***8 July‡***	**25.4**
Total	433.4	12 July	12.4
		15–16 July	11.4
		19 July	7.1
		27 July	14.2
		8 Aug.‡	**25.4**
		Total	357.6

† Days ≥ 37.0 C° (2012; 29 June, 21 July, 31 July) (2013; 8 Aug.).

‡ Irrigation event equivalent to 25.4 mm of rainfall.

reported that crop rotation of grain sorghum with either cotton or soybean prevented a yield decline observed with continuous grain sorghum, which they concluded was due mostly to increasing levels of johnsongrass (*S. halepense* L.) infestation in the monocrop system. They also reported no yield increase in grain sorghum was observed between conventional tillage practices and deep tillage, which included annual subsoiling to a depth of 0.4 m each autumn.

The lack of recent published data on grain sorghum production in the lower Mississippi River Valley and current interest in reducing irrigation demands on the Alluvial Aquifer led to development of this experiment. The objectives of this study were to compare the influence of furrow irrigation, varying seeding rates, and twin-row vs. single-row planting configurations on yield and yield components of grain sorghum on a clay soil commonly used for its production in the mid-South.

MATERIALS AND METHODS

The experiment was conducted during the 2012 and 2013 growing seasons at the USDA-ARS, Crop Production Systems Research Farm located 2 km north of Elizabeth, MS. The soil was a Tunica clay soil (clayey over loamy, montmorillonitic, non-acid, thermic Vertic Halaquept) The previous crop before initiating the experiment was cotton. The experimental design was a split-plot of a randomized complete block replicated twice. Whole plots were either furrow irrigated or non-irrigated treatments. Within each whole plot were a factorial arrangement of treatments consisting of one of four seeding rates (98,000; 148,000; 197,600; or 248,000 kernels ha^{-1}) and planted either in a single-row configuration spaced 102 cm apart or a twin-row configuration with a pair of rows spaced 25 cm apart and centered 102 cm between pairs. Each experimental unit was eight single-rows or pairs of rows 12 m long and replicated twice within each whole plot. Irrigated and non-irrigated whole plots were separated by a non-irrigated buffer of four single rows seeded at 98,000 kernels ha^{-1}.

Field preparation began each autumn before seeding by being disked level. Then in late winter 40 cm high ridges, spaced 102 cm apart were formed. Before seeding the ridges were harrowed to form a 40 cm wide seedbed in which to plant. Single-row plots were seeded using a John Deere model 7100 vacuum planter (John Deere, Inc., Moline, IL) and twin-row seedings were accomplished using a Monosem NG-3 vacuum planter (Monosem Inc., Edwardsville, KS). The hybrid used in this experiment was Pioneer 83P17. Seeding occurred on 10 May 2012 and 8 May 2013.

Soil tests before initiating the experiment showed no need for supplemental P or K fertilizer. Nitrogen fertilizer in the form of a urea/NH_4NO_3 solution at a rate of 220 kg N ha^{-1} was applied 14 d before seeding in 2012 and at Growth Stage 2 in 2013. Weed control, both years was accomplished with the pre-plant application of Lexar (Syngenta Crop Protection, Inc.; Greensboro, NC) (S-metolachlor 19%, atrazine 18.6%, atrazine related compounds 0.39%, and mesotrione 2.44%) at 7 L ha^{-1} 28 d before seeding. Sorghum midge [*Contrainia sorghicola* (Coquillett)] was controlled both years by two applications of insecticides at labeled rates 7 d apart, beginning at early anthesis (growth stage 6). In 2012 the first insecticide applied was Lambda cyhalothrin (Syngenta Crop Protection Inc., Greensboro, NC), followed by an application of Zeta-Cypermethrin (FMC, Corp., Philadelphia, PA). In 2013 two applications of Gamma-cyhalothrin (Loveland Products, Inc., Greeley, CO) were made.

Rainfall and irrigation events that occurred during the experiment are presented in Table 1 along with days of temperatures above 37°C. In 2012 furrow irrigation at a rate of 25.4 ha mm was applied to the entire experiment 5 d after seeding to facilitate germination and prevent losing the study due to drought. A second irrigation was applied 9 d later (growth stage 1) only to the plots designated for irrigation throughout the season. Successive irrigations were applied to those plots again on 22 June at growth stage 5, at growth stage 6 on 3 July, and growth stage 8 on 27 July, just before physiological maturity (growth stage 9). In 2013 irrigation was not needed until 18 June, at growth stage 5 and was applied every 7 d until 12 July, when light showers began occurring over the next 14 d relieving some drought stress. A final irrigation was applied 6 August, at growth stage 8. Because available irrigation equipment was shared among other research, scheduling applications for this experiment based on available soil moisture levels determined by instrumentation was not possible.

In 2012, an application of Defol5 (Sodium chlorate) (Drexel Chemical Co., Memphis, TN) at 5.5 kg a.i. ha^{-1} was applied at physiological maturity to facilitate grain dry down. In 2013, this was accomplished with an application of glyphosate at 02.0% v:v (Monsanto, St. Louis, MO) 10 d before harvest. Before harvest the mean number of heads per hectare was determined by counting the number of heads in a randomly selected meter of row within the center two middle rows of each experimental unit. A random five-head sample was then harvested from either row two or seven of each experimental unit to be later threshed, the total grain weighed along with a 1000 kernel sample and those data used to estimate the kernels per head. Grain was harvested from the four center rows of each plot using a Kincaid 8XP plot combine equipped with a Harvest Master GrainGage weighing, bulk density, and seed moisture system (Juniper Systems, Inc., Logan, UT). Data were later analyzed using PROC MIXED of the Statistical Analysis System 9.4 (SAS Institute, Cary, NC). Means separation was

Table 2. Type three tests of fixed and covariance parameter estimates of an irrigated and non-irrigated grain sorghum × row type × seeding rate experiment conducted at Stoneville, MS, on a Tunica clay in 2012 and 2013.

Source	df	Heads ha^{-1}	1000 kernel wt.	Kernels head^{-1}	Yield
		$P > F$	$P > F$	$P > F$	$P > F$
			g		kg ha^{-1}
Irrigation	1	0.5422	0.0562	0.0561	0.4762
Seeding rate	3	<0.001	0.8368	<0.0001	0.7924
Row type	1	0.0005	0.0237	0.0854	0.5723
Year	1	0.2801	0.0341	0.0201	0.0033
Irrigation × row type	1	0.8696	0.5181	0.7437	0.9595
Row type × seeding rate	3	0.3913	0.5548	0.7964	0.5525
Irrigation × year	1	0.9781	0.0173	0.999	0.0711
Seeding rate × year	3	0.0073	0.6142	<0.001	0.4273
Irrigation × seeding rate	3	0.6403	0.7543	0.3585	0.6326
Row type × year	1	0.4541	0.881	0.7913	0.5624
Irrigation × seeding rate × year	3	0.8931	0.9271	0.5168	0.4564
Irrigation × row type × seeding rate	3	0.8345	0.2263	0.276	0.4043
Irrigation × row type × year	1	0.9615	0.8061	0.9528	0.5583
Row type × seeding rate × year	3	0.7636	0.4028	0.8915	0.9975
Irrigation × row type × seeding rate × year	3	0.9879	0.1064	0.0978	0.142
Covariance parameter estimates		Estimate	Estimate	Estimate	Estimate
Whole reps (years)		0	0	0	0
Whole reps × irrigation (years)		0	0	0	0
Subreps (whole reps × irrigation × years)		0	0.0412	4434.43	16,514
Whole reps × row type × seeding rate (irrigation × year)		8,449,061	0	0	0

preformed using lsmeans ($\alpha = 0.05$). The analyses of variance are presented in Table 1. Random effects were: whole reps(year), whole reps × irrigation(year) subreps(whole reps × irrigation × year), whole reps × seeding rates × row type (year × irrigation).

RESULTS AND DISCUSSION

Irrigation had little impact on dependent variables measured in this experiment (Table 2). The 1000 kernel weights of the irrigated plots averaged 2.1 g less in 2013 (25.4 g) than irrigated plots in 2012 (27.5 g). Other interactions included with irrigation failed to be statistically significant. Except for the first irrigation applied to the entire field in 2012, as necessitated by the uncommon early drought, supplemental irrigation appears to have had no positive effect on grain sorghum production and would likely be an unnecessary expense in the Midsouth under normal seasonal conditions.

Heat stress was likely not an issue in this experiment because there were only 2 d with temperatures at or above 37°C in 2012 and only one, late in the season in 2013. Grain sorghum is also purported to be more tolerant of high temperatures than most other crops.

Increasing seeding rates tended to increase the number of heads per hectare while decreasing grain yield per head. Significant ($P \leq 0.05$) increases in heads per hectare as seeding rates increased, occurred among all seedings in 2012. However, in 2013, no significant differences in heads per hectare are was noted between the seeding rates of 148,000 and 198,000 kernels ha^{-1} while the heads per hectare of the other two differed from all others. The number of heads per hectare at the seeding rate of 99,000 kernels was significantly ($P \leq 0.05$) greater in 2013 than 2012. No other differences among seeding rates between years though were noted for any of the remaining data.

The weight of grain per head was observed to decline as seeding rates increased (Table 3). No significant differences in 1000 kernel weights were observed among seeding rates nor were significant interactions for these data noted. As a result of these

Table 3. Yield and yield components of irrigated and non-irrigated grain sorghum grown on a Tunica clay with different seeding rates.†

Seeding rate	Heads ha^{-1}‡ 2012	Heads ha^{-1}‡ 2013	Heads ha^{-1}‡ Mean	Head wt.§	1000 kernel wt.¶	Kernels§ per head	Yield¶
1000 kernels ha^{-1}				g	g		kg ha^{-1}
99	137,500d	171,048c#	154,274d	46.5a	27.2	1728a	5229.8
148	175,269c	188,095b	181,682c	40.0b	26.9	1518b	5167.3
198	203,125b	190,034b	196,580b	37.2bc	26.7	1403bc	5321.2
247	231,250a	220,000a	225,625a	33.3c	26.6	1267c	5331.4

† Means of irrigated and non-irrigated treatments, seeded either in single row 102-cm plantings and 15-cm twin-row plantings spaced 102 cm apart, with two whole replications and two subreplications.

‡ Means followed by the same letter within a column are not significantly different by lsmeans ($\alpha = 0.05$).

§ Means of 2 yr (2012 and 2013). Means followed by the same letter or letters are not significantly different by lsmeans ($\alpha = 0.05$).

¶ Means of 2 yr (2012 and 2013). Means are not significantly different.

Mean for 2013 are greater than 2012.

sets of data, the estimated kernels per head declined with increasing seeding rates due to the decline in grain produced per head.

Grain yield in this experiment was unaffected by seeding rate, irrigation, or row type (Table 2). The overall mean yields across years was significantly ($P \leq 0.05$) less in 2012 (4560.0 kg ha^{-1}) than 2013 (5094.3 kg ha^{-1}). However, no interactions with year and any other independent variable were statistically significant for grain yields. The lack of differences in yields across seeding rates (Table 3) was due to the decline in kernels per head and a lack of change in 1000 kernel weights as seeding rates increase. Grain sorghum has long been known for its ability to stabilize his yield through compensatory effects among its various yield components (Bartel et al., 1935; Bruns and Horrocks, 1984). The increase in heads per hectare due to increases in seeding rate would have increased intra-row competition between plants for available nutrients and sunlight. This would have resulted in fewer kernels per head being produced. However, the increase in heads per hectare with increased seeding rates resulted in stabilizing grain yield across seeding rates.

Twin-row seedings produced more heads per hectare (199,340) than single-row seedings (179, 740) but less grain per head (37.1 vs. 41.7 g) and smaller kernels as evidenced by 1000 kernel weights (26.3 vs. 27.4 g). These data resulted in a lack of significant differences in grain yield between row types. This further demonstrates grain sorghum's ability for compensation among yield components that results in stabilizing yield. No statistically significant interactions between row type and other independent variables were noted.

CONCLUSIONS

Grain yields in this experiment were generally lower than those reported in cultivar trials conducted in neighboring states (Allen and Johnson, 2010; Bond et al., 2013; Mascagni et al., 2012). Further research into seeding rates and fertility needs would be useful. Based on these data seeding rates more than 98,000 kernels ha^{-1} are unnecessary and although grain sorghum seed is comparatively less expensive per hectare than corn, cotton, or soybean, a much lower seeding rate may prove to yield as much grain as the low rate in this study due to the crop's ability to tiller and compensate with changes in head size and kernel weight. This experiment does demonstrate that irrigation is generally unnecessary to produce a grain sorghum crop in the Lower Mississippi River Valley thus potentially helping reduce the demand for water from the Mississippi Alluvia Aquifer for crop production purposes.

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