ABSTRACT

SCHMITT, KYLE. Experiments on Optimization of Corn and Sweet Corn Production through Cultural Practices in Eastern North Carolina. (Under the direction of Dr. Jonathan R. Schultheis and Dr. Ronnie W. Heiniger.)

Corn (*Zea mays*) and Sweet Corn (*Zea mays* L.) are both important crops in North Carolina. The goal of these experiments was to maximize yield through modification of cultural practices. Two experiments were focused on determining ideal plant population density for corn and sweet corn in the tidewater region of North Carolina. These experiments also investigated the effects of changing the way plants are oriented in the field through the use of the twin-row cropping system. The twin-row cropping system attempts to imitate the effects of closer row spacing without requiring a farmer to invest in the new equipment that is required to modify between-row spacing. A third experiment was completed which investigated the effect of short-term temperature stress on field corn ear quality.

The sweet corn population density experiment was completed in 2012 in Swanquarter, NC. The data that is represented is taken from two iterations of the experiment, which were planted 31 days apart. The plant population densities that were investigated in the sweet corn experiment were 29,640, 39,520, 49,400, 59,280, 69,160, and 79,040 plants ha^{-1}. The results indicate that the highest yields of high-quality sweet corn ears were found at the highest population density investigated in this experiment (79,040 plants ha^{-1}), with a predicted maximum yield occurring at a population density of 88,100 plants ha^{-1}. An economic analysis indicated that maximum revenue would occur at a population density 79,040 plants ha^{-1}, although decreasing economic returns are seen at high plant population densities. The use of twin rows did not significantly impact the yield of economically valuable ears when compared with single rows.

The field corn population density experiment was completed in 2013, and took place in Plymouth, NC. The data that is represented is taken from two iterations of the experiment, one planted in 2012 and one planted in 2013. The plant population densities that were investigated in the corn experiment were 44,460, 64,220, 83,980, 103,740, 123,500, and 143,260 plants ha^{-1}. Results from 2012 indicate that maximum yield of grain corn occurred a population density of 103,740 plantsha^{-1}, and a regression analysis indicated that maximum yield would occur at a population density of 98,426 plantsha^{-1}. Results from 2013 indicate that maximum yield of grain occurred a population density of 143,260 plantsha^{-1}, and a regression analysis indicated that maximum yield would occur at a population density of 118,643 plantsha^{-1}.

A greenhouse experiment was also completed which quantified the effects of short-term temperature fluctuation on corn ear quality. This experiment was performed at the Tidewater Research Station in Plymouth, North Carolina. One greenhouse and two growth chambers were utilized. The greenhouse was maintained at temperatures between 19°C and 29°C, with an ideal temperature of 24°C. One growth chamber was maintained at a temperature of 35°C, and another growth chamber was maintained at a temperature of 10°C. Twelve stages of corn growth were investigated in this experiment, grouped into six pairs: V5-V6, V7-V8, V9-V10, V11-V12, V13-V14, and VT-R1. After planting, the corn plants were allowed to grow until the majority of them were at the V5-V6 stage. Twenty-four of these plants were then designated ready for treatment: 8 went into the 10°C chamber, 8 went into the 35°C chamber, and 8 stayed in the greenhouse. They remained in this location for a total of 72 hours, after which they were returned to the greenhouse to develop. The plants were than allowed to mature, dry down, and were harvested. The results of this experiment

indicate that the size and quality of the harvested ear of corn is sensitive to temperature

fluctuations at the certain developmental stages.

Experiments on Optimization of Corn and Sweet Corn Production through Cultural Practices
in Eastern North Carolina

by
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DEDICATION

For anyone and everyone who puts family first in their life.

BIOGRAPHY

My name is Kyle Schmitt. I grew up in the panhandle of Florida. I did my undergraduate work at the University of Florida. After graduation, I began working primarily in molecular biology and ornamental breeding under the guidance of Dr. Kevin Folta, Dr. David Clark, and Dr. Thomas Colquhoun. I came to North Carolina in 2011 to begin learning about commercial production of horticultural and agricultural crops, under the guidance of Dr. Jonathan Schultheis and Dr. Ron Heiniger. The person I am today has been fundamentally shaped by these experiences and these people.

I've always been crazy, but it's kept me from going insane.

ACKNOWLEDGMENTS

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CHAPTER I. PLANT POPULATION DENSITY AFFECTS YIELD AND QUALITY OF FRESH-MARKET SWEET CORN IN THE SOUTHEASTERN UNITED STATES

Kyle Schmitt, Ronnie W. Heiniger, Gary Bullen, Christopher C. Gunter, and Jonathan R. Schultheis

Fresh market sweet corn (*Zea mays* L.) is an important crop in much of the United States, with 106,437 ha grown in 2012. The main objectives of this experiment were to determine the ideal plant population density for yield, quality, and economics. This experiment also investigated the use of twin rows as a possible method to increase yield. The experimental design was a split-split plot randomized complete block, with four replications per field test. This experiment was conducted in 2012, with two studies that were planted 34 days apart. The population densities evaluated in this study were 29,640, 39,520, 49,400, 59,280, 69,160, and 79,040 plants ha^{-1}. Harvested ears were graded and quality data were collected, with ears of lengths between 15.2 to 17.8 cm being 'select' and ears of length greater than 17.8 cm being 'premium'. The results of this experiment indicate that a plant population of 79,040 plants ha^{-1} produces the greatest quantity of both select and premium ears, and would generate the greatest revenue, although the increases in revenue become much smaller after increasing population density past 59,280 plants ha^{-1}. Ear quality suffers at the expense of increased yield, with increasing population densities resulting in shorter, lighter ears. The ideal plant population should produce a high yield, or more importantly revenue, while meeting the quality standards of the producer, and it appears that a plant population density of 59,280 plants ha^{-1} produces revenue similar to the higher population

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densities investigated, 69,160 and 79,040 plants ha^{-1}, without incurring any unnecessary decreases in ear weight and length, which decrease linearly for every increase in population density. The use of twin rows had a minimal impact on yield and quality when compared with single rows in this experiment.

Introduction

Plant populations, or densities, are an important factor to be considered in agricultural crop production. Plant population refers to how many plants are grown in a given area, usually reported as thousands of plants per ac or per ha. Plant populations affects yield in crops, with maximum yield occurring at the optimum planting density (Raymond, 2009). Plant population can also affect the quality of the crop, with some populations producing a more marketable final product than others (Rangarajan et al., 2002). The effects of population density on corn quality have been documented, with higher plant populations producing lighter weight ears of corn when compared to lower plant populations (Dungan et al., 1958), and increasing plant populations have also been shown to lead to a linear decrease in ear diameter and ear length (Colville, 1962). In the case of field corn, plant population even has an effect on the final milk yields of the cows to which it was fed (Cox and Cherney, 2001). The crop of interest to this study is sweet corn, which is grown and enjoyed many places in the United States, with 106,437 ha of fresh-market sweet corn planted in 2012 (USDA 2012). A study conducted in 1944 concluded that the ideal plant population for sweet corn was 54,340 plants ha^{-1} (Pickett, 1944), while another study completed in 1957 found that the ideal plant population was between 51,870 and 79,040 plants ha^{-1} (Wolf and Burdine, 1957). This experiment analyzes the effect of plant population density ('population') on fresh-market sweet corn yield and quality. Sweet corn populations can play an important role in determining marketable yield, and because of this it is important to determine at what population maximum economic yield can be achieved.

This is not the first study to examine the effects of plant population on fresh-market sweet corn yield (Morris et al., 2000; Rangarajan et al., 2002), but what sets this study apart from the previous sweet corn population studies that have been published is our interest in three key factors: secondary ear formation, the effects of 'twin row' planting in sweet corn systems, and the investigation of the economic considerations between yield and seed number ha^{-1}. Secondary ears are defined in this study to be any ear left on a corn stalk after the first ear has been harvested. Secondary ears on sweet corn stalks may or may not develop in a particular cropping system, and may or may not be harvested by the producer. A study published in 1967 found that the occurrence of multiple ears per corn stalk was greater at lower populations than at higher populations, and that there were more secondary ears produced during wet years than dry years (Andrew, 1967). It was a goal of this study to determine the effect population has on secondary ear formation using modern hybrids.

The twin-row planting system attempts to optimize the water use efficiency and nutrient uptake of a crop by simulating the effect of narrow row spacing without the requirement that a producer invest in a new tillage, cultivation, and harvesting equipment that would otherwise be necessary to make the change to narrower row spacing (Karlen and Camp, 1985). Crops such as cotton have seen increases in yield through use of the twin-row planting system (Oron, 1984). The twin-row planting system did not offer an advantage in sweet corn production in a previous study, however, due to advancements in germplasm and hybrid development, revisiting of the topic seemed prudent (Phene and Beale, 1979).

The objectives of this study were as follows: (1) quantify the effects of population on sweet corn yield using modern sweet corn hybrids in the southeast region of the United

States, (2) determine the effects of population on sweet corn secondary ear formation, (3) determine the effects that twin-row planting has on yield, (4) determine the effects that population has on ear quality, and (5) to determine the economic costs and benefits that result from changing population densities.

Methods

This experiment was conducted in two sites in 2012 in Swan Quarter NC, USA. The studies were separated by both location and time. The experiments were conducted at Tunnel Farms, where substantial commercial sweet corn acreage is located. The first site was planted on 10 April 2012 and harvested on 2 July 2012. The second site was planted on 14 May 2012 and harvested 23 July 2012. The first site was harvested 84 days after planting, and the second site was harvested 71 days after planting. The time separation between the planting and harvests of the two sites was intended to investigate any differences in quality and yield that might occur as a result of commercial operations staggered planting dates. These differences may be the result of earlier plantings experiencing cooler temperatures and less stresses than later plantings, which typically experience hot and dry growing conditions. There was a total of 35.2 cm of rainfall that occurred during the growing period of the first site (Figure 1), and a total of 54.2 cm of rainfall occurred during the growing period of the second site (Figure 2). For a table listing the daily precipitation, please refer to the appendix (Appendix, Table 1 and Table 2). The soil at the first site of the experiment was 100% Hydeland silt loam (Fine-silty, mixed, semiactive, thermic Umbric Endoaqualfs), and the soil of the second site of the experiment was 75.1% Scuppernong muck (Loamy, mixed, dysic,

thermic Terric Haplosaprists) and 24.9% Roper muck (Fine-silty, mixed, semiactive, acid, thermic Histic Humaquepts). Both of the experimental sites were managed in the same fashion: Nitrogen fertilization consisted of 268.0 kg ha^{-1} of ammonium nitrate applied at planting, and 234.2 kg ha^{-1} of ammonium nitrate applied at lay-by. Lay-by refers to the time period at which plants are becoming too tall to get normal equipment into the field to perform maintenance, and usually occurs about 30 days after planting, depending on equipment, which would put the date of application 10 May 2012 for the first site and 9 June 2012 for the second site. In addition, 67.4 kg ha^{-1} of Phosphorous and 67.4 kg ha^{-1} of Potash were applied before planting. For weed control, there was a 2.1 L ha^{-1} application of S-Metolachlor (Dual II Magnum®, Syngenta Crop Protection, Inc., Greensboro, North Carolina 27409), and a 0.842 kg ha^{-1} Lorox (Dupont^{TM} Lorox® DF, E.I. du Pont de Nemours and Company, Wilmington, Delaware, 19898) application.

The experiment was a randomized complete block split-split plot design, with four replications per experimental site. The populations chosen for the experiment were 29,640 plants ha^{-1} (29k), 39,520 plants ha^{-1} (39k), 49,400 plants ha^{-1} (49k), 59,280 plants ha^{-1} (59k), 69,160 plants ha^{-1} (69k), and 79,040 plants ha^{-1} (79k). The plots used in this study were 3.7 m wide and 9.1 m long, with 1.5 m between plots and 3.1 m between replications. The between-row spacing was 91.4 cm. For the single-row plots, the following in-row planting distances were used between plants (in cm): for the 29k population 36.6, for the 39k population 27.7, for the 49k population 21.8, for the 59k population 18.3, for the 69k population 15.8, and for the 79k population 13.7. For the twin-row plots, the plants were offset 7.6 cm from the row center. The following in-row planting distances were used between plants for the twin-row

plots (in cm): for the 29k population 73.2, for the 39k population 55.4, for the 49k population 43.4, for the 59k population 36.6, for the 69k population 31.5, and for the 79k population 27.2 (Table 1). The populations investigated in this experiment included the grower's current population, 59k, as well as higher and lower populations that also correlate with previous experiments conducted in a different region than this experiment (Morris et al., 2000). Two commercially available sweet corn hybrids were used, both of them of the shrunken2 endosperm type: 'Obsession' (Seminis Vegetable Seeds, Oxnard CA) and 'Garrison' (Syngenta AG, Wilmington DE). 'Obsession' is a bicolor variety, and 'Garrison' is a yellow hybrid, both of which mature at 79 days after planting. The plots were seeded using a Wintersteiger precision dynamic disc planter model 1401 (Wintersteiger Inc., Provo, UT). Plots were overseeded by 25%, and the plots were thinned to desired stand when most of the corn plants were at the V3 stage of corn growth (Iowa State University Extension, 2009; Nielsen, 2010), which occurred on 10 April 2012 for site 1 and 30 May 2012 for site 2.

All the data taken from this experiment were obtained from within the center two rows of each sub-plot. These rows were 9.1 m long, and the interior 6.1 m were used for data collection, as the ends of the plot were avoided to insure uniform competition between plants at each density and row treatment. The plants designated for harvest were marked with spray paint so that there would be no confusion where the data collection area began or ended. Each sub-plot was hand-harvested twice: the primary ears (defined as the single largest ear on the stalk) were harvested first, and then a second pass the same or following day through the plots was completed to harvest the secondary ears, which were defined as any ear left on the corn stalk after the removal of the primary ear that was equal to or greater than 15.2 cm

and without obvious defect. The primary ears were classified by length into three groups: ears less than 15.2 cm in length were 'culls', ears between 15.2 and 17.8 cm in length were 'select', and ears greater than 17.8 cm in length were 'premium'. Ear length was determined using a standard ruler and measuring from the base of the cob to the tip. It should be noted that the classification of corn into quality groups based on length is part of the USDA standards for sweet corn, but the stringency standards were higher in this study than the USDA requires: the highest grade of sweet corn ears are classified as 'U.S. Fancy' by the USDA, and only needs to be longer than 15.2 cm to meet this requirement (USDA 1992). The reason for the higher level of stringency for 'premium' status in these studies is based on the continuing consumer demand for higher quality produce, as well as the fact that the collaborating commercial grower in these studies produces high quality fresh-market sweet corn that easily exceeds the USDA guidelines. These primary ears were then counted and weighed according to that grouping. A subsample of five primary ears from each plot was then collected and used to determine ear quality. The secondary ears were classified into two groups by visual inspection, marketable or not marketable. The secondary ears classified as marketable were counted as one group, and the secondary ears classified as non-marketable were not harvested.

The quality data that were investigated in this experiment were ear length, ear width, ear weight, and the number of kernel rows per ear. Ear length was measured from the base of the ear to the tip using a ruler. Ear width was measured from the widest part of the ear, and was a measure of diameter and not circumference. Ear weight was determined using a digital scale. The number of kernel rows on the ear of corn was determined by visual analysis.

To determine the statistical significance of the independent variables in this experiment, the PROC ANOVA procedure was conducted using SAS 9.3. To evaluate the effects of population, row type, variety, and planting site, when significant, on premium ear yield, select ear yield, cull yield, secondary ear yield, ear length, ear width, ear weight, and kernel row number, the PROC MIXED procedure was conducted using SAS 9.3. The PROC GLM procedure was conducted using SAS 9.3 for regression analysis. The results are represented in two ways: when planting site did not have a significant affect, the data from the two sites were combined and run as one set. When planting site did have a significant affect, the results will be represented by planting site. Please refer to the ANOVA tables for specific significance levels (Appendix, Table 3 and Table 4).

Results

Population density was the only factor that influenced yield of the class of ears that were equal to or greater than 17.8 cm in length (Appendix, Table 3). The regression analysis completed on the class of ears that were 17.8 cm or greater indicated that the relationship between population and yield in ears ha^{-1} is quadratic, and the coefficient of determination (R^2=0.79) indicates that the model was statistically significant (Figure 3). As population density is increased, the yield of ears increases to a maximum. Based on the calculated regression formula, maximum yield of this classification of ear should occur at a population density of approximately 88,100 plants ha^{-1}, and would result in a yield of 62,292 ears that were greater than 17.8 cm. Based on the regression model, any increase in population density beyond 88,100 plants ha^{-1} results in a decreased yield of ears greater than 17.8 cm. Using least

squares means and the Tukey-Kramer procedure, the greatest yields of this classification ear were indeed obtained at the 79k population, the highest population density tested in this experiment, with a total of 60,967 earsha^{-1}, and the lowest yields were found in the 29k population, the lowest population density tested in this experiment, which produced 29,640 earsha^{-1} (Appendix, Table 5).

Population density and planting site were the only factors that influenced yields of the class of ears that were between 15.2 cm and 17.8 cm in length (Appendix, Table 3). The regression analysis completed on the class of ears that were between 15.2 and 17.8 cm indicated that the relationship between population and yield is linear (R^2=0.415) for the first planting site (Figure 4), and that the relationship between population and yield is quadratic (R^2=0.564) for the second planting site (Figure 5). For the first planting site, yield of this class of ear increased for every increase in population, which explains why the relationship between population density and yield is linear. For the second planting site, increasing plant population density did not result in a significant increase in the yield of this class of ear until the 59k population was reached, after which every increase in population density resulted in significant yield increases, which explains why the relationship between population density and yield is quadratic in the second planting site. Using least squares means and the Tukey-Kramer procedure, the 79k population produced the greatest number of this class of ears in both planting sites, with a total of 7344 ears ha^{-1}produced in the first planting site, and 7288 ears ha^{-1}produced in the second planting site (Appendix, Table 6). The 29k population consistently produced the fewest number of this class of ears for both planting sites, with 953

ears ha^{-1}produced in the first planting site and 449 ears ha^{-1}produced in the second planting site.

Population density, planting site, variety, and row type all influenced yields of secondary ears, and there was a significant interaction between population density and row type (Appendix, Table 3). Regression analysis completed on the yield of secondary ears indicated that the relationship between secondary ear yield and population is linear (R^2=0.583) for the first planting site (Figure 6), and that the relationship between ear yield and population is quadratic (R^2=0.789) for the second planting site (Figure 7). The fit of the regression model was very good for planting site 1, and excellent for planting site 2, based on the high values of the coefficients of determination. The greatest number of secondary ears were produced at low plant populations in the first site, and a fewer number of secondary ears were produced as plant populations increased (Appendix, Table 7). Similar to the first planting site, the greatest number of secondary ears in the second site were found in the lower plant populations densities. However, the response to an increase in populations differed between site 1 and site 2. Secondary ear production leveled off to less than 1000 ears ha^{-1}when the 59k population was reached. Variety also had a significant influence on the number of secondary ears produced, with 'Garrison' producing an average of 8848 ears ha^{-1} and 'Obsession' producing an average of 7277 ears ha^{-1} (Appendix, Table 8). Plants grown in single rows produced an average of 8262 secondary ears ha^{-1}and plants grown in twin rows produced an average of 7363 secondary ears ha^{-1} (Appendix, Table 9). The interaction effect between population density and row type indicates that at the lowest population used in these

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studies, there were more secondary ears produced in the single rather than twin rows (Table 2).

Population density was the only main factor that influenced yields of primary culls in this experiment, although there was a significant interaction between population density and planting site (Appendix, Table 3). Regression analysis completed on the yield of primary culls indicated that the relationship between primary culls and population is quadratic, but the model was not a very good fit (R^2=0.27) (Appendix, Figure 1). At population densities of 59k and below, the yields of primary culls were similar (Table 3). The greatest number of culls were produced at the 69k and 79k populations (Table 3). The interaction effect between population density and planting site is interesting, as there was not a significant planting site main effect. The results of the interaction demonstrate that the second planting site produced more primary culls than the first planting site at high population densities, while simultaneously tending to produce fewer primary culls than the first planting site at the lower population densities (Table 4).

Ear weight was significantly affected by population, variety, row type, and planting site, and there was a significant interaction between population density and planting site (Appendix, Table 4). The relationship between population density and ear weight was linear for both planting sites, with the weight of the ear decreasing as population density is increased, although the degree of model fit varies greatly between site 1 (R^2=0.0654) and site 2 (R^2=0.368) (Appendix, Figure 2 and Figure 3). In the first planting site, the heaviest ears were produced at the 39k population and weighed 253.1 g, while the lightest ears were produced at 59k populations or higher, and weighed between 230.2 g and 234.1 g (Table 5).

In the second planting site, the heaviest ears were produced at the 29k population and weighed 244.9 g, while the lightest ears were produced in the 79k population and weighed 210.2 g (Table 5). The 'Obsession' hybrid had a heavier ear than the 'Garrison' hybrid, with the ears from 'Obsession' plants weighing 239.4 g and ears from 'Garrison' plants weighing 224.8 g (Appendix, Table 10). Ear weight was greater for plants that were grown in the single-row cropping system than for ears that came from plants grown in the twin-row cropping system, with weights of 234.9 g and 229.3 g, respectively (Appendix, Table 11). The interaction effect between population density and planting site reinforces the main effects of the both population density and planting site implying that in this case, ear weight was more impacted by planting site than by population density (Appendix, Table 12).

Ear length was significantly affected by planting site, population density, and variety, and there were significant interactions between population density and variety as well as planting site and variety (Appendix, Table 4). The relationship between population density and ear length was linear for both planting sites, with the length of the ear decreasing as population density was increased, although the fit of the regression model is not high for site 1 (R^2=0.110) or site 2 (R^2=0.152) (Appendix, Figure 4 and Figure 5). In the first planting site ears with the greatest length were produced at the 29k population with a mean length of 20.5 cm, and ears with the shortest length were produced at the 79k population with a mean length of 19.9 cm (Table 6). In the second planting site, the longest ears were produced at the 29k population with a mean length of 21.7 cm, and the shortest ears were produced at the 79k population with a mean length of 20.7 cm (Table 6). The 'Obsession' hybrid had a longer ear than the 'Garrison' hybrid, with mean lengths of 21.3 cm and 20.1 cm respectively

(Appendix, Table 13). The results from the interaction between variety and population density and the interaction between variety and planting site help highlight the overwhelming importance of genetics in determining ear quality: at every population density the 'Obsession' hybrid had a longer ear than the 'Garrison' hybrid, and at both planting sites the 'Obsession' hybrid produced longer ears than the 'Garrison' hybrid (Appendix, Table 14 and Table 15).

Ear width was significantly affected by variety and planting site, and there was a significant interaction between population density and variety (Appendix, Table 4). Ears produced by the 'Obsession' hybrid had an ear width of 5.0 cm, and ears produced by the 'Garrison' variety had an ear width of 4.8 cm. Ears from plants grown in the first planting site had an average width of 5.0 cm, and ears from plants grown in the second planting site had an average width of 4.8 cm. The interaction between population density and variety indicates that the effect of variety is more important than the effect of population density, with the 'Obsession' hybrid, although not significant, producing a wider ear than the 'Garrison' hybrid in almost every case at corresponding plant densities (Table 7).

The number of kernel rows was significantly affected by hybrid, and there were significant interactions between population density and planting site as well as variety and planting site (Appendix, Table 4). 'Garrison' had 18.1 kernel rows per ear, and 'Obsession' had 17.4 kernel rows per ear. No other treatment factors were significant in determining the number of kernel rows per ear. Accurate interpretation of the interaction effect between population density and planting site is tenuous at best, as neither population density nor planting site were significant main effects (Appendix, Table 16). Interpretation of the

interaction effect between variety and planting site reinforces the varietal main effect: the 'Garrison' hybrid has a greater number of kernel rows than the 'Obsession' hybrid (Appendix, table 17).

Discussion

Ears longer than 17.8 cm have a quadratic relationship with population. The yield of this class of ears increased to a maximum, then will begin to decrease further with increasing population density. Assuming that this regression model is sound, the maximum number of this class of ear would be produced at a population of 81,700 plants ha^{-1}, and yield would then begin to decrease for every further population increase. The decrease in yield of ears of this length past the maximum population may be a result of the linear decrease in ear length as population increases.

The relationship between population and yield of the ears between 15.2 and 17.8 cm is linear in the first planting site and quadratic in the second planting site. Because the relationships are positive, every increase in population density should lead to an increase in yield of this class of ear. It is possible that the increase in yield of this classification of ears with increasing population density is related to the linear decrease in ear length with increasing population density. As populations increase, ear length decreases, resulting in smaller ears. Decreasing ear length as a result of increasing population is a trend that has been established by previous experiments, and the results of this study indicate that this relationship still holds true for modern fresh-market sweet corn hybrids (Coleville, 1962; Williams, 2012). Ears that had the potential to be longer than 17.8 cm at a lower population

density experience decreases in length as population is increased, resulting in a greater share of ears between 15.2 and 17.8 cm in length. In the first planting, excluding culls and secondary ears, only 3.2% of the ears produced at the 29k population were between 15.2 and 17.8 cm in length, compared with 10.7% of the ears produced at the 79k population that were between 15.2 and 17.8 cm in length. The results for the second planting are very similar, with 1.5% of the ears produced at the 29k population being between 15.2 and 17.8 cm in length, compared with 10.7% of the ears produced at 79k being between 15.2 and 17.8 cm, if culls and secondary ears are excluded.

The relationship between population and yield of secondary ears is linear in the first planting site, and quadratic in the second planting site. In both cases the relationship is negative, meaning that every increase in population density will result in a decrease in yield of secondary ears. The relationship between population and secondary ear production in this experiment was similar to findings previously established in a study completed in 1967, with increasing population density leading to decreased secondary ear formation (Andrew, 1967). In the study completed in 1967, it was established that secondary ear formation is also related to rainfall, with greater secondary ear formation occurring in drier seasons than in wetter ones. While these studies were completed in one season, the first planting received 19 cm less rainfall than the second planting. At every population investigated in these studies, more secondary ears were formed in the first planting than in the second planting: at the 59k population the difference between plantings was greatest, with the first planting producing 1665% more secondary ears than the second planting. While many factors could possibly vary between plantings in this experiment, a difference of 19 cm of precipitation makes a

strong case that the results of this experiment reinforce the conclusion reached by Andrew: less rainfall leads to more secondary ears being produced.

Population density has everything to do with resource competition, but it is not necessarily straightforward: increasing plant populations actually leads to an increase in the amount of leaf area produced per plant, which in turns leads to greater light interception per plant, but increasing plant population also leads to a significant delay in crop development, including delayed silk emergence (Williams, 2012). The decrease in secondary ear formation as populations are increased is definitely a result of plant competition, but perhaps not through a direct mechanism. As plant populations are increased, the plant must invest more heavily in vegetative growth, increasing its leaf area, but at the cost of reproductive growth, indicated by the delay in silk emergence that is an effect of increasing plant population. Increasing plant populations have also been shown to result in decreased kernel mass per ear as well as decreased kernel size (Lemcoff and Loomis, 1994). Increasing plant population is correlated with increased light uptake efficiency in corn, but also leads to a decrease or delay in many of the reproductive processes of the plant. The decrease in secondary ear formation as plant populations are increased is a result of this dichotomy between vegetative and reproductive growth, although the exact mechanism of action cannot be determined from these studies. The relationship between population and yield of primary culls is also related to competition. The quadratic relationship between population and yield of primary culls implies that every increase in population density will result in an increase in the yield of primary culls. This increase in primary cull yield is very likely related to the delay in silking experienced at higher plant populations. If silking is sufficiently delayed, poor pollination

will occur, leading to poor seed set (Lauer, 1998). Whatever the exact environmental cause may be, the relationship between increased primary cull yield and increasing plant population has been well documented (Pendleton and Seif, 1961; Andrews, 1967; Colville, 1962).

The use of twin rows did not have a significant effect on the yield of premium or select ears, but did have a significant effect on the yield of secondary ears. Studies that have been completed previously on corn and sweet corn have not found that significant yield increases can be achieved through the use of twin rows (Phene and Beale 1979, Robles et al. 2012, Novacek et al. 2013). Twin rows should theoretically reduce plant-to-plant competition and increase interception of photosynthetically active radiation (PAR) by the crop. Corn grown in the twin row system have been shown to intercept more PAR at early growth stages, but this advantage is lost as the plants achieve canopy closure later during their vegetative growth (Robles et al., 2012). Twin rows have been effective in increasing yields in some crops such as cotton (Oron, 1984), but the results of this experiment reinforce the lack of impact that the twin row planting system has on sweet corn yield. The only quality measure that was affected by the use of twin rows was ear weight. Ears from plants grown using twin rows weighed less than ears from plants grown using single rows. Ears from plants grown using single rows weighed 5.6 g more than ears from plants grown using twin rows. The yield of secondary ears was reduced through the use of twin rows compared to single rows: plants grown in twin rows produced 1399 fewer secondary ears ha^{-1}than plants grown in single rows. It has been established that secondary ear formation is affected by precipitation, with more rain leading to fewer secondary ears being produced. This result is an indication that the use of twin rows may reduce between-plant competition for water,

leading to more moisture uptake per plant, and a reduction in secondary ear yield, although there is not a significant increase in primary ear yield that accompanies this possible effect.

An economic analysis was completed using the data from this experiment, the goal of which was to determine which population density would produce the greatest revenue for a corn producer. For this analysis, no production costs were considered beyond the cost of the seed. It is important to note that these results are not intended to be an endorsement by the authors of modifying existing production practices by any producer. This experiment was completed in one season over two different time periods of the production season on highly fertile land and the corn was grown by an expert farmer. Each growing season and its production circumstances are unique to any given study. This experiment is no different, but we believe it will provide some guiding principles. In these studies, ears were classified into two groups: premium and select. The relationship between premium ear yield and increasing population density was quadratic, but the population densities investigated never reached a point at which the slope of that relationship became negative. The relationship between population density and yield of select ears was linear for one planting site and quadratic for another planting site, but in both cases, the relationship between increasing population density and increasing select ear yield was positive. These results imply that for every increase in population density, there is an increase in the yield of both premium and select ears. Ears classified as premium or select in this study both fall under the USDA guideline for 'U.S. Fancy', the highest grade of fresh market sweet corn in the United States. In 2011, a survey completed by the National Agricultural Statistics Service determined that the price received for fresh-market sweet corn was $26.60 per short hundredweight, which is a unit of

measure equal to 100 pounds (USDA, 2012b). The seed cost in this study was $7.24 per 1000

seed for the 'Obsession' hybrid, and $6.15 per 1000 seed for the 'Garrison' hybrid, with the

seed being sold in units of 100,000 for those particular prices. For the economic analysis, the

yield of premium and select ears, averaged between both sites, were combined to create the

number of ears that could be sold as 'U.S. Fancy'. Using combined yield and weight data, the

number of hundredweights produced per hectare was calculated, and the value determined

using the price of $26.60 per short hundredweight. From that crop value the cost of seed was

subtracted, to give a value that is useful for comparison, although this calculation does not

take into account the true costs of production (Figure 8). The percent increase in revenue

generated for each incremental increase in population density is also provided (Figure 8). For

this experiment, every increase in plant population would increase ear yield, with the 29k

population generating the smallest yields and the 79k population generating the largest

yields. While this experiment indicates that every increase in population density would result

in increased yield (Figure 3-5), ear weight and ear length decrease with increasing population

density (Appendix, Figures 2-5). As the weight of the ear decreases with increasing

population, the added value of additional ears also decreases in turn: more ears are required

at the 79k population to produce the unit of sale (the hundredweight) than at the 29k

population. There is a 24.9% increase in revenue that would be gained by increasing plant

populations from 29k to 39k, a 15.5% increase in revenue that would be gained by increasing

plant populations from 39k to 49k, a 9.8% increase in revenue that would be gained by

increasing plant populations from 49k to 59k, but only a 1.7% increase in revenue would be

gained by increasing plant populations from 59k to 69k. The diminishing returns of increased

revenue beyond the 59k population, combined with the decreases in ear quality that occur for every increase in population density, make the 59k population density the ideal population density for this particular experiment.

The results of this analysis are dependent on which market the ears would be sold to and at what price. This analysis uses USDA-collected average price data and USDA sweet corn standards to determine the value of the crop. This experiment was conducted at a location where the highest quality sweet corn is grown on contract for retailers very selective about quality, and the economic analysis was conducted with that in mind. Corn that will be sold at a roadside stand will have more variable quality standards than corn grown on contract for a major retailer, and the decreased weight of sweet corn ears produced at the 69k and 79k populations may not affect the value of the crop. The value of secondary ears produced in this experiment was also not considered in the economic analysis, as some producers may harvest all of them, some producers may selectively harvest them, and some producers may not harvest them at all. Secondary ears are considered to be of lower quality than primary ears, because they are generally smaller than the primary ear. The worst-case scenario for a sweet corn producer that grows on contract is the rejection of a load of sweet corn because quality standards were not met. If even a few low quality secondary ears are discovered during inspection at the receiving facility, the result could be the rejection of the whole load of otherwise perfect ears. Selective harvest of secondary ears requires faith in the ability of a harvest crew to determine which secondary ears will meet quality standards. Not every corn producer will have access to harvest crews with that level of experience, so some producers will choose not to harvest them at all. A producer growing sweet corn for sale at

local markets, such a roadside stand, may harvest and attempt to sell all of the secondary ears, which would affect what their own ideal plant population would be.

The results of this experiment are straightforward: increasing population density leads to an increasing yield of sweet corn ears that could be sold, with a corresponding decrease in the overall quality of the ear of corn. In the world of processing sweet corn, recent studies have indicated that maximum yield occurs at ultra-high population densities. An experiment conducted in Washington state in 2012 on irrigated processing sweet corn indicated that the highest yields of processing sweet corn were achieved at the ultra-high population density of 86,450 plants ha^{-1} (Waters et al., 2012). This result corresponds with the predictions of the regression analysis of this experiment: that maximum yield of ears greater than 17.8 cm would occur at a predicted ultra-high population density, 81,700 plants ha^{-1}in the case of this experiment. Had the focus of this experiment been on processing sweet corn, where ear quality is less of a factor in determining value, the recommendation of this experiment would be that a plant population density of 79,040 plants ha^{-1} would be ideal for this particular producer. This experiment was not conducted on processing sweet corn, however, and for fresh-market sweet corn, there are more factors at play at determining an ideal plant population than just yield.

The results of the economic analysis reinforce the findings of other experiments conducted on fresh-market sweet corn population density. A study conducted in the northeastern United States in 2001 on fresh-market sweet corn determined that the current population density recommendations for the region were too low, and that increasing population density from 34,600 plants ha^{-1}to 59,300 plants ha^{-1}resulted in increased yields

(Morris et al., 2000). A review of sweet corn production was produced for the state of North Carolina in 1994, and at the time period the ideal plant population for the state was suggested as 41,990 plants ha^{-1}. This publication suggested that increasing plant population to 59,280 plants ha^{-1} could result in increased yields over the current recommendation of the time (Schultheis, 1994). The results of these studies, combined with the economic analysis, confirm that a plant population of 59,280 plants ha^{-1}, given the current production practices and land used for this experiment, is likely the ideal fresh-market sweet corn population density for this producer.

The purpose of this experiment was to investigate the effect of population density on sweet corn yield and quality with the focus being on the fresh sweet corn shipping market. The results of this experiment indicate that the current plant population density of 59,280 plants ha^{-1} appears to be ideal for maximizing revenue without sacrificing quality. This experiment does not attempt to promote any particular plant population density as ideal for all sweet corn producers. Location, market, contract price, production costs, and other factors that vary by location and producer can all affect what the ideal sweet corn population will be. It is our hope that these results have been thought provoking, and that any sweet corn growers that read this paper will consider talking to their local extension agent about performing their own population density test to determine if their current plant population density maximizes their yield and revenue, while simultaneously ensuring their own quality standards are met.

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Table 1. Population densities investigated in this experiment and associated in-row spacing distance.

Population density	In-row spacing (cm)	
	Single row	Twin row
29,640	36.6	73.2
39,520	27.7	55.4
49,400	21.8	43.4
59,280	18.3	36.6
69,160	15.8	31.5
79,040	13.7	27.2

Table 2. Secondary ears produced per hectare, as affected by an interaction effect between population density and row type.

Population density	Number of secondary ears produced per hectare	
	Single Row	**Twin Row**
29,640	18725 a [Z]	13567 b
39,520	15922 ab	13006 bc
49,400	9015 cd	8746 cd
59,280	4261 e	4653 de
69,160	2130 e	2411 e
79,040	2523 e	1794 e

[Z]Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 3. Primary cull ears produced per hectare by different population densities.

Population density	Primary culls per hectare
29,640	1149 c [Z]
39,520	897 c
49,400	1233 c
59,280	1878 bc
69,160	3504 ab
79,040	4793 a

[Z] Means followed by the same letter are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Regression equation: $y = 4240.69 - 174.36(x) + 2.32(x)^2$; $R^2=0.270$

Table 4. Primary cull ears produced per hectare, as affected by an interaction between population density and study.

Population density	Number of primary culls produced per hectare	
	Study 1	**Study 2**
29,640	1570 cd^Z	729 d
39,520	1570 cd	224 d
49,400	1177 cd	1290 cd
59,280	2411 bcd	1346 cd
69,160	2130 cd	4877 ab
79,040	3532 abc	6055 a

^{Z}Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 5. Ear weight as affected by different planting densities.

Population density	Ear weight (g)	
	Study 1	Study 2
29,640	237.0 ab^Z	244.9 a
39,520	253.1 a	235.7 ab
49,400	244.0 ab	226.2 bc
59,280	234.1 b	223.4 bcd
69,160	230.2 b	216.5 cd
79,040	231.7 b	210.2 d

^{Z}Means followed by the same letter, in the same column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Regression equation, site 1: $y = 254.779 - 0.305(x)$; $R^2=0.0654$

Regression equation, site 2: $y = 263.676 - 0.688(x)$; $R^2=0.368$

Table 6. Ear length as affected by different planting densities.

Population density	Ear length (cm)	
	Study 1	**Study 2**
29,640	20.5 a ^{Z}	21.7 a
39,520	20.5 a	21.5 ab
49,400	20.2 ab	21.4 abc
59,280	20.2 ab	21.1 bcd
69,160	19.9 b	20.9 cd
79,040	19.9 b	20.7 d

^{Z}Means followed by the same letter, in the same column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Regression equation, site 1: y = 20.943 – 0.0138(x) ; R^2=0.110

Regression equation, site 2: y = 22.542 – 0.221(x) ; R^2=0.152

Table 7. Ear width as affected by an interaction between population density and variety.

Population Density	Ear width (cm)	
	Obsession	**Garrison**
29,640	5.1a [Z]	4.8 abc
39,520	4.9 abc	4.9 abc
49,400	5.0 ab	4.8 bc
59,280	4.8 bc	4.9 abc
69,160	5.0 ab	4.7 c
79,040	4.9 abc	4.8 abc

[Z]Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Daily Precipitation Site 1
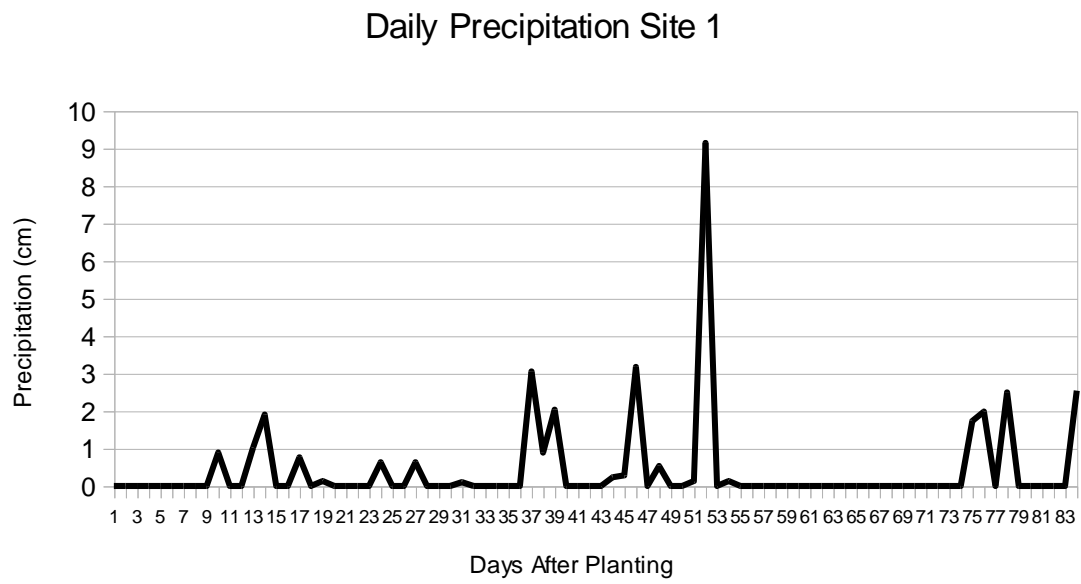
Figure 1. Daily precipitation for first planting site throughout growing period.

Daily Precipitation Site 2
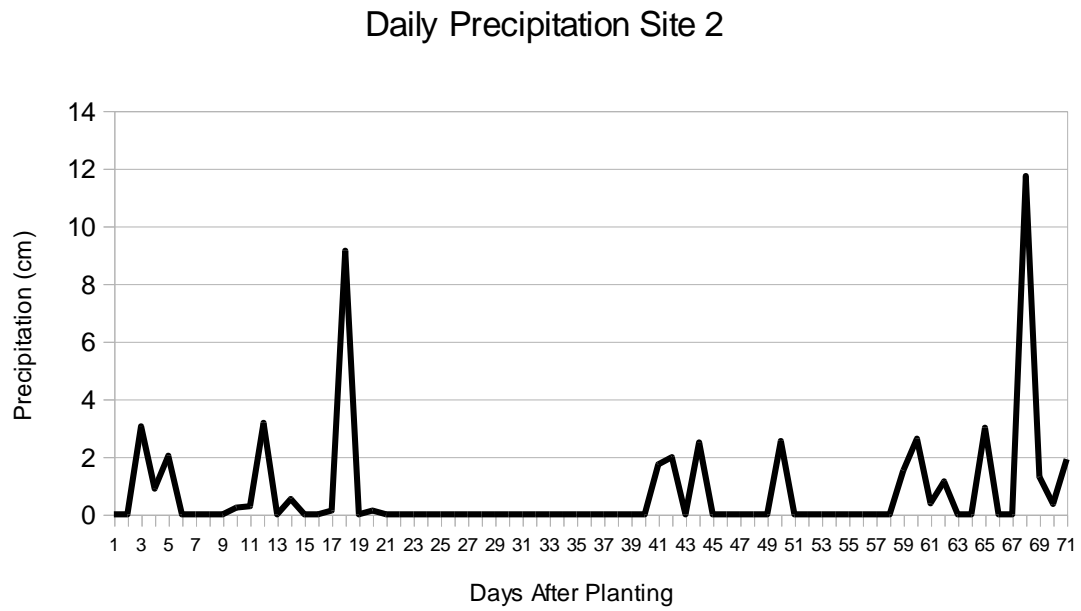
Figure 2. Daily precipitation for second planting site throughout growing period.

Effect of population density on yield of premium ears

$R^2 = 0.791$

$y = -13626.50 + 1723.35(x) - 9.78(x)^2$

Number of premium ears produced per hectare

Number of plants per hectare, in thousands

Fit   □ 95% Confidence Limits   − − − − 95% Prediction Limits
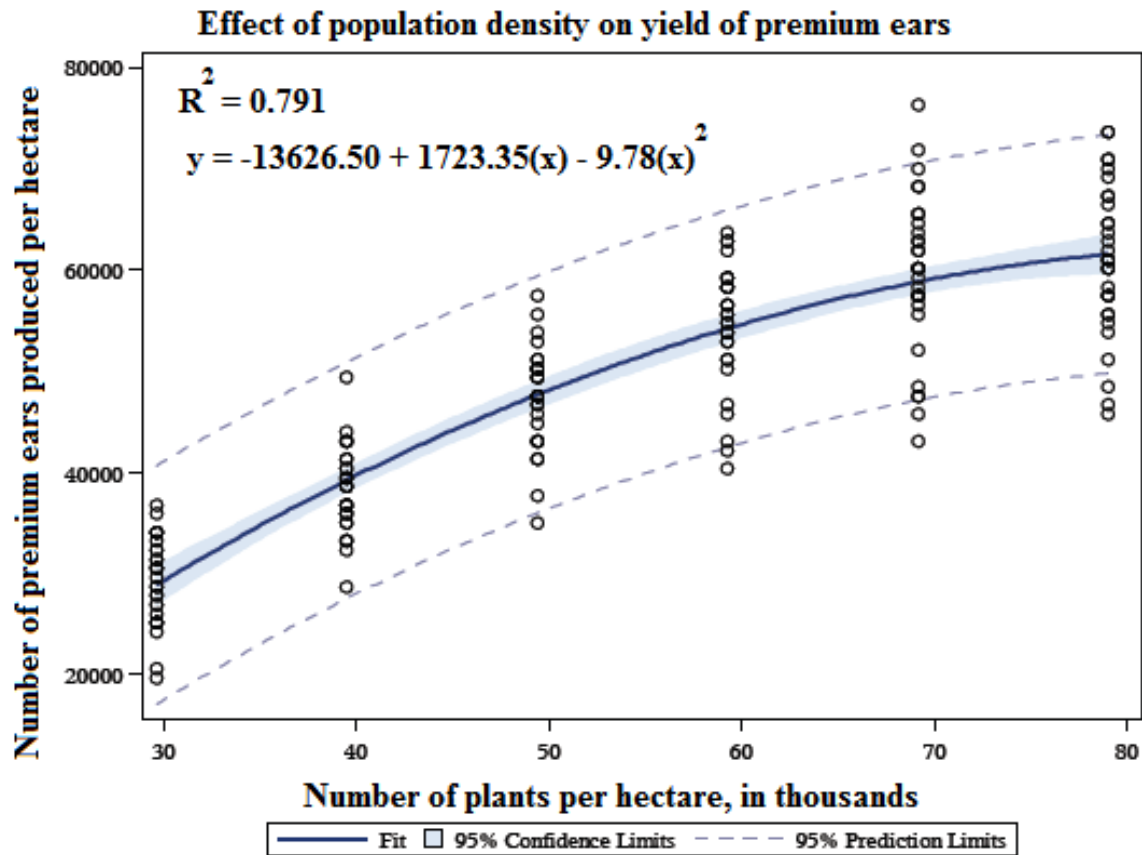
Figure 3. Yield of 'premium' ears (length 17.78 cm or greater) as affected by plant population density. Relationship is quadratic.
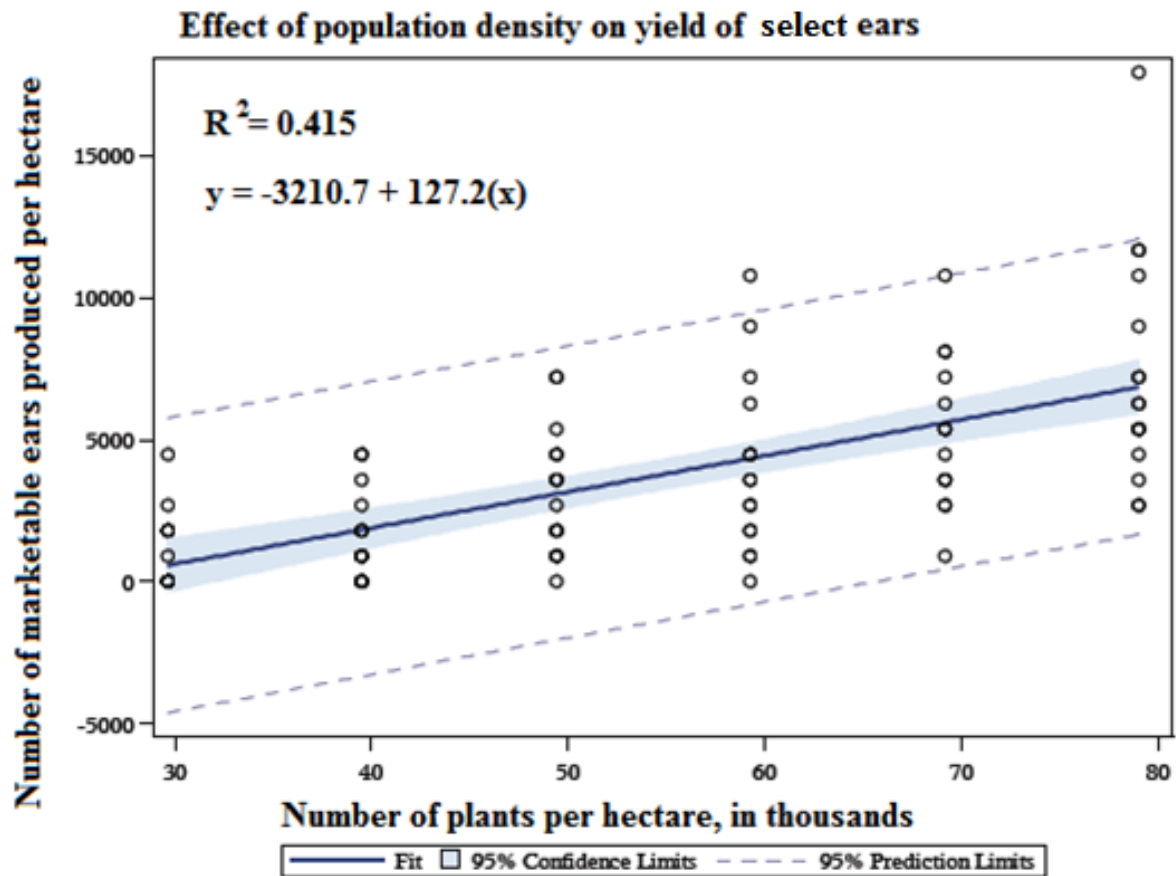
Figure 4. Yield of 'select' ears (length between 15.2 cm and 17.8 cm) as affected by plant population density, first planting site. Relationship is linear.
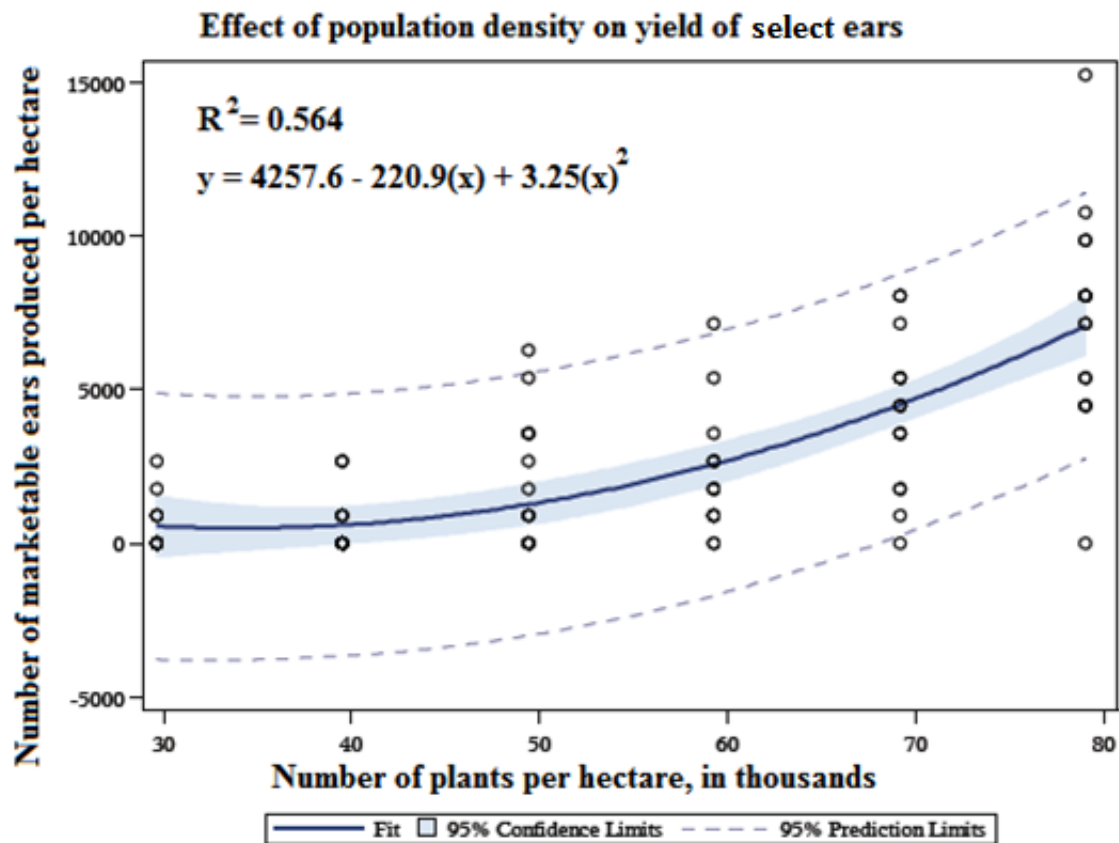
Figure 5. Yield of 'select' ears (length between 15.2 cm and 17.8 cm) as affected by plant population density, second planting site. Relationship is quadratic.

Effect of population density on yield of secondary ears

$R^2 = 0.583$

$y = 32133.7 - 375.9(x)$

Number of secondary ears produced per hectare (y-axis)

Number of plants per hectare, in thousands (x-axis)

Fit — 95% Confidence Limits — 95% Prediction Limits
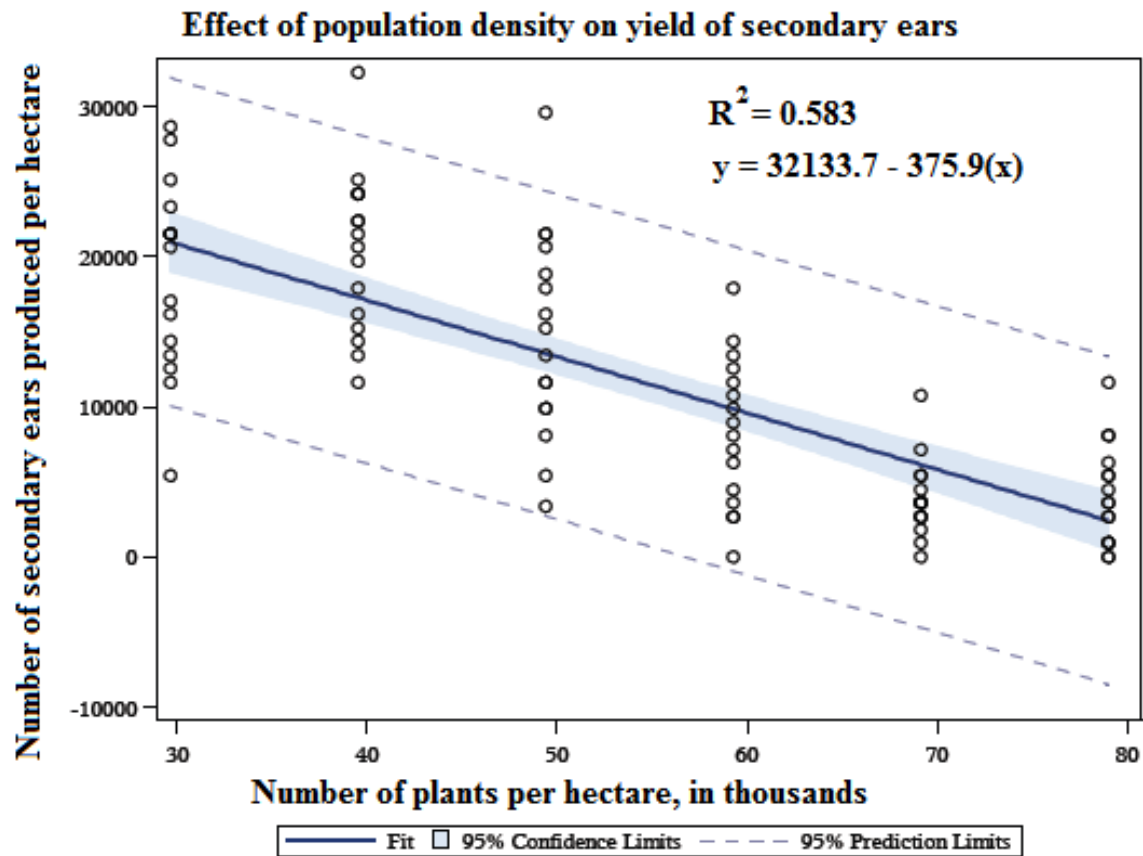
Figure 6. Yield of 'secondary' ears (length 15.2 cm or greater) as affected by plant population density, first planting site. Relationship is linear.

Effect of population density on yield of secondary ears

$$R^2 = 0.789$$
$$y = 43666.3 - 1254.2(x) + 8.9(x)^2$$
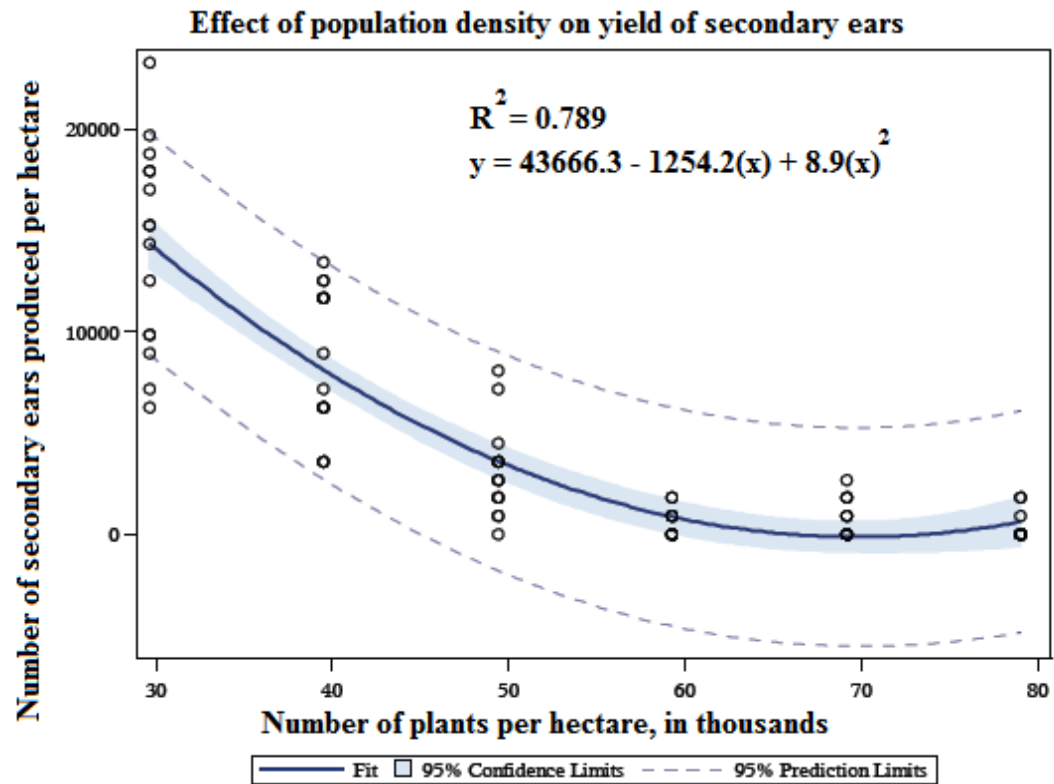
Figure 7. Yield of 'secondary' ears (length 15.2 cm or greater) as affected by plant population density, second planting site. Relationship is quadratic.

Revenue per hectare, minus cost of seed

Percent increase in revenue vs previous population
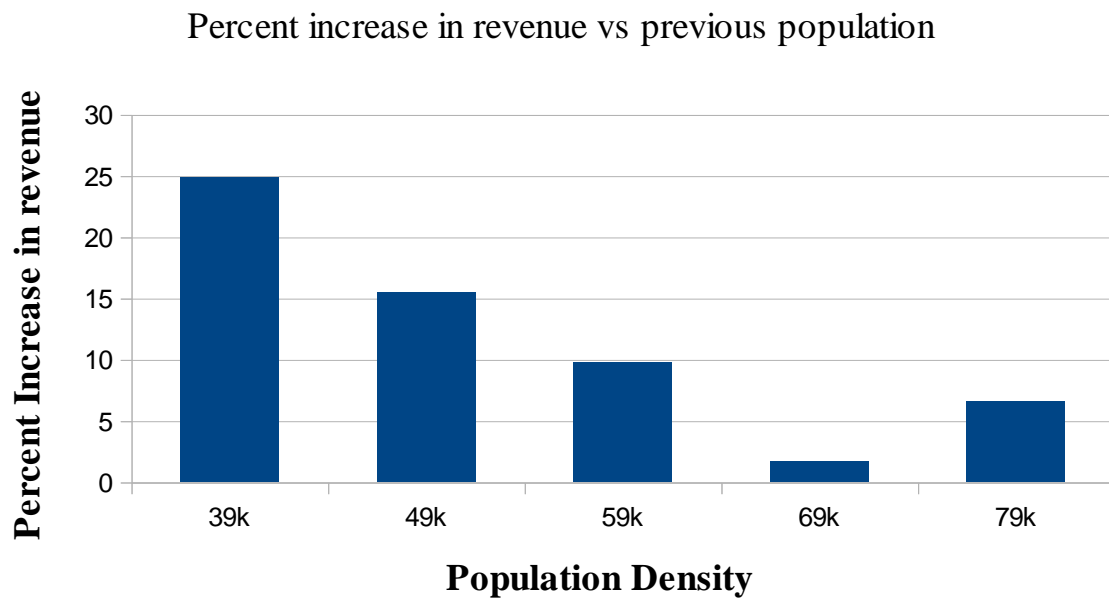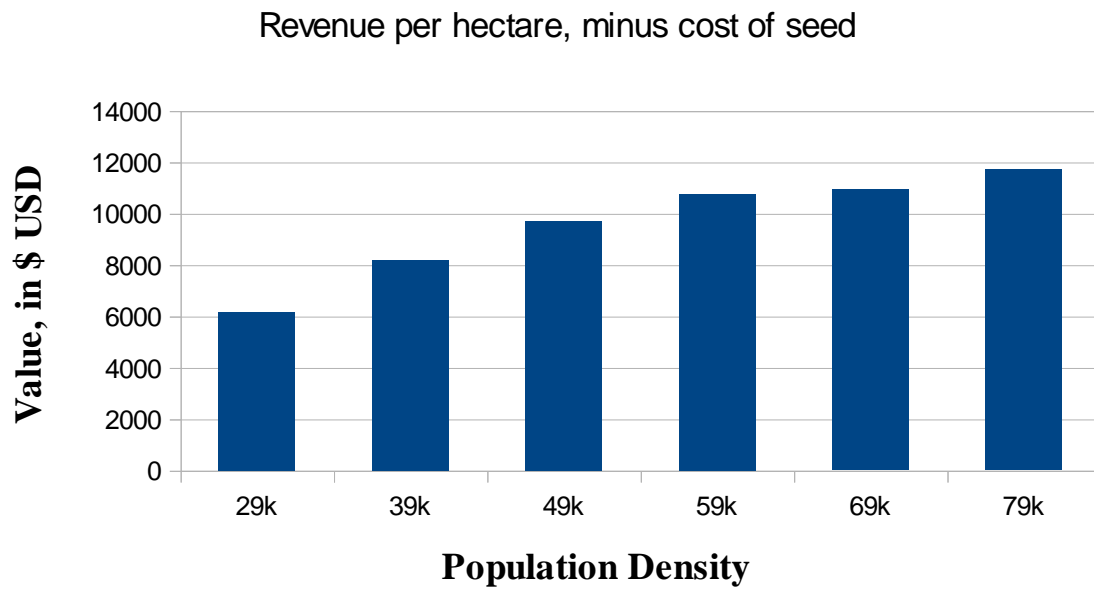
Figure 8. Results of economic analysis.

CHAPTER II. SHORT-TERM TEMPERATURE FLUCTUATIONS EFFECTS ON FIELD

CORN QUALITY

Kyle Schmitt, Jonathan R. Schultheis, Leah Boerema, Christopher C. Gunter, and Ronnie W.

Heiniger

Field corn (*Zea mays*) is an important crop worldwide, where over 39 million ha were planted in 2012, with an economic value of over $77 billion. This experiment focuses on the effects of short-term temperature fluctuations on corn ear quality. Short-term temperature fluctuations during certain periods of corn development could negatively affect corn ear weight and quality. In this experiment, corn plants were exposed to either hot, cold, or ambient temperatures for three days at different stages of development and then allowed to mature in ambient temperatures. After maturity, the ears were harvested and analyzed for size and quality differences. The leaf collar method was used for determining corn developmental stage, and is based on the number of leaf collars currently on the corn plant. This experiment investigated twelve corn growth stages, grouped in pairs: V5-V6, V7-V8, V9-V10, V11-V12, V13-V14, and VT-R1. Heat and cold stress at many of the growth stages investigated did not result in serious decreases in corn ear quality when compared with plants that did not undergo temperature stress, although heat and cold stress at the earliest and latest stages investigated produced drastic differences in final ear quality. Heat stress at the VT-R1 stage significantly decreased the length of the final ear of corn. Heat stress at the V5-V6 stage of corn growth resulted in the production of an ear of corn with poor kernel fill and low weight. Cold stress at the V5-V6 stage of corn growth resulted in significant delays in silk

emergence as well as low ear weight and poor kernel fill. The results of this experiment confirm that short-term temperature stress at the earliest (V5-V6) and last (VT-R1) stages of vegetative growth can both result in serious decreases in corn ear quality, while short-term temperature stress at other developmental growth stages had no effect on corn ear quality.

Introduction

Field corn is an important crop for many reasons, primarily because it is used as a key source of food for humans and other animals alike. Corn is also used in the production of ethanol for biofuel purposes (Tan et al., 2012), and polylactic acid made from corn can be used as a replacement for petroleum-derived plastics in some applications (Royte, 2006). There were more than 39 million ha of corn planted in the US in 2012, with an economic value of $77 billion (USDA, 2012a). With so much invested in this crop, failure of the corn to mature properly can be economically devastating to a producer. Unpublished observations from corn growers in the Midwest suggested that short-term temperature fluctuations during certain periods of corn development could negatively affect the final corn ear weight and quality. Work done previously in this area has determined that stresses during the pollination or grain filling periods tends to create the greatest reductions in yield (Gardner, 1981). Exposure to cold temperatures throughout growth leads to a decline in photosynthetic rate in corn, although the decrease is hybrid dependent (Lee and Estes, 1982). Unfortunately, there has been little research on the effects of short term temperature fluctuations which are more commonly found in the field. The goal of this experiment was to determine the effects of short-term, extreme exposure to either cold or hot air temperature at different growth stages on corn ear size and quality.

Corn goes through several developmental stages as it grows. In the current labeling system, the number of leaves with visible collars on the plant is used to determine the vegetative stage of the plant (Iowa State University, 2009). There are typically eighteen of these phases, represented by V1 through V18. Visible tasseling (VT) follows V18, and is

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defined as the final vegetative stage. After visible tasseling, there are six reproductive phases (R1 through R6), and silking is generally considered to mark the beginning of these stages (Nielsen, 2013).

As a corn plant develops, the number of stalk nodes on the plant increase as the apical meristem continues creating new tissue. The oldest and first initiated stalk node is located at the bottom of the plant, and the youngest stalk node is found at the top of the plant. It is worth noting that the number of stalk nodes does not correlate directly with the number of visible leaf collars at an early stage of corn growth: the apical meristem is usually done initiating all of the stalk nodes and leaf primordia of the corn plant by the V5 stage, months before the last visible collar will appear (Nielsen, 2007). At each stalk node, an axillary meristem develops. The axillary meristem is responsible for the initiation of husk leaves at the particular node as well as the eventual initiation of an ear of corn at that node. A corn plant actually produces many potential or primordial ears throughout its growth, with a potential ear typically located at every stalk node of the plant (Nielsen, 2007).

Initially, the ears on the lower nodes are larger than the ears on the upper nodes of the plant, because the lower nodes were initiated earlier in time than the upper nodes and have had more time to grow. As the plant continues to grow, the development of the ears on upper nodes is given priority over development of ears on lower nodes, so the ears on the lower nodes stay small while the ears on the upper nodes continue to develop. The reasons for this are suspected to be environmental, possibly due to the proximity of that particular ear to the most photosynthetically active part of the canopy. The biggest ear of the plant tends to be the uppermost ear on the plant, which will usually be found around the 8th and 10th stalk nodes.

This uppermost ear will also tend to have the greatest number of kernel rows found among any of the ear-bearing nodes on the plant (Alexander, 1952). The initiation of the topmost and final axillary meristem, which will produce what will become the largest ear on the plant, takes place at the V5 stage, very early in the plant's overall growth. (Nielsen, 2007). Understanding that the ear of corn that is harvested by a grower was actually started extremely early in the plant's life underscores the sensitivity of the corn plant to stresses during its early stage of growth. If the ear located at the final stalk node is stressed or damaged to the point of abortion, an ear will begin development on a node below it. This secondary ear will usually suffer from poor pollination due to being out of sync with pollen release, and therefore decreases in economic value (Lejeune, 1996).

A previous study that was published in 1996 investigated the effects of chilling temperatures (10°C) on ear abortion using a scanning electron microscope to determine immediate damage (Lejeune, 1996). In this experiment, plants were grown under standard conditions until the plants reached V5 or V8. When they reached the prescribed stage, they were exposed to the 10°C for 7 days, then were examined for aborted axillary meristems. Cold treatment at both the V5 and V8 stage increased the percentage of aborted axillary meristems, with the V8 stage being more sensitive than the V5 stage to cold-induced ear abortion.

The goal of this experiment was to determine the effects that short-term air temperature fluctuations have on the size and quality of the final, harvested ear of corn. In this experiment, corn plants were exposed to either heat stress, cold stress, or ambient greenhouse temperatures for three days at different stages of growth and then allowed to

mature in ambient temperatures. After maturity, the ears were harvested and analyzed for size and quality differences. The parameters of interest were ear length, ear weight, the number of kernel rows on the ear, the number of days after planting it takes a plant to begin to silk, and the percentage of kernels on the ear that filled.

Methods

This experiment was conducted at the Tidewater Research Station in Plymouth, North Carolina. The experiment consisted of two greenhouse growth chamber studies, each arranged using a randomized complete block design with four replications per study. The first study was planted on 6 Jan 2012 and was harvested on 19 Apr 2012, which was 104 days after planting. The second study was planted on 20 Jan 2012 and was harvested on 17 May 2012, which was 118 days after planting.

One greenhouse and two growth chambers were utilized. The greenhouse was maintained at temperatures between 19°C and 29°C, aiming at an ideal temperature of around 24°C. One growth chamber was maintained at a temperature of 35°C, and the other growth chamber was maintained at a temperature of 10°C. The growth chambers were constructed using standard pressure treated wood insulated with a transparent sheet of plastic. The dimensions of the chamber were: 2.4 m wide, 2.4 m long, and 4.3 m high. The 35°C chamber was kept at that temperature with the use of a 240V, 4,200 watt electric heater, controlled by an analog thermostat, placed inside the chamber with the plants being treated. The 10°C chamber that was held at that temperature with the use of a 120V, 10,000 BTU window air conditioning unit, also controlled by an analog thermostat.

Twelve stages of corn growth were investigated in this experiment: V5, V6, V7, V8, V9, V10, V11, V12, V13, V14, VT, and R1. These twelve stages were grouped into pairs out of a desire to investigate as many growth stages as possible, stay within the constraints of our infrastructure, and as a defense against slightly asynchronous growth rates between the two varieties. Corn that was temperature treated at either the V5 or V6 stage of growth was grouped into the V5-V6 unit. The same was done with corn that was treated at the V7 or V8 stages, grouping them into the V7-V8 unit. In all, there were six groupings: V5-V6, V7-V8, V9-V10, V11-V12, V13-V14, and VT-R1.

Two varieties of corn were investigated in this experiment: Dekalb 'DKC 68-44' and Dekalb 'DKC 69-72'. Dekalb 'DKC 68-44' was selected for use in this experiment as it had been previously been reported this variety was sensitive to low temperatures, while Dekalb 'DKC 69-72' was selected as it had been identified as having high adaptability to North Carolina growing conditions (Nielsen, personal communication). For each study, 144 plants were tested, or 24 plants per investigated stage. The seeds were planted in 11.4 L pots, with 3 seeds of the same variety per pot. The potting media consisted of a house-mixed substrate containing sand (65%), peat (25%), perlite (5%), and vermiculite (5%). Two weeks after planting, the seedlings were thinned to 1 plant per pot, discarding the excess seedlings. The plants were allowed to grow until the majority of them were at the V5-V6 stage, which occurred on 20 Jan 2012, or 45 days after planting, for the first study, and on 24 Feb 2012, or 35 days after planting, for the second study. Twenty-four of these plants, 12 of the 'DKC 68-44' variety and 12 of the 'DKC 69-72' variety, were then marked on their topmost leaf with the relevant stage, written in permanent marker. Of these twenty-four plants marked as being

at the correct stage for treatment, 8 plants went into the cold growth chamber (4 'DKC 68-44' plants, 4 'DKC 69-72' plants), 8 went into the hot growth chamber (4 'DKC 68-44' plants, 4 'DKC 69-72' plants), and 8 stayed in the greenhouse (4 'DKC 68-44' plants, 4 'DKC 69-72' plants). They remained in this location for a total of roughly 72 hours. The movement of plants into the growth chambers happened on Friday morning of any week that plants were ready, and the plants were returned to the main greenhouse the following Monday morning and allowed to develop in the greenhouse without encountering any further temperature extremes. This continued on weekly intervals as the plants grew into the appropriate stages, which averaged approximately a stage per week, and ending with the VT-R1 stage. The plants were then allowed to mature, dry down, and were harvested.

The corn was harvested and shucked by hand. The length of the ear was measured with a ruler from base of the cob to the tip. The weight of the ear was determined through the use of a digital scale. The number of kernel rows on each ear of corn was counted by hand. Percent kernel fill was also calculated in the following manner: four kernel rows were chosen per ear of corn, with each kernel row as equidistant from the other three as possible. The total number of properly developed kernels per row were counted, as well as the number of kernels on that row that did not develop. The number of developed kernels were added together from the four rows, and then divided by the sum of the developed and undeveloped kernels across the four rows and multiplied by 100 to give the percentage of kernels that were filled on the ear.

To evaluate the effects of the temperature treatment at the given stage on ear length, ear weight, the number of days from planting until silk emergence, the percentage of kernels

that filled on the ear, the number of kernel rows on the ear, the PROC MIXED procedure (SAS 9.3, SAS Inc., Cary, NC) was used to determine significant differences. Mean separation was achieved through the use of the Tukey-Kramer procedure.

Results

The length of the ear of corn was significantly affected by study, treatment, and variety, and there were significant interactions between treatment and study, study and variety, and an interaction between study, treatment, and variety (Table 1). The result of the three way interaction between treatment, variety, and study helps show the similarity between hybrids within the each study (Figures 1-4). In the first study, the longest ears came from plants exposed to the heat stress at V7-V8 (21.4 cm), although this was not significantly different from the control (21.1 cm) (Table 2). In the second study, the longest ears came from plants exposed to cold stress at V13-V14 (20.3 cm), although this was not significantly different from those cold or heat stressed at all growth stages, the exception being those heat stressed at VT-R1 (Table 2). In both studies, the shortest ears were found on the plants that underwent the heat treatment at the VT-R1 stage (15.6 cm). In both studies, the next shortest ears were from groups that received heat treatment at the V11-V12 and V13-V14 stages, and ears that were treated at the V5-V6 stages in either the hot or cold chambers (Table 2). There were varietal differences as well, with 'DKC 69-72' being longer than 'DKC 68-44', with respective lengths of 20.7 cm and 17.0 cm (Table 3). The interaction effect between study and treatment shows that, in general, ear length was numerically greater in the first study than in the second, if the same treatments are compared (Table 4). The results of the

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interaction between study and variety demonstrate that there was not a significant difference in average ear length between studies for 'DKC 68-44', while there was a significant difference in average ear length between studies for 'DKC 69-72' (Table 5).

The weight of the ear of corn was significantly affected by treatment, and there were significant interactions between treatment and study, as well as study and variety (Table 1). The heaviest ears in this study came from plants exposed to the cold treatment at V13-V14 (225.3 g), although these ears were not significantly different from the control (214.2 g) (Table 2)(Figure 5). The ears on the plants that underwent heat treatment at the V5-V6 stage (147.4 g) produced the lightest ears and were significantly different from the control treatment (Table 2). The only other treatment that differed significantly from the control was the high temperature treatment at VT-R1 (157.6 g) (Table 2)(Figure 5). The result of the two way interaction between treatment and study indicates that ears from the second study weighed numerically more than the first study, given the same treatment, in most but not all cases and that the only significant effect in the second study was an increase in ear weight for the cold treatment applied at V13-V14 (Table 6). The result of the two way interaction between variety and study reveals that the average weight of 'DKC 68-44' was significantly different between study 1 and study 2, while the average weight of 'DKC 69-72' was not significantly different between studies (Table 7).

The number of days from planting to silking stage was affected by treatment, study, and variety, and there were significant two way interactions between treatment and variety, treatment and study, as well as between study and variety (Table 1). Plants from the first study took longer to reach the silking stage than plants from the second study, given the same

treatment, with plants from the control group taking 82.6 days to reach the silking stage in the first study and 78.8 days to reach the silking stage in the second study (Table 2). The maximum difference in time that it took the plants to reach the silking stages among treatments was also different between studies: 8.6 days for the first study, and 6.4 days for the second study (Table 2). In both studies, plants that underwent cold stress at the V5-V6 stage of growth took the longest amount of time to reach the silking stage, with plants treated in this way taking 90.6 days to reach the silking stage in the first study, and 81.5 days in the second study (Table 2)(Figures 6-9). The number of days required to reach the silking stage also differed by variety, with 'DKC 68-44' taking an average of 81.7 days to reach silking, and 'DKC 69-72' taking an average of 82.6 days to reach silking (Table 3). The interaction effect between study and treatment demonstrates that for every treatment, it took longer to reach the silking stage in the first study than the second study (Table 8). The interaction effect between treatment and variety demonstrates that, given the same treatment, 'DKC 69-72' tends to take longer to reach silking than 'DKC 68-44', with two exceptions: heat stress at the V11-V12 stage, and cold stress at the V5-V6 stage (Table 9). The results of the interaction between study and variety indicate that the average time required to reach silking in the first study was the same for both hybrids, 86.4 days, and that in the second study the average time required to reach the silking stage was different between varieties, with 'DKC 68-44' taking 77.0 days to reach silking, while 'DKC 69-72' took 78.8 days to reach silking (Table 10).

The percentage of kernels on the ear that were properly filled was affected by treatment, and there was a significant variety by treatment interaction as well as a three way

interaction between study, variety, and treatment (Table 1). The greatest percentage of kernels were filled on ears from plants that were exposed to cold treatment at the VT-R1 stage (74.4%) (Table 2)(Figure 10). This was not statistically different from plants that were exposed to cold at the V13-V14 stage or the control (72.2% and 68.8% respectively) (Table 2). The lowest percentage of kernels were filled on ears from plants that were exposed to heat treatment at the V5-V6 stage (48.6%) (Table 2). When the variety by treatment interaction is investigated, the main difference that is apparent is how drastically the kernel fill differs between varieties when they are exposed to heat treatment at V5-V6 (Table 11). 'DKC 69-72' had only 29.6% kernel fill when placed in the hot chamber at the V5-V6 stage, and 'DKC 68-44' had 67.7% kernel fill when treated at the same stage (Table 11). There were no other significant differences between varieties, given the same treatment, other than the heat treatment at the V5-V6 stage (Table 11). The result of the three way interaction between treatment, variety, and study, while statistically significant, does not add any additional information that is not represented by the results of the significant main effects and two way interactions.

The number of kernel rows on the ear was affected by variety (Table 1). The number of kernel rows that will occur on the ear is determined before the V5 stage. The treatments applied in this experiment took place at the V5 stage onward, so the number of kernel rows would not be affected by the treatment. The number of kernel rows was different between hybrids, with the 'DKC 68-44' averaging 17.2 kernel rows per ear and 'DKC 69-72' averaging 15.0 kernel rows per ear (Table 3).

Discussion

The length of the ear of corn was significantly affected by the treatments applied. The results suggest that heat stress at the later stages of development investigated in this experiment (VT-R1, V11-V12, V13-V14) are most detrimental to ear elongation, and results in a shorter ear of corn. In both studies, heat treatment at the VT-R1 stage lead to the shortest ears, and in both studies heat treatment at the V11-V12 and V13-V14 stages resulted in ears that were statistically similar to the ear length of plants placed in the hot chamber at the VT-R1 stage. The results also suggest that heat stress at the earliest stage investigated (V5-V6) may also be detrimental to ear elongation, as some of the next shortest ears came from that group in both studies. These results may seem contradictory – that the shortest ears come from plants that were either stressed at the beginning or the end of vegetative development, but not the middle stages. The most likely explanation is that heat stress at the early stage of growth affected the number of ovules formed on the ear resulting in a shorter cob, while heat stress at the latter stages led to abortion of ovules or poorly developed ovules. It may also seem unusual that stresses at the V5-V6 stage should lead to a decrease in ear length, while the ears from plants that underwent heat stress at the V7-V8 stage did not suffer the same decrease in length. The primary ear primordia has been created at the V5 stage of growth, and has weeks to develop before the V8 stage of growth. It is possible that in the time it takes the corn plant to go from V5-V6 to V7-V8, the primordial ear has become less sensitive to temperature-induced kernel loss since the ovules are already formed and just starting to develop.

The weight of the ear of corn was also significantly affected by the treatment applied. The lightest ears originated from plants that were placed in the hot chamber at the V5-V6 stage (147.4 g). The next lightest ears were from plants that were placed in the hot chamber at the VT-R1 stage (157.6 g). Both of these treatments were statistically different from the control (214.2 g). Much like with ear length, we see the greatest decreases in ear weight when stress is applied at the earliest and latest stages that were investigated. The weight of the ears is a factor of both the cob length as well as the number of kernels developed on the cob. The most likely explanation is that the heat stress applied at the V5-V6 stages caused less ovules to be formed and a shorter cob. This treatment could also have resulted in desynchronization of pollination. This delay in silk emergence could lead to poor pollination and a loss of kernels. Plants heat stressed at the V7-V8 stage did not differ in ear weight from the control, again emphasizing the idea that some physiological change has occurred between V5 and V8 that makes the primordial ear less sensitive to damage or abortion. The low weight of the ears from plants heat stressed at the VT-R1 stage is most likely due to heat-induced damage of the emerging silks, which resulted in poor pollination. This finding reinforces the results of a previous study that determined heat stress during the pollination period can have a negative impact on grain yield (Gardner et al., 1981). This is supported by the fact that the heat treatment at VT-R1 had a low percentage of filled kernels. The possibility that the physical isolation from the majority of the other plants during silk emergence led to poor pollination and low weight is another explanation, but the plants cold-stressed at the VT-R1 underwent the same physical isolation at the same stage and did not differ in weight from the control, making that explanation unlikely.

The number of days it took the plants to go from planting date to silk emergence was also significantly affected by the treatments that were applied. Plants that experienced cold stress at V5-V6 were the group that experienced the greatest time delay in initiation of silking in both studies, with silk emergence delayed 8.0 days in the first study and 2.7 days in the second study, compared with the control. Plants that were placed in the hot chamber at the V5-V6 stage also experienced large time delays when compared with the other treatments, with plants placed in the hot chamber at V5-V6 being statistically similar to those that were placed in the cold chamber at the same stage. As mentioned earlier, temperature stress at the V5-V6 stage appears to have the detrimental effect of desynchronizing silk development, resulting in fewer ovules pollinated.

Kernel fill was also affected by the treatment applied. The ears which had the lowest percentage of filled kernels were from plants placed in the hot chamber at the V5-V6 stage, followed by ears from plants placed in the hot chamber at the VT-R1 stage. Only the ears from plants placed in the hot chamber at the V5-V6 stage were significantly different than the control. Kernel fill is directly related to ovule development and pollination efficiency. It appears that heat stress at the V5-V6 stage induces ovule formation resulting in malformed or missing ovules. In comparison, heat stress at VT-R1 results in poor pollination which affected kernel development and fill. This result also corresponds with the results of a previous study that determined heat stress during the pollination period can have a negative impact on grain yield (Gardner et al., 1981). The results also indicate that 'DKC 69-72' has a much lower percentage of filled kernels than 'DKC 68-44' when exposed to heat stress at the

V5-V6 stage (29.6% and 67.7% respectively). This result suggests that there is a difference in sensitivity to heat damage at the V5-V6 stage that is genetic.

There were significant interactions between studies and variety for several variables investigated in this experiment: ear length, ear weight, and the number of days it takes the corn plant to reach the silking stage. In the cases of ear length and days until silking, study was a significant main effect, while for the variable ear weight, study was not a significant main effect. The two studies were separated in time, with the first study planted on 6 Jan 2012 and the second study planted on 20 Jan 2012. Harvest occurred 104 days after planting for the first study, and 118 days after planting for the second study. In terms of ear length, this study by variety interaction indicates that 'DKC 68-44' had a longer ear in the second study than in the first by 0.6 cm, while 'DKC 69-72' had a longer ear in the first study than the second study by 1.7 cm. While statistically significant, these length differences are small in comparison to the difference among treatments, with a maximum length difference of 5.8 cm for the first study and 4.7 cm for the second study. The number of days it takes a plant to reach the silking stages was also affected by an interaction between variety and study, with 'DKC 68-44' taking 9.4 days longer to reach the silking stage in the first study than the second study, and 'DKC 69-72' taking 7.6 days longer to reach the silking stage in the first study than the second study. Ear weight was also significantly affected by an interaction between study and variety, with the average weight of 'DKC 68-44' being greater in the second study than the first, while the average weight of 'DKC 69-72' was similar between studies.

There were significant differences between studies in this experiment for some variables, especially the number of days required to reach the silking stage. The second study may have received greater light intensity than the first study because it was planted two weeks later than the first study in a time period when light intensity is increasing in the United States, which could result in between-study differences. In the first study, plants placed in the cold chamber at V5-V6 took 90.6 days to reach the silking stage, compared with 81.5 days in the second study, but these exact numbers aren't important: what is important is that cold stress at V5-V6 resulted in corn plants that took much longer to reach the silking stage than the other treatments for both studies.

The results of this experiment clearly indicate that the size and quality of the harvested ear of corn is highly sensitive to temperature fluctuations at the certain stages of development. Plants that underwent heat stress at V5-V6 consistently produced lighter ears with inferior kernel fill. Cold stress at the V5-V6 stage led to significant delays in silk emergence. Temperature stress was also detrimental to overall ear quality when applied at the later stages of vegetative growth, especially at the VT-R1 stage. Heat stress at the VT-R1 stage resulted in significantly shorter ears with poor kernel fill and low weight. While the results indicate that many of the treatments were not statistically different from the control, it cannot be denied that temperature stress at the earliest and latest stages of growth investigated in this experiment led to the greatest decreases in corn ear size and quality. Temperature stress is an inevitability of commercial agriculture, but timing makes all the difference: a hot spell during the V7-V8 stage of growth may cause no detrimental effects,

while the same heat stress at the V5-V6 stage could induce catastrophic results for a corn

grower.

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Table 1. Analysis of varianceresults for the significance of independent variables.

Source of variance	Degrees of freedom	Ear length	Ear weight	Number of days to silking stage	Percent kernel fill	Number of kernel rows
				Prob > F		
Study	1	<.0001	0.5	<.0001	0.1	0.06
Treatment	12	<.0001	<.0001	<.0001	0.02	0.5
Variety	1	<.0001	0.1	<.0001	0.07	<.0001
Treatment * Variety	12	1.0	0.09	0.007	0.0005	0.3
Treatment * Study	12	0.005	<.0001	<.0001	0.3	0.3
Study * Variety	1	0.0004	0.03	0.005	0.3	0.7
Treatment * Variety * Study	12	0.002	0.09	0.7	0.01	0.2

Table 2. The effect of short-term temperature fluctuation on greenhouse-grown field corn quality. When study is significant, results are presented by study.

Treatment	Length of ear (cm)		Weight of ear (g)	Days to silking stage		Kernel fill percentage (out of 100%)	Number of kernel rows
	Study 1	**Study 2**		**Study 1**	**Study 2**		
Control	21.1 a ^{Z}	18.6 a	214.2 a	82.6 e	78.8 ab	68.8 a	16.3 a
Hot V5-V6	19.5 abcd	18.1 ab	147.4 c	89.1 ab	79.8 ab	48.6 b	15.7 a
Hot V7-V8	21.4 ab	19.6 a	211.3 ab	86.1 bcd	77.4 bc	68.5 ab	16.0 a
Hot V9-V10	20.0 abcd	19.3 a	190.6 abc	84.9 cde	76.8 bc	63.0 ab	16.4 a
Hot V11-V12	17.2 cde	17.7 ab	174.6 abc	86.3 bcd	77.3 bc	63.4 ab	16.4 a
Hot V13-V14	16.8 de	18.2 a	168.2 abc	89.6 ab	76.7 bc	65.1 ab	16.6 a
Hot VT-R1	15.6 e	15.6 b	157.6 bc	81.4 e	78.6 abc	59.0 ab	15.8 a
Cold V5-V6	18.1 bcde	19.1 a	166.1 abc	90.6 a	81.5 a	61.7 ab	16.2 a
Cold V7-V8	20.8 abc	18.1 ab	183.7 abc	88.4 abc	79.3 ab	64.1 ab	16.0 a
Cold V9-V10	20.2 abcd	18.4 a	191.6 abc	87.3 abc	78.1 abc	61.2 ab	16.0 a
Cold V11-V12	16.5 cde	19.2 a	207.3 abc	87.6 abc	77.2 bc	65.6 ab	16.4 a
Cold V13-V14	19.7 abcd	20.3 a	225.3 a	86.9 abc	75.1 c	72.2 a	16.6 a
Cold VT-R1	21.1 abcd	18.7 a	210.8 abc	82.0 de	76.4 bc	74.4 a	16.0 a

^{Z}Means followed by the same letter, in the same column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 3. The effect of hybrid on greenhouse-grown field corn quality.

Hybrid	Length of ear (cm)	Weight of ear (g)	Days to silking stage	Kernel fill percentage (out of 100%)	Number of Kernel Rows
DKC 68-44	17.0 b[Z]	184.8 a	81.7 b	66.2 a	17.2 a
DKC 69-72	20.7 a	191.9 a	82.6 a	62.2 a	15.0 b

[Z]Means followed by the same letter, in the same column, are not significantly different

according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 4. Ear length (cm) as affected by an interaction between treatment and study.

Treatment	Ear length (cm)	
	Study 1	**Study 2**
Control	21.1 a [Z]	18.6 cd
Hot V5-V6	19.5 abcd	18.1 bcde
Hot V7-V8	21.4 ab	19.6 abcd
Hot V9-V10	20.0 abcd	19.3 abcd
Hot V11-V12	17.2 de	17.7 cde
Hot V13-V14	16.8 de	18.2 bcde
Hot VT-R1	15.6 e	15.6 e
Cold V5-V6	18.1 bcde	19.1 abcde
Cold V7-V8	20.8 abc	18.1 bcde
Cold V9-V10	20.2 abcd	18.4 bcde
Cold V11-V12	16.5 cde	19.2 abcd
Cold V13-V14	19.7 abcd	20.3 abcd
Cold VT-R1	21.1 abcd	18.7 abcde

[Z]Means followed by the same letter, regardless of column, are not significantly different

according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 5. Ear length (cm) as affected by an interaction between variety and study.

Variety	Ear length (cm)	
	Study 1	**Study 2**
DKC 68-44	16.5 c [Z]	17.1 c
DKC 69-72	21.6 a	19.9 b

[Z]Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 6. Ear weight (g) as affected by an interaction between treatment and study.

Treatment	Ear weight (g)	
	Study 1	**Study 2**
Control	231.7 ab^Z	190.9 bcd
Hot V5-V6	143.5 d	151.3 bcd
Hot V7-V8	182.3 abc	240.3 abc
Hot V9-V10	182.4 abc	198.8 abcd
Hot V11-V12	167.1 bcd	182.1 abcd
Hot V13-V14	140.4 d	195.5 abcd
Hot VT-R1	155.5 bcd	159.6 bcd
Cold V5-V6	155.6 bcd	176.5 bcd
Cold V7-V8	178.5 bcd	188.9 abcd
Cold V9-V10	198.0 abcd	184.9 abcd
Cold V11-V12	133.1 bcd	224.7 abcd
Cold V13-V14	179.0 bcd	271.63 a
Cold VT-R1	212.3 abcd	229.6 abcd

^{Z}Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 7. Ear weight (g) as affected by an interaction between study and variety.

Variety	Ear weight (g)	
	Study 1	**Study 2**
DKC 68-44	157.9 b ^{Z}	202.2 a
DKC 69-72	192.4 a	194.3 a

^{Z}Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 8. The number of days required to reach the silking stage, as affected by an interaction between treatment and study.

Treatment	Days to silking stage	
	Study 1	**Study 2**
Control	82.6 ef [Z]	78.8 ghi
Hot V5-V6	89.1 ab	79.8 fghi
Hot V7-V8	86.1 bcd	77.4 hij
Hot V9-V10	84.9 cde	76.8 hij
Hot V11-V12	86.3 bcd	77.3 hij
Hot V13-V14	89.6 ab	76.7 hij
Hot VT-R1	81.4 efg	78.6 ghij
Cold V5-V6	90.6 a	81.5 efg
Cold V7-V8	88.4 abc	79.3 ghi
Cold V9-V10	87.3 abc	78.1 ghij
Cold V11-V12	87.6 abc	77.2 hij
Cold V13-V14	86.9 abc	75.1 j
Cold VT-R1	82.0 defgh	76.4 ij

[Z]Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 9. Number of days required to reach the silking stage, as affected by an interaction between treatment and variety.

Treatment	Days to silking stage	
	DKC 68-44	**DKC 69-72**
Control	79.8 fhi[Z]	81.6 deg
Hot V5-V6	83.8 abcde	85.1 abc
Hot V7-V8	81.4 cdefgh	82.1 bcdefgh
Hot V9-V10	80.0 efgh	81.6 cdefgh
Hot V11-V12	82.5 abcdefg	81.0 defgh
Hot V13-V14	82.6 abcdef	83.8 abcde
Hot VT-R1	78.6 ghi	81.4 cdefgh
Cold V5-V6	86.3 a	85.9 ab
Cold V7-V8	83.3 abcde	84.4 abcd
Cold V9-V10	82.6 abcdef	82.9 abcdef
Cold V11-V12	82.7 abcdefgh	83.0 abcde
Cold V13-V14	81.8 cdefgh	80.3 efgh
Cold VT-R1	79.5 defgh	78.5 h

[Z]Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 10. Number of days required to reach the silking stage, as affected by an interaction between study and variety.

Variety	Days to silking stage	
	Study 1	**Study 2**
DKC 68-44	86.4 a [Z]	77.0 c
DKC 69-71	86.4 a	78.8 b

[Z]Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 11. Kernel fill percentage, as affected by an interaction between variety and treatment.

Treatment	Kernel fill percentage (out of 100%)	
	DKC 69-72	**DKC 68-44**
Control	68.5 a [Z]	67.6 a
Hot V5-V6	29.6 b	67.7 a
Hot V7-V8	65.5 a	71.6 a
Hot V9-V10	76.3 a	49.6 ab
Hot V11-V12	56.4 ab	70.4 a
Hot V13-V14	58.0 ab	74.3 a
Hot VT-R1	59.2 ab	59.9 ab
Cold V5-V6	62.6 ab	60.8 ab
Cold V7-V8	69.4 a	58.9 ab
Cold V9-V10	61.8 ab	58.8 ab
Cold V11-V12	61.0 ab	62.4 ab
Cold V13-V14	62.8 ab	81.6 a
Cold VT-R1	77.9 a	77.5 a

[Z]Means followed by the same letter, regardless of column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Figure 1. Length of ear (cm) as affected by treatment, study 1, DKC 69-72.

Data points followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Figure 2. Length of ear (cm) as affected by treatment, study 1, DKC 68-44.

Data points followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Figure 3. Length of ear (cm) as affected by treatment, study 2, DKC 69-72.

Data points followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Figure 4. Length of ear (cm) as affected by treatment, study 2, DKC 68-44.

Data points followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Figure 5. Weight of ear (g) as affected by treatment.

Data points followed by the same letter are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)
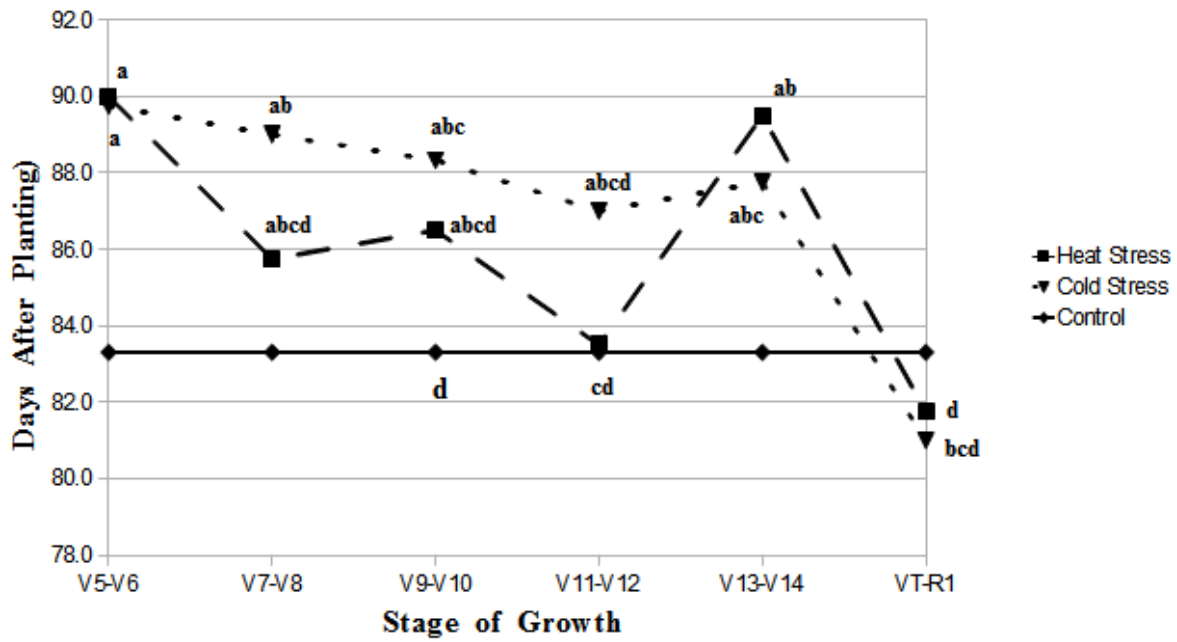
Figure 6. Number of days to reach silking stage as affected by treatment, first study, DKC 69-72.

Data points followed by the same letter are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)
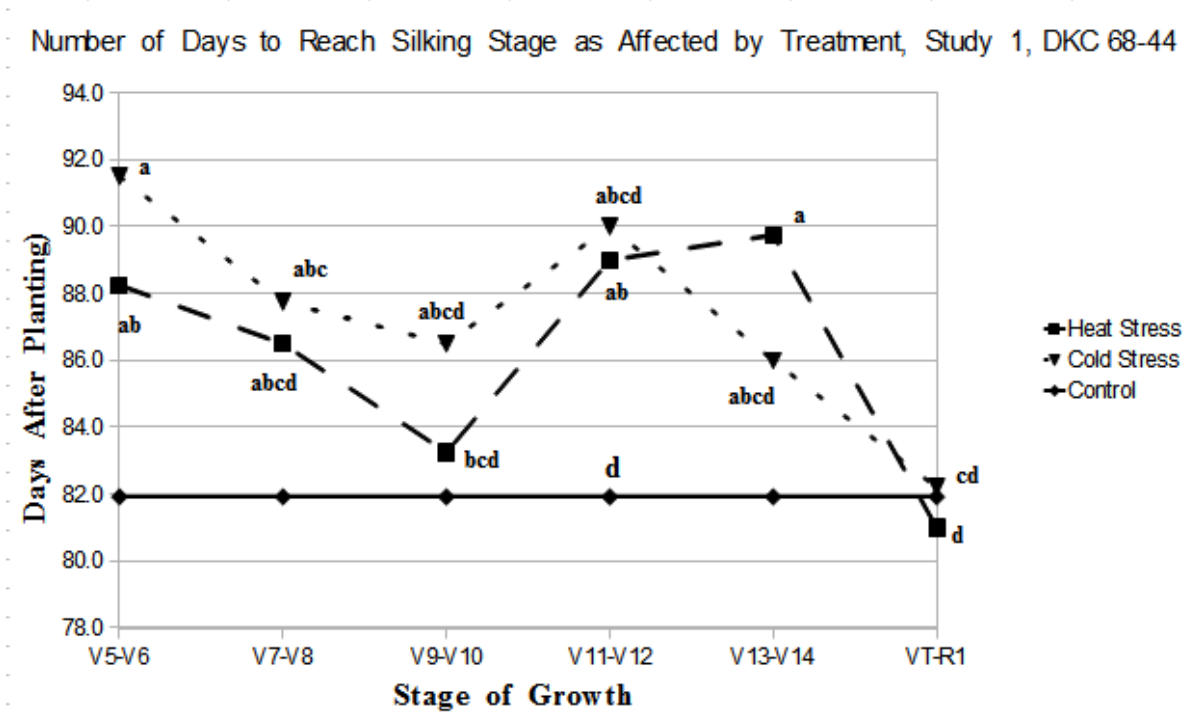
Figure 7. Number of days to reach silking stage as affected by treatment, first study, DKC

68-44.

Data points followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)
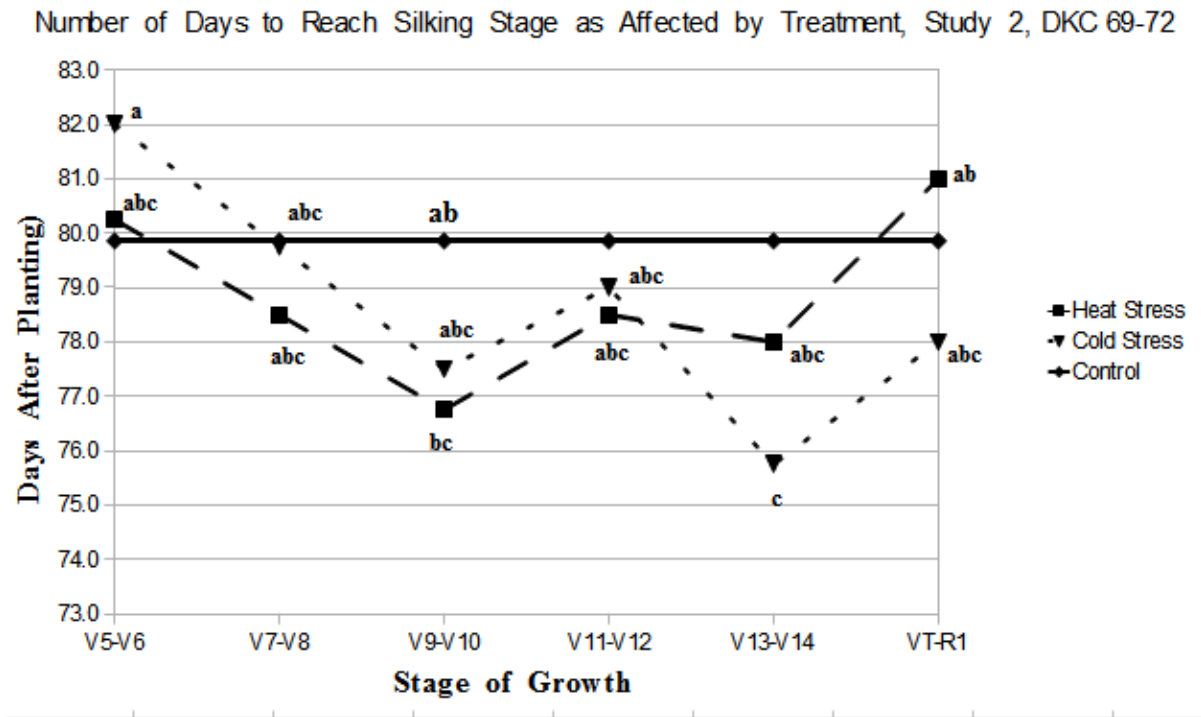
Figure 8. Number of days to reach silking stage as affected by treatment, second study, DKC 69-72.

Data points followed by the same letter are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)
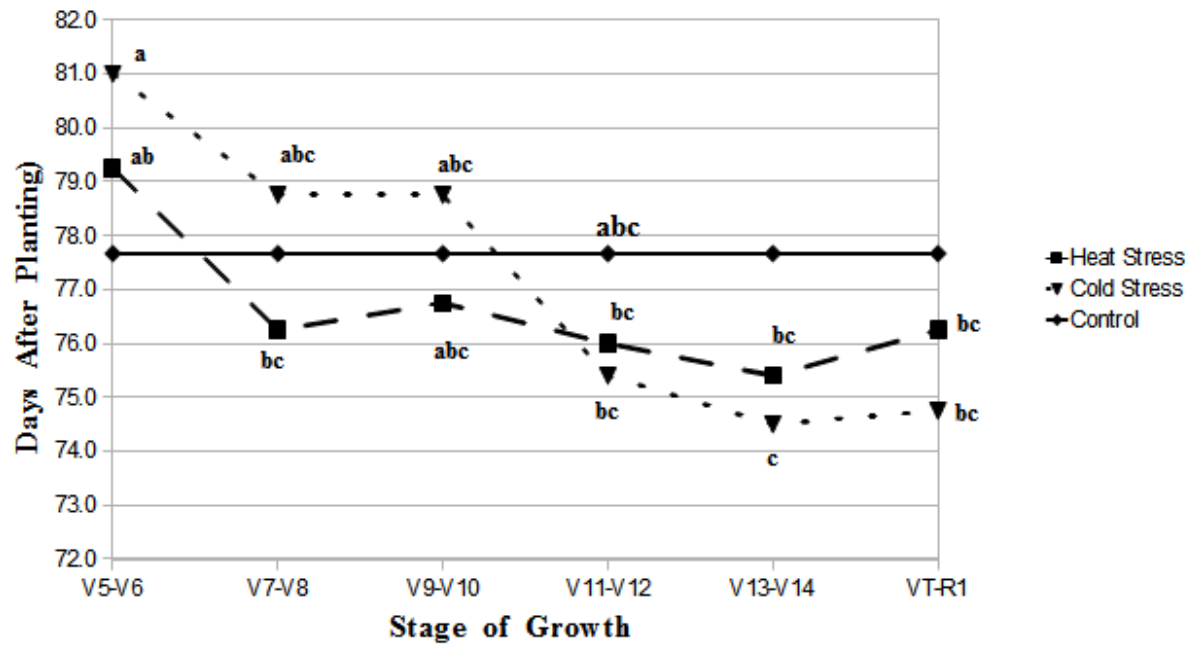
Figure 9. Number of days to reach silking stage as affected by treatment, second study, DKC 68-44.

Data points followed by the same letter are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)
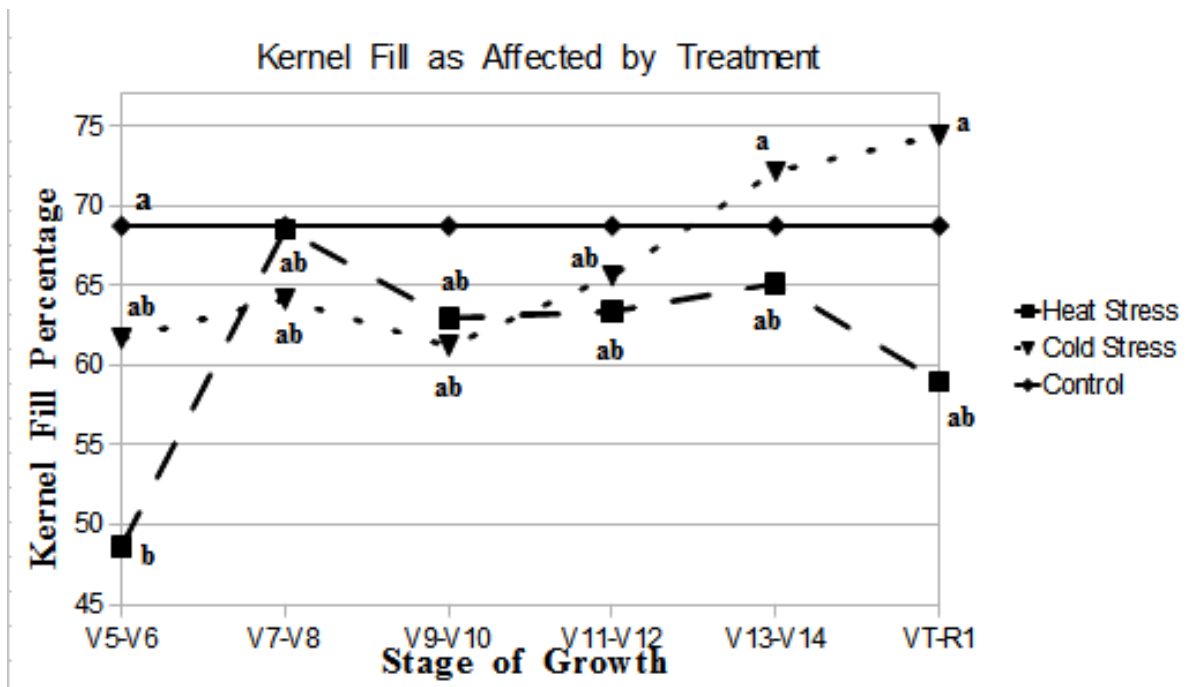
Figure 10. Percent kernel fill as affected by treatment.
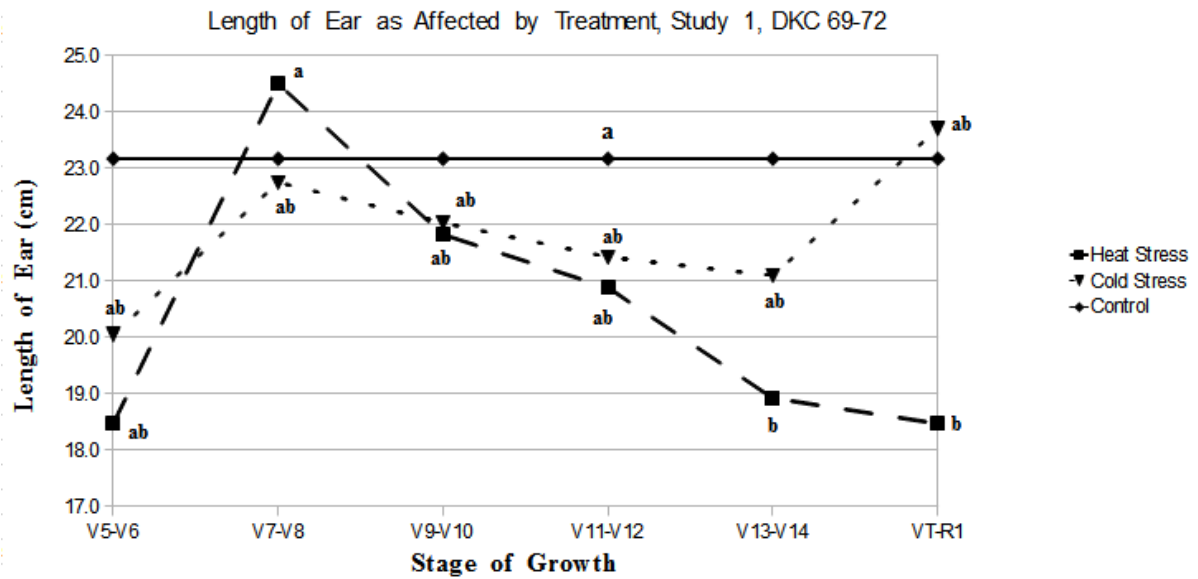
Data points followed by the same letter are not significantly different according to calculated

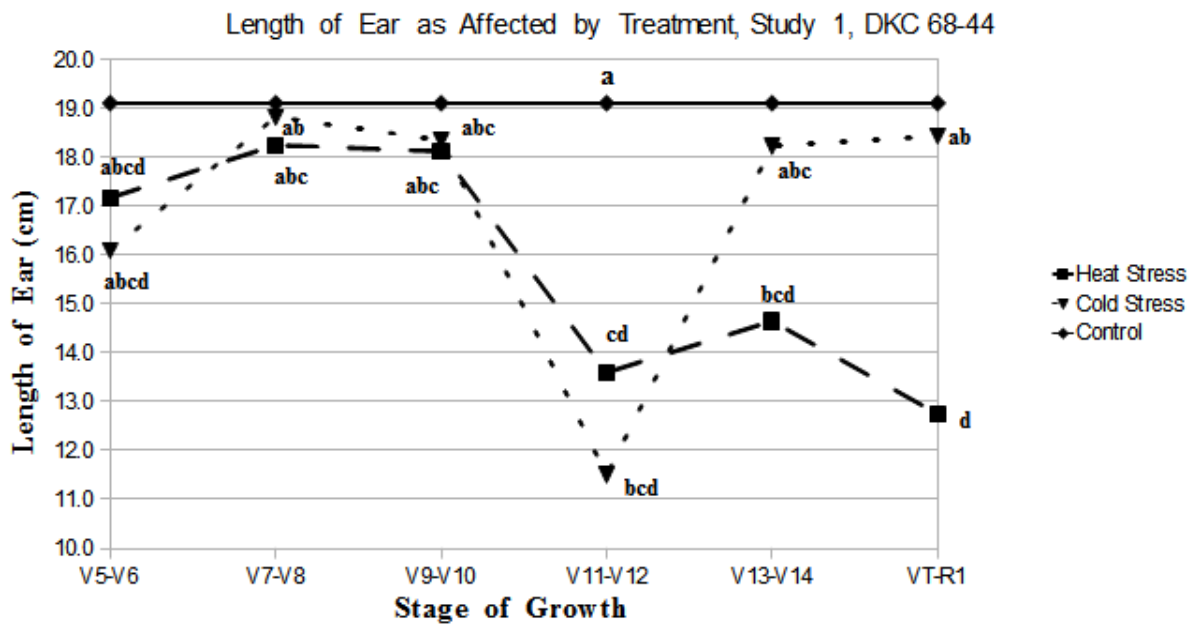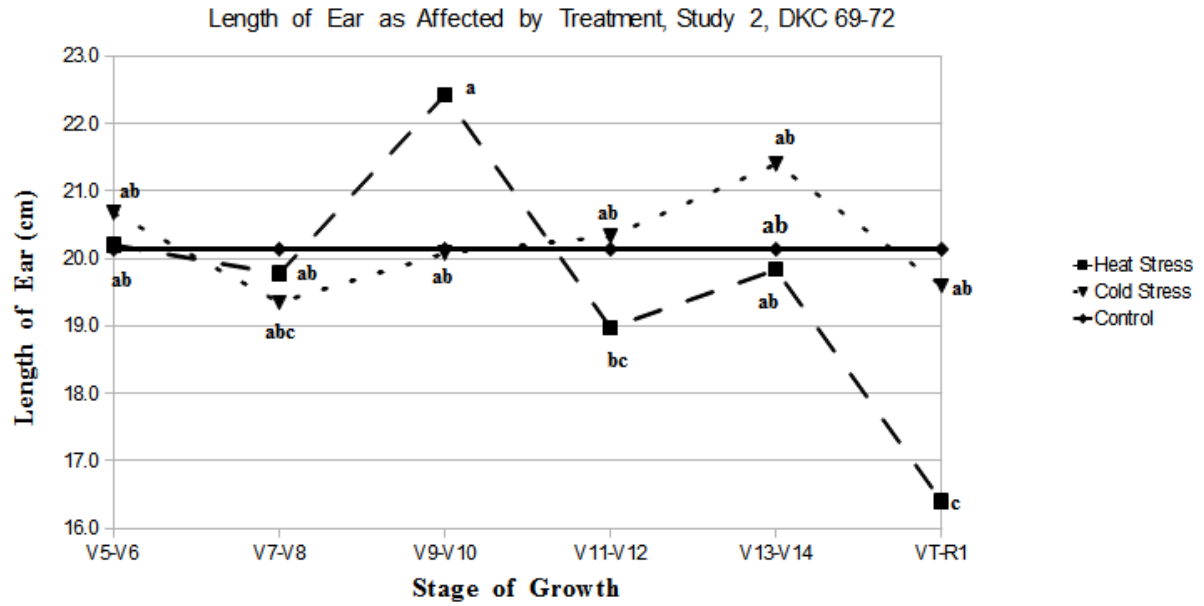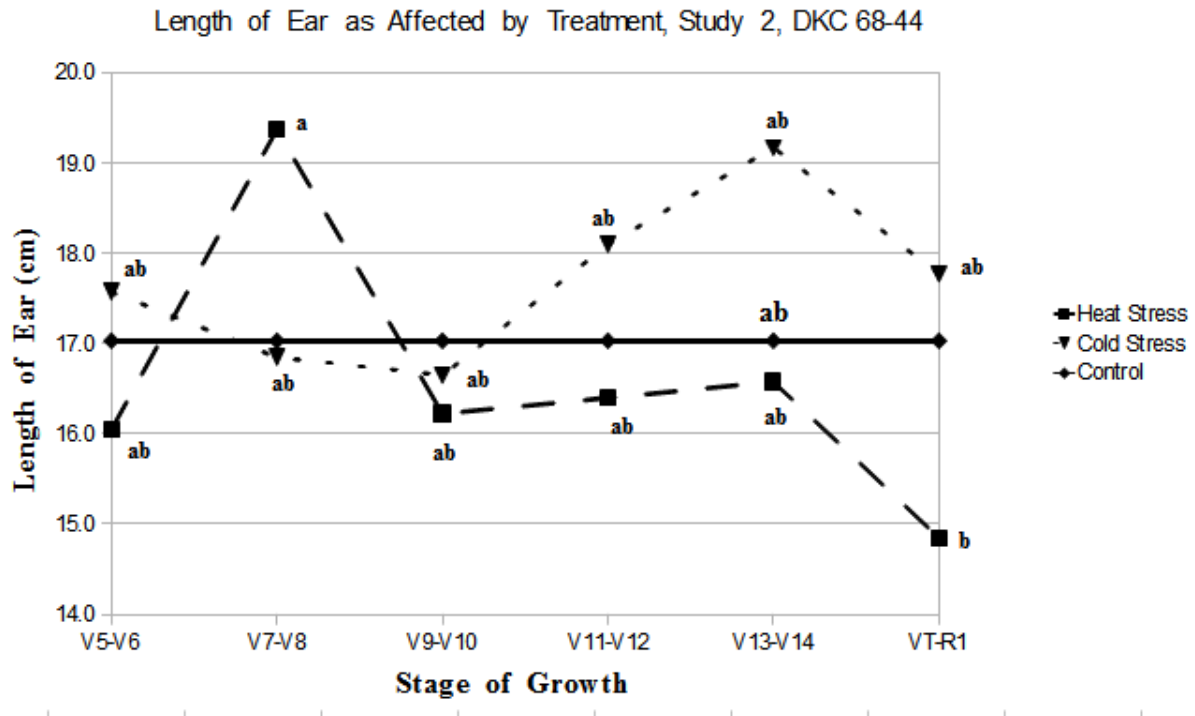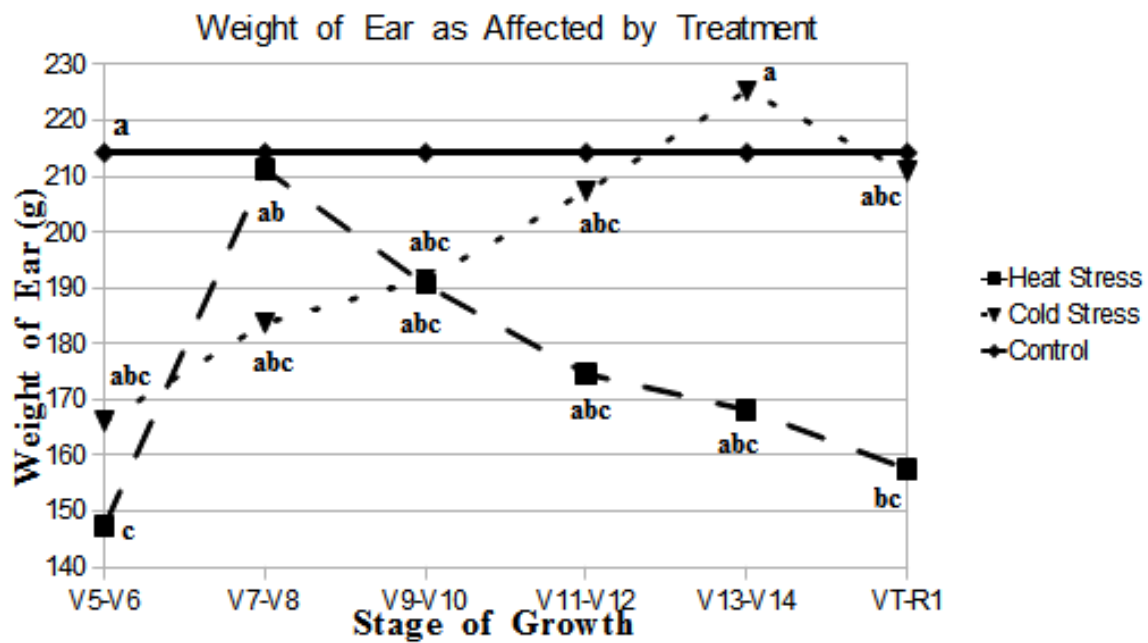least squares means using the Tukey-Kramer procedure (P≤0.05)

CHAPTER III. PLANT POPULATION DENSITY AND ROW CONFIGURATION AFFECTS FIELD CORN YIELD IN THE SOUTHEASTERN UNITED STATES

Kyle Schmitt, Jonathan R. Schultheis, Christoper C. Gunter, and Ronnie W. Heiniger

Field corn (*Zea mays*) is an important agricultural crop, and has many different applications and uses. Management practices, such as seeding rate and row spacing, are important for maximizing light interception and yield of the crop. The goal of this experiment was to determine the plant population density which would produce the greatest yield of grain corn in eastern North Carolina, as well as to investigate what effect, if any, that the twin-row planting system has on corn yield in the region. This experiment was conducted in Plymouth, NC in 2012 and 2013. The 2012 study used hybrids Dekalb 'DKC 68-44' and 'DKC 69-72'. The 2013 study used hybrids Dekalb 'DKC 68-05' and 'DKC 64-69'. The experimental design of the study was a split-plot randomized complete block, with four replications. The plant population densities that were investigated in this study were 44,460, 64,220, 83,980, 103,740, 123,500, and 143,260 plants ha^{-1}. Results from 2012 indicate that maximum yield of corn occurred at a plant population density of 103,740 plants ha^{-1}, while the results of a regression analysis indicated that maximum yield would occur at a plant population density of 98,426 plants ha^{-1}. In 2013, maximum yield of corn occurred a plant population density of 143,260 plants ha^{-1}, while regression analysis predicted that maximum yield occurred at a plant population density of 118,643 plants ha^{-1}. Maximum predicted yield for the 2012 study was 202.6 bushelsha^{-1}, while maximum predicted yield for the 2013 study was 458.2 bushelsha^{-1}. The differences in yield and ideal plant population density between

years are most likely due to the varieties of corn used. The use of twin rows had a negative

impact on corn yield in both the 2012 and 2013 studies, with the use of twin rows decreasing

grain yield by 11.1% in 2012 and 6.5% in 2013 when compared with the use of single rows.

Introduction

Field corn is an important crop for many reasons – it is used as a source of food for humans and other animals alike, plays a large role in many processed products, and is used in several industrial processes, including the production of plastic (Royte, 2006). There were more than 39,317,294 hectares of corn planted in the US in 2012, with an economic value of more than $77 billion (USDA 2012). Increasing the yield of field corn per acre has been a long-running goal in corn research, and in recent decades the majority of progress has been made by decreasing the in-row distances and between-row distances between plants. In the early 1960s, the ideal corn plant population was considered to be around 59,280 plants ha^{-1} (Colville, 1962), but recent studies indicate that the ideal corn plant population could be upwards of 70,000 to 80,000 plants ha^{-1} (Bruns and Abbas, 2005; Tahmasvand et al., 2012). Depending on the location, reducing between-row spacing has produced mixed results (Lee, 2006), but, in general, reducing between-row spacing tends to increase yield (Farnham, 2001). Given the variation in yield responses found in the literature there is a need to examine seeding rates and the effects of the twin-row planting configuration in the Southeastern United States.

Selection of the right plant population for production is about more than just yield and economic returns. Identifying the ideal plant population can lead to increases in the water use efficiency of a crop (Al-Kaisi, 2003), and optimizing plant population can also increase water removal from the soil profile (Norwood, 2001). In arid areas where water is limited and irrigation is required for crop production, maximizing water use efficiency and water

removal from the soil profile is of the utmost importance for the health of the aquifer, and both of these factors are affected by plant population.

Adjusting a plant population typically involves modifying either the in-row spacing between plants or modifying the between-row spacing between plants. Decreasing between-row spacing while maintaining the same overall plant population has been shown to increase yields in some corn hybrids but not in others (Farnham, 2001), and has been shown to increase nitrogen use efficiency of a corn crop by up to 15% (Barbieri et al., 2008). Increased nitrogen use efficiency can decrease the overall amount of nitrogen that needs to be applied, decreasing a farmers input costs. The benefits of decreasing between-row spacing may not outweigh the costs, as decreasing between-row spacing requires significant infrastructure investments.

The twin-row planting system was developed to try to attain the benefits of decreased between-row spacing without the investment costs that coincide with changing between-row spacing (Karlen and Camp, 1985). The seeds are planted offset of the center of the row, attempting to mimic the effect of closer between-row spacing while maintaining the normal row width, so that additional equipment purchases are not required beyond a planter that can set seeds in this way. The results of this method have been mixed: cotton grown in the twin row system has been shown to have a yield advantage over cotton grown in the single-row system (Oron, 1984), while studies performed on the twin-row system in corn have not indicated it has an advantage in grain yield over the traditional single-row system (Robles et al., 2012; Novacek et al., 2013).

The objectives of this study were as follows: (1) quantify the effect of plant population on corn grain yield and in the southeast region of the US, and (2) determine what effect, if any, the twin-row system has on corn yield.

Methods

This experiment was performed at the Tidewater Research Station in Plymouth NC. The experiment was performed over two years, 2012-2013, with one study performed per year. Each study was a randomized complete block split-split plot design, with four replications per study. There were six population densities (main plot factor), two varieties (sub-plot factor), and two row types (sub-subplot factor) investigated in these studies. The first study was planted on 10 April 2012 and was harvested on 12 September 2012 (156 days after planting). The second study was planted on 19 April 2013 and was harvested on 25 September 2013 (160 days after planting). The study planted in 2012 received a total of 110.9 cm of rainfall during the growing period, and the study planted in 2013 received a total of 58.0 cm of rainfall during the growing period (Table 1). The soil type at the experimental sites is primarily a Portsmouth fine sandy loam (fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic typic umbraquults).

The 2012 study used Dekalb 'DKC 68-44' and 'DKC 69-72'. The 2013 study used Dekalb 'DKC 68-05' and 'DKC 64-69'. 'DKC 68-44' and 'DKC 69-72' are both older varieties, and are known to produce lower yields than more modern hybrids such as 'DKC 68-05' and 'DKC 64-69'. The goal of this experiment was to determine which plant population density produced the greatest yields in the area of the study, and it was seen as

prudent to evaluate the effect of population density on both lower-yielding and higher-

yielding varieties in this experiment. The plant populations investigated in this study were

44,460 plants ha^{-1} (44k), 64,220 plants ha^{-1} (64k), 83,980 plants ha^{-1} (83k), 103,740 plants ha^{-1} (103k), 123,500 plants ha^{-1} (123k), and 143,260 plants ha^{-1} (143k). This experiment

changed in-row plant spacing to modify plant population densities, both in the single-row and

twin-row planting systems. For the single-row plots, the following in-row plant spacing was

used for the given populations: for the 44k population 23.9 cm, for the 64k population 17.0

cm, for the 83k population 13.0 cm, for the 103k population 10.4 cm, for the 123k population

8.9 cm, and for the 143k population 7.6 cm. For the twin-row plots, each plant was offset

from the center of the row by 7.6 cm to the left and the right, for a total of 15.2 cm between

the "twin" rows. The following in-row spacings were used for the given populations in the

twin-row system: for the 44k population 49.3 cm, for the 64k population 34.0 cm, for the 83k

population 26.2 cm, for the 103k population 21.1 cm, for the 123k population 17.8 cm, and

for the 143k population 15.2 cm (Table 2). The plots used in this study were 3.7 m wide and

9.1 m long, with 1.5 m between plots and 3.0 m between replications.

The plots were seeded using a Wintersteiger precision dynamic disc planter model

1401 (Wintersteiger Inc., Provo, UT). The plots were overseeded and thinned to desired

stand when most of the corn appeared to be at the V3 stage of growth (Iowa State University,

2009), which occurred on 24 May 2012 for the 2012 study, and on 16 May 2013 for the 2013

study. In both studies, the plots were overseeded, but at different rates: the plots were

overseeded by 25% in 2012 and 10% in 2013. The seed used in 2012 had excellent rates of

germination and stand establishment, so decreasing to 10% overseeding in 2013 was seen as

a prudent way to reduce the waste of seed and labor. The plots were harvested and yield data recorded using a Gleaner K2 combine equipped with a Harvestmaster Grain Gage (Juniper Systems, Inc., Logan, UT).

Results

Yield of grain corn was significantly affected by both population density and row type in the 2012 study (Table 3). The best fit relationship between population density and yield was quadratic (Figure 1). The coefficient of determination (R^2) for the relationship between plant population density and yield had a value of 0.24 for this study, indicating that the relationship accounted for 24% of the variability in the data. Based on the results of the regression analysis, the greatest yield of corn would occur at a population density of 98,426 plants ha^{-1}, and would produce 202.6 bushelsha^{-1}. The population density which produced the greatest quantity of corn in 2012 was the 103k population, which produced 206.7 bushelsha^{-1}, although the yields of the 64k, 83k, and 123k populations were all statistically similar to the 103k population (Table 4). The population density which produced the smallest quantity of corn was the 44k population, which produced 153.9 bushelsha^{-1}, and the yield of the 143k population was statistically similar to the 44k population (Table 4). Row type also had a significant effect on yield: plants grown in the single-row configuration produced an average of 195.2 bushelsha^{-1}, compared with an average of 173.5 bushelsha^{-1} produced by plants grown using the twin-row configuration (Table 5).

Yield of grain corn was significantly affected by both population density and row type in the 2013 study (Table 3). The best fit relationship between population density and

yield was quadratic (Figure 2). The coefficient of determination (R^2)for the relationship between plant population density and yield had a value of 0.53 for this study, indicating that the quadratic relationship accounted for 53% of the variability in yield. Based on the results of the regression analysis, the greatest yields would occur at a population density of 118,643 plants ha^{-1}, and would produce 458.2 bushelsha[-1]. The population density which produced the greatest quantity of corn in 2013 was the 143k population, which produced 454.7 bushelsha[-1], although the yields of the 83k, 103, and 123k populations were all statistically similar to the 143k population (Table 4). The population density which produced the smallest quantity of corn in 2013 was the 44k population, which produced 318.7 bushelsha[-1], and this population density produced yields that were not statistically similar to any of the other tested densities (Table 4). Row type also had a significant effect on yield: plants grown in the single-row configuration produced an average of 433.1 bushelsha[-1], compared with an average of 404.8 bushelsha[-1] produced by plants that were grown using the twin-row configuration (Table 5).

Discussion

There is a large disparity in yield between the 2012 planting and the 2013 planting of this study. It is not possible to absolutely differentiate between the effect of planting year (environment) and the effect of variety on yield in this study, as varieties can vary with planting year. However, this difference in yield is most likely a result of genetics, as opposed to any differences in cultural practices or meteorological conditions that differ between the two years. The hybrids used in 2013, 'DKC 68-05' and 'DKC 64-69', are modern hybrids found in use in commercial agriculture today. The hybrids used in 2012, 'DKC 68-44' and

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'DKC 69-72', are not commercially active. Improving yield has been a staple goal of corn breeding, and the difference in yields between 2012 and 2013 highlight the importance of selecting the correct hybrids for a given production system. The results from the 2013 study are more likely to represent the yield response of modern corn hybrid than the results of the 2012 study.

There are large numerical differences in yield when comparing the 2012 and 2013 studies, with even the lowest yielding treatments in 2013 producing greater yields than the best yielding treatments in 2012. The regression analysis reveals that despite the numerical differences in grain yield between studies, the plant population densities that will produce the greatest yields are not that different: in 2012, maximum yield was predicted to occur at a plant population density of 98,426 plants ha^{-1}, while in 2013 maximum yield was predicted to occur at a plant population density of 118,643 plants ha^{-1}. The predicted maximum yield for 2012 was 202.6 bushelsha^{-1}, while the predicted maximum yield for 2013 was 458.2 bushelsha^{-1}. This difference in maximum yield is quite large, but regardless of the total yield, the predicted maximum yield occurs at very similar plant population densities in both 2012 and 2013.

There are indeed large differences in yield when 2012 and 2013 are compared, but both years reveal the same trend: that the relationship between corn yield and population density is quadratic, with any increase in population density resulting in an increase in yield until a yield maximum is reached. With any increases in population density beyond this maximum plant population density, yield begins to decrease. The exact value of this ideal plant population density varied between 2012 and 2013, although it was approximately

100,000 plants ha^{-1}in both 2012 and 2013. A study published in 2005 indicated that the highest corn yields were achieved at a plant population density of 70,000 plants ha^{-1}, a population density that was considered to be ultra-high at the time (Bruns and Abbas, 2005). A study conducted in Iran and published in 2012 indicated that maximum corn yield was achieved at a plant population density of 85,000 plants ha^{-1} (Tahmasvand et al., 2012). A study conducted in Canada and published in 2006 determined that maximum corn yield was achieved at a plant population density of 100,000 plants ha^{-1} (Baron et al., 2006). The results of this experiment reinforce these findings, and while the ideal population densities are not exactly the same in these experiments, the overall message is clear: increased yields can be achieved by increasing plant population densities beyond traditionally recommended plant population densities.

In both 2012 and 2013, the use of twin rows decreased overall yield when compared with single rows. In 2012, corn grown in twin rows produced yields that were 88.9% of the yields of single rows, and in 2013 plants grown in twin rows had yields that were 93.5% of the yields of single rows. A study published in 1979 indicated that the use of twin rows did not significantly affect yield when compared with the use of single rows (Phene and Beale, 1979). A study published in 2007 determined that corn yield was reduced by the use of twin rows when compared with the use of single rows (Nelson, 2007). A study published in 2000 determined that the use of twin rows did not significantly affect corn yield when compared with yields achieved through the use of traditional single rows (Harbur and Cruse, 2000). Using twin rows appear to result in either no difference in yield, or a decrease in yield, when compared with the use of single rows. The results of this experiment indicate that corn yield

was decreased by the use of twin rows when compared with single rows, which supports previously published results. The use of twin rows has been shown to improve yield in many crops, including soybean and cotton, but corn does not share this response (Oron, 1984; Ken et al., 2006). It is possible that field corn breeding has focused on the production of hybrids that perform best in the single row configuration. It is also possible that instances where yield has been increased through the use of twin rows have not been adequately documented in scholarly journals. Based on the currently available literature and the results of this experiment, the use of the twin rows is not recommended for corn production.

Corn yield is a factor of many variables: some of these variables can be controlled by man, while others cannot. Plant population density is not the only factor that affects corn yield, but it is one of the most important factors that a farmer can control. The power and impact of the variables which man cannot control, including climate, rainfall, and soil type, makes it impossible to determine a global ideal plant population density. These results are not intended to promote a particular plant population density as appropriate for every location, although this experiment demonstrates that for this planting site, corn yield could be increased by increasing plant population density beyond the current recommendations for the area, which is 78,794 plants ha^{-1} (North Carolina State University, 2000). Growers should use data and results from studies conducted in their local area to determine their own ideal plant population density.

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Table 1. Rainfaill (cm), average high temperature (^{o}C), and average low temperature (^{o}C) in 14 day intervals.

Days After Planting	Rainfall (cm)		Average daily high (^{o}C)		Average daily low (^{o}C)	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**
0 - 13	2.2	3.1	22.0	19.4	8.8	8.8
14 - 27	1.9	2.9	24.6	23.4	13.9	12.6
28 - 41	3.7	1.2	25.0	27.1	14.4	14.9
42 - 55	11.9	5.9	27.7	30.0	18.6	19.4
56 - 69	1.5	4.1	26.5	29.3	15.7	19.7
70 - 83	5.9	11.3	32.8	30.5	19.4	22.4
84 - 97	9.4	2.8	32.7	31.4	23.5	22.9
98 - 111	20.8	3.6	32.6	29.7	22.6	19.9
112 - 125	9.9	12.8	30.4	29.0	22.0	21.5
126 - 139	11.6	7.3	29.3	29.4	20.8	18.9
140 - 153	31.3	0.4	30.3	27.9	21.0	15.3
154 – 155 (2012)	0.6		25.2		11.7	
154 – 159 (2013)		2.4		23.6		12.4

Table 2. Population densities investigated in this study and associated in-row spacing distance.

Population density	In-row Spacing (cm)	
	Single-row	**Twin-Row**
44,460	23.9	49.3
64,220	17.0	34.0
83,980	13.0	21.2
103,740	10.4	21.1
123,500	8.9	17.8
143,260	7.6	15.2

Table 3. Analysis of Variancefor yield of grain corn.

Source of variance	Degrees of freedom	Dependent variable	
		Yield, 2012	**Yield, 2013**
		Prob > F	
Population Density	5	<.0001	<.0001
Row Type	1	0.0002	0.003
Variety	1	0.3	0.8
Row Type * Variety	1	0.8	0.07
Row Type * Population Density	5	0.3	0.7
Variety * Population Density	5	0.4	0.4
Variety * Row Type * Population Density	5	0.5	0.3

Table 4. Yield of corn in bushels per hectare as affected by plant population density.

Population density	Yield of corn in bushels/ha	
	2012	**2013**
44,460	153.9 c^Z	318.7 c
64,220	190.1 ab	409.5 b
83,980	196.8 ab	434.8 ab
103,740	206.7 a	449.1 a
123,500	183.3 ab	446.7 a
143,260	175.4 bc	454.7 a

^{Z}Means followed by the same letter, in the same column are not significantly different

according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 5. Yield of corn in bushels per ha as affected by row type.

Row Type	Yield of corn in bushels/ha	
	2012	**2013**
Single Row	195.2 a [Z]	433.1 a
Twin Row	173.5 b	404.8 b

[Z]Means followed by the same letter, in the same column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)
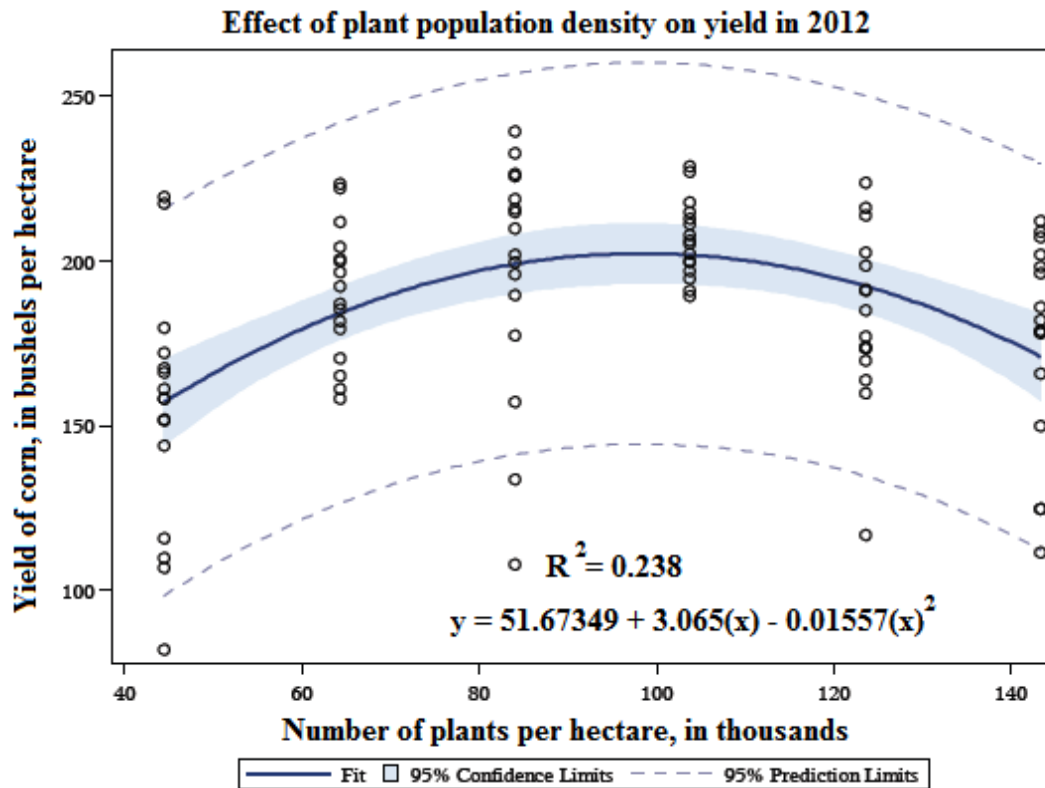
Figure 1. Yield of corn in bushels per hectare as affected by plant population density in 2012. Due to limits in decimal availability in PROC GLM estimates, total population has been divided by 1000: 44.46 is equivalent to 44,460. Results are not affected by this change, but should the regression equation be used to estimate yield, divide the total population by 1000 and use that number in the equation.
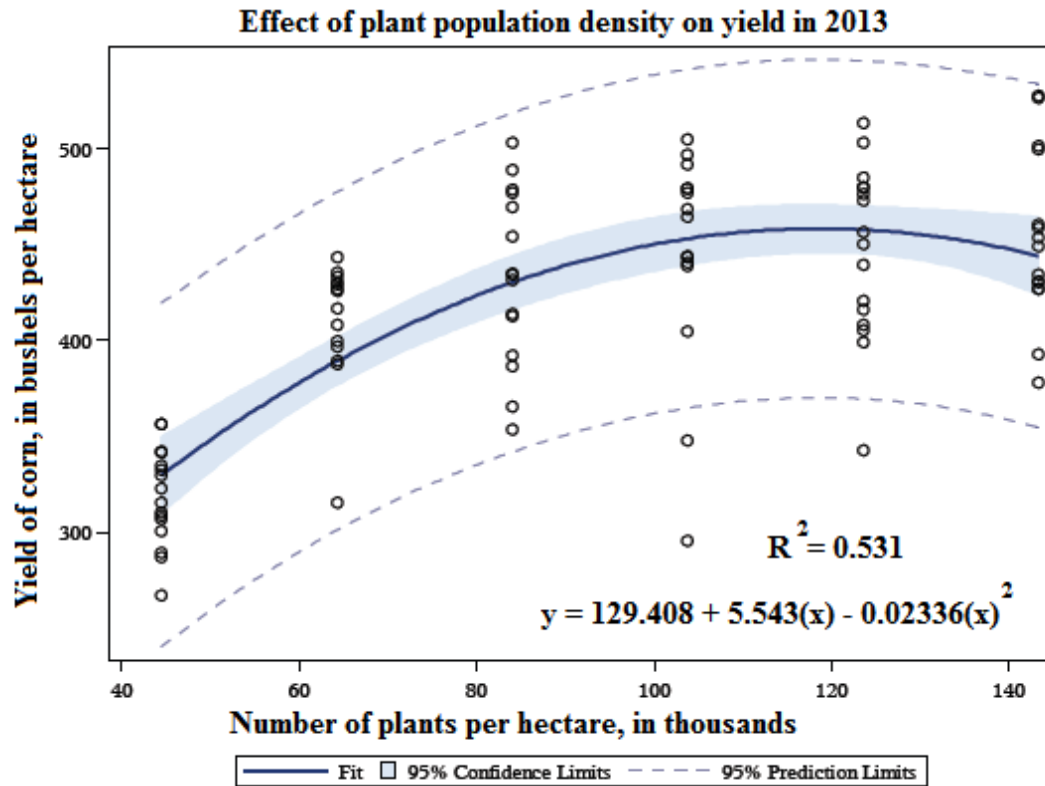
Figure 2. Yield of corn in bushels per hectare as affected by plant population density in 2013.

Due to limits in decimal availability in PROC GLM estimates, total populations has been

divided by 1000: 44.46 is equivalent to 44,460. Results are not affected by this change, but

should the regression equation be used to estimate yield, divide the total population by 1000

and use that number in the equation.

APPENDICES

Table 1. Total rainfall over 14 day periods, study 1.

Days after planting, 14 day intervals	Total precipitation during time interval (cm)
0 - 13	3.8
14 - 27	2.2
28 - 41	6.1
42 - 55	13.6
56 - 69	0.0
70 - 83	8.7

Table 2. Total rainfall over 14 day periods, study 2.

Days after planting, 14 day intervals	Total precipitation during time interval (cm)
0 - 13	10.2
14 - 27	9.4
28 - 41	3.7
42 - 55	5.0
56 - 69	22.1
70 - 71	1.9

Table 3. Analysis of variance for sweet corn yield, classified by ear type.

Dependent Variable	Source	DF	Anova SS	Mean Square	F Value	Pr > F
Premium Ears (>17.8 cm length)	S [z]	1	25495545	25495545	0.4	0.6
	Pop[y]	5	24273250300	4854650060	66.6	<.0001
	Var[x]	1	62372729	62372729	0.9	0.4
	Row[w]	1	115475876	115475876	1.6	0.2
	Pop * Var	5	303063410	60612682	0.8	0.6
	Pop * Row	5	348321773	69664355	0.9	0.5
	Pop * S	5	244194013	48838803	0.6	0.7
	Var * Row	1	266119175	266119175	3.5	0.06
	Var * S	1	32451923	32451923	0.4	0.5
	S * Row	1	268198	268198	0.00	0.9
	Pop* S * Row	5	324737137	64947427	0.9	0.5
	Pop * Var * Row	5	73771132	14754226	0.2	0.9
	S * Row * Var	1	54460897	54460897	0.7	0.4
	S * Pop * Var	5	479219017	95843803	1.3	0.3
	S * Pop * Var * Row	5	247613534	49522707	0.7	0.7

Table 3 Continued.

Select Ears (15.2 – 17.8 cm length)	S	1	39429253.6	39429253.6	6.9	0.01
	Pop	5	972170594	194434118.8	33.9	<.0001
	Var	1	1211080.3	1211080.3	0.2	0.7
	Row	1	3524285.5	3524285.5	0.6	0.4
	Pop * Var	5	15710518.8	3142103.8	0.5	0.8
	Pop * Row	5	24460469.1	4892093.8	0.8	0.6
	Pop * S	5	17923149.9	3584630	0.6	0.7
	Var * Row	1	4027156.2	4027156.2	0.7	0.4
	Var * S	1	205338.9	205338.9	0.03	0.9
	S * Row	1	2216821.7	2216821.7	0.4	0.5
	Pop * S * Row	5	14805351.6	2961070.3	0.5	0.8
	Pop * Var * Row	5	33713290.0	6742658.0	1.10	0.4
	S * Row * Var	1	22331649.8	22331649.8	3.63	0.06
	S * Pop * Var	1	3742196.1	748439.2	0.12	0.9
	S * Pop * Var * Row	5	26974822.6	5394964.5	0.9	0.5

Table 3 Continued.

Secondary Ears	S	1	2548247163	2548247163	131.2	<.0001
	Pop	5	6028605904	1205721181	62.1	<.0001
	Var	1	118556964	118556964	6.1	0.01
	Row	1	94036989	94036989	4.8	0.03
	Pop * Var	5	132849220	26569844	1.8	0.1
	Pop * Row	5	193455197	38691039	2.6	0.03
	Pop * S	5	571794999	114359000	7.8	<.0001
	Var * Row	1	1709928	1709928	0.1	0.7
	Var * S	1	237770845	237770845	16.1	<.0001
	S * Row	1	45499909	45499909	3.1	0.08
	Pop * S * Row	5	87450053	17490011	1.2	0.3
	Pop * Var * Row	5	12019448	2403890	0.2	0.9
	S * Row * Var	1	18143743	18143743	1.2	0.3
	S * Pop* Var	5	84982634	16996527	1.2	0.3
	S * Pop * Var * Row	5	48105449	9621090	0.7	0.7

Table 3 Continued.

Primary Culls	S	1	6051210.8	6051210.8	1.1	0.3
	Pop	5	392138573.4	78427714.7	13.7	<.0001
	Var	1	8112980.7	8112980.7	1.4	0.2
	Row	1	821355.5	821355.5	0.1	0.7
	Pop * Var	5	1039266.1	207853.2	0.04	1.0
	Pop * Row	5	15471655.3	3094331.1	0.6	0.7
	Pop * S	5	134551437.5	26910287.5	5.0	0.0003
	Var * Row	1	2028245.2	2028245.2	0.4	0.5
	Var * S	1	1357750.9	1357750.9	0.3	0.6
	S * Row	1	9655117.5	9655117.5	1.8	0.2
	Pop * S * Row	5	20617698.8	4123539.8	0.8	0.6
	Pop * Var * Row	5	13057875.9	2611575.2	0.5	0.8
	S * Row * Var	1	5431003.6	5431003.6	1.0	0.3
	S * Pop * Var	5	84982634	16996527	1.2	0.3
	S * Pop * Var * Row	5	48105449	9621090	0.7	0.7

[z] S - Study
[y] Pop - Population Density
[x] Var - Variety
[w] Row - Row Type

Table 4. Analysis of variance for sweet corn ear quality.

Dependent Variable	Source	DF	Anova SS	Mean Square	F Value	Pr > F
Ear Weight	S [z]	1	6924.2	6924.2	26.8	<.0001
	Pop [y]	5	14734.6	2946.9	11.4	<.0001
	Var [x]	1	10266.9	10266.9	39.8	<.0001
	Row [w]	1	1716.6	1716.6	6.7	0.01
	Pop * Var	5	2283.6	456.7	1.9	0.1
	Pop * Row	5	596.4	119.3	0.5	0.8
	Pop * S	5	4282.3	856.5	3.5	0.005
	Var * Row	1	518.9	518.9	2.1	0.1
	Var * S	1	4.6	4.6	0.02	0.9
	S * Row	1	2.8	2.8	0.01	0.9
	Pop * S * Row	5	759.8	152.0	0.6	0.7
	Pop * Var * Row	5	969.7	193.9	0.8	0.6
	S * Row * Var	1	160.9	160.9	0.7	0.4
	S * Pop * Var	5	1416.0	283.2	1.2	0.3
	S * Pop * Var * Row	5	988.3	197.7	0.8	0.5

Table 4 Continued.

Ear Length	S	1	51.1	51.1	196.3	<.0001
	Pop	5	16.6	3.3	12.7	<.0001
	Var	1	70.4	70.4	270.6	<.0001
	Row	1	0.003	0.003	0.01	0.9
	Pop * Var	5	7.6	1.5	7.0	<.0001
	Pop * Row	5	0.3	0.05	0.2	0.9
	Pop * S	5	2.5	0.5	2.3	0.05
	Var * Row	1	0.2	0.2	1.0	0.3
	Var * S	1	1.2	1.2	5.7	0.02
	S * Row	1	0.04	0.04	0.2	0.7
	Pop * S * Row	5	2.2	0.4	2.1	0.07
	Pop * Var * Row	5	0.4	0.09	0.4	0.8
	S * Row * Var	1	0.7	0.7	3.1	0.08
	S * Pop * Var	5	0.3	0.06	0.3	0.9
	S * Pop * Var * Row	5	0.6	0.1	0.6	0.7

Table 4 Continued.

Ear Width	**S**	1	1.8	1.8	32.0	<.0001
	Pop	5	0.7	0.1	2.3	0.06
	Var	1	0.7	0.7	13.3	0.0003
	Row	1	0.03	0.03	0.5	0.5
	Pop * Var	5	0.8	0.2	2.9	0.02
	Pop * Row	5	0.2	0.04	0.7	0.6
	Pop * S	5	0.6	0.1	2.3	0.5
	Var * Row	1	0.003	0.003	0.06	0.8
	Var * S	1	0.1	0.1	2.4	0.1
	S * Row	1	0.02	0.02	0.4	0.5
	Pop * S * Row	5	0.3	0.05	1.0	0.5
	Pop * Var * Row	5	0.1	0.03	0.5	0.8
	S * Row * Var	1	0.07	0.07	1.4	0.2
	S * Pop * Var	5	0.2	0.05	0.9	0.5
	S * Pop * Var * Row	5	0.2	0.04	0.7	0.6

Table 4 Continued.

Number of Kernel Rows	**S**	1	0.08	0.08	0.1	0.7
	Pop	5	2.7	0.5	0.6	0.7
	Var	1	31.1	31.1	37.1	<.0001
	Row	1	1.8	1.8	2.2	0.1
	Pop * Var	5	3.9	0.8	1.1	0.4
	Pop * Row	5	3.2	0.6	0.9	0.5
	Pop * S	5	10.6	2.1	3	0.01
	Var * Row	1	0.4	0.4	0.5	0.5
	Var * S	1	9.8	9.8	13.9	0.0003
	S * Row	1	1.0	1.0	1.4	0.2
	Pop * S * Row	5	2.0	0.4	0.6	0.7
	Pop * Var * Row	5	4.6	0.9	1.3	0.3
	S * Row * Var	1	2.2	2.2	3.1	0.08
	S * Pop * Var	5	4.7	0.9	1.3	0.3
	S * Pop * Var * Row	5	7.8	1.6	2.2	0.06

[z] S - Study
[y] Pop - Population Density
[x] Var - Variety
[w] Row - Row Type

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Table 5. Premium ears produced per hectare by different population densities.

Population density	Premium ears per hectare (>17.8cm length)
29,640	28536 e [Z]
39,520	38318 d
49,400	47428 c
59,280	52810 bc
69,160	57716 ab
79,040	60995 a

[Z]Means followed by the same letter are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 6. Select ears (between 15.2 and 17.8 cm in length) produced per hectare by different population densities.

Population density	Select ears (15.2 – 17.8 cm length) per hectare	
	Study 1	**Study 2**
29,640	953 d ^{Z}	449 c
39,520	1514 cd	505 c
49,400	3139 bcd	1850 c
59,280	4036 bc	2074 bc
69,160	4877 ab	4261 b
79,040	7344 a	7288 a

^{Z}Means followed by the same letter, in the same column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 7. Secondary ears produced per hectare by different population densities.

Population Density	Secondary ears per hectare	
	Study 1	Study 2
29,640	18893 ab ^{Z}	13399 a
39,520	20350 a	8577 b
49,400	14677 b	3083 c
59,280	8409 c	505 d
69,160	4036 c	673 d
79,040	3868 c	280 d

^{Z}Means followed by the same letter, in the same column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 8. Secondary ears produced per hectare as affected by variety.

Variety	Secondary ears per hectare
Garrison	8848 a [Z]
Obsession	7277 b

[Z]Means followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 9. Secondary ears produced per hectare as affected by row type.

Row Type	Secondary ears per hectare
Single row	8262 a [Z]
Twin row	7363 b

[Z]Means followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 10. Ear weight as affected by variety.

Variety	Ear weight (g)
Obsession	239.4 a [Z]
Garrison	224.8 b

[Z]Means followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 11. Ear weight as affected by row type.

Row type	Ear weight (g)
Single row	234.9 a [Z]
Twin row	229.3 b

[Z]Means followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 12. Ear weight as affected by an interaction between population density and study.

Population density	Ear weight (g)	
	Study 1	Study 2
29,640	237.0 abc[Z]	244.9 ab
39,520	253.1 a	235.7 abc
49,400	244.0 ab	226.2 bcde
59,280	234.1 bcd	223.4 cde
69,160	230.2 bcd	216.5 de
79,040	231.7 bcd	210.2 e

[Z]Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 13. Ear length as affected by variety.

Variety	Ear length (cm)
Obsession	21.3 a ^{Z}
Garrison	20.4 b

^{Z}Means followed by the same letter are not significantly different according to calculated

least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 14. Ear length as affected by an interaction between population density and variety.

Population Density	Ear length (cm)	
	Obsession	Garrison
29,640	21.9 a [Z]	20.2 cd
39,520	21.8 a	20.3 cd
49,400	21.6 a	20.1 d
59,280	20.9 b	20.3 cd
69,160	20.9 b	19.9 d
79,040	20.8 bc	19.8 d

[Z]Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 15. Ear length as affected by an interaction between study and variety.

Variety	Ear length (cm)	
	Study 1	**Study 2**
Obsession	20.7 b^Z	21.9 a
Garrison	19.7 c	20.5 b

^{Z}Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 16. Number of kernel rows found on the ear, as affected by an interaction between population density and study.

Population Density	Number of kernel rows per ear	
	Study 1	**Study 2**
29,640	17.2 b^Z	18.2a
39,520	17.9 ab	18.1 ab
49,400	18.1 ab	17.6 ab
59,280	17.8 ab	17.6 ab
69,160	17.8 ab	17.5 ab
79,040	17.8 ab	17.7 ab

^{Z}Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)

Table 17. Number of kernel rows found on the ear, as affected by an interaction between variety and study.

Variety	Study	Number of kernel rows per ear	
	Study 1	Study 2	
Obsession	17.6 bc^Z	17.1 c	
Garrison	17.9 b	18.4a	

^{Z}Means followed by the same letter, within row or column, are not significantly different according to calculated least squares means using the Tukey-Kramer procedure (P≤0.05)
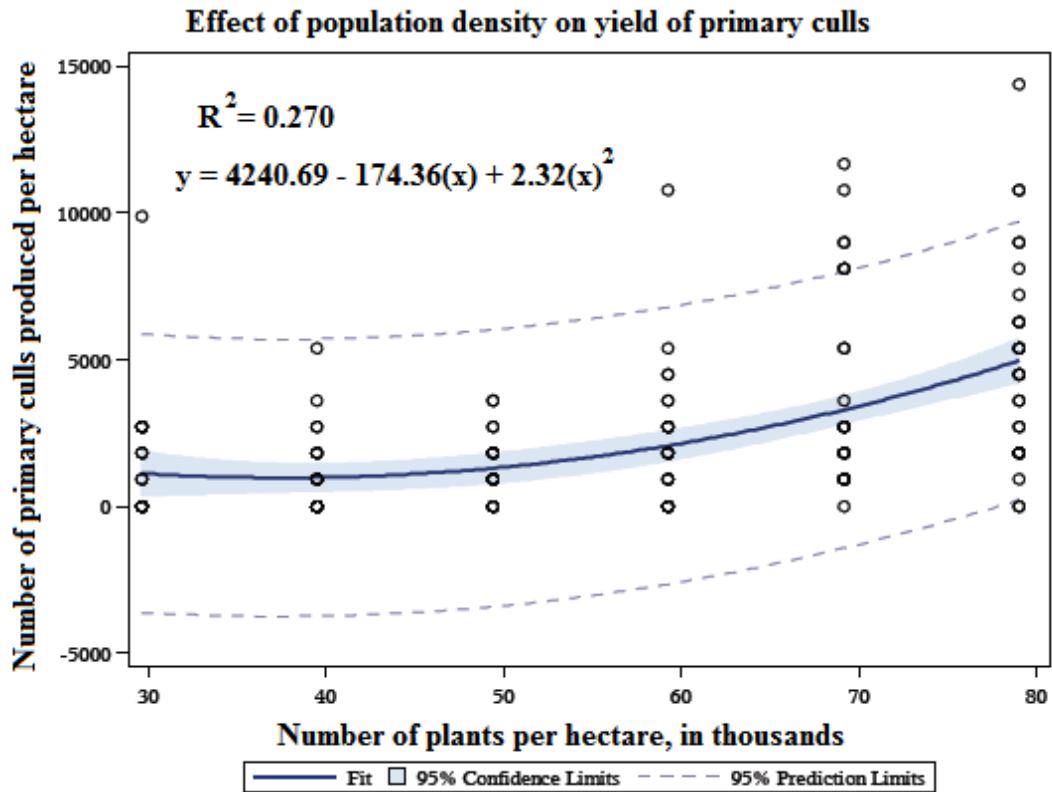
Figure 1. Yield of primary culls as affected by plant population density.
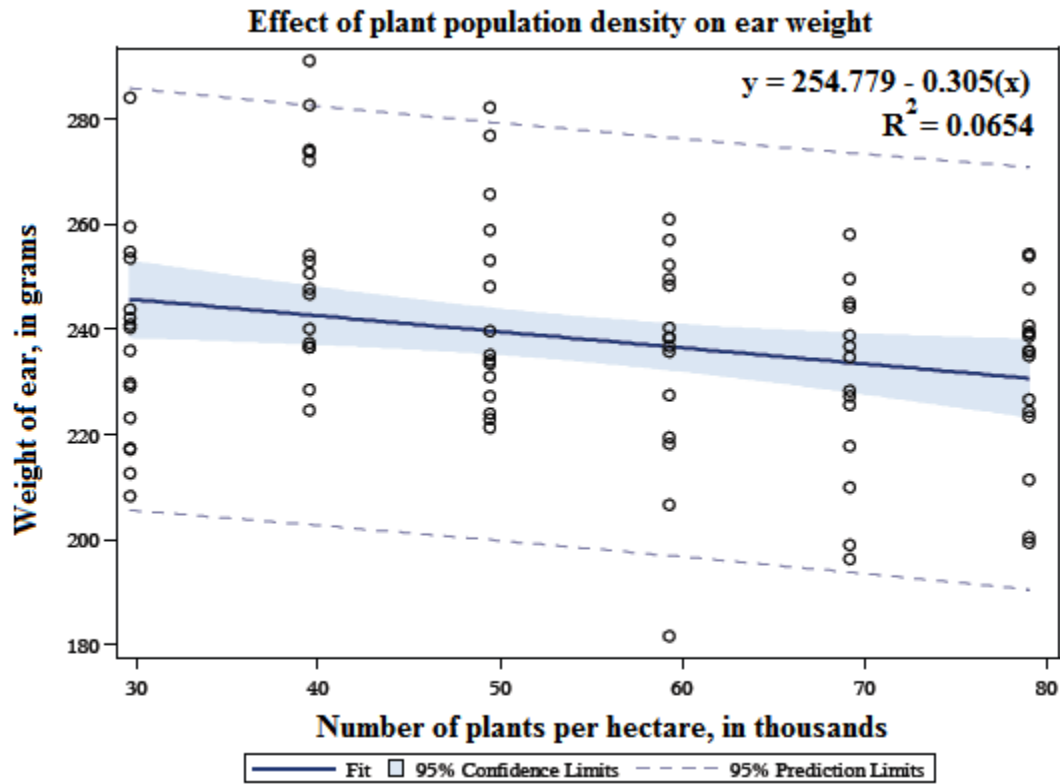
Figure 2. Ear weight as affected by population density, first planting site. Relationship is linear.
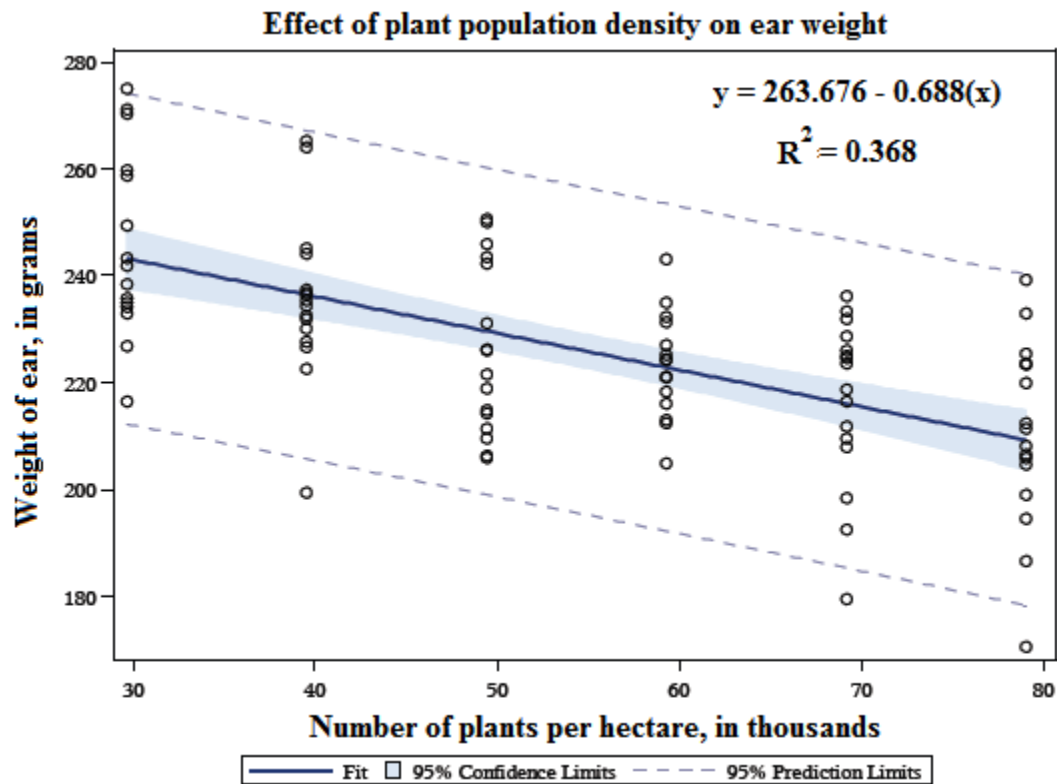
Figure 3. Ear weight as affected by population density, second planting site. Relationship is linear.

Effect of plant population density on ear length
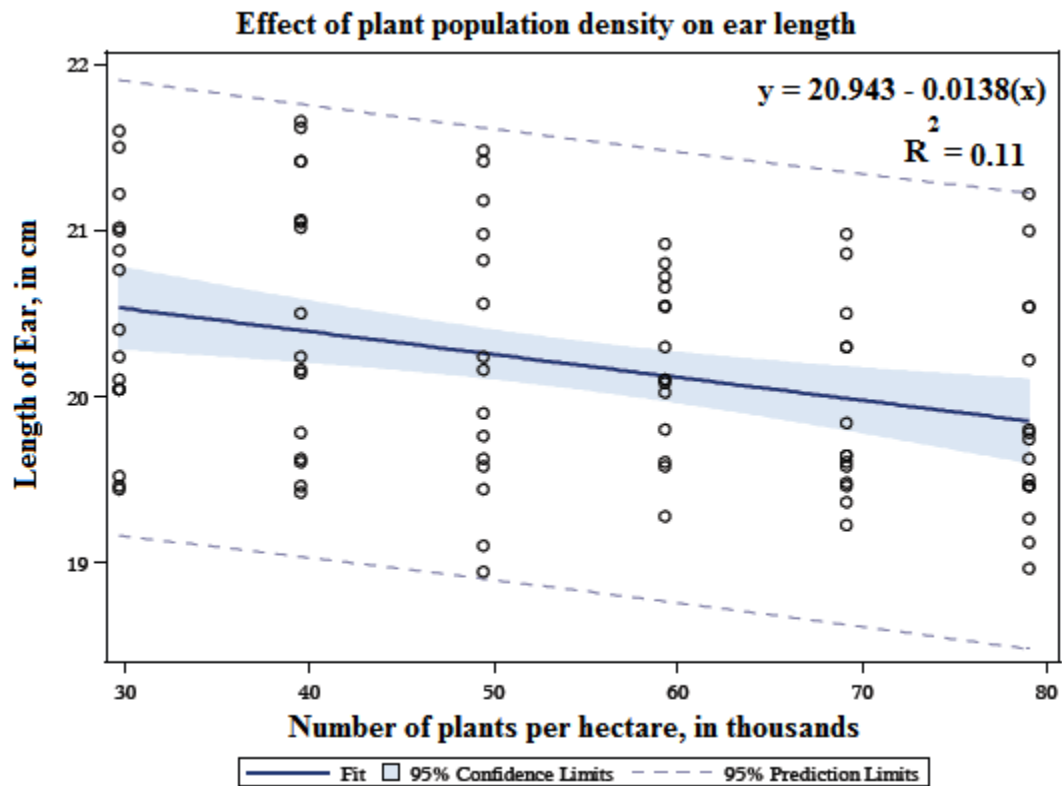
$$y = 20.943 - 0.0138(x)$$

$$R^2 = 0.11$$

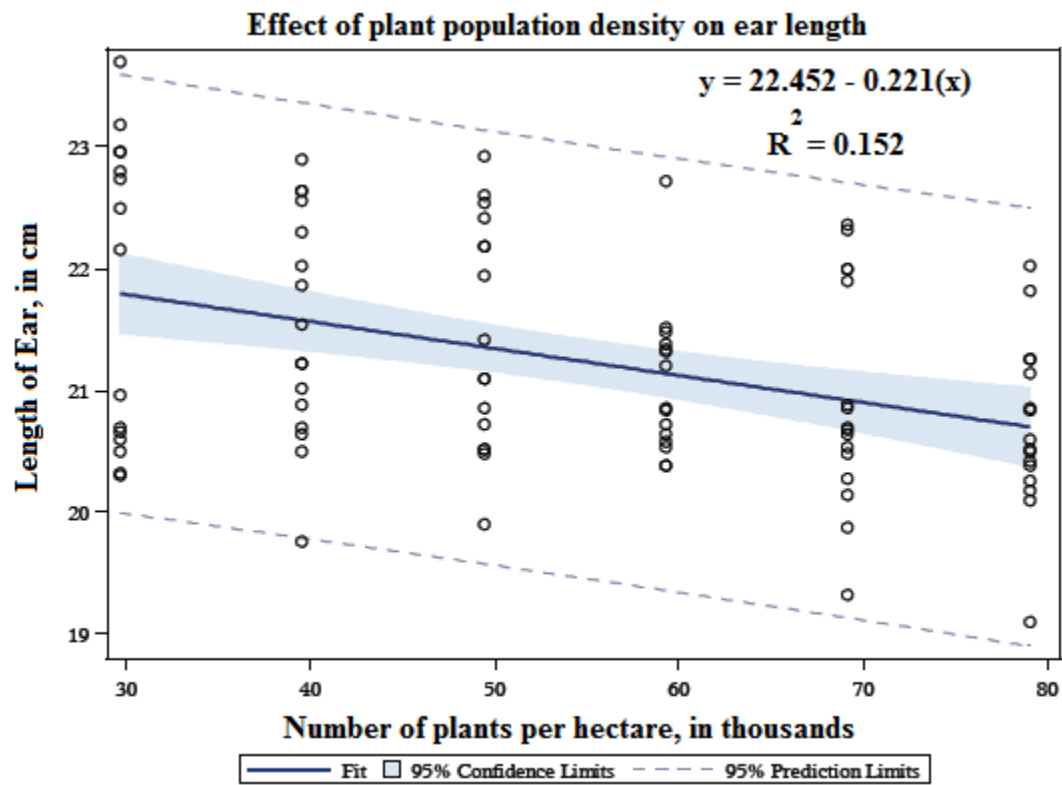Figure 4. Ear length as affected by population density, first planting site. Relationship is linear.

Figure 5. Ear length as affected by population density, second planting site. Relationship is linear.