Hindawi
International Journal of Agronomy
Volume 2020, Article ID 4518062, 10 pages
https://doi.org/10.1155/2020/4518062

Research Article

Corn Response Across Plant Densities and Row Configurations for Different Moisture Environments

Kipling S. Balkcom[1] **and Kira L. Bowen**[2]

[1]*USDA-ARS, National Soil Dynamics Laboratory, 411 S. Donahue Dr., Auburn, AL 36832-3439, USA*
[2]*Department of Entomology and Plant Pathology, 209 Rouse Bldg., Auburn University, Auburn, AL 36849-5412, USA*

Correspondence should be addressed to Kipling S. Balkcom; kip.balkcom@ars.usda.gov

Received 31 May 2019; Accepted 23 November 2019; Published 5 March 2020

Academic Editor: Allen Barker

Corn (*Zea mays* L.) production in the Southeast can be negatively impacted by erratic summer rainfall and drought-prone, coarse-textured soils, but irrigation combined with conservation tillage and cover crops may support greater plant densities arranged in different row configurations to improve yield. We examined five site-years of data across two soil types in Alabama to compare corn yields in a conservation system across three plant densities for single- and twin-row configurations in dryland and irrigated moisture regimes. Treatments were arranged with a split plot treatment restriction in a RCB design with three replications. Main plots were irrigation level (no irrigation and irrigation), and subplots were a factorial arrangement of three plant densities (5.9, 7.4, and 8.9 plants m^{-2}) and row configurations (single and twin). A moisture environment (low and moderate) variable, defined by growing season rainfall, was used to average over site-years. In general, irrigation in the moderate-moisture environment improved each measured variable (plant height, stover yield, corn yield, and test weight) and decreased grain N concentration and aflatoxin levels compared to the low-moisture environment with no irrigation. Benefits of increased rainfall and irrigation to reduce soil moisture stress across drought-prone soils were evident. Pooled results across all site-years indicated no yield response as plant density increased, but greater yields were observed with the greatest plant densities in the moderate-moisture environments. No advantage for twin-row corn production was observed across five site-years in Alabama, which indicates either row configuration can be successfully adopted.

1. Introduction

Sporadic summer rainfall combined with coarse-textured soils across the Southeast can limit corn production. Moisture deficits that occur during corn pollination can be particularly damaging to corn yields [1–3]. Increased aflatoxin production by *Aspergillus flavus* has also been associated with high temperatures and low average rainfall amounts during the silking to the late dough stage of corn development in southern production areas [4–6]. This suggests that timing of moisture deficits may be more important than season-long moisture deficits [7]. The uncertainty associated with experiencing favorable growing conditions for corn across the Southeast has prompted some growers to eliminate corn production from their operations. Endale et al. [3] attributed the decline in southeastern corn production to producers voluntarily limiting planting to avoid risk of financial loss that may be due to unreliable yields and/or aflatoxin contamination.

One production practice that may offset limitations of soils with low water holding capacities for corn production is a conservation system that employs both conservation tillage and cover crops. Cover crops used in conjunction with conservation tillage can enhance soil physical properties, although benefits may be site specific [8, 9]. Degraded Ultisols, prevalent across the Southeast, typically respond favorably to reduced surface tillage that promotes residue retention on the soil surface. Increases in organic matter and improvements in soil structure lead to improved infiltration, which potentially increases plant available water [10, 11]. For example, Edwards et al. [12] attributed higher soybean (*Glycine max* L.) yields to moisture conservation by surface mulch present in strip tillage or no tillage. Strip tillage is designed to disrupt the soil beneath the crop row with minimal surface disturbance across the row middles, while no tillage is a form of conservation tillage that maximizes surface residue retention compared to conventional tillage [13].

Soil moisture conservation benefits associated with these tillage systems may help to overcome yield-limiting drought periods that occur during critical growth stages (i.e., reproductive phase) attributed to erratic seasonal rainfall distribution across soils with low water holding capacities [14]. Endale et al. [3] reported no tillage with a rye cover crop and poultry litter as the N source improved corn yields over a 5 yr period when rainfall ranged from 20 to 95% of optimum during the tasseling to early dough stage based on 70 yr daily rainfall records. These soil moisture conservation benefits are usually promoted for dryland crop production, but the benefits are also effective for irrigated producers to improve irrigation efficiency [3, 10]. Southeastern corn growers with the ability to cost effectively implement irrigation on their farms can expect yield increases [2, 15]. In addition, irrigation can also help to minimize aflatoxin contamination as part of an integrated aflatoxin management strategy [16, 17].

Conservation tillage, cover crops, and irrigation should improve corn yield potential across the Southeast. The favorable season-long soil moisture conditions that are possible by combining all three practices may also support yield increases through greater plant densities. Reducing row spacings can increase plant densities, which creates more equidistant plant spacing to reduce competition among plants for light, nutrients, and water [18]. Fulton [19] indicated greater plant densities produced higher yields compared to low plant densities under adequate soil moisture conditions. However, there is a point when competition for resources among plants will produce a yield decline. The point where the relationship between row spacing and plant population are optimized differs with cultivar and environment [20]. For example, Tollenaar [21] found that recently released corn hybrids, with erect leaf architecture that improves light interception, allow these hybrids to better withstand stresses compared to older hybrids.

Agronomically, narrow rows may be beneficial for corn production, but narrow rows are not easily adopted due to required changes related to field operations (i.e., tillage, planting, and harvesting) [2]. A twin-row configuration has been proposed to minimize equipment modifications, while preserving advantages of narrow rows [2, 22]. Karlen and Camp [2] reported an average yield increase for twin-row corn of 640 $kg \cdot ha^{-1}$ compared to single rows with irrigation using conventional tillage across Atlantic Coastal Plain soils. However, Balkcom et al. [23] reported no consistent yield advantage for twin-row corn with conservation tillage and a cover crop across sandy loam and silt loam soils in Alabama. Balkcom et al. [23] also noted that soil moisture may have limited twin-row corn production because no supplemental irrigation was provided. The researchers speculated irrigation was necessary for a consistent twin-row yield advantage. Therefore, our objective was to compare conservation tillage corn yield potential across three plant densities for single- and twin-row configurations in dryland and irrigated moisture regimes.

2. Materials and Methods

Field experiments were conducted at the Field Crops Unit of the E.V. Smith Research Center (EVS) near Shorter, AL (32°25′19.53″ N; 85°53′20.13″ W) during the 2011, 2012, and 2014 growing seasons and the Tennessee Valley Research and Extension Center (TVS) in Belle Mina, AL (34°41′27.57″ N; 86°53′01.80″ W) during the 2012 and 2013 growing seasons. Soil types at each location corresponded to Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult) at EVS and Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudult) at TVS.

The experimental design was a split plot treatment restriction in a randomized complete block design with three replications. Main plots (7.3 m × 73.2 m–EVS; 23.8 m × 18.3 m-TVS) consisted of irrigation and no irrigation while subplots were a factorial combination of corn plant densities representing low (5.9 plants m^{-2}; 23,888 plants ac^{-1}), medium (7.4 plants m^{-2}; 29,962 plants ac^{-1}), and high (8.9 plants m^{-2}; 36,035 plants ac^{-1}) plant densities and row configurations (single vs. twin). Subplot dimensions were 3.7 m × 12.2 m for EVS and 3.0 m × 11.9 m for TVS. At EVS, irrigation levels were achieved with a three-section lateral irrigation system that allowed one-half of each section to be randomly selected for no irrigation by blocking nozzles to create an irrigated and dryland section underneath each section of the lateral. At TVS, each subplot could be irrigated, depending on treatment with four sprinkler nozzles located in each corner of each subplot that were aligned to uniformly irrigate specific plots to create the irrigated and nonirrigated main plots. At both locations, all plots were irrigated approximately every 7 d, depending on rainfall received and judgement of local staff. This irrigation approach is a common strategy adopted by growers in the region and commonly used in research for general irrigation. Minimum single irrigation application amounts corresponded to ~20 mm at each location to prevent surface runoff. A single hybrid, DKC 64–69® (Dekalb Genetics Corporation; Dekalb, IL), was chosen for both locations and all years of the experiment.

Each experimental location consisted of a conservation system that included a rye (*Secale cereale* L.) cover crop established with a no-till drill and seeded at 100 $kg \cdot ha^{-1}$ each fall, prior to corn planting. Rye was fertilized with 34 kg $N \cdot ha^{-1}$ each year as NH_4NO_3 (33-0-0–10) to enhance biomass production. The cover crop was terminated each year with glyphosate [isopropylamine salt of N-(phosphonomethyl) glycine] at least 2 wk prior to corn planting. Biomass measurements were determined immediately prior to chemical termination by cutting all aboveground tissue from two random 0.25 m^2 areas within each plot, drying at 55°C for 72 h, and weighing. Cover crop termination timing was not based on the growth stage, but corresponded to the anticipated corn planting date to allow maximum biomass production and soil moisture recharge by natural rainfall [24, 25]. No irrigation was applied at either location each year when the cover crop was present. All relevant information pertaining to cover crops is summarized in Table 1.

Approximately 2 d prior to corn planting, all plots at EVS were in-row subsoiled 35 to 40 cm deep with a KMC Generation I Rip-Strip (Kelly Manufacturing Co., Tifton, GA). This strip tillage configuration consisted of a coulter, shank, and pneumatic press wheels. At TVS, corn was seeded directly into the soil without any prior tillage. These tillage scenarios were representative of tillage practices for each location, prior to planting corn, based on soil type.

At EVS, single rows were seeded with a John Deere 1700 MaxEmerge Plus (Deere & Co., Moline, IL) planter equipped with Dawn (Dawn Equipment Co., Sycamore, IL) row cleaners. Twin rows were seeded with a Monosem (Monosem Inc., Edwardsville, KS) twin-row planter that had a coulter mounted in front of each individual row. Single- and twin-row configurations were seeded with a Great Plains 1510P Precision Three-Point (Great Plains Manufacturing Inc., Salina, KS) planter at TVS. In the twin-row configuration at both locations, individual plant densities for both rows of the twin-row configuration were reduced by one-half to match the equivalent plant density of the single-row configuration. Row spacing at EVS was 91 cm and 76 cm at TVS. The Great Plains 1510P Precision Planter did not have the capability to plant rows >76 cm; therefore, a single planter could not be used at both locations. Farm equipment (i.e., tractors, sprayers, and combines) could not be altered for both row spacings; therefore, available existing equipment was utilized at each location to manage each experiment. Dates that correspond to select cultural practices including planting, sidedress N, irrigation, and harvesting for each site-year are summarized in Table 2.

Every year, composite soil samples (~10 samples) were randomly collected in the fall across blocks with a 2.54 cm soil probe to a depth of 30 cm to evaluate soil test ratings for P, K, and soil pH. Preplant applications of P, K, and lime were applied as necessary at each location to ensure soil test ratings were considered "high" based on Alabama Experiment Station recommendations for corn [26]. Nitrogen fertilizer was surface-applied as a starter application at 56 kg N·ha^{-1} in a granular form, either as 17-17-17 at EVS or NH_4NO_3 (33-0-0-10) at TVS, prior to planting. The remaining N (185 kg·ha^{-1}) was injected at sidedress as 28% (EVS) or 32% (TVS) urea-ammonium-nitrate.

Plant heights were measured from the ground to the uppermost node of the plant below the tassel at physiological maturity from 10 randomly selected plants in each plot. Immediately prior to harvest, corn stover samples were collected from each subplot by clipping all aboveground plant material from a 0.91 m^2 (EVS) and 0.76 m^2 (TVS) area. Different sampling area sizes were required due to different row spacings used at each location. All corn stover (cobs, stalks, leaves, and husks) was dried at 55°C for 72 h prior to weighing.

Corn was harvested each year using a mechanical combine. All grain yields were adjusted to a moisture content of 155 g·kg^{-1}. A subsample of grain was obtained from each plot and dried at 55°C for 72 h. A portion of the grain subsample was ground to pass through a 2 mm screen with a Wiley mill (Thomas Scientific, Swedesboro, NJ) and then ground further to pass through a 1 mm screen with a Cyclone grinder (Thomas Scientific, Swedesboro, NJ). Each subsample following grinding was analyzed for total N by dry combustion on a LECO TrueSpec-CN analyzer (Leco Corp., St. Joseph, MI). The remaining portion of the subsample was used to determine test weights by weighing grain contained in a standard volumetric cup designed by Seedburo Equipment Company (Des Plaines, IL).

A second subsample of grain was also collected for aflatoxin assays. This subsample was also ground with a Wiley mill to pass through a 6 mm screen. Ten g of the ground corn sample was assayed for aflatoxin using the Veratox test (Neogen Corp., Lansing, MI). This enzyme-linked immunosorbent assay (ELISA) is valid for 5–50 ppb total aflatoxins. If the assay indicated levels >50 ppb, the extraction was diluted and assayed again. A minimum of 10% of the samples were assayed twice to confirm aflatoxin content.

2.1. Statistical Analysis. Data from measured variables (plant density, plant height, stover yield, grain yield, test weight, grain N, and aflatoxin content) that did not fit a normal distribution were rank-transformed for means separation. Aflatoxin content was transformed as (ln (ppb + 1)) prior to analysis. Generalized linear mixed model analyses using PROC GLIMMIX (SAS 9.4, SAS Institute, Cary, NC) were conducted on all measured variables. In preliminary analyses, site-year, irrigation, row pattern, and plant density were fixed effects in the model while block and block × irrigation were random effects. Nontransformed means of variables are presented. Factor effects were determined to be significant when $P < 0.05$.

3. Results and Discussion

3.1. Climate Data. Rainfall totals for each corn growing season ranged from 381 mm to 675 mm across the five site-years examined in this study (Table 3). At EVS, rainfall totals for all three years were below the 10 y average for the location, although 2014 was similar (±5%) to the 10 y average (Table 3). At TVS, a dry (2012) and wet (2013) year was observed compared to the 10 y average for the location (Table 3). Rainfall distribution was variable across site-years, which is also highlighted by monthly distribution of rainfall (Table 3). For example, 2011 at EVS was much drier based on rainfall totals compared to 2012 at EVS; however, more irrigation was applied in 2012 as compared to 2011 (Table 3). In 2011, rainfall for the month of July was 143% higher than the corresponding month in 2012 at EVS. The wet July of 2011 negated the need for late season irrigation at EVS compared to 2012, which reduced total irrigation amounts.

The variability in rainfall observed across locations, despite irrigation, created different moisture environments. Preliminary analyses indicated site-year affected ($P < 0.0001$) all measured variables (Table 4), but two site-years stood out

Table 1: Planting dates, N fertilizer application dates, termination dates, and aboveground biomass measured for a rye ("Wrens Abruzzi") cover crop at five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.

Site-year[a]	Planting date	N fertilizer date	Termination date	Biomass ($kg·ha^{-1}$)
EVS 2011	November 3, 2010	February 16, 2011	March 23, 2011	2300 (130)[b]
EVS 2012	November 7, 2011	February 24, 2012	March 21, 2012	3435 (175)
EVS 2014	December 16, 2013	February 18, 2014	March 27, 2014	835 (40)
TVS 2012	October 26, 2011	December 9, 2011	March 19, 2012	3365 (190)
TVS 2013	November 16, 2012	March 3, 2013	March 28, 2013	2190 (155)

[a]EVS, E.V. Smith Research Center; TVS, Tennessee Valley Research and Extension Center. [b]Standard error.

Table 2: Dates for select cultural practices that include planting, sidedress N, irrigation, and harvest at five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.

Field operation	EVS[a]			TVS[b]	
	2011	2012	2014	2012	2013
Planting date	April 4	April 2	April 13	April 4	April 13
Sidedress N	April 27	May 7	May 20	May 11	May 24
Irrigation events[c]					
1st	April 26	April 25	July 1	May 23	May 30
2nd	May 10	April 30	July 14	May 24	June 13
3rd	May 27	May 27	July 31	May 29	June 18
4th	June 3	June 20	August 12	June 12	June 20
5th	June 13	June 29		June 14	June 25
6th	June 15	July 18		June 19	June 27
7th				June 21	July 2
8th				June 26	July 18
9th				June 28	July 30
10th				July 3	
11th				July 5	
12th				July 26	
13th				August 7	
14th				August 9	
Harvest	August 16	August 27	September 2	August 30	September 12

[a]EVS, E.V. Smith Research Center. [b]TVS, Tennessee Valley Research and Extension Center. [c]Each irrigation event (20 mm) was initiated every 7 d unless rainfall received exceeded 25 mm.

from the others in that season-long rain amounts were low (<480 mm; EVS11 and TVS12; Table 3). Further analyses used two groups of environments based on rainfall to distinguish between moisture environments; EVS11 and TVS12 were considered "low", and the remaining three (EVS12, EVS14, and TVS13) were considered "moderate."

3.2. Plant Heights and Stover Yield.

Moisture environment ($P < 0.0001$) and irrigation ($P = 0.0179$) each affected plant height (Table 5). The moderate-moisture environment produced plants 45% taller compared to the low-moisture environment, while irrigation produced plants 8% taller compared to no irrigation (data not shown). The moisture environment × irrigation interaction ($P = 0.0330$; Table 5) was due to similar plant heights with or without irrigation for the moderate-moisture environment, while plant height in the low-moisture environment was 16% shorter for no irrigation compared to irrigation (Table 6). Plant height in low-moisture environments was 25% and 37% shorter than in moderate-moisture environments with and without irrigation, respectively (Table 6). The moisture environment × row pattern interaction ($P = 0.0126$; Table 5) indicated plant height averaged 45% taller in the moderate-moisture environment compared to the low-moisture environment, regardless of row pattern (data not shown).

Irrigation ($P = 0.0005$; Table 5) improved stover yield by 27% compared to no irrigation (data not shown). However, the moisture environment × irrigation interaction ($P = 0.0083$; Table 5) indicated stover yield was greatest in the low-moisture environment with irrigation and lowest in the low-moisture environment with no irrigation; stover in moderate-moisture environments was intermediate (Table 6). The greatest stover production measured in the low-moisture environment with irrigation indicates that rainfall and irrigation timing may have been optimal to maximize stover production.

Irrigation, regardless of moisture environment, tended to favor taller plants with more stover biomass production for the hybrid used in this experiment. In the low-moisture environments, plant height correlated positively with stover production (Table 7). Blanco-Canqui and Lal [27] reported positive correlations between corn plant heights at silking and soil water content. Mourtzinis et al. [28] reported that plant height has been used as a critical variable in previous statistical models to assess corn yields. However, yield prediction relationships are improved by including other morphological measurements, agronomic information, and climate data [28].

Table 3: Distribution by month and totals for rainfall and irrigation at five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.

Month	EVS[a]				TVS[b]		
	2011	2012	2014	10 y avg.[c]	2012	2013	10 y avg.[c]
				Rainfall mm			
April	48	24	130	79	41	108	125
May	56	176	114	108	80	165	108
June	57	77	107	97	34	85	77
July	204	84	89	131	222	250	142
August	16	133	75	118	87	56	77
September	0[d]	0	0	0	0	11	4
Total	381	494	515	533	464	675	533
				Irrigation mm			
April	10	71					
May	42	41			44	13	
June	64	81			102	95	
July		81	85		44	51	
August			23		25		
Total	116	274	108		215	159	

[a]EVS, E.V. Smith research center. [b]TVS, Tennessee Valley Research and Extension center. [c]Dates correspond to the earliest planting and latest harvest dates at each location for the 2004 to 2014 time period. [d]"0" represents no rainfall documented because the harvest date occurred in August or no rainfall was received during September, prior to the harvest.

Table 4: Overall averages for plant height, stover yield, corn yield, test weight, grain N concentration, and aflatoxin content at five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.

Site-year	Plant height, cm	Stover, $\text{kg}\cdot\text{ha}^{-1}$	Yield, $\text{kg}\cdot\text{ha}^{-1}$	Test weight	Grain N, $\text{g}\cdot\text{kg}^{-1}$	Aflatoxin
EVS 2011	162.2e	7648.4d	3130d	60.8a	15.2a	17.62a
EVS 2012	253.7a	ND[a]	11445b	58.4c	12.5c	24.33a
EVS 2014	229.1b	9459.9c	11183b	60.8a	12.4c	2.97b
TVS 2012	158.9e	14309a	7294c	58.9c	15.3a	27.58a
TVS 2013	215.9c	11184b	15061a	59.8b	13.1b	3.53b

[a]Not determined; dry weights were not collected prior to grinding.

Table 5: *P* values from a general linear mixed model analysis for specific treatments over five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.

Effect	df	Plant height	Stover yield[a]	Yield	Test weight	Grain N	Aflatoxin
Environment (ME)[b]	9	**<0.0001** [c]	0.8571	**<0.0001**	0.6502	**<0.0001**	**<0.0001**
Irrigation (I)	1	**0.0179**	**0.0005**	**<0.0001**	0.8858	**0.0001**	**0.0212**
ME × I	9	**0.0330**	**0.0083**	**0.0422**	**0.0159**	**0.0083**	**0.0498**
Row pattern (RP)	1	0.7984	0.2163	0.3999	0.1086	0.2771	0.4824
ME × RP	9	**0.0126**	0.4597	0.3993	0.9476	0.8240	0.3996
I × RP	1	0.4926	0.6485	0.7227	0.6243	0.5054	0.7913
ME × I × RP	9	0.7957	0.9267	0.7841	0.3440	0.7331	0.5400
Population (P)	2	0.8039	0.8286	0.5571	0.8000	**0.0416**	0.1225
P × ME	18	0.2453	0.9691	0.3463	0.4508	0.5197	0.8758
P × I	2	0.5393	0.8704	0.8412	0.8834	0.6799	0.8561
P × ME × I	18	0.9848	0.8577	0.9470	0.9273	0.3391	0.8885
P × RP	2	0.7517	0.9884	0.9546	0.8459	0.6785	0.9104
P × ME × RP	18	0.6544	0.8433	0.8672	0.9495	0.7538	0.7111
P × I × RP	2	0.7240	0.8480	0.6709	0.4135	0.5950	0.9686
ME × I × RP × P	18	0.9677	0.9462	0.8353	0.9203	0.9971	0.7074

[a]One site-year (E.V. Smith in 2012) was excluded from the analysis because dry weights for samples were not obtained. [b]Environment represents moisture environments where <480 cm rainfall at two site-years (EVS11 and TVS12) were "low moisture" and other site-years were "moderate moisture." [c]Bold values indicate significant differences ($P < 0.05$).

Table 6: Average plant height, stover yield, yield, test weight, grain N concentrations, and aflatoxin content measured across irrigated and dryland treatments within low- and moderate- moisture environments for five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.

Effect	Plant height, cm	Stover yield, $kg{\cdot}ha^{-1}$	Yield, $kg{\cdot}ha^{-1}$	Test weight	Grain N, $g{\cdot}kg^{-1}$	Aflatoxin ppb	Aflatoxin samples ≥20 ppb (%)
Low ME[a]; irrigated	174.9b	13249a	8178c	59.5ab	14.7b	11.06b	36.1
Moderate ME; irrigated	233.7a	10510ab	13532a	59.9ab	12.6c	3.66c	22.2
Low ME; dryland	146.2c	8708c	2246d	60.0a	15.7a	32.24a	75.0
Moderate ME; dryland	233.0a	10044b	11504b	59.4b	12.7c	4.10c	24.0

[a] Moisture environment.

Table 7: Spearman's rank correlation coefficients (R), P values, and number of observations (n) between plant height, stover yield, yield, grain N concentration, and aflatoxin values. Upper right cells are for the low-moisture environment; lower left cells are for the moderate-moisture environment.

Moderate-moisture environment	Low-moisture environment				
	Plant height	Stover yield	Yield	Grain N	Aflatoxin
	R	0.2345	0.5063	−0.5491	−0.1834
Plant height	P value	0.0474	<0.0001	<0.0001	0.1231
	n	72	72	71	72
	−0.2220		0.7176	−0.3570	−0.0738
Stover yield	0.0647		<0.0001	0.0022	0.5376
	70		72	71	72
	−0.4026	0.4410		−0.6251	−0.2630
Yield	<0.0001	0.0001		<0.0001	0.0256
	106	70		71	72
	−0.2430	0.3204	0.0284		0.3817
Grain N	0.0121	0.0061	0.7725		0.0010
	106	72	106		71
	0.4828	0.2025	−0.1286	0.2337	
Aflatoxin	<0.0001	0.0880	0.1889	0.0149	
	106	72	106	108	

Measurements of stover production can quantify differences in plant growth among treatment variables. Stover production estimates have gained importance recently due to the use of stover as a bioenergy source for biofuel production. Identifying harvestable amounts of corn stover that minimizes negative impacts on the soil has been a primary question in this area of research [29].

3.3. Yield.

Moisture environment ($P < 0.0001$) and irrigation ($P < 0.0001$) each affected corn yield (Table 5). The moderate-moisture environment increased corn yield 140%, while irrigation increased corn yield 58%, compared to the low-moisture environment and no irrigation, respectively (data not shown). Corn yield increases, across the Southeast, with sufficient rainfall amounts and/or irrigation during critical growth periods throughout the growing season are not surprising. Many southeastern soils are characterized as degraded Ultisols with coarse textures, poor structure, and low organic matter contents (<1%), which contribute to limited soil water storage [30]. The moisture environment × irrigation interaction was significant ($P = 0.0422$; Table 5) and corn yield was greatest in the moderate-moisture environment with irrigation compared to all other combinations (Table 6). Corn yield was 15% lower in the moderate-moisture environment without irrigation compared to with irrigation (Table 6). In the low-moisture environments, corn yield with irrigation was 3.6x greater than without irrigation (Table 6).

Yield was positively ($R = 0.51$, $P < 0.0001$) correlated to plant height in the low-moisture environment, but negatively ($R = -0.40$, $P < 0.0001$) correlated in the moderate-moisture environment (Table 7). Regardless of moisture environment, yield was positively ($R > 0.44$, $P < 0.0001$) correlated to stover production (Table 7). Plants with the greatest ability to intercept light (i.e., increased stover), although not always the tallest plants, produced the greatest yields. Reeves and Mullins [31] also reported cotton (*Gossypium hirsutum* L.) yields increased as the photosynthetic area of the plant increased.

No yield response to row pattern was observed, despite examining yield data between the two different moisture environments (Table 5). Balkcom et al. [23] had also observed a lack of corn yield response to row pattern across similar soil types in Alabama, but they attributed this to limited soil moisture despite using a conservation system. Potential soil moisture benefits associated with the conservation system did not produce greater twin-row yields compared to single rows. The limited ability to produce cover crop biomass preceding corn (Table 1), due to the early termination time required, could limit soil moisture conservation benefits of the system [32]. However, twin-row peanut (*Arachis hypogea* L.) production is popular across the Southeast [13, 33]; therefore, corn growers should experience no yield reduction if they choose to use the same planter for corn and peanut production.

Plant density measurements collected 3 weeks after planting corresponded to 6.0 plants m^{-2}, 7.0 plants m^{-2}, and 8.9 plants m^{-2} for the low, medium, and high plant densities, respectively (data not shown). Plant densities examined in this study represent a wide range to encompass dryland producers and irrigated producers. However, plant density nor interactions with plant density had no effect on corn yield (Table 5). In general, as plant densities increase, corn yields increase, but once plant densities reach a certain point that varies with environment, yields will decline [2, 20].

Pooling data across all site-years and irrigation treatments indicated no statistical yield response associated with plant densities. No response to plant density does have implications for seed cost that may be significant at higher plant densities. Although there was not a significant yield response due to increases in plant density in the pooled data, greater yields were observed with greater densities for some site-years. Analysis of only the moderate-moisture environments showed that the greatest plant densities resulted in significantly greater yields than medium or lower densities. In the low-moisture environments, the greatest plant density had numerically lower yield than other planting densities. In the site-year with most restricted moisture (EVS 11), lower yields were noted with medium density than with low plant density, even with irrigation. These results support previous research that indicates nonlimiting soil moisture conditions must exist to support increased corn plant densities across coarse-textured soils of the Southeast [23].

Figure 1 shows rainfall and irrigation received across a time period that includes silking for the two site-years included in the low-moisture environment. Dry periods of 15 d that began on 28 May (Figure 1(a)) and 23 d that began on 12 June (Figure 1(b)) illustrate corresponding irrigation amounts supplied during these periods. At TVS, the stationary sprinkler nozzles located in each plot enabled more frequent, timely irrigation applications compared to the lateral irrigation system used at EVS during extended dry periods.

3.4. Test Weight and Grain N Concentration.

Test weight, an indicator of grain quality, was not affected by moisture environment or irrigation, but an interaction between moisture environment and irrigation ($P = 0.0159$) was observed (Table 5). No irrigation in the low-moisture environment produced a greater test weight than no irrigation in the moderate-moisture environment (Table 6). Test weights in the low and moderate-moisture environments with irrigation were intermediate of these values (Table 6). Economic differences associated with measured test weights were not calculated, but the small differences, although significant, were minimal compared to yield differences across moisture environments and irrigation levels.

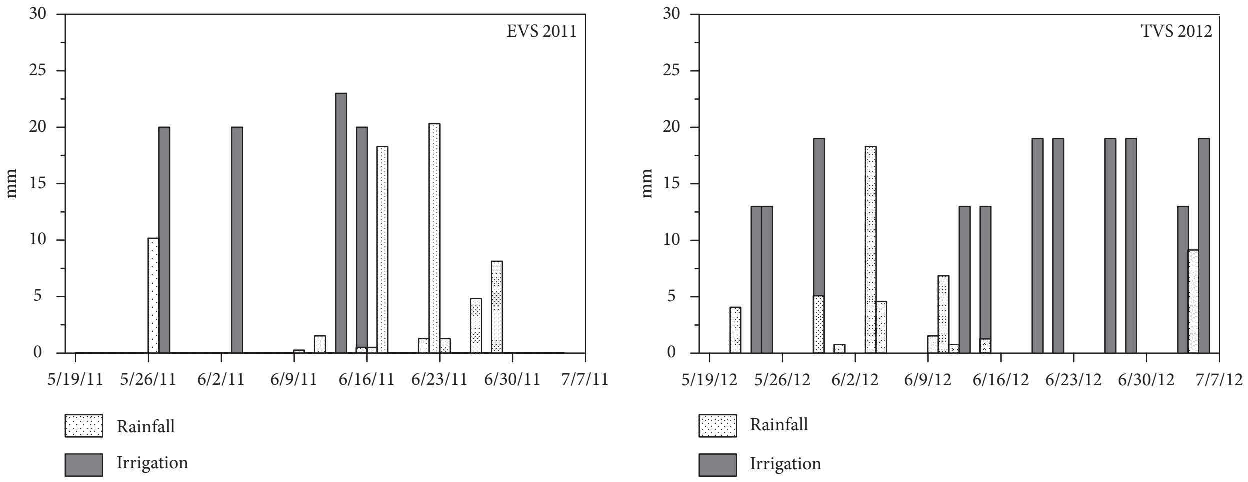
Moisture environment ($P < 0.0001$) and irrigation ($P = 0.0001$) each affected grain N concentration (Table 5). Grain N concentrations were 16% less in the moderate-moisture environment compared to the low-moisture environment, while irrigation produced grain N concentrations 4% less than no irrigation (data not shown). Increased soil moisture, regardless of moisture environment or irrigation, is thought to increase corn growth and produce a dilution of grain N concentration present in the plant. Justes et al. [34] have described this phenomenon for wheat (*Triticum aestivum* L.), but the principle would also apply to corn. Plant density ($P = 0.0416$) also affected grain N concentration, but the differences were small. The low plant density produced grain N concentrations 3% greater than grain N concentrations from the high plant density, while the medium density produced grain N concentrations intermediate of these levels (data not shown). The moisture environment × irrigation interaction ($P = 0.0083$; Table 5) was due to significantly decreased grain N with irrigation in the low-moisture environments while there was not an effect due to irrigation in the moderate-moisture environments (Table 6).

Regardless of moisture environment, grain N concentration was negatively correlated to plant height ($R > -0.24$, $P < 0.0121$). However, while grain N was negatively correlated to stover production in the low-moisture environment ($R = -0.35$, $P = 0.0022$), it was positively correlated ($R = 0.32$, $P = 0.0061$) with stover production in the moderate-moisture environment (Table 7). As noted previously, grain N is decreased with greater plant growth (reflected by stover quantity), which was substantially increased with irrigation in low-moisture environments (Table 6); however, in moderate-moisture environments, irrigation had little impact on stover quantity.

Estimates of grain N concentration are critical to determine grain N removal calculations necessary for calculating a N balance [35]. Although beyond the scope of this experiment, estimates of a N balance help determine optimal N fertilizer rates to maximize profits and minimize environmental N losses. Plant breeders' propensity to select hybrids for higher yields has created an unintended consequence of grain N concentrations decreasing over time [36]. As previously stated, the common explanation for this inverse relationship is a dilution effect, but Tenorio et al. [35] reported a weak, positive relationship between grain N concentration and yield representing numerous comparisons from the US North Central Region. This region represents a large corn production area of the US, but this relationship has not been examined extensively across other regions of the US, such as the Southeast.

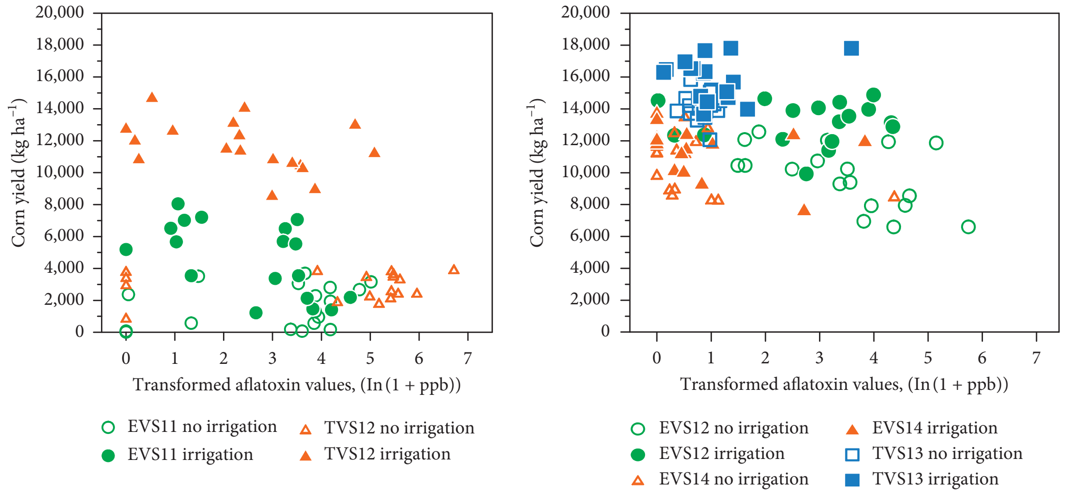
3.5. Aflatoxin.

Moisture environment ($P < 0.0001$) and irrigation ($P = 0.0212$) also affected aflatoxin levels (Table 5). Average aflatoxin content of corn from the moderate-moisture environments was 48% lower compared to the low-moisture environment; 23.1% of moderate-moisture plot



(a) (b)

FIGURE 1: Rainfall and irrigation received at the low-moisture environments of EVS in 2011 (a) and TVS in 2012 (b) from May 19 to July 7 of each growing season that corresponds to the corn silking time period for all five site-years during the 2011 to 2014 growing seasons across northern and central Alabama.



(a) (b)

FIGURE 2: The relationship between corn yields and transformed aflatoxin values in the low (a) and moderate (b) moisture environments for five site-years during the 2011 to 2014 growing seasons across northern and central Alabama. Aflatoxin content (ppb) transformed as (ln (1 + ppb)); threshold of 20 ppb = 3.04 on x-axis.

samples and 58.3% of low-moisture plot samples had >20 ppb aflatoxins. Twenty-five percent of samples from irrigated corn had >20 ppb aflatoxin, while 44.4% of samples from nonirrigated plots were above this threshold (data not shown). The moisture environment × irrigation interaction ($P = 0.0498$; Table 5) was due to a significant reduction in average aflatoxin content with irrigation in low-moisture environments while irrigation did not significantly affect aflatoxin in moderate-moisture environments (Table 6). The low-moisture environment and no irrigation resulted in the highest aflatoxin contamination (Table 6) and greatest number of samples with >20 ppb aflatoxin.

In the low-moisture environment, aflatoxin was negatively correlated ($R = -0.26$, $P = 0.0256$) with yield (Table 7). Aflatoxin content was positively correlated with grain N concentration in both the low- and moderate- ($R > 0.23$, $P < 0.01$) moisture environments (Table 7). Aflatoxin was also positively correlated ($R = 0.48$, $P < 0.0001$) with plant height in the moderate-moisture environment (Table 7). These results appear to be contradictory to previous observations indicating that N deficits contribute to higher aflatoxin content [17]. However, most studies have only looked at N fertility and not N partitioning relative to aflatoxins. Work by Nasielski et al. [37] suggests that N uptake can be increased in plants grown under moisture stress, and this could explain our results. Alternatively, the low R^2 suggests substantial variability in these relationships that might indicate no biological significance.

In the low-moisture environment, irrigation at TVS allowed consistent corn yields as aflatoxin levels increased compared to nonirrigated corn yields (Figure 2(a)). At EVS, the effect was not as pronounced between irrigation levels (Figure 2(a)). In the moderate-moisture environments, average corn yields across all site-years decreased as aflatoxin levels increased (Figure 2(b)). Aflatoxin levels remained low at TVS in the moderate-moisture environment regardless of irrigation (Figure 2(b)).

Drought and heat stress are primary factors to avoid because they contribute to aflatoxin contamination, especially during the grain filling period [17]. These conditions are prevalent in the Southeast, which increases the potential for aflatoxin contamination [38]. Early planting is used to minimize heat stress effects, while irrigation can help avoid drought stress and subsequent aflatoxin contamination [17]. The negative correlation between yield and aflatoxin contamination appears to support this argument. However, Bruns [38] reported no difference in aflatoxin levels between irrigated and nonirrigated corn. Despite the advantages of irrigation, other factors, such as adequate N levels, may sometimes impact aflatoxin levels [17]. Damianidis et al. [6] also reported a relationship between in-season weather conditions, primarily minimum temperature and rainfall that explained between 60 and 76% of observed aflatoxin variability. For example, in the moderate-moisture environment at EVS in 2014, aflatoxin levels remained low across the test except for one plot, despite no irrigation (Figure 2(b)). This indicates, for the growing conditions observed that site-year, irrigation was not the primary factor affecting measured aflatoxin levels. Plant density had no effect on aflatoxin levels which has been observed in other studies [6].

4. Conclusions

Moisture environment and/or irrigation affected all measured variables for this experiment, except test weight. Benefits of reduced soil moisture stress across these drought prone soils were evident, particularly for yield and aflatoxin contamination. Each variable was affected by the interaction between moisture environment and irrigation. Row configuration produced no effect across the variables examined in this study, except for a plant height interaction between moisture environment and row pattern, indicating that plant height increased, regardless of row pattern in the moderate-moisture environment. Plant density only affected grain N concentrations, but the greater grain N concentrations measured in the low plant densities were small (~3%) compared to that with high plant densities. Pooled results across all site-years indicated no yield response as plant density increased, but yields were maximized with the greatest plant density in the moderate-moisture environments. The lack of response between row configurations indicates that either row configuration can be successfully adopted by Alabama corn growers, particularly if the twin-row configuration is being used for other crops in their operation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

Mention of trade names and/or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or Auburn University.

Conflicts of Interest

The authors declare there are no conflicts of interest regarding the publication of this manuscript.

Acknowledgments

The authors would like to express their appreciation to Jeffrey Walker, Agricultural Science Technician, for his assistance with the collection of research data and acknowledge the technical support he provided that ensured success of this project. The authors would also like to recognize the assistance provided by Mr. Shawn Scott, superintendent of Auburn University's Field Crops Unit, located at the E.V. Smith Research Center in Shorter, AL, and Mr. Chet Norris, superintendent of Auburn University's Tennessee Valley Research and Extension Center, located in Belle Mina, AL. This research was supported by commodity funds from the Alabama Wheat and Feed Grains Commission and the Agricultural Research Service of the United States Department of Agriculture.

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