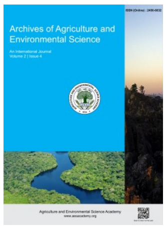
Archives of Agriculture and Environmental Science 3(2): 157-162 (2018)
https://doi.org/10.26832/24566632.2018.030209

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: www.aesacademy.org



ORIGINAL RESEARCH ARTICLE

CrossMark

Grain sorghum (*Sorghum bicolor* L. Moench) fails to consistently respond to N-fertilizer when grown on a Tunica clay soil in the lower Mississippi River Valley, USA

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ARTICLE HISTORY

Received: 14 April 2018
Revised received: 22 April 2018
Accepted: 04 May 2018

Keywords

Irrigation
Sorghum (*Sorghum bicolor*)
Tunica clay soil
Yield
Yield components

ABSTRACT

Information on producing grain sorghum (*Sorghum bicolor* L. Moench) on clay soils found in the Mississippi Delta and similar regions is comparatively limited to what is known for the crop in other environments, especially regarding nitrogen fertility. A study conducted in 2014 and 2015 on a Tunica clay soil (clayey over loamy, montmorillonitic, non-acid, thermic, Vertic Halaquept) examined the effects of three N-fertilizer rates (0.0, 112.0, and 224.0 kg N ha^{-1}) on yield and yield components of six commercially available hybrids. The 2014 seeding did not require irrigation while three irrigations were applied in 2015. No yield differences in hybrids or N-fertility treatments were observed in 2014 likely due to waterlogged soil, resulting in denitrification, but added N did increase yields in 2015. No consistent differences in yield or yield components occurred between hybrids either year. Yields in 2014 and at 0.0 or 112.0 kg ha^{-1} added N-fertilizer in 2015 were sub-standard to regional variety trial data. Rates of N-fertilizer of at least 224.0 kg N ha^{-1} appear necessary for grain sorghum grown on clay soils in the humid sub-tropics.

Citation of this article: Bruns, H.A. (2018). Grain sorghum (*Sorghum bicolor* L. Moench) fails to consistently respond to N-fertilizer when grown on a Tunica clay soil in the lower Mississippi River Valley, USA. *Archives of Agriculture and Environmental Science*, 3(2): 157 -162, https://dx.doi.org/10.26832/24566632.2018.030209

INTRODUCTION

Since 2000, grain sorghum production increased from approximately 50,220 to 252,858 ha in 2016 for the combined lower Mississippi River Valley states of Arkansas, Louisiana, and Mississippi (USDA-NASS, 2016). Though not considered a major crop for the region, the concentration of this production exceeds most areas in the United States except for the West Central and Southern Great Plains. Despite recent invasion by the sugarcane aphid (*Melanaphis saccharia*), the crop continues to retain interest for rotational purposes and as a drought tolerant option for limited or non-irrigated cropping systems.

Extensive irrigation from the Mississippi Alluvial Aquafer, the primary water source for agricultural and municipal use for much of the Mississippi Delta, is depleting this water resource at unattainable rates (Pennington, 2009). Bruns (2015) recently reported that furrow irrigation of grain sorghum on a clay soil in the Mississippi Delta did not improve yields over non-irrigated plots. This lack of difference was due in part to the species' ability to compensate among the various yield components to stabilize seed production. These data supported previous work by Heatherly *et al.* (1990) and Wesley *et al.* (2001) and Ottman and Olsen (2009). These data also supported the premise of grain sorghum as a potential partial solution to reducing irrigation demands on limited water resources.

Grain sorghum, as with most all other cereals, requires ample amounts of N nutrition to produce a profitable seed yield. Blum and Feigenbaum (1969) reported that grain sorghum seed yields were affected by N-fertility due to changes in panicle weight and 1000 kernel weight. Panicles per hectare were not found to influence yield in their study due to a high seeding rate that did not encourage tillering. Langer (1966) had earlier stated that N-nutrition influenced tillering in all cereals. Later, Roy and Wright (1973) found that whole plant dry matter, grain yield, and kernel

-N increased by 26.0, 47.6 and 14.5% respectively with the addition of 56.1 kg N ha^{-1} as opposed to no added N-fertilizer and that at 112.2 kg N ha^{-1} an additional increase of 9.0, 8.8 and 10.9% respectively in yield, above the original 56.1 kg N ha^{-1} was observed. More recently research in the Great Plains by Mahama *et al.* (2014) showed yield increases of several hybrids and inbred grain sorghums of 13 to 48% above a 0.0 kg N ha^{-1} control treatment with applied N-fertility rates of 40.8 and 81.6 kg N ha^{-1} respective. Espinoza (2004) stated that a grain sorghum yield of 6725 kg ha^{-1} will remove nearly 101 kg N ha^{-1}. The recommended rate of N-fertilization in Arkansas is 122.4 kg N ha^{-1} for irrigated crops and 114.2 kg N ha^{-1} for non-irrigated (Bond *et al.*, 2015). Information from Arizona recommends that a 6120 kg ha^{-1} yield of grain sorghum will require about 150.0 lbs. N A^{-1} (MSUES, 2016). In Texas, as a general rule 2.0 kg N ha^{-1} of N-fertilizer is required for every 153 kg ha^{-1} yield goal in grain (Stichler *et al.*, 1997). It is also recommend that N-fertilizer be applied within 20 d of emergence to avoid root pruning in the application process that will impede soil water and nutrient uptake by the plant.

Nitrogen fertility recommendations for grain sorghum production in Mississippi are based mainly on previously mentioned information from Arkansas (Bond *et al.*, 2015). The effects of N-fertility on grain sorghum grown on the heavy textured clay soils of the lower Mississippi River Valley are limited. These soils are often relegated to produce soybean (*Glycine max* L. Merr.) and rice (*Oryza sativa* L.) while lighter textured soils such as clay loams, loams and sandy loams are usually reserved for cotton (*Gossypium hitduyum* L.) and corn (*Zea mays* L.) production. This experiment was conducted to determine the effects of varying N-fertility rates on the yield and yield components of several grain sorghum hybrids grown on a Tunic clay soil that is common to the Mississippi Delta and similar in physical and chemical properties to other clay soils in humid subtropical river deltas.

MATERIALS AND METHODS

The experiment was conducted during the 2014 and 2015 growing seasons on a Tuncia clay site one mile north of Elizabeth, MS on land leased by the Crop Production Systems Research Unit of the USDA-ARS Jamie Whitten Delta States Research Center in Stoneville, MS. Tunica clay is one of several clay soils found in the lower Mississippi River Valley with a clay content of between 35 to 75% most of which is Montmorillinite. Results from a soil test of the site, conducted by Mississippi State University Soil Testing Laboratory, Mississippi State, MS were as follows; pH=6.5, P=94.8 kg ha^{-1}, K=451.9 kg ha^{-1}, Ca=5637.5 kg ha^{-1}, Mg=1060.8 kg ha^{-1}, S=145.9 kg ha^{-1}, Zn=2.0 kg ha^{-1}, and a CEC= 20.7 meq 100 g^{-1}. No deficiencies in any of the macro-nutrients were noted and pre-plant applications of P, K, Ca, or Mg were not recommended. Organic matter content for the site was $\leq$1.0%. Tests for available soil N are not conducted by the laboratory because N is considered ephemeral under the environmental conditions of the Lower Mississippi River Valley. By spring, seldom will any previously applied N be present because to the humid sub-tropical environment that allows volatilization during the winter due of waterlogged soils, leaching, and/or continuous biological de-nitrification as a result of soil temperatures never getting below 40.0° F (Crouse *et al.*, 2016; MSUES, 2016).

The experimental design used for the study was a split-plot of a randomized complete block replicated four times. Whole plots were one of three N-fertility treatments 0.0, 112.0 or 224.0 kg N ha^{-1} randomly assigned in each block and applied in the form of a urea: NH_4NO_3 solution. In 2014 N-fertilizer was applied 7 d prior to planting. The original seeding was made10 d earlier and destroyed by glyphosate drift 1 hr after N application. In 2015 N application was made11 d after seeding. Split-plots were one of six hybrid grain sorghum cultivars: Pioneer[1] brand 83P17 (Pioneer-DuPont, Johnston, IA), Dekalb brand[1] DKS5403 (Monsanto, St. Louis, MO), Asgrow A571 (Monsanto, St. Louis, MO), Sorghum Producers brand[1], KS735, NK6638, or SP6929 (Chromatin, Lubbock, TX) randomly assigned within each whole plot. Individual experimental units were eight 102 cm spaced rows, 12 m long.

Site preparation for planting began by disking the land level each autumn followed by the forming of 60.8 cm high ridges, spaced 102 cm apart in late winter. The previous crop on the site prior to initiating the experiment had been corn. Prior to planting the ridges were harrowed to form a 38.1 cm wide seedbed. A seeding rate of 98,800 kernels ha^{-1} was made using a John Deere[1] model 7100 vacuum planter (John Deere, Inc., Moline IL) and occurred on 27 May, 2014 and 4 June, 2015.

In 2014 irrigation was unnecessary due to frequent rainfall throughout the season to support crop growth to maturity, but in 2015 three irrigations were applied to reduce drought stress, beginning 5 d after seeding and on 15 July and 4 August (Table 1). Irrigation was accomplished using a furrow system with each irrigation event applying approximately 22.5 mm ha of water. Weather data were acquired at an official weather reporting station that was approximately 1.6 km from the experimental site and managed by Mississippi State University's Delta Research and Extension Center at Stoneville, MS.

Both years, weed control, was achieved with a pre-plant application of Lexar[1] (Syngenta Crop Protection, Inc.; Greensboro, NC) (S-metolachlor 19%, atrazine 18.6%, atrazine related compounds 0.39%, and mesotrione 2.44%) at 7.0 L ha^{-1} 28 d prior to seeding followed by a 14 d post emergence application of 0.9 kg ha^{-1} atrazine. Control of sorghum midge (*Contrainia sorghicola* (Coquillett) both years was accomplished by two applications of Gamma-cyhalothrin[1] (Loveland Products, Inc.; Greeley, CO) at labeled rates 7 d apart, beginning at the onset of anthesis (growth stage 6). Sugarcane aphid was controlled with applications of sulfoxaflor[-1], (Dow AgroSciences Indianapolis, IN) applied at labeled rates beginning at growth stage 7 and again 14 d later.

Upon reaching physiological maturity (Growth Stage 9) (Vanderlip and Reeves, 1972), a 0.15% v:v solution of glyphosate herbicide was applied 8 September, 2014 and 2 September, 2015 to kill the plants in preparation for harvest 14 d later. Prior to harvest the mean heads ha^{-1} were determined by counting the grain baring heads of a 1 m length of row mid-way of each sub-plot. A sample of five randomly selected heads were then harvested from either rows two or seven from each sub-plot, dried at 70° C for 48 h to be later used for determining mean grain weight per head, mean 1000 kernel weight and calculate the kernels per head. Total grain yield and relative moisture content were determined by harvesting the four center rows of each sub-plot with a Kincaid[1] 8XP combine (Kincaid Equipment Heston, KS), equipped with a Juniper[1] Harvest Master (Juniper Systems, Logan, UT) weigh system. All grain yields were later adjusted to a 110 g kg^{-1} moisture level before data analysis.

Data were analyzed using the PROC MIXED procedure of the Statistical Analysis System 9.4 (SAS Institute, Cary, NC). Means separation was performed using $lsd_{0.05}$. The analyses of variance are presented in Table 2.

RESULTS AND DISCUSSION

Large differences in rainfall between the two growing seasons were recorded during this experiment (444.5 mm for 2014 vs. 136.1 mm + 76.2 mm irrigations in 2015) (Table 1). In this study added N-fertilizer had no effect on grain yield of among hybrids across all levels of applied N-fertilizer in 2014, the year in which no supplemental irrigations were applied (Table 3). During that year there were five periods of heavy rain that caused water logging of soil for extended periods of several days (28 May to 3 June; 7 to12 June; 24 to 29 June; and 15 to 21 July. All of these rain events were observed to have left water standing in the furrows for ≥ 24 hrs. During June the soil was saturated and/or waterlogged most of the month resulting in anaerobic conditions within the root zone. There is strong likelihood that the applied N fertilizer in 2014 was prematurely lost through de-nitrification and became unavailable during reproductive growth thus having little impact on grain yield (Schwenke *et al*., 2014).

Grain yields in this experiment were generally sub-standard compared to variety trials from surrounding states (Bond *et al*., 2015; Fromme, 2015). However, in 2015 at 224.0 kg N ha^{-1} yields were similar to those previously reported for a study conducted at the same location and receiving the same amount of N fertilizer (Bruns, 2015) (Table 3). In 2015 grain yields in the 0.0 kg N ha^{-1} treatment were lower than 2014 for all hybrids except KS735 and NK6638. The dryer soil conditions of 2015 may have led to some drought stress, particularly at the 0.0 kg N ha^{-1} treatment, that did not occur in 2014. Among hybrids in the 0.0 kg N ha^{-1} treatment in 2015 KS735 and NK6638 had greater yields that the other four. A similar observation was made for the 112.0 kg N ha^{-1} treatment that year. The hybrids KS735 and NK6638 had superior grain yield than all other hybrids at this N -fertility level except SP6929 which had a greater yield than DKS5403 and A571. No other significant differences were observed among hybrids for this N-fertility treatment in 2015. Comparison of the 112.0 kg N ha^{-1} treatment between years found that only A571 and DKS5403 did not yield more grain in 2015 than in 2014. The 224.0 kg N ha^{-1} fertility rate resulted in three hybrids having superior grain yields to the other three in the experiment in 2015. The hybrids KS735, NK6638 and 83P17 all had comparable yields >4000.0 kg ha^{-1}. Yields for the remaining hybrids SP6926 (3811 kg ha^{-1}) ≥ DKS5403 (3163 kg ha^{-1}) ≥ A571 (2889 kg ha^{-1}).

Observations on individual yield components showed that the plots receiving N-fertilizer produced more heads per m^2 especially in 2014 (Table 4). In 2014 each additional 112.0 kg N ha^{-1} of fertilizer resulted in a significant (P≤0.05) increase in heads per m^2. In 2015 both levels of added N-fertilizer produced a mean of one more head m^{-2} than the 0.0 lbs N A^{-1} but no difference between 112.0 and 224.0 kg N ha^{-1} in heads per m^2 were noted. These observations are supported by those of Langer (1966), regarding N-fertility and tillering as previously discussed. The greater number of heads m^{-2} observed in the fertilized plots in 2014 indicate that denitrification, as previously discussed, was not complete in the early part of that growing season and that the added N along with cooler mean maximum temperature (30.0° C (2014) vs 33.0° C (2015) (MSUES, 2018) encouraged tillering. Barber and Trostle (2007) stated that the production of lateral tillers in grain sorghum increases with cooler temperatures and Gerik and Neely (1987) found that grain baring tiller production ceased about growth stage 3 (10 leaves on the main culm). The warmer mean maximum temperature encountered 28 d post seeding in 2015 (33.0°C) is likely responsible for there being no difference in heads per m^2 of the fertilized treatments in 2015.

Mean 1000 kernel weights were greater in 2015 (21.3 g) than 2014 (18.4 g), the hybrid x N-fertilizer rate interaction was statistically significant (P≤0.05). However, no trends of inferiority or superiority in 1000 kernel weight for any hybrid or group of hybrids across the different levels of N-fertilizer rates were evident (Table 5). The interactions of year × hybrid and year × N-fertility for kernels $head^{-1}$ were statistically significant (P≤0.10) but only year × N-fertility interaction demonstrated any discernable trend. No consistent trend of any hybrid or hybrids being superior or inferior in kernels $head^{-1}$ was evident. However, in 2015 the 224.0 kg N ha^{-1} treatment produced more kernels $head^{-1}$ than the 0.0 kg N ha^{-1} control for the same year and was superior in kernels $head^{-1}$ to the 224.0 kg N ha^{-1} treatment in 2014 (Table 6).

Mean seed yield per head in 2014 was greater for the 0.0 kg N ha^{-1} treatment than for either of the two N-fertilized treatments (Table 7). The increased heads m^{-2} of the fertilized treatments of 2014 combined with the lack of greater grain yields for those treatments that year, over the 0,0 kg N ha^{-1} plots, would lead one to expect less grain yield per head for the fertilized plots. No differences seed yield $head^1$ were observed among N-fertility treatments in 2015. However, both N-fertilized treatments did produce more grain in 2015 than their comparable treatments in 2014. Seed yield per head among hybrids across the two growing seasons showed no consistency with one or more hybrids being either inferior or superior in yield per head (Table 8). Data from this study along with the previously reported experiment (Bruns, 2015) does point to a need of applying at least 224.0 kg. N ha^{-1} supplemental fertilizer, especially if the crop is to be irrigated. These findings are similar to those reported by Roy and Wright (1973) and Mahama *et al.* (2014).

Table 1. Precipitation and irrigation events during the growing seasons at a grain sorghum hybrid x N-fertility treatments experiment conducted near Elizabeth, MS in 2014 and 2015 (MSUES, 2018).

2014	Precipitation (mm)	2015	Precipitation (mm)
5/28-6/3	113.5	9-Jun†	25.4
6/7-6/12	65.5	3/14-6/15	14.5
6/24-6/29	68.6	6/25-7/1	49.8
7/10-7/11	30.7	7/4-7/6	51.8
7/15-7/21	90.7	15-Jul†	25.4
7/31-8/2	6.1	26-Jul	7.1
8/9-8/12	38.4	4-Aug†	25.4
8/30-9/1	31.0	17-Aug	13.0
Total	444.5	Total	212.4

†Signifies and irrigation event.

Table 2. Type three tests of fixed and covariance parameter estimates of grain sorghum hybrid x N-fertility treatments experiment conducted near Elizabeth, MS in 2014 and 2015.

		Yield	Heads m^{-2}	Yield per head	1000 Kernel wt.	Kernels/head
		kg ha^{-1}		g	g	
Source	df	P>F	P>F	P>F	P>F	P>F
Year	1	0.2560	0.0257	0.0454	<0.0065	0.3357
N	2	0.0295	0.0013	0.0621	<0.0001	0.4559
Hybrid	5	<0.0001	0.0617	0.0009	0.0025	0.1375
N × Hybrid	10	0.3195	0.9375	0.1663	0.0854	0.5288
Year × N	2	0.0188	0.0502	0.0032	0.1389	0.1023
Year × Hybrid	5	<0.0001	0.1216	<0.0001	0.0283	0.0002
Year × N × Hybrid	10	0.0057	0.6027	0.2159	0.3289	0.0700
Covariance parameter estimates						
Rep (Year)		15332	0.2716	14.1737	0.09369	33613
Rep × N (Year)		157215	0.1173	0	0	1338.86
Residual		232400	3.3981	112.16	7.7988	303831

Table 3. Grain sorghum yields (kg grain per ha at 11.0% H_2O) of six hybrids grown with three levels of supplemental N fertilizer over two years on a Tunica clay soil near Elizabeth, MS.

Hybrid	0.0 kg N ha^{-1}		112 kg N ha^{-1}		224 kg N ha^{-1}	
	2014†	2015	2014†	2015	2014†	2015
83P17	3539.3axy	1467.5bz	2855.7aby	3090.3bx	2929.4axy	4608.9aw
A572	2880.5bw	1752.7bx	2774.8bw	3380.4bcw	2754.3aw	2889.9cw
DKS5403	3059.2aw	1760.1bx	2909.0aw	2464.2cwx	2809.9aw	3163.5bcw
KS735	2795.4by	3670ax	3473.6abxy	4274.2aw	2903.3ax	4904.2aw
NK6638	2994.8bx	3214.1ay	3490.6ax	4707.9aw	3151.2axy	4883.4aw
SP6929	3214.7axy	2111.3bz	2779.9byz	4070aw	3299.5axy	3811.5bwx

†Means of 3 replications; for means within a column followed by the same letter or letters (a,b or c) and a row (w,x,y or z) are not significantly different by $lsd_{0.05}$ =734.8.

Table 4. Mean heads per m^2 of six grain sorghum hybrids (83P17, A572, DKS5403, KS735, NK6638, and SP6929) grown using three levels of supplemental N fertilizer over two years on a Tunica clay soil near Elizabeth, MS.†

Year	Heads m^{-2}		
	0.0 kg N ha^{-1}	112.0 kg N ha^{-1}	224.0 kg N ha^{-1}
2014	11	13	15
2015	10	11	11

†Means of 3 replications, $lsd_{0.05}$=1 for means within a row and column.

Table 5. Mean 1000 kernel weight of six grain sorghum hybrids, grown for two years with three supplemental N fertilizer treatments on a Tunica clay soil near Elizabeth, MS.†

Hybrid	1000 kwt (g)	
	2014	2015
83P17	19.7	22.8
A572	18.1	17.7
DKS5403	17.7	22.5
KS735	18.1	20.7
NK6638	17.3	19.9
SP6929	18.1	23.9

†Means of 3 replications and two years (2014 and 2015) $lsd_{0.05}$=1.8 for means within a row or a column.

Table 6. Mean kernels per head of six grain sorghum hybrids, grown for two years with three supplemental N fertilizer treatments on a Tunica clay soil near Elizabeth, MS.†

kg N ha	Kernels Head^{-1} 2014	2015
0.0	2427ax	2398bx
112.0	2549ax	2665abx
224.0	2263ay	2825ax

†Means of 3 replications and two years (2014 and 2015). Means within a column followed by the same letter or letters (a, or b) or in a row (x, or y) are not significantly different by $lsd_{0.05}$=672.

Table 7. Mean seed yield per head of six grain sorghum hybrids grown with three levels of supplemental N fertilizer on a Tunica clay soil near Elizabeth, MS for two years.†

	Seed yield per head (g)		
Year	**0.0 kg N ha^{-1}**	**112.0 kg N ha^{-1}**	**224.0 kg N ha^{-1}**
2014	50.6	44.1	38.2
2015	53.2	57.9	55.5

†Means of 6 hybrids (83P17, A572, DKS5403, KS735, NK6638, or SP6929) and 3 replications $lsd_{0.05}$=7.0 for means within a row or a column.

Table 8. Mean seed yield per head of six grain sorghum hybrids grown in 2014 and 2015 using three levels of supplemental N fertilizer on a Tunica clay soil near Elizabeth, MS†

Hybrid	**Grain yield per head (g) 2014**	**2015**
83P17	61.2	52.2
A572	32.7	47.4
DKS5403	38.3	59.4
KS735	47.1	52.2
NK6638	45.3	54.0
SP6929	41.2	65.2

†Means of 3 N-fertilizer treatments (0.0, 112.0 and 224.0 kg N kg^{-1}) and 3 replications $lsd_{0.05}$=8.2 for means within a row or a column.

Conclusion

The results of this investigation concluded that the sub-standard yields of sorghum observed in most of this experiment though do suggest that soils such a Tunica or others with high clay content in an alluvial river delta may not be as well suited to grain sorghum production as more friable soils with better drainage. A study similar to this on an alluvial soil with less clay would be in order to better determine the effects of N-fertilization on grain sorghum production in a humid sub-tropical environment such as the Mississippi River Delta.

ACKNOWLEDGEMENT

Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name, propriety product, or specific equipment does not constitute a guarantee or warranty by the USDA-ARS and does not imply approval of the named product to the exclusion of other similar products.

Conflicts of interest: The author declares there are no conflicts of interests regarding this research and subsequent publication.

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