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Effect of Population Density Changes and Ear Style on Kernel Size and Yield in Grain Corn

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EFFECT OF POPULATION DENSITY CHANGES AND EAR STYLE ON KERNEL SIZE AND YIELD IN GRAIN CORN

by

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INTRODUCTION

"Ear flex" in corn (*Zea mays* L.) is defined as the variability of ear size which results from environmental conditions throughout the growing season (Anderson, 2000). Ear flex is determined by three components; ear length (number of ovaries per row), ear girth (number of rows around the ear) and kernel size (volume/kernel). Of these components, kernel size is often overlooked. Kernel size takes into account the depth, width, length, and weight of the individual kernels (Penn State Extension, 2014). The number of kernel rows in ears of hybrid corn typically range from 10 to 24. The final kernel row number is determined by branching patterns at the rachis apex around V6 growth stage of the plant. The number of ovaries per row of the ear is complete about one to two weeks before silk emergence occurs and the final ear length (cm) is determined after anthesis. (Purdue Agronomy Department, 2002). The environmental conditions during these developmental stages impact potential kernel number. Some of the factors that limit kernel set include; the lack of moisture, too much moisture, lack of nutrients, insufficient light reception, various diseases, and/or pest issues to list a few. Ideal growing conditions enable the development of more kernel rows and more ovaries per row or longer ear length. Both of these factors are determined primarily by genetics. The number of ovary rows is fairly stable across environments. Ovaries per row, however, can be more variable.

Once the number of potential kernels has been set, the next step of kernel yield development is the ability of the plant to fill this preset grain potential. This development is also dependent on and determined by the environmental conditions during the remainder of the season. The growing conditions between pollination and black layer formation (defined as physiologically mature in this creative component according with corn production terminology) can impact the size and weight of each kernel (Borras *et al.*, 2004). When growing conditions are ideal, kernel size is maximized, leading to larger, heavier seed. Conversely, when the crop is growing under stressful environmental conditions, the kernel size is reduced.

Genetic makeup is also a major contributor to potential ear development. “A hybrids genetics is instrumental in determining the potential number of rows per ear, environmental factors have a lesser influence” (Iowa State University, 2006). Each corn hybrid has a genetically predetermined range of kernel rows. Certain hybrids produce ears with fewer rows of kernels (from 10-16 rows) while others produce ears with 18-24 rows. Logically, hybrids that produce 18-24 kernel rows should yield more than hybrids with 10-16 rows. However, this is not always the case. For example, ears with high kernel counts may have smaller kernels and, therefore, it takes more kernels to make a bushel. The combination of these factors contribute to the final grain yield components of corn: kernel number, kernel weight, and ears per area as demonstrated in Figure 1 (Lauer, 2006)

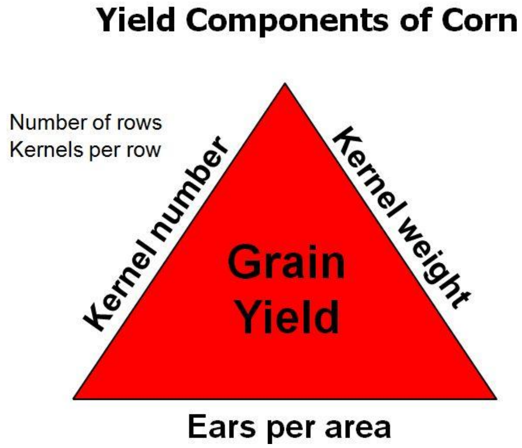


Figure 1 – Yield components of corn (Lauer, 2006)

Each year prior to harvest, growers, consultants, and agronomist conduct general yield estimates in corn fields. Often these yield estimates are truly estimates. If the same formula is used for all hybrids, and the kernel size is not taken into consideration, the estimates do not compare very well to actual yields. Bruce Due, Mycogen Agronomist has done a kernel size study for the last several years (pers. comm., 2015). He evaluated different hybrids and recorded the number of kernels from each hybrid in a bushel of grain. Harvest populations (final plant count with viable ear at harvest) were collected at each site by hybrid. His results illustrated there can be large differences in kernel size across hybrids. Penn State Extension suggests using similar kernel estimates when trying to estimate yield as shown in Table 1 below. Kernel count per bushel ranged from 70,000 kernels in the high yield environment to 100,000 kernels/bushel in low yield environment (Penn State Extension, 2014).

Table 1. Impact of kernel size on grain yield in corn (Adopted from Penn State – Corn yields and kernel size)

Kernels/bushel	**g/100 kernels @ 15.5%**	**g/100 kernels @ 25%**	**Yield (bu/acre)***
100000	25.4	28.6	179
90000	28.2	31.8	199
80000	31.8	35.8	224
70000	36.3	40.9	256

*assuming 16 kernel rows, 35 kernels/row and an ear count of 32,000/acre

Higher plant populations may create additional stresses and limitations, such as reduced light interception or nutrient supply, which could negatively affect grain fill. Maddonni *et al.* (1998) showed that “Small kernel hybrids (Kernel Weight <300mg), with large kernel number (3500 to 5500 kernels m^{-2}), depended more on reserve mobilization than large-kernel hybrids (KW >300mg) with reduced kernel number (2800 to 4000 kernels m^{-2})". These results show the interactions between source versus sink limitations within plants and their effect on grain fill and kernel abortion. Similarly, yield reductions under high plant populations may be the result of limitations in the endosperm's capacity for growth, either by number, size, or activity of the endosperm cells (Sangoi, 2001). A study done by Jeremy Milander at University of Nebraska-Lincoln showed kernel weights decreased linearly from 30.1 grams to 27.0 grams per 100 kernels as populations increased from 65,000 plant/ha to 105,000 plant/ha (Milander, 2015).

My personal experience from field observations is that hybrids with more kernel rows are more responsive to increases or decreases in seeding rate or number of kernels planted per acre. These hybrids seeded at lower population rates have shown a positive yield response in commercial production fields, which seems counter intuitive. Since individual kernel size on an ear with more kernel rows should be smaller, an increase in the planting population should result in more kernels. This observation lead me to the hypothesis that these kinds of hybrids have more "kernel flex" or variation of kernel size in response to low plant population density. This variation in seed size could impact the plants' ability to completely fill all kernels (kernel number) during grain fill, which is dependent on environmental conditions.

This experiment compares four corn hybrids, at three plant populations, across three locations to determine how these variables can impact final kernel size weight. The objectives of this experiment are to determine how planting population impact average kernel size based on hybrid selection for number of kernel rows; and to evaluate if final kernel size variation could be predicted or correlated to these variables.

MATERIALS AND METHODS

Locations

The experimental plan included three Dow AgroScience research locations across southern Minnesota and Northern Iowa during the 2016 growing season. Two locations were in Minnesota near Blue Earth and Olivia, and one location near George, Iowa. Two additional locations were planted but were not used in the analysis. Data from these locations were lost to weed competition and the other to planting error. The soil type at Blue Earth, MN was 197 Kingston Silty Clay Loam (Fine-silty, mixed, superactive mesic Aquic Hapludolls); at Olivia, MN was 927 Harps-Glencoe-Seaforth Complex (Harps Clay Loam: Fine-loamy, mixed, superactive, mesic Typic Calciaquolls; Glencoe Clay Loam: Fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls; Seaforth Loam: Fine-loamy, mixed, superactive, mesic Aquic Calciudolls), and at George, IA was 310B Galva Silty Clay Loam (Fine-silty, mixed, superactive, mesic Typic Hapludolls) (USDA Soil Web Survey, 2018).

Experimental Design

Four hybrids were planted at each location using three plant population densities. Each hybrid was randomized within each population and location. These four hybrids included two hybrids, A and B, that produce 16 kernel rows or more and two hybrids, C and D, that produce ears with 16 kernel rows or less. Each hybrid was planted with a research planter

(Almaco 360 Seed Pro with Sky Trip, Nevada, IA) at three plant populations in increments of 5,000 plant/acre (12,355 plant/hectare) as shown in Table 2. The “medium” plant populations were set according to the typical planting recommendations for the area.

Table 2 – List of research site locations and plant populations at each location.

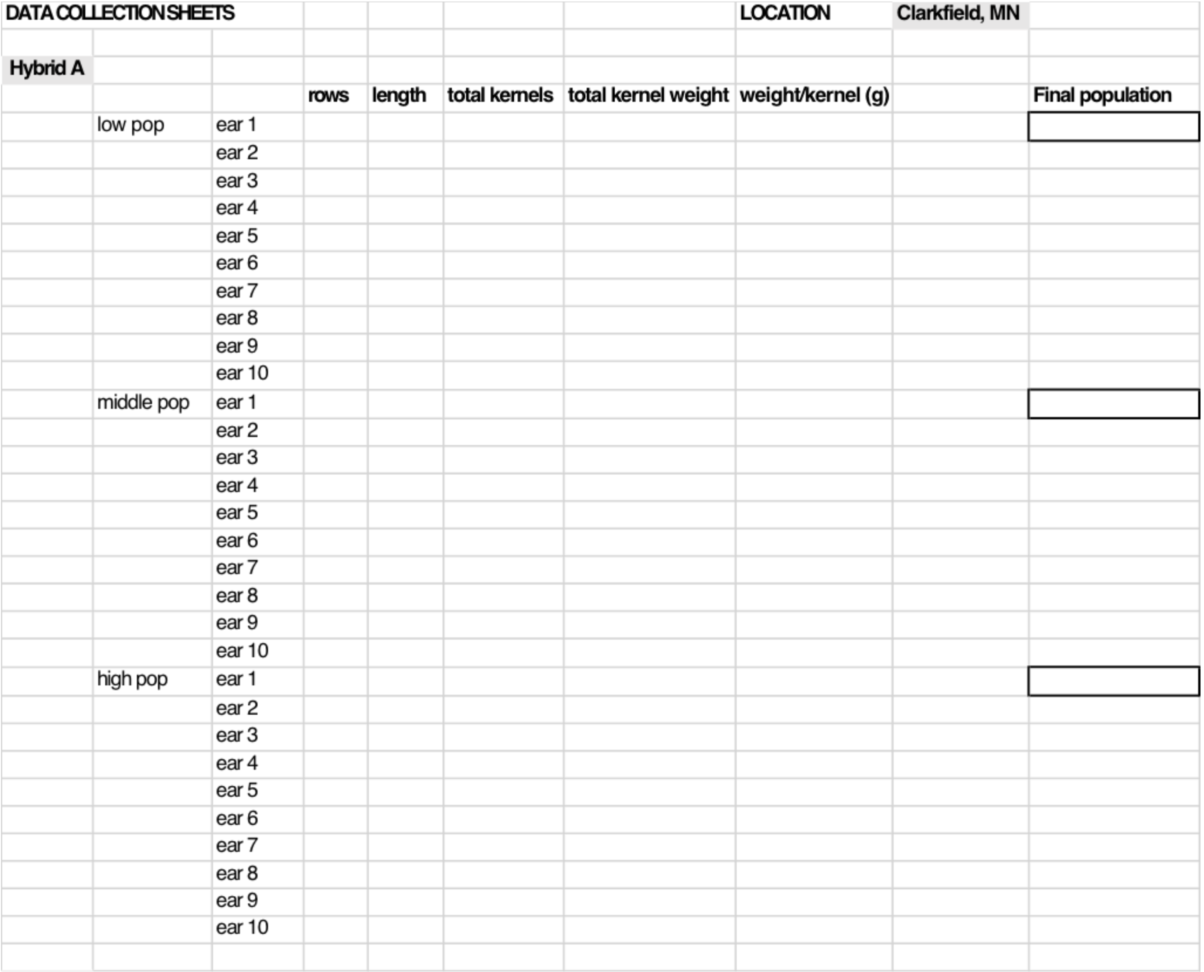
				Plant Populations		
Locations:	**City**	**State**		**Low**	**Medium**	**High**
Location 1	Olivia	MN		30,000	35,000	40,000
Location 2	Blue Earth	MN		29,000	34,000	39,000
Location 3	George	IA		29,000	34,000	39,000

Evaluation Process

Final plant populations for each hybrid and location were recorded when ear samples were harvested. A measurement of 2.4 m (10 ft) was made from the alley to determine the first ear in each row to harvest. The next ten consecutive ears, from each hybrid and population, were harvested by hand. Each ear was placed in an individually labeled mesh bag and then each of these bags were placed into a larger mesh bag labeled for each hybrid by population per location. After all ear samples collected from each research location, ears were dried to approximately 15.0% moisture utilizing a laboratory/research seed dryer.

Each ear sample was evaluated individually. The number of kernel rows and the number of kernels per row were counted and recorded. Ears were shelled individually, using an ear sheller (Agriculex SCS-2; Guelph, Ontario Canada) and kernel samples from each ear were saved. The shelled kernel samples were screened, weighed, and the total kernel weight per ear was recorded. The kernel samples were counted using an automated seed counter (Agriculex ESC-2; Guelph, Ontario Canada) to acquire kernel counts used in analysis. The total kernel weight per ear was divided by the total number of kernels per ear to obtain the individual kernel weight. An example of a "Data Collection" sheet is included in Figure 2.

Figure 2 – Example of Data Collection sheets used for each hybrid at each location



DATA COLLECTION SHEETS							**LOCATION**	**Clarkfield, MN**	
Hybrid A									
			rows	**length**	**total kernels**	**total kernel weight**	**weight/kernel (g)**		**Final population**
	low pop	ear 1							
		ear 2							
		ear 3							
		ear 4							
		ear 5							
		ear 6							
		ear 7							
		ear 8							
		ear 9							
		ear 10							
	middle pop	ear 1							
		ear 2							
		ear 3							
		ear 4							
		ear 5							
		ear 6							
		ear 7							
		ear 8							
		ear 9							
		ear 10							
	high pop	ear 1							
		ear 2							
		ear 3							
		ear 4							
		ear 5							
		ear 6							
		ear 7							
		ear 8							
		ear 9							
		ear 10							

Statistical Analysis

Regression equations between the different ear flex parameters and yield were calculated. The experimental design is a split-block design with locations as blocks. Data for kernel rows, kernels per row, kernels per ear, and grams per kernel were collected from this experiment were also analyzed using ANOVA. Hybrid and population were considered fixed effects, while location was considered random. Error terms (all interactions of main effects with location) were computed using the random statement in SAS and these error terms were used to test fixed effects according to expected mean squares generated. These tests were run on each of the dependent variables; rows per ear, kernels per row, kernels per ear, grams per kernel, and yield. The means for the main effects of hybrid and population were LSD at $p \leq 0.05$. The raw data can be found in Appendix A.

RESULTS

Regression equations between the various parameters of ear flex were calculated to understand their relationships to grain yield. The R^2 value for most regression equations were very low, with the exception of the number of kernels per row and ear size expressed as grams of grain per ear. Figures 2 through 5 show the regression equations and corresponding R^2 values for each hybrid tested, respectively. As the number of kernels per row increased, so did ear size (grams/ear). The R^2 values for these equations ranged from 0.56 to 0.73, indicating that number of kernels per row explained 56 to 73 percentage of the variation observed in ear size for all hybrids tested, respectively.

Figure 2 – Regression equation between number of kernels/row and ear size expressed in grams of grain per ear for Hybrid A.

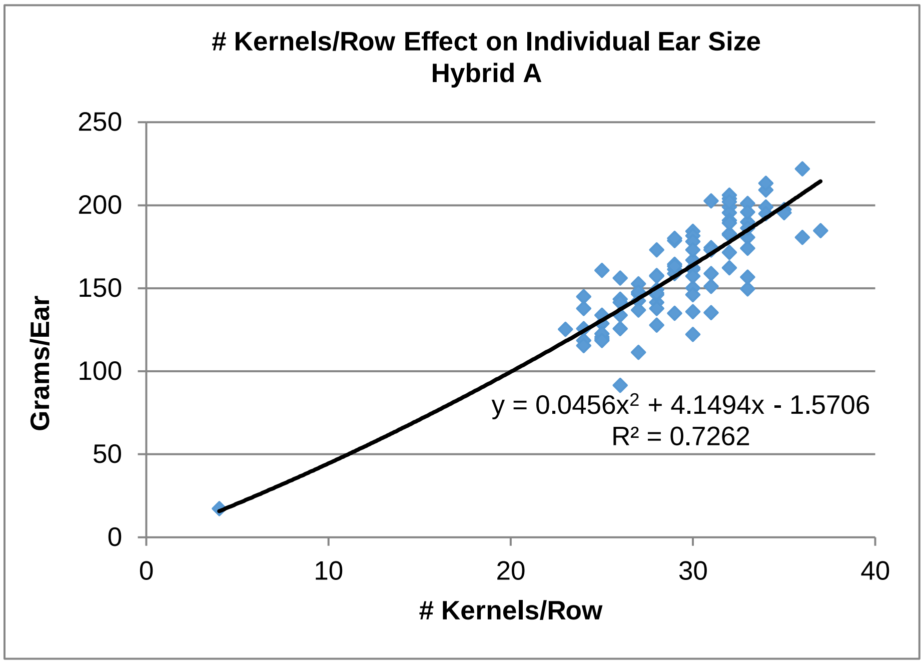


Figure 3 – Regression equation between number of kernels/row and ear size expressed in grams of grain per ear for Hybrid B.

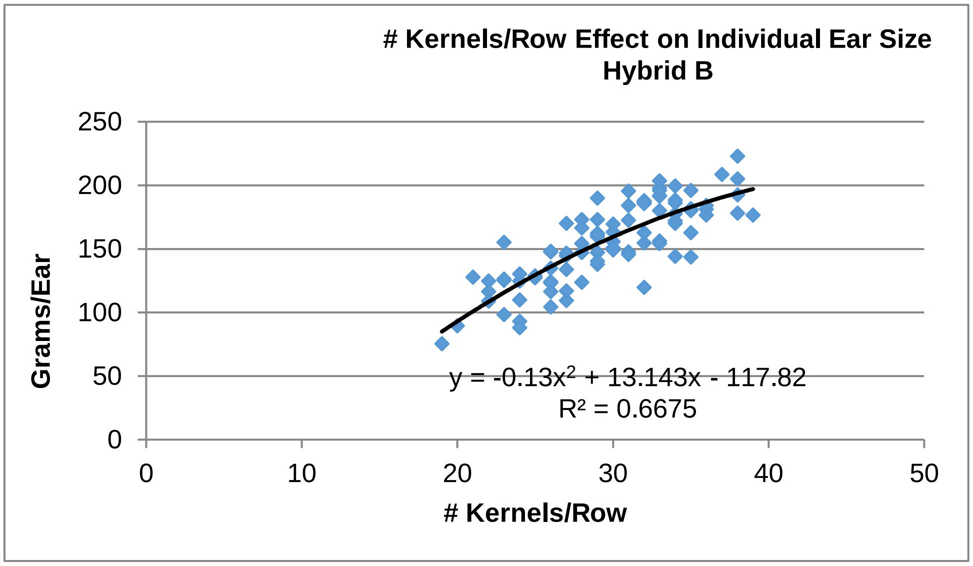


Figure 4 – Regression equation between number of kernels/row and ear size expressed in grams of grain per ear for Hybrid C.

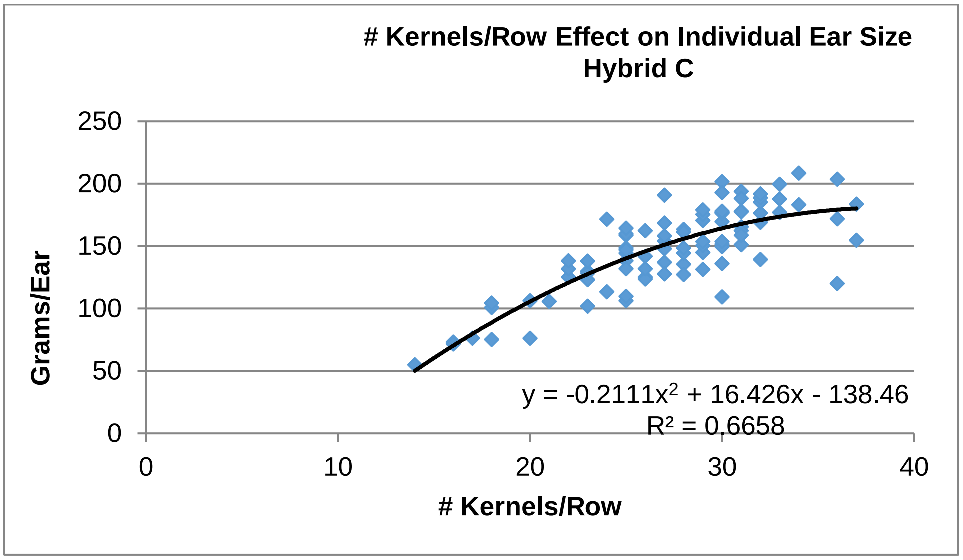
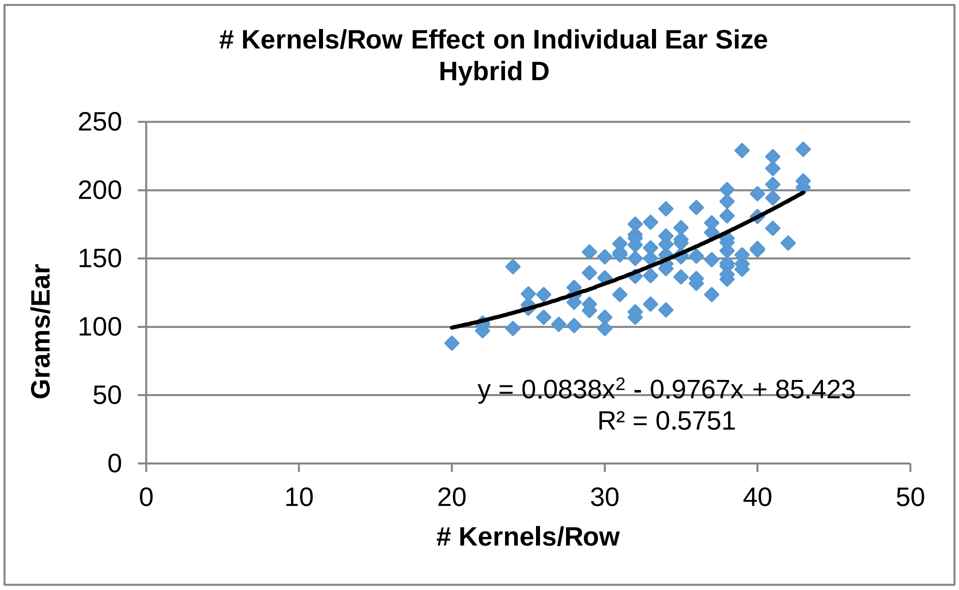


Figure 5 – Regression equation between number of kernels/row and ear size expressed in grams of grain per ear for Hybrid D.



The Analysis of Variance for all ear parameters measured in this experiment are summarized in Table 3. The results indicated there were no significant (*$p \leq 0.05$*) hybrid by plant population density interactions for number of rows per ear, number of kernels per row, number of kernels per ear, grams per kernel and yield. The interactions between location and hybrid, and location and plant population density were not significant (*$p \leq 0.05$*) for most parameters measured, with the exception of number of kernels per ear.

Table 3. Mean Square values from the analysis of variance for location, hybrid and plant population density effects and their interactions.

Source	DF	Rows/ ear	Kernels/ Row	Kernels/ Ear	Grams/ Kernel	Yield
Location	2	0.074	11.22	5117.86	0.0037	4236.7 *
Hybrid	3	12.360 *	62.39 *	17035.7 *	0.0041 *	1017.1 *
Location*Hybrid	6	0.633	2.91	2498.60 *	0.0004	192.5
Population	2	3.354	76.23 *	42883.1 *	0.0005	141.7
Location*Pop.	4	0.538	5.60	4179.32 *	0.0001	168.4
Hybrid*Pop.	6	0.735	4.41	1290.96	0.0001	169.4
Error	12	0.312	5.32	529.28	0.0002	183.3

*Means are significantly different at the 0.05 level of probability

The main effect means for hybrid and population interactions were then evaluated using the results of the t-Test and corresponding LSD values. These results are summarized in Tables 4 and 5 respectively.

Table 4. Mean values for number of rows per ear (Rows), number of kernels per row (Kernel/Row), weight of a kernel in grams (Grams/Kernel), and yield in bushels per acre (Yield) for four hybrids overall locations and plant populations. Least significant difference (LSD) values are calculated at the 0.05 level of probability.

Hybrid	**Rows**	**Kernels/Row**	**Grams/Kernel**	**Yield**
Hybrid A	17.7	29.3	0.31	212.4
Hybrid B	18.0	29.7	0.29	215.2
Hybrid C	16.4	27.4	0.33	195.6
Hybrid D	15.5	33.7	0.28	195.3
$LSD_{0.05}$	0.92	1.97	0.023	16.0

Table 5. Mean values for number of rows per ear (Rows), number of kernels per row (Kernel/Row), number of kernels per ear (Kernels/Ear), weight of a kernel in grams (Grams/Kernel), and yield in bushels per acre. (Yield) for three plant population densities overall locations and hybrids. Least significant difference (LSD) values are calculated at the 0.05 level of probability.

Population	**Rows**	**Kernels/Row**	**Grams/Kernel**	**Yield**
Low	17.4	32.4	0.31	208.5
Medium	17.0	30.3	0.30	203.4
High	16.3	27.4	0.30	201.9
$LSD_{0.05}$	0.83	2.68	0.010	14.71

In the evaluation of the hybrid effect there were several noteworthy findings. The number of rows per ear in Hybrids A and B were significantly greater ($P<0.05$) than Hybrids C and D. These same hybrids (A and B) also yielded significantly greater ($P<0.05$) in this experiment.

The evaluation of the population effect did indicate an impact on the various parameters of ear development. The number of rows per ear was significantly fewer in high population density than in low population and significantly fewer ($p<0.05$) than both the low and medium population for kernels per row and total number of kernels per ear. These changes in population density, however, did not lead to a significant difference ($p\leq0.05$) in yield.

The hybrid did not indicate any significant difference ($p\leq0.05$) in grams per kernel that corresponded to the hybrid groups of A and B versus C and D, either both higher or both lower, as initially suspected at the onset of this experiment. The population effect on grams per kernel showed no significant difference ($p\leq0.05$) either.

DISCUSSION AND CONCLUSION

The driving question behind this research was how hybrid selection, based on genetic tendency for number of kernel rows on an ear, might vary across population densities and locations. The purpose of this experiment was to identify interactions among ear-types and changing plant populations. It was hypothesized that hybrids with more kernel rows per ear would show more “kernel flex” or variation per individual kernel size than hybrids with fewer kernel rows in response to an imposed stress factor, specifically plant population density.

The results from this study did not support the hypothesis; however, valuable information was obtained from the experiment. First, the selection process for the hybrids, based on rows per ear influenced by genetic tendencies, could produce significantly different hybrid groups and variation among the products selected for this experiment. This selection process was important because it is the first step for determining hybrid choices for different locations. Secondly, the remaining ear components from each hybrid were evaluated; kernels per row, kernels per ear, and finally weight per kernel. If hybrids with more kernel rows per ear are influenced by plant population management decisions, then hybrids A and B should have been significantly different than hybrids C and D, especially in regards to grams per kernel. However, results from this experiment did not support this assumption. The four hybrids did not respond consistently based simply on their rows per ear. For example, Hybrid B and D were the two hybrids with the largest mean difference in rows per ear. Hybrid B had 18.0 rows per ear and hybrid D had 15.5 rows per ear as shown in Table 4. Even though these two hybrids have different numbers of kernels per row and yield, they had the same grams per kernel or grain weight. This relates back to the Yield Components of Corn triangle that was discussed in the introduction (Lauer, 2006). Yield is driven by the number of ears per area (plant population), by the number of kernels per ear or the combination of kernel rows by kernels per row, and by the weight of the grain. Each corn plant reaches its maximum yield potential through a different combination of these yield components, which falls somewhere different within the yield triangle. This variability was evident in this research and was shown by the variability of the ear components from hybrid to hybrid.

Stresses throughout the growing season can impact corn developmental processes, which includes how and when corn kernels are initiated, developed, and filled. According to

Milander (2015), early season stress has the potential to reduce the number of ears, late-season stress has the potential to reduce kernel weight, and midseason stress has the potential to reduce the number of kernels. Midseason stress can impact the kernel set on the ear, first the number of rows around and then the length potential of the ear. Late season stress can impact how well the individual kernels are filled. The locations used for this experiment did not experience prolonged stressful weather conditions throughout the 2016 growing season. The average monthly temperatures for each test location are shown in Figure 6. The average monthly rainfall amounts by location are shown in Figure 7. Monthly temperatures at all locations were very similar, while rainfall was evenly distributed throughout the growing season.

Figure 6 – Average monthly temperatures at Blue Earth and Olivia, MN and George, IA in 2016 (created from MN DNR annual data, 2018)

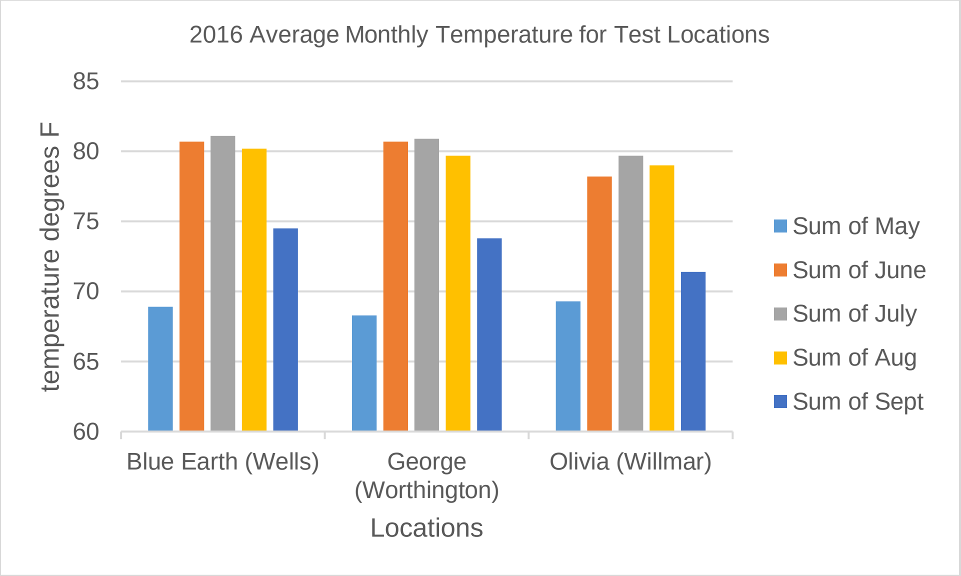
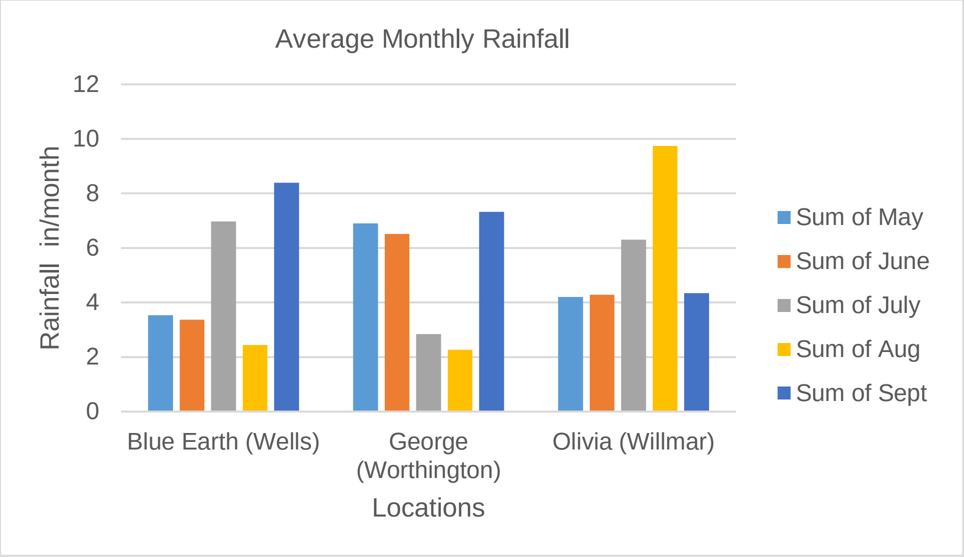


Figure 7 – Average monthly rainfall at Blue Earth and Olivia, MN and George, IA in 2016 (created from MN DNR annual data, 2018)



The favorable growing conditions across all locations produced very similar growing environments that had little or no effect on the grain yield parameters measured. Future experiments should consider evaluating similar variables under various circumstances based on environmental conditions and time. The first option would be to use a single testing location, with better control over environmental stress (e.g. irrigated plots). The experiment should also include multiple replications at a single site and/or with hybrids exhibiting wider ranges in kernel rows. If under these controlled environments, a consistent correlation between the number of rows and the other ear components is established, then using multiple locations may have merit. The second option would be to conduct a longitudinal study over several years in order to collect data on natural changing weather patterns and analyze trends and data over time.

The number of kernel rows is variable in corn production and can be impacted by both genetics (as demonstrated by this experiment) and by environmental conditions and their interactions. A study conducted by Bokanski *et al.* (2009) established inbred tendencies for phenotypic characteristics correlated with yield. They observed the best correlation with hybrid yield from selecting inbreds with longer ears and taller plant height on one side of the hybrid cross, and inbreds with greater number of kernel rows and heavier kernel weight on the other side.

The corn seed production industry currently relies more on marker assisted breeding efforts to help identify, prior to planting new hybrids in the field, inbreds and hybrids that have more desirable phenotypic characteristics. The advancements in this particular field of study have been tremendous over the last couple decades. An early study by Stuber *et al.* (Stuber *et al.*, 1986) recognized that additive gene action for ear components (ear number, kernel rows, and ear grain weight) could be useful in identifying quantitative trait loci. Being able to identify how these ear component affect consistent yield outcomes is valuable information for breeders and producers.

A more recent and ongoing study by Tianru Lan and colleagues "*QTL mapping and genetic analysis for corn kernel size and weight in multi-environments"* (Lan *et al.*, 2018), evaluated ear components of kernel length, width, thickness and weight over seven environments. They identified variation in these ear components due to population density changes. Using genetic mapping to identify novel plant characteristics and understand how these characteristics may change in various environmental situations, could be one of the next big advancements in modern agricultural.

The corn plant is an amazing production factory with many ways to compensate for changes in the growing environment in order to complete its primary task of developing and finishing grain on the ear. The complexity of corn production with the many management and seasonal influences on individual ear development is very interesting. Even though this experiment did not support my original hypothesis, this project created a better understanding and appreciation of corn production. There is limited information on the topic of individual parameters of ear development but this experiment does contribute to the information within this field.

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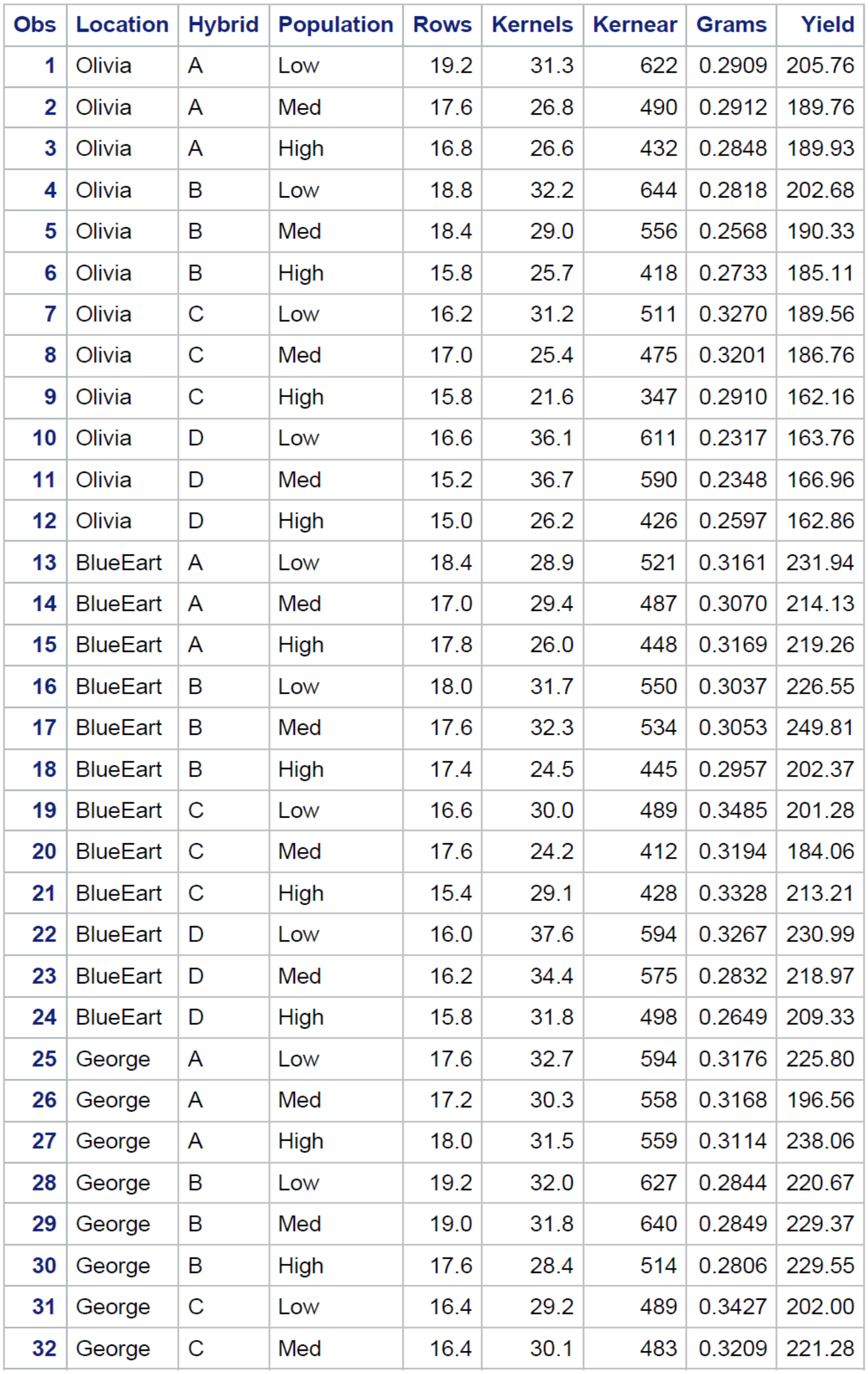
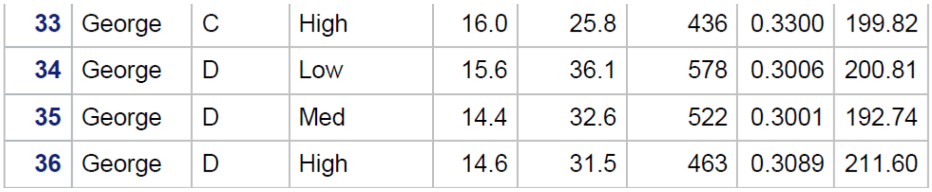
APPENDIX A

Mean experiment results by location, hybrid, and population in record format.



Obs	Location	Hybrid	Population	Rows	Kernels	Kernear	Grams	Yield
1	Olivia	A	Low	19.2	31.3	622	0.2909	205.76
2	Olivia	A	Med	17.6	26.8	490	0.2912	189.76
3	Olivia	A	High	16.8	26.6	432	0.2848	189.93
4	Olivia	B	Low	18.8	32.2	644	0.2818	202.68
5	Olivia	B	Med	18.4	29.0	556	0.2568	190.33
6	Olivia	B	High	15.8	25.7	418	0.2733	185.11
7	Olivia	C	Low	16.2	31.2	511	0.3270	189.56
8	Olivia	C	Med	17.0	25.4	475	0.3201	186.76
9	Olivia	C	High	15.8	21.6	347	0.2910	162.16
10	Olivia	D	Low	16.6	36.1	611	0.2317	163.76
11	Olivia	D	Med	15.2	36.7	590	0.2348	166.96
12	Olivia	D	High	15.0	26.2	426	0.2597	162.86
13	BlueEart	A	Low	18.4	28.9	521	0.3161	231.94
14	BlueEart	A	Med	17.0	29.4	487	0.3070	214.13
15	BlueEart	A	High	17.8	26.0	448	0.3169	219.26
16	BlueEart	B	Low	18.0	31.7	550	0.3037	226.55
17	BlueEart	B	Med	17.6	32.3	534	0.3053	249.81
18	BlueEart	B	High	17.4	24.5	445	0.2957	202.37
19	BlueEart	C	Low	16.6	30.0	489	0.3485	201.28
20	BlueEart	C	Med	17.6	24.2	412	0.3194	184.06
21	BlueEart	C	High	15.4	29.1	428	0.3328	213.21
22	BlueEart	D	Low	16.0	37.6	594	0.3267	230.99
23	BlueEart	D	Med	16.2	34.4	575	0.2832	218.97
24	BlueEart	D	High	15.8	31.8	498	0.2649	209.33
25	George	A	Low	17.6	32.7	594	0.3176	225.80
26	George	A	Med	17.2	30.3	558	0.3168	196.56
27	George	A	High	18.0	31.5	559	0.3114	238.06
28	George	B	Low	19.2	32.0	627	0.2844	220.67
29	George	B	Med	19.0	31.8	640	0.2849	229.37
30	George	B	High	17.6	28.4	514	0.2806	229.55
31	George	C	Low	16.4	29.2	489	0.3427	202.00
32	George	C	Med	16.4	30.1	483	0.3209	221.28



33	George	C	High	16.0	25.8	436	0.3300	199.82
34	George	D	Low	15.6	36.1	578	0.3006	200.81
35	George	D	Med	14.4	32.6	522	0.3001	192.74
36	George	D	High	14.6	31.5	463	0.3089	211.60