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Research Article

Agronomic Response of Corn (*Zea mays* L.) Hybrids to Plant Populations

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Field studies were conducted in 2016 and 2017 under rain-fed conditions in south-central Louisiana, (a) to determine the effects of plant density levels on plant height, ear height, stalk diameter, lodging, corn grain yield, test weight, and photosynthetically active radiation with modern corn hybrids in central Louisiana and (b) to test the hypothesis that the response of grain yield to plant population density would depend on the reproductive plasticity (flex, semiflex, or fixed ear) of the hybrids evaluated. Rainfall was above average while air temperatures were below average during the growing season in both years. Grain yield showed a hybrid response in one of two years (fixed ear greater than semiflex ear) while yields increased as plant populations increased. Test weights were less with the fixed ear hybrid and the effect of plant populations was inconsistent with increased populations resulting in greater test weight in one of two years. Lodging increased as plant populations increased with the fixed ear hybrid resulting in greater lodging in one of two years. There was a hybrid by plant population interaction for ear height and seed weight. The effect of plant populations is an important factor for corn yield; however, yield gains associated with higher plant populations may be dependent on the genetic predisposition of corn hybrids (regardless of the reproductive plasticity) to tolerate various environmental conditions and stresses associated with higher populations.

1. Introduction

Corn or maize (*Zea mays* L.) producers are constantly questioning variables such as hybrids and plant populations that play an important role in yield and subsequently the net returns they receive. The demand is constantly increasing for food, fuel, and feed, and corn is a common crop grown both in the US and globally that is often used to meet these demands. The current world population is 7.6 billion people in 2018 [1], and although the rapid population growth has slowed, continuously decreasing mortality due to improved health, increased access to education, and economic growth coupled with slower birth rates guarantee continued growth for years to come [2]. Increasing use of food crops such as corn for biofuel production will worsen the risk of hunger for the world's poor. The challenge to agriculture is to produce enough food to meet the demands of an increased population and biofuel production demand, and this is particularly relevant to corn, which is one of the top three most important cereal crops in the world [3].

Optimizing harvestable corn grain yield requires matching the best corn hybrids with optimal plant populations. Research indicates that plant populations have increased dramatically in corn production over the past 40 years [3]. Duvick [4] reported that older hybrids out-yielded newer hybrids at lower plant populations, while at higher plant populations, the reverse occurred. The major genetic contribution to the increase in yield has been to increased "crowding stress" tolerance [5]. This tolerance has resulted in increased grain yield through planting higher corn plant populations. The introduction of multiple sources of insect resistance through biotechnology and plant breeding has resulted in improved plant health which has resulted in increased corn populations.

Plant population density has important effects on vegetative [6] and reproductive development of corn [7, 8]. Corn yield is low with low plant density because of little plasticity in leaf area per plant [8–10]. Additionally, corn plants have a small capacity to develop new reproductive structures in response to an increase in available resources per plant [11, 12]. However, if the plant density is too high, the decrease in the availability of resources per plant in the period surrounding silking generates a marked fall in yield per plant that is not offset by the increase in the number of plants [13, 14]. In dense populations, many kernels may not develop. This occurs in some hybrids due to poor pollination resulting from a delayed silking period compared with tassel emergence [15, 16] and/or due to a limitation in assimilate supply that caused kernel and ear abortion [17–19].

Also, the optimum plant density (number of plants that maximizes grain yield) depends on the hybrid [10, 20, 21]. Optimum plant population density is usually higher for short-season than for full-season hybrids [22–24]. For short-season hybrids more plants are needed to reach the same amount of cumulative intercepted radiation [24] because of their small leaf area per plant and small leaf area plasticity [25–28] and a shorter duration of growth.

Most corn hybrids have been developed to produce a single harvestable ear under normal production conditions [29]. Single-eared corn hybrids are often characterized as having either an indeterminate or determinate ear growth habit [30]. According to some seed companies, ear size (i.e., length and girth) and number play a significant role in determining a hybrid's yield potential at varying plant populations [30]. A "fixed" ear hybrid is associated with a relatively determinate ear size that limits its capacity to compensate for variation in plant populations while a "flexible" ear hybrid has an indeterminate ear size that can compensate for variation in plant populations [30].

The objectives of this research were (a) to determine the effects of plant density levels on plant height, ear height, stalk diameter, lodging, corn grain yield, test weight, and photosynthetically active radiation with modern corn hybrids in central Louisiana and (b) to test the hypothesis that the response of grain yield to plant population density would depend on the reproductive plasticity (flex, semiflex, or fixed ear) of the hybrids evaluated.

2. Materials and Methods

2.1. Study Site. Corn was planted on slightly raised seedbeds under rain-fed conditions in south-central Louisiana, southeast of Alexandria (31.1094° N, 92.24827° W; 31.1085° N, 92.2429° W) on 22 March, 2016 and 13 March, 2017, respectively. Soils at these locations were a Coushatta silt loam (fine-silty, mixed, superactive, and thermic Fluventic Eutrudepts) with less than 1% organic matter and 7.1 pH. The previous crop at each location was soybean (*Glycine max* L.). Each year, the test locations were fertilized with a blend of 225 kg·ha^{-1}·N, 36 kg·ha^{-1}·P, 71 kg·ha^{-1}·K, and 0.6 kg·ha^{-1} Zn according to soil test recommendations provided by the Louisiana Soil Testing and Plant Analysis Laboratory.

2.2. Corn Hybrids and Plant Populations. Three common corn hybrids (all with the VT2P traits), DK 67–14, considered a flex ear with 117 day relative maturity, DK 67–72, considered a fixed ear also with 117 day relative maturity, and DK 68–29, considered a semiflex ear with 118 day relative maturity were planted at the plant population goal of 49400, 61800, 74100, 86500, 98800, 111200, 123500, and 135900 plants·ha^{-1}. After corn emergence, the actual plant population counts were 43600, 53500, 64900, 75200, 85900, 94900, 107200, and 117700 plants·ha^{-1} and this was constant over the two study years. These figures will be used when discussing the plant density results. All corn hybrids contain the trait for glyphosate resistance. The test area was maintained with a raised seedbed as is the method of bed preparation in the area.

2.3. Plot Setup and Planting. A randomized complete-block experimental design was used and treatments were replicated four times. Treatments consisted of a factorial arrangement of the three corn hybrids with eight plant populations (described above). In each experiment, corn was planted 5 cm deep using an Almaco row cone planter (Almaco, 99 M Ave, Nevada, Iowa 50201) capable of planting 4 rows spaced on 97 cm apart. Plot length was 15.2 m. Weeds were controlled in 2016 with a preemergence application of *S*-metolachlor plus atrazine (Bicep Magnum®) at 4.49 L·ha^{-1} followed by a postemergence application of thiencarbazone-methyl plus tembotrione (Capreno) at 0.19 L·ha^{-1}. In 2017, weeds were controlled with a preemergence application of *S*-metolachlor (Medal II®) at 1.22 L·ha^{-1} and 2.9 L·ha^{-1} of atrazine (Atrazine 4L®) followed by a postemergence application of atrazine at 2.34 L·ha^{-1}.

2.4. Plant Measurements and Harvest. Plant counts were taken 4 to 6 wk after planting to assure that each plot was within the desired plant populations. Plant height, ear height, and stalk diameter measurements (10 plants plot^{-1}) were taken at the R1 growth stage when silks were visible out of the husk. Ear height measurements were taken from the ground line up to the point where the ear attaches to the stalk while plant height measurements were taken from ground line to the tip of the top leaf. Stalk diameter was measured at the first internode above the brace roots with an electronic caliper (Mitutoyo Corporation, 965 Corporate Blvd, Aurora, IL 60502). Lodging observations were recorded before harvest. Plants were considered lodged if corn stalks were broken below the ear. The percent lodging was calculated based upon the total number of plants per plot. Kernel weight was based on 300 seed count. Grain samples for moisture readings were collected at harvest and measured with GAC 2500-AGRI (DICKEY-John, Auburn, IL 62615).

Photosynthetically active radiation (PAR) is the light wavelength range that is best fit for photosynthesis to occur. The optimum reading for photosynthesis is in the 400 to 700 nanometer range. PAR readings were taken only in 2017. Photosynthetically active radiation was measured using an AccuPar PAR/LAI ceptometer (Decagon Devices, Inc., 2365

NE Hopkins Court, Pullman Washington 99163) between 1100 and 1300 h on a clear and calm day from all plots when corn was in the R1 growth stage. Three independent measurements were taken from the center portion of the center two rows of each plot by placing the sensor diagnolly across the row, with the external sensor simultaneously held level and above the top of the canopy. Intercepted photosynthetically active radiation was calculated manually [31].

Corn was harvested 2 September, 2016 and 23 August, 2017 using a 2-row small plot combine. The middle 2 rows of the 4 row plot were harvested and plot weights were adjusted to 15.5% moisture.

2.5. Data Analysis. Data were analyzed using GLIMMIX procedure of SAS [32] and a model statement appropriate for a factorial design. Corn hybrid and plant populations were considered fixed effects while year, rep, and all interactions with these effects were considered random. Treatments means were separated by Fisher's protected least significant difference test at $P = 0.05$.

3. Results and Discussion

3.1. Rainfall and Temperature. In 2016, rainfall was generally higher than the 30 yr average with the exception of April and May which were reduced 28 and 44%, respectively, compared with the 30 yr average (Table 1). In 2017, only March rainfall was below the 30 yr average. Water stress, such as what occurred in 2016, during pollination and fertilization has a great effect on corn yield [33, 34]. Stress during pollen shed and silking can cause more yield loss than almost any other period in the crop's development [33]. Inadequate plant water potentials can slow down silk elongation, resulting in delay or failure of the silks to emerge from the ear shoot. Silks that do emerge may desiccate rapidly when the plant is enduring severe moisture deficits, becoming nonreceptive to pollen [33].

Temperature readings in 2016 and 2017 were above the 30 yr average in March and April but below the average in June through August (Table 1). March temperatures in both years were at least 2°C greater than the 30 yr average while April temperatures in 2016 were higher than the 30 yr average by 0.8°C and in 2017 April was 1.4°C warmer than the 30 yr average. Although temperatures were not an issue during pollination and kernel development, high temperatures can cause problems even when soil moisture is adequate and will compound problems in drought-stressed corn especially during pollination (VT-tassel through R1-silk) [35–37].

3.2. Plant Height. Since there was not a year by corn hybrid interaction, data were combined over years for corn hybrid; however, there was a plant population by year interaction so that data are presented separately by years (Table 2). DK 67–14 (flex ear) produced the greatest height while DK 67–72 (fixed ear) resulted in the shortest and DK 68–26 (semiflex ear) produced an intermediate height.

Table 1: Average monthly rainfall and air temperatures during the growing season in 2016 and 2017 compared with the 30-year average.

Month	2016	2017	30 yr avg[a]
Rainfall (mm)			
March	231	63	135
April	84	328	116
May	67	165	120
June	148	195	137
July	113	104	112
August	349	280	104
Total	992	1135	724
Air temperature (°C)			
March	17.7	17.9	15.6
April	20.2	20.8	19.4
May	23.1	22.0	23.9
June	26.4	25.3	27.2
July	27.8	27.4	28.3
August	27.1	26.3	28.3

[a]Average rainfall and air temperature based on weather information collected from 1981 to 2010 at the Alexandria International Airport approximately 56 km from research site.

Table 2: Plant height and stalk diameter of corn hybrids and plant populations in 2016 and 2017.

	Plant height[a]		Stalk diameter[a]
	cm		mm
Hybrid			
DK 67–14	83.3 a		25.0 a
DK 67–72	75.5 c		24.2 b
DK 68–26	81.6 b		24.7 a
Plant population (1000 plants·ha^{-1})			
	2016	2017	
43.6	202.9 c	200.1 a	28.5 a
53.5	206.8 ab	199.7 a	26.9 b
64.9	207.9 ab	200.8 a	25.7 c
75.2	207.5 ab	201.7 a	24.9 d
58.9	207.3 ab	202.1 a	24.0 e
94.9	210.0 a	198.3 a	23.0 f
107.2	210.3 a	196.2 a	22.1 g
117.7	204.2 bc	202.1 a	21.7 g

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance. [a]Plant height and stalk diameter data were pooled over years for hybrid while only stalk diameter data were pooled over years for plant population.

In 2016, the lowest plant population (43600 plants·ha^{-1}) resulted in the shortest height while populations of 94900 and 107200 plants·ha^{-1} resulted in the greatest height (Table 2). In 2017, there were no differences in corn plant height between populations.

McFarland [38] reported similar results with other hybrids. In a two-year study, plant height decreased for only two of six hybrids for one of two years as populations increased across single- and twin-row plantings.

3.3. Stalk Diameter. Corn hybrid data and plant populations were combined over years due to a lack of interaction between years (Table 2). DK 67–14 and DK 68–26 produced a greater stalk diameter than DK 67–72 while stalk diameter decreased as plant populations increased. This agrees with work in Indiana [39] and Minnesota [40] that has previously shown that as plant populations increase, stalk diameter decreases. In another study, Van Roekel and Coulter [41] reported that stalk diameter was not affected by hybrid or plant populations. They felt that the lack of stalk response among hybrids may have been related to variability among site years when compared with previous work [40].

3.4. Ear Height. There was a hybrid by plant population interaction for ear height (Table 3) with results consistent over years; therefore, data were combined over years. With the flex ear hybrid, DK 67–14, ear height was greater with plant populations of 64,900 plants·ha^{-1} or greater when compared with the two lower plant populations while with the semiflex ear, (DK 68–26) the higher plant population (117,700 plants·ha^{-1}) resulted with the greatest ear height compared with the other populations. With the fixed ear hybrid, DK 67–72, plant populations of 75,200 or greater resulted in the greatest ear height. McFarland [38] reported that plant population had no effect on ear height of the majority of hybrids in each year (affecting only one hybrid in each year of a two-year study).

3.5. Stalk Lodging. There was a hybrid by year interaction for stalk lodging, and data are presented separately by years while plant populations were consistent by years for lodging and those data were combined over years (Table 4). There was no difference in percent lodging between hybrids in 2016; however, in 2017, DK 67–72 produced greater lodging than the flex or semiflex hybrids (Table 4).

Lodging was affected by population as 117,700 plants·ha^{-1} resulted in the highest percent lodging (3.19%) while plant populations below 85,900 plants·ha^{-1} resulted in 1.44% or less. Typically, increased lodging occurs with higher ear placement because the wind can cause stalk breakage [31]. With all three hybrids, especially DK 67–14 and DK 67–72, as the population increased, ear height was greater (Table 3) thus contributing to greater lodging at higher populations. Roekel and Coulter [41] reported that stalk lodging was not affected by hybrid or plant populations in their study in Minnesota. However, in Ohio, Thomison and Jordan [30] reported that differences in stalk lodging were influenced by hybrid and plant density with the least lodging observed in the low plant density plots. Widdicombe and Thelen [21] reported that plant populations of 81,000 and 90,000 plants·ha^{-1} resulted in greater stalk lodging than that at populations of 56,000 to 73,000 plants·ha^{-1}.

3.6. Grain Moisture. Since there was no year interaction, data for hybrid and plant populations were pooled across years. The semiflex hybrid (DK 68–26) resulted in less moisture than the other two hybrids while the lowest moisture was obtained with the lowest plant populations (Table 4). Widdicombe and Thelen [21] reported that both

Table 3: Corn ear height of the three hybrids with various plant populations over the two years.

Plant population (1000 plants·ha^{-1})	DK 67–14	DK 67–72	DK 68–26
		cm	
43.6	94.7 bc	82.2 c	85.7 c
53.5	93.4 c	83.4 c	89.1 bc
64.9	100.2 a	86.1 bc	88.2 bc
75.2	97.4 ab	89.8 ab	89.5 b
85.9	98.2 ab	94.1 a	90.3 b
94.9	97.5 ab	92.9 a	90.9 b
107.2	100.7 a	92.4 a	90.9 b
117.7	98.7 a	94.1 a	94.7 a

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance. Data were pooled across years.

hybrid and plant populations had an effect on grain moisture at harvest. They reported that as plant populations increased from lowest to highest, grain moisture decreased. Porter et al. also [42] reported a hybrid by plant population interaction for grain moisture at two of three locations evaluated.

3.7. Grain Yield. There was a hybrid and plant population by year interaction; therefore, data for each are presented separately by years (Table 4). In 2016, DK 67–72 (fixed ear) produced greater yield than DK 68–26 (semiflex ear) while DK-67-14 (flex ear) was intermediate. Plant populations of 75,200 plants·ha^{-1} or greater produced higher yields than the lower populations of 64,900 plants·ha^{-1} or less. In 2017, no differences in yield was noted between hybrids while plant populations of 85,900 plants·ha^{-1} yielded more than a population of 43,600 plants·ha^{-1}. All other plant populations were intermediate in yield (Table 4). From this study, it would seem that optimum plant populations can vary from year to year but 85,900 plants·ha^{-1} are required for optimum yield in this area of Louisiana.

The response between flex and fixed ear hybrids seemed to vary. Kratochvil and Taylor [43] reported that response to plant population varied by location, hybrid, and row spacing. However, Thomison and Jordan [30] reported that hybrid ear type was of limited importance in determining optimum plant population. Smart et al. [44] reported that flex ear types, when planted at low population densities under optimal growing conditions, can increase yields by increasing the number of kernels per square meter.

Widdicombe and Thelen [21] reported that plant populations had an effect on grain yield in Michigan. The highest plant populations evaluated (90,000 plants·ha^{-1}) resulted in the highest grain yield. Nielsen [45] found that 90,000 plants·ha^{-1} was greater than optimum for the conditions at three locations in Indiana while Porter et al. [42] reported inconsistent optimal plant populations ranging from 86,000 to 101,270 plants·ha^{-1} for corn grain yield across three Minnesota locations. The studies by Nielsen [45] and Porter et al. [42] were conducted in the mid to late 1980s and 1990s, respectively, and plant densities in corn production has changed a lot in the last twenty to thirty years.

Table 4: Stalk lodging, moisture, grain yield, test weight, and photosynthetically active radiation readings of the three hybrids at the various plant populations in 2016–2017.[a]

	Lodging[a] %		Moisture[b] %	Yield $Kg{\cdot}ha^{-1}$		Test weight $Kg\ h{\cdot}L^{-1}$		PAR[c] $Umol\ m^{-2}{\cdot}s^{-1}$
Hybrid	2016	2017		2016	2017	2016	2017	
DK 67–14	0.62 a	1.84 b	15.5 a	10935 ab	10721 a	74.8 a	71.4 a	198.4 b
DK 67–72	0.16 a	5.01 a	15.5 a	11016 a	19980	73.5 b	69.6 b	295.3 a
DK 68–26	0.24 a	0.69 b	15.0 b	10225 b	10596 a	75.1 a	70.9 a	293.9 a
Population ($1000\ plants{\cdot}ha^{-1}$)								
43.6	0.50 bc		14.9 d	7526 c	8914 b	72.0 c	70.5 ab	460.8 a
53.5	0.31 c		15.1 cd	8706 c	10255 ab	74.6 ab	69.2 b	317.9 b
64.9	0.46 bc		15.2 bc	11016 b	10586 ab	75.4 a	70.8 ab	285.4 bc
75.2	1.44 bc		15.3 bc	11223 ab	9886 ab	74.6 ab	71.4 a	205.7 bc
85.9	2.02 ab		15.5 ab	11330 ab	11550 a	74.9 ab	70.9 ab	234.1 bc
94.9	1.52 bc		15.7 a	12083 ab	10727 ab	75.1 ab	70.9 ab	241.3 bc
107.2	1.96 abc		15.4 b	12385 a	11038 ab	74.9 ab	71.1 ab	185.4 c
117.7	3.19 a		15.4 b	11531 ab	11100 ab	74.2 b	70.4 ab	169.9 c

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.[a]Population data for lodging pooled over years. [b]Pooled over years. [c]Reading taken in 2017 only.

3.8. Test Weight. There was a year by hybrid and a year by plant population effect so each year is presented separately (Table 4). In 2016, both the flex (DK 67–14) and semiflex ear (DK 68–26) resulted in greater test weight than the fixed ear (DK 67–72) while the effects of plant populations were variable. The lowest plant population produced the lowest test weight while all other plant populations, with the exception of 117,700 plants·ha^{-1}, produced test weights which ranged from 74.6 to 75.4 Kg·h·L^{-1}.

In 2017, similar trends as seen in 2016 were noted with hybrids (Table 4). The flex and semiflex ear hybrids produced a greater test weight than the fixed ear hybrid. A plant population of 75,200 plants·ha^{-1} resulted in the highest test weight while a population of 53,500 plants·ha^{-1} produced the lowest test weight with all other plant populations being intermediate. Grichar and Janak [46] reported that hybrid and plant populations affected test weight in a two-year study. Hybrid affected test weight in both years while in one year, test weight decreased as the plant population increased from 53,000 to 71,000 plants·ha^{-1}, whereas in another year, no differences were noted. In a study by Widdicombe and Thelen [21], the opposite was noted. In their study, test weight increased slightly as plant populations increased from 56000 to 90000 plants·ha^{-1}.

3.9. Photosynthetically Active Radiation Readings (PAR). These readings were taken in only one year of the study, and since there was no hybrid by plant population interaction, each variable (hybrid or plant population) is presented separately. The flex ear hybrid (DK 67–14) intercepted more sunlight than the fixed ear hybrid (DK 67–72) and the semiflex hybrid (DK 68–26). Depending on leaf architecture, Stewart et al. [47] found that hybrids with upright leaves, in certain circumstances, may allow more sunlight to penetrate the soil surface reducing the amount of intercepted PAR (IPAR). Readings of IPAR increased or intercepted more sunlight as plant populations increased (Table 4). Maddonni and Otegui [48] stated that increased plant populations lead to a greater leaf area index and increased interception of PAR from the mid-vegetative to early grain-fill stages. Van Roekel and Coulter [40] reported that there was a quadratic response of PAR to plant density with maximum PAR occurring at the highest plant populations (108,700 plants·ha^{-1}). Tollenaar and Lee [49] stated that an increase in total biomass accumulated via sustained photosynthesis during grain filling has been implicated as the major physiological determinants of the yield increase.

3.10. Kernel Weight. There was a hybrid by plant population by year interaction; therefore, each year's data are presented separately. With the flex ear hybrid, DK 67–14, in both 2016 and 2017, as the plant population increased, seed weight decreased (Table 5). In 2016, the least seed weight occurred with plant populations of 94,900 plants·ha^{-1} or greater, while in 2017, the least seed weight occurred at plant populations greater than 75,200 plants·ha^{-1}.

With the fixed ear hybrid, DK 67–72, in 2016, seed weight decreased as plant populations increased; however, the decrease was inconsistent (Table 5). The highest seed weights were with plant populations of 43,600 to 64,900 plants·ha^{-1} and 85,900 plants·ha^{-1} while the least seed weight was with a population of 117,700 plants·ha^{-1}. In 2017, the lowest plant population (43,600 plants·ha^{-1}) resulted in the highest seed weight and plant populations of greater than 53,500 plants·ha^{-1} the least seed weights.

With the semiflex ear hybrid, DK 68–26, in 2016, no differences in seed weight was noted with any plant populations while in 2017 similar trends to those seen with DK67-72 in the same year were noted (Table 5). The lowest plant population resulted in the highest seed weight and plant populations of 53,500 plants·ha^{-1} or greater produced the least seed weight.

Van Roekel and Coulter [40, 41] found that as the plant population increased from 40,700 to 107,700 plants·ha^{-1}

Table 5: Kernel weight of the three corn hybrids in 2016 and 2017.[a,b]

	DK 67–14		DK 67–72		DK 68–26	
	2016	2017	2016	2017	2016	2017
	Grams					
Population ($1000\ plants{\cdot}ha^{-1}$)						
43.6	113.0 ab	116.4 a	110.3 abc	116.4 a	109.3 a	109.3 a
53.5	113.8 a	109.2 b	115.0 a	103.3 b	106.8 a	105.0 b
64.9	108.0 cd	104.6 b	113.3 ab	106.2 b	107.5 a	103.6 b
75.2	109.5 bc	96.1 c	108.8 bc	104.9 b	107.5 a	103.2 b
85.9	104.5 de	96.5 c	115.3 a	99.7 b	110.3 a	103.7 b
94.9	100.5 f	92.9 c	106.8 cd	99.1 b	108.3 a	102.5 b
107.2	103.8 ef	91.2 c	108.3 bc	97.5 b	107.5 a	102.4 b
117.7	100.5 f	92.2 c	101.3 d	99.2 b	105.5 a	103.0 b

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance. Weights based on 300 seed count.

kernel weight decreased. Haegele et al. [50] reported that when averaged across the two hybrids tested, kernel weight was greatest ($280\ mg\ kernel^{-1}$) at a plant population of $61{,}775\ plants{\cdot}ha^{-1}$ and decreased by $13\ mg\ kernel^{-1}$ at the highest plant populations of 111,195 and 135,905 $plants{\cdot}ha^{-1}$.

4. Conclusion

Finding the optimum plant populations that produce the maximum yield per unit area under different environments and with different hybrids has been a major concern in many studies and with many agronomists. The superiority of new hybrids over old hybrids at high plant populations has been attributed to several factors including lower lodging frequencies of new hybrids [51], greater N use efficiency [50, 52], higher leaf photosynthesis rate [38, 53], and more efficient stomatal conductance and leaf photosynthesis under water stress conditions [54]. Also, when selecting hybrids for higher plant populations, Thomison and Jordan [30] reported that hybrid ear type was of limited importance in determining optimum plant populations.

The positive response of higher plant populations resulting in greater yields in this study may be partially attributed to favorable weather conditions during the growing season. Less than normal rainfall occurred in April and May of 2016; however, in all the other months of the growing season, rainfall was average or above average. The timing of water stress has been used to determine the relationship between grain and yield components [55]. Eck [56] found that water deficit during vegetative growth reduced the number of kernels per ear but had little effect on kernel weight. The number of kernels produced was not influenced by water deficit during grain fill but kernel weight was reduced [56, 57].

Also, temperatures were above normal only in March and April of both years. The effect of temperature in reducing the length of the growth cycle, especially the grain filling phase, is the most important factor in explaining reduced yields at warmer temperatures [58]. By accelerating crop development, elevated temperatures limit the amount of solar radiation received by the plant during the development stage. Aggregated over the entire growing period, less interception of solar energy is problematic [59]. With less fuel to drive photosynthesis, plant structures (such as leaves and ears) tend to be smaller and less abundant, bringing matured plant biomass below potential levels [60–63]. Therefore, independent of other stresses, the highest crop yields are attained when relatively mild temperatures maximize the total duration of growth [64].

Plant population is an important factor for corn yield; however, yield gains associated with higher plant populations may be dependent on the genetic predisposition of corn hybrids (regardless of the reproductive plasticity) to tolerate various environmental conditions and stresses associated with higher populations and respond with additional yield. In these studies, the three hybrids were selected to represent differences in hybrid yield response to plant populations. It was expected that the fixed ear hybrid would show the greatest yield response to a change in plant population with the flex ear hybrid showing the least and the semiflex hybrid intermediate in response. However, this was not the case as no yield differences were noted between the flex and fixed ear in either year while the semiflex ear did produce lower yields in one of two years (Table 4). Thomison and Jordan [30] stated in their studies that yield responses to plant populations were not consistent across years or locations, and the relative hybrid yield performance (ranking) was not influenced by plant population regardless of ear type. With only one hybrid representing differences in ear growth habit, conclusion about hybrid responses to changes in plant populations is limited. Corn hybrids with different genetic backgrounds should be considered in future studies; however, other variables such as weather conditions, including rainfall, and temperature play a greater role in determining seeding rates.

Data Availability

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

Conflicts of Interest

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

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