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HYBRID, ROW WIDTH, AND PLANT POPULATION EFFECT ON CORN YIELD IN KENTUCKY

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HYBRID, ROW WIDTH, AND PLANT POPULATION EFFECT ON CORN YIELD IN KENTUCKY

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Agriculture at the University of Kentucky

By
Chelsea Clay McFarland

Director: Dr. Chad D. Lee, Professor of Agronomy
Lexington, KY
2013

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ABSTRACT OF THESIS

HYBRID, ROW WIDTH, AND PLANT POPULATION EFFECT ON CORN YIELD IN KENTUCKY

Studies were conducted in 2011 and 2012 to determine if narrow row corn (Zea mays L.) and/or greater plant populations could affect yield, time to silking, and other physiological characteristics. Main plots of six hybrids were arranged as a randomized complete block design with three replications. Split plots were row widths of 76-cm (wide rows) and 20-cm rows on 76-cm spacing (twin rows). Split-split plots were target plant populations of 75 000 and 111 000 plants ha\(^{-1}\). Corn was no-till seeded into soybean stubble near Lexington, KY in 2011 and 2012. Year interacted with most factors analyzed in the study. This was expected, given the extreme differences in weather. 2011 ASI (days) approached zero as plant population increased in wide rows in two out of four hybrids. ASI response to plant population in twin rows was not significant for any hybrid. In 2011, yield was greater in twin rows than wide rows. For significant equations, in 2011 grain yield increased as plant population increased, but in 2012 grain yield decreased as plant population increased, across both row widths. Kernel number per ear decreased as plant population increased in 2011 and 2012, but at different rates for wide and twin rows.

KEYWORDS: Zea mays L., ASI, plant population, grain yield, row width

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April 27, 2013
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This work is dedicated to the Farmer.
ACKNOWLEDGEMENTS

Having grown up on a farm, in a fourth generation farm family gave me a strong sense of appreciation for agriculture and initiated my passion for the products of the land. It is for that reason that I dedicate this thesis to the farmer. Seeing my father, and his before him, so entrusted to carrying on traditions of production agriculture humbled me as a young person and continues to inspire me as I follow my career path in the same industry. Throughout the duration of my graduate studies, I have focused not only on gaining knowledge of crop science, but also transmitting that knowledge and sharing it with farmers and agriculturists. It is my hope that the contents of this thesis may help at least one farmer answer one question, or that it may be of good reference for anyone to whom it may concern. It is with gratitude that I thank my advisor, Dr. Chad Lee, for allowing me to work on this project and be a part of his research team. I am forever grateful for his positive influence as a mentor and educator. I would also like to thank committee members, Dr. Dennis Egli and Dr. Jonathan Green for their efforts. The accomplishments of this thesis would not have been possible without help from James Dollarhide and various interns who helped with the planting, sample processing, and data collection for this study. I am greatly appreciative to fellow graduate students Katie Russell, Grant Mackey, John Orlowski, and many others for of all of the helpful pointers, support, and friendship throughout our semesters and growing seasons together. Mostly I want to thank my entire family and my fiancé for all of their support, encouragement, and words of wisdom as I pursued my graduate degree. I feel so blessed in being surrounded by such genuine individuals who are as strong of advocates for agriculture, and its innovations and advancements, as I am.
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Chapter 1: Literature Review

Introduction

Corn or maize (Zea mays L.) is a globally valuable crop domesticated in prehistoric Mesoamerica. By the time Christopher Columbus found the West Indies, corn was cultivated in nearly the entire Western Hemisphere. Today, maize is grown on about 80 million acres (32 million hectares) in the U.S. and about 1.4 million acres (583 000 hectares) in Kentucky (USDA-ERS, 2012). The leading producers of maize are the U.S., China, Brazil, Argentina, Mexico, Indonesia, India, South Africa, and France (FAO 2012). Maize is used as livestock feed, food and ethanol production.

Daynard et. al. (1971) defines grain yield as the product of average rate of grain production (dry weight increment per unit ground area per unit time) and duration of grain formation (units of time). For the purposes of this research, this definition is used as the primary description for grain yield. Grain yield takes into account both seed number and seed size (weight per seed). Seed number is the first component that is determined and accounts for environmental variation in yield. This is the first chance that the crop has to adjust its reproductive potential (Egli, 1998). Seed size is determined later in the yield production process and can only adjust to changes in the environment after seed number is fixed (Egli, 1998).

Since the dawn of the Green Revolution after World War II, much effort has been devoted to research, development, and technology transfer initiatives. These efforts have increased industrialized agriculture production greatly, both in the United States and around the globe. Historical increases in yield resulted from modification of the plant
(plant breeding) and/or the plant’s environment (crop management), and often complementary changes were required (Duvick and Cassman, 1999). Griliches, (1957) explained that the development of better cultivars and/or improved management practices was only the beginning of the process of technological change and adoption of innovations. Thanks to significant advancement in plant breeding in the past sixty years, genetic variation has been key for continued success in maize yields, which at present seems to be adequate looking toward the future (Fehr, 1999; St. Martin, 1999; Duvick, 2005). An important goal of maize breeders has been to enhance the stability of performance of maize when exposed to stresses (Campos et al., 2006). Thus, evidence suggests that much of the observed genetic gain in yield during the past 30 years can be attributed to greater stress resistance rather than in increase in yield potential (Duvick and Cassman, 1999).

**Corn stress response to narrow rows and increased plant population**

Van Roekel and Coulter (2011) noted that, over time, corn hybrids have been bred for increased tolerance to the stresses associated with high plant populations. Much emphasis has been placed on long-term research and the impact of stress tolerance on maize at varying plant populations. Taking the crop management tools into consideration, hybrids introduced in the 1990’s tolerate high plant populations much better than genotypes used in the past (Almeida and Sangoi, 1996; Almedia et al., 2000). Particular hybrid yields were examined from eras of release ranging from the 1930s to the 2000s by Hammer et al. (2009). The authors concluded that much of the yield increase associated with newer hybrids was due to increased stress tolerance, which allowed growers to adopt higher plant populations and thus obtain higher yields. In his research over a number of
years, Hammer et al. (2009) studied grain yield of corn hybrids released in the past 70 years. He found in several years that at the low density of 10 000 plants ha\(^{-1}\) grain yield increased at a rate of 0.01 Mg ha\(^{-1}\) yr\(^{-1}\), but at the high density of 79 000 plants ha\(^{-1}\) grain yield increased at a rate of 0.11 Mg ha\(^{-1}\) yr\(^{-1}\). Tollenaar (1989) notes that hybrids developed in recent years are able to withstand higher plant population levels than older hybrids. A research study conducted by Widdicombe and Thelen (2002), observed that plant population had a significant effect on grain yield, moisture, test weight, and stalk lodging. Interestingly, the highest plant population in the study (90 000 plants ha\(^{-1}\)) resulted in the highest grain yield. Nielsen (1988) observed that the 90 000 plants ha\(^{-1}\) plant population was greater for optimum yield at three locations evaluated in Indiana. Also, Porter et al. (1997) reported inconsistent optimal plant population levels ranging from 86 000 to 101 000 plants ha\(^{-1}\) for corn grain yield across three Minnesota locations.

Average row spacing declined from 107 cm (1930’s standard) to 102 cm in the 1950’s, to 96 cm a decade later, and to 90 cm in 1979 (Cardwell, 1982). Rossman and Cook (1966) summarized 10 studies in which reducing row widths from over 100 to less than 60 cm generally increased yields 3 to 20%. When reduced from what is referred to as a wide row (76 cm) down to a width as narrow as 38 cm, narrow rows resulted in a range of responses from no yield advantage of planting corn in narrow rows (Johnson et al., 1998; Farnham, 2001) to a 7% increase in yield (Porter et al., 1997). According to Farnham (2001), narrow rows spacings showed a 6.2% advantage in the northern U.S. Corn Belt and diminished as the trials moved south where wide row spacings showed a 4.1% advantage. According to Karlen et al. (1987) the narrow row spacing system, including the twin row configuration (46 and 20 cm) increases yield, because in theory, at
comparable populations, the narrower row decreases intrarow plant competition for water, nutrients, and light.

Bullock et al. (1988) observed that corn grown in an equidistant plant-spacing pattern (38 cm) often yields more grain per unit area of land than corn grown in conventional plant spacing patterns (76 cm) rows. The study that allowed for this conclusion tested two hybrids near Lafayette, IN in 1983 and 1984. Pioneer brand 3732 and B73 x LH58 which were planted in both row spacings. The yield increase in both years, as a result of the equidistant plant spacing was approximately 11% greater for the B73 x LH58 hybrid as compared to the Pioneer hybrid.

Shibles et al. (1966) observed nearly 1.5% yield increase in Iowa, for 76-cm row spacings compared with 102-cm row spacings and an additional 3.5% yield advantage for 51-cm row spacings. In the southeastern U.S. (Georgia), Brown et al. (1970) showed a 33.7% yield increase for corn grown in 51-cm row spacing configurations. In the state of Virginia, a 5% yield increase was reported for 76-cm row spacings compared with 102-cm row spacings, and there was a 2.7% additional yield advantage for 38-cm row spacings (Lutz et al., 1971). Ottman and Welch (1989) reported no difference in grain yield between 76-cm single-and 12-cm twin-row corn on 76-cm centers in an irrigated, high yield production system (Drummer silty clay loam) in Urbana, IL. In conjunction with those results, Kratochvil and Taylor (2005) found no increase in corn grain yield with twin-row spacing in the Delmarva region. Fulton (1970) reported a significant plant population x row spacing (50 cm) interaction in only one of four experimental years in Canada. This interaction indicated that the effect of narrow row spacings was greater at high plant populations (54 000 plants ha\(^{-1}\)) than at low plant populations (40 000 plants...
ha\(^{-1}\)) provided that adequate moisture was available. Rossman and Cook, (1966) acknowledge that higher plant population was found to have a greater effect on yield than row width or planting pattern. Sangoi (1996) considers this an important feature because the greater benefits of reducing maize row width occur at high plant populations.

Although the altering of row spacing and plant population is not a new management approach, there are some drawbacks that have prevented the spread and adoption of the approach besides the mixed results of grain yield that have occurred throughout current research. According to Hallman and Lowenberg-DeBoer (1999), widespread adoption of narrow row corn has been limited due to risk and lack of profitability which has been affected by harvest equipment availability, increased production costs related to insect management, and poor equipment resale. As more and more research has occurred on this subject and in time, manufacturers are ready to deliver equipment for narrow row production, as long as it proves to be cost-effective and profitable to maize growers (Sangoi et al., 2001). Profitability is associated with high grain yields, in a perfectly competitive market where grain prices are high and farm inputs are low.

**Light interception and yield**

Since there is a positive relationship between high yields and canopy photosynthesis, the amount of light intercepted by the maize canopy (on a community basis) is a major determinant of grain yield. Tollenaar and Lee (2006) state that an increase in total biomass accumulated via sustained photosynthesis during grain filling have been implicated as the major physiological determinants of the yield increase.
The primary driving force behind photosynthesis is light. The amount and efficiency to which the corn plant can capture and use the photosynthetically active radiation (PAR) from the sun, contributes to above ground biomass, and essentially yield of the plant and crop community as a whole. There are varying wavelengths of radiation that the sun emits, but plants use most the red wavelengths within the 0.4 to 0.7 μm photosynthetically active waveband (Meek et al., 1984). According to Gallo et al., 1993, intercepted radiation is defined as the difference between the incident radiation flux density at the top of the canopy and the transmitted flux density at the soil surface. Gallo further explains that absorbed radiation is the algebraic sum of (i) incident flux density above the canopy, (ii) reflected flux density above the canopy, (iii) flux density transmitted through the canopy to the soil surface and (iv) flux density reflected by the soil below the canopy.

Increased intercepted photosynthetically active radiation (IPAR) may be an added advantage of narrow-row corn early in the season. Dalley et al. (2004) indicate the competitive potential of narrow row corn in increasing light interception, but found in their study that light interception in cases of wide rows (76 cm) was similar to that of narrow rows (38 cm) by the VT (tassel emergence) stage of growth. A study by Nelson and Smoot (2009) focused on the effect of row spacing on intercepted photosynthetically active radiation and grain yield. There was no grain yield advantage of any particular row spacing when narrow, twin, and single-row corn was studied.

In an experiment conducted by Stewart et al. (2003), light interception and canopy photosynthesis was calculated using two-dimensional leaf distributions. When used as a model, row width was reduced by half (from 76 cm to 38 cm), with the same plant
population (60,000 plants ha$^{-1}$). Daily photosynthate production was calculated assuming shape and leaf area of the individual plants did not change with row width and the consistent plant population. In the Yuyu5 hybrid, daily photosynthate production increased by 17.2% compared to a 6.4% increase for Pioneer 3861, and a 3.76% for Mycogen TMF 94, when the row width was reduced by half.

Whether changes in leaf erectness contribute significantly to the increased biomass accumulation of modern maize hybrids remains uncertain (Luque et al., 2006). However, Duncan (1971) conducted research with the goal of indicating a way of estimating the quantitative significance of leaf area modification. In his paper, he acknowledged that studies with models have shown that for high leaf area indices (LAI), greater than 3.0, the efficiency of photosynthesis is greater with more erect leaves as compared with a leaf angle horizontal in nature. He found that within the range of LAI values usually encountered in the field (3.0-5.0), the two leaf types (vertical and horizontal) showed relatively small differences.

Leaf area index was first defined by Watson (1947) as being the total one-sided area of photosynthetic tissue per unit ground surface area. LAI is influenced by plant population, plant arrangement, plant age, etc. (Hammer et al., 2009). It can be measured by using a light bar produced by manufacturers such as LI-COR. Photosynthetically active radiation is measured per one meter area and recorded on an attached data logger in units of µmol m$^{-2}$ s$^{-1}$. The light that is not measured by the light bar at the bottom of the canopy, is assumed to be intercepted by the corn plants.
Withstanding of crowding in a maize crop is made possible by leaves being more upright (vertical) on the plant, minimizing self-shading. Note that yield increases are due to more plants per unit area which results in increased yield per area rather than per plant (Tollenaar and Aguilera, 1992). Recent studies conducted by Van Roekel and Coulter (2012) addressed the question of crowding and yield relative to IPAR and LAI. Phenotypically, the authors found that maximum IPAR (96.1%) occurred at the highest plant population they tested (109 000 plants ha\(^{-1}\)) The same trend was true for LAI at the same plant population, when averaged across row widths and hybrids. The row width treatments in the study included 51- and 76-cm with three relative maturity group hybrids; 95-, 101-, and 105-d. They tested plant populations ranging from 41 000 to the highest, 109 000 plants ha\(^{-1}\).

Van Roekel and Coulter (2011) noted that a shorter canopy with more upright leaves enhances the photosynthetic rate of leaves near the ear. Stewart et al. (2003) made a similar observation that while upright leaves may in certain circumstances improve the efficiency of PAR utilization, they have the negative quality of keeping leaves close to the stalk in maize and, therefore, allowing more radiation to penetrate to the soil surface. Because of this determination, the authors found that to accurately evaluate the importance of leaf angles in maize, both leaf angles and leaf area have to be incorporated in two dimensions to adequately describe the plant phenotype. The model that was used may have applications in quantifying the effect of canopy structure and planting patterns on crop photosynthesis and, when integrated over the growing season, on crop yield. Furthermore, results indicated that the proposed model of leaf area distribution and PAR
interception will be useful for quantifying the effect of canopy structure and planting patterns on crop photosynthesis.

Seed growth rate is accountable for most of the variation in corn kernel size. This relates to IPAR because if photosynthesis increases, seed number increases. Borrás et al. (2004) conducted an experiment looking at source-sink manipulations in wheat, maize and soybean as a quantitative scientific measure. He found that maize displayed a consistent trend to dramatic reductions in seed dry weight when assimilates produced during seed filling are reduced, but a virtual lack of responsiveness to improvements in potential availability of assimilates per growing seed unlike soybeans, which seem to experience a large degree of co-limitation by the source and the sink, as seeds greatly respond to source-sink modifications. This results in a sink-limited corn crop in most growing conditions, but a source-limited corn crop if resource availability is strongly reduced during seed filling. Assimilate supply acquired by a corn crop can be affected. It is important to take into account that this single physiological affect in seed growth rate is not the only one. Temperature and water stress have impacts along with genetic differences. Concerning the complementary component of yield, seed number, photosynthesis is one mechanism influencing that. Andrade et al. (2000) concluded that, kernel set per plant and per apical ear were well explained by intercepted photosynthetically active radiation per plant during a thirty day period bracketing silking. This helps explain that seed number is a function of assimilate supply during the critical period. Borrás et al. (2004) concludes that yield is usually more sink- than source-limited during seed filling. With the source being photosynthesis, directly, an increase in photosynthesis should increase potential sinks.
**Anthesis-Silking Intervals**

Corn is a monecious plant, producing both male and female flowers on one single plant and gametes of both sexes are produced in physically separate parts of the plant (Irish and Nelson, 1989). Flowering in Kentucky for most hybrids occurs roughly 1400 GDD after emergence (Lee, 2011). The male flower occurs on the vegetative corn tassel itself, while the female flower consisting of the stigma, style, and ovary is represented by what is commonly referred to as the silk. For an individual plant, anthesis for the male flowers is defined by Borrás et al. (2009) as occurring when at least one flower exerts anthers that dehisce and shed pollen. The female flowers are considered open when the first pollen receptive stigmas emerge from the ear, referred to as silking from that point forward. Duvick et al. (2004) reported that a yield advance was associated with a decrease in the anthesis-silking interval (ASI). A narrower interval between anthesis and silking, as recognized by Van Roekel and Coulter (2011), has been observed in corn hybrids being bred for increased tolerance to the stresses associated with high plant populations. Consequently, a characteristic of corn under stress conditions is an increase in the ASI. Kamara et al. (2009) note that, delaying planting generally increased days to flowering, the ASI, and reduced dry matter production and yield components.

Anthesis-silking intervals have been studied with early cultivars having environmental stress as the main focus. Badu-Apraku et al. (2011) conducted a study focused on selection for improved yield performance under low-N without sacrificing yield performance under high-N. Twenty-four hybrids were tested that were early maturing in contrasting environments. Drought stress was also an important response measured in the study. A Genotype x Trait (GT) biplot of cultivars under drought stress
found that selecting for reduced ASI under either drought or low-N stress would result in simultaneous improvement on grain yield in both environments.

Research has been conducted focusing on evidence of biomass partitioning. Borrás et al. (2009) notes that, genotypic differences in rapid silking under stress conditions seem to be more related to differences in biomass partitioning than to plant biomass production around flowering. Thus, selecting for a shorter ASI interval during stressful conditions can aid in greater biomass partitioning to the developing ear. A study by Borrás et al. (2009) tested the hypothesis among 36 treatment combinations simulating ASI based on plant growth rate (PGR) and biomass partitioning to the ear using a modeling approach. He found that there were also differences in everything from plant and ear biomass accumulation around flowering to simulating time to silking when looking at plants on an individual level, as compared to a canopy level. The model accurately predicted the proportion of plants that did not reach silking. Moss and Stinson (1961) studied the impact that reduced plant growth has on biomass partitioning to the ear and reported genotypic differences in time to silking. Also, according to Edmeades et al. (1999), ASI can be thought of as an external indicator of increased partitioning of assimilates to the growing ear. When combined with data on barrenness, ASI is a useful selection tool for improving partitioning.

**Ear types**

Two types of ears are portrayed through hybrid genetics in corn that harbor genotype differences and are available to producers and researchers: flex ear and fixed ear, also referred to as determinant versus indeterminate ear hybrids. Flex ear hybrids when planted at low population densities, when subjected to optimal growing conditions,
can increase yields by increasing the number of kernels per square meter (Smart et al., 1993). In contrast, fixed-ear hybrids show much less variability in potential kernels per square meter and result in more stable yields over environments. Adjustments of both ear types (mostly flex ear hybrids) include number or ears per plant, number of kernels per ear, and number of rows per ear.

A study was conducted by Kratochvil and Taylor (2005) that involved two hybrids: a semi-flex ear with erect leaves and a flex ear with lax leaves. The objectives of the study at three locations in the northeast U.S. was to (i) evaluate the performance of corn hybrids (grain system) produced in twin rows compared to 76-cm rows and (ii) compare both row spacing arrangements over a range of plant populations. The authors found that since there was no interaction between hybrid and row spacing observed either year, the different leaf morphologies had no influence upon twin-row yield.

The difference between flex and fixed ear hybrids seemed to vary. Kratochvil and Taylor (2005) observed that response to plant population varied by location, hybrid, and row spacing. On the other hand, Thomison and Jordan (1995) reported that hybrid ear type was of limited importance in determining optimum plant population. Van Roekel and Coulter (2012) evaluated three hybrids of three relative maturity ratings (Pioneer 38P43 (95-d), Pioneer 37N68 (101-d), and Pioneer 35F44 (105-d)) with ear flex ratings around 5 (5, 4, 5, respectively) on a scale from 1 to 9 with 9 indicating excellent ear flex, where there was an apparent response of yield components to increasing plant population, and 1 indicating a fixed-ear type hybrid, were there was little change in grain yield components to increasing plant population. Grain weight, grain yield, and kernels per
square meter were affected by hybrid and did not interact with row width, and plant population.

Plant configuration and uniformity can have a great influence on grain yield among fixed-ear or flex-ear hybrids. Andrade and Abbate (2005) tested two hybrids in a research study in Argentina showing greater reduction in corn grain yield for the differing ear types with uneven interplant spacing. However, the hybrid harboring flex ear characteristics (DK752) yielded more than the more fixed ear hybrid, M400. With the increase in within-row interplant spacing, resulting from narrower rows, this suggests that flex-ear hybrids may respond more positively than fixed-ear hybrids to narrow rows.

**Objectives**

The objectives of this study were

1.) To determine the effect of hybrid, row width and plant population on grain yield.

2.) To determine the effect of hybrid, row width and plant population on crop development.

3.) To determine the effect of hybrid, row width, and plant population on yield parameters.
Chapter 2: Field Studies

Materials and Methods

Research was conducted in 2011 and 2012 at the Kentucky Agricultural Experiment Station Spindletop Farm (38° 01’ N, 84° 35’ W) in order to determine if corn (Zea mays L.) hybrids in narrow rows and/or higher plant densities affected crop physiology and yield. The study was arranged as a split-split plot in a randomized complete block design with hybrid as the main plot (three replicates), row width as the split and plant population as the split-split plot.

Studies were conducted on a Loradale silt loam (fine-silty, mixed, mesic Typic Argiudoll) (Seta and Karathanasis, 1997) following soybean both years with no-till planting. Weeds were managed prior to corn planting with a burndown application of 1.67 L ha\(^{-1}\) of glyphosate, [N-(phosphonomethyl) glycine], (as RoundUp WeatherMax, Monsanto Co. St. Louis) and a preemergence application of 7.02 L ha\(^{-1}\) premix of S-metolachlor, atrazine and mesotrione (Lexar, Syngenta Crop Protection LLC, Greensboro, NC). Insecticide treatment occurred in 2012 only, with 0.18 kg ha\(^{-1}\) S-Cyano (3-Phenoxyphenyl) methyl (+) cis/trans 3-(2.2-dichloroethenyl)-2.2 dimethylcyclopropane carboxylate (MustangMax, FMC Corporation, Philadelphia, PA).

Seed of glyphosate tolerant hybrids DKC66-96, DKC62-97, P1480HR, 33D49 (33D44 in 2012), A6533VT3, and A6632VT3 were planted on 9 May, 2011 and 24 April, 2012. Liquid urea ammonium nitrate (224 kg N ha\(^{-1}\)) was surface applied the day after planting each year and in excess of university recommendations. Phosphorus, potassium and zinc were not necessary in either year based on soil tests.
Individual plots were either four 76-cm rows or four sets of twin rows (20-cm twins on 76-cm centers). Target plant populations were 77 000 plants ha$^{-1}$ or 111 000 plants ha$^{-1}$. Temperatures and rainfall in 2011 were near average whereas, the 2012 production season experienced warmer temperatures and less rainfall (Table 2.1), putting corn under environmental stress. In both years low pressure drip irrigation tape was used to irrigate the plots. The tapes were spaced 152 cm apart. About 2.57 cm irrigation was applied 27 July, 2011. A total of 42.8 cm was added from 25 June 2012 through physiological maturity on 27 August 2012. In both years, The University of Nebraska-Lincoln water use curve (Kranz et al., 2008) was used in determining water requirements for the crop. The protocol allowed for determination of water requirements needed for the corn crop to reach each stage of growth.

Stand counts were taken at the VE growth stage (Abendroth et al., 2011) and the plants were growth staged weekly from VE and through R6. Light interception was measured at growth stage V8 under clear skies near solar noon (11:00 am – 2:00 pm) using a LI-191 Line Quantum Sensor (Li-Cor, Lincoln, NE). One initial measurement was taken above the plants followed by three measurements at soil level in each plot following the methods of Van Roekel and Coulter (2011). At V12 beginning 1.5 m from the end of the plot, 20 consecutive plants were marked with tags and all measurements after V12 including the final harvest, were based on those 20 consecutive plants.

Plants were evaluated daily from tassel emergence to brown silk to determine ASI according to Table 2.1. Individual ratings for each plant on each day were averaged across each plot. If a plant was given a silking rating of “3” before a rating indicating anthesis (6 or 9), then a negative interval in days accumulated until a rating of anthesis
was reached. In the cases where a rating of “9” was given, a positive interval in days accumulated until a rating of silking was reached (6 or 9). In 2011, the measurements began on 9 July and ended on 25 July. In 2012, the measurements began on 25 June and ended on 16 July. In 2011, both AgriGold hybrids were not reported since plants did not reach 50% anthesis during the 17 day (d) period of flowering. In 2012, A6632VT3 was not reported for that same reason. Stalk diameters on the second visible internode were measured with calipers. Plant heights, ear heights, and plant-to-plant spacing of the 20 plants was measured. These measurements were taken on 15 and 16 August, 2011 and 13 and 14 August, 2012.

Ears from the 20 labeled plants were hand-harvested on 13 September, 2011 and on 3 September, 2012. Each ear was bagged and processed individually. Community yield was based on the 20 plants in each plot. Kernel weights were totaled for each plot (20 plants in each), and yield was determined as kernel weight per unit area. Upon harvest, a fresh weight of each ear(s) was measured. The ears were placed in the dryer at 99 degrees Celsius for six days before the dry weight was determined. Number of kernel rows per ear, tip-back length and ear length were measured after drying on the dominant or uppermost ear on each plant. “Tip-back” exists when kernels have been aborted during grain fill and show evidence of kernels that are undeveloped at the tip of an ear of corn. The distance from the last developed kernel to the tip of the cob was measured. A hand sheller was used to remove kernels from each ear. The collective dried kernels were then weighed and counted using a 850-2 electronic seed counter (The Old Mill Co., Savage, MD) in 2011 and an ESC-1 electronic seed counter (Agriculex, Inc., Guelph, Ont., Canada) in 2012.
Final plant populations were highly variable compared to the target seeding rates, resulting in a continuous set of population data. Corn response to plant population was one objective to this research. As a result of the continuous data of plant population, all observations are reported as a function of the actual plant population (plants ha$^{-1}$).

Table 2.1: Anthesis-silking interval rating system.

<table>
<thead>
<tr>
<th>Original Rating</th>
<th>Modified Rating</th>
<th>Description of Rating</th>
<th>ASI Interval</th>
<th>Silk Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>VN Growth Stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Visible Tassel</td>
<td></td>
<td>Without</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Fully Emerged Tassel</td>
<td></td>
<td>Silk</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Silk Only</td>
<td>Negative Interval</td>
<td>With Silk</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Visible Tassel</td>
<td></td>
<td>With Silk</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Fully Emerged Tassel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Pollination Started</td>
<td>ASI = 0 Days</td>
<td>With Silk</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1/2 Pollen Drop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Full Pollination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Pollination Started</td>
<td>Positive Interval</td>
<td>Without</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>1/2 Pollen Drop</td>
<td></td>
<td>Silk</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Full Pollination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Pollination Finished/Complete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>Visible tassel, 1/2 Pollen Drop</td>
<td>ASI = 0 Days</td>
<td>With Silk</td>
</tr>
<tr>
<td>14</td>
<td>9</td>
<td>Visible tassel, 1/2 Pollen Drop</td>
<td>Positive Interval</td>
<td>Without Silk</td>
</tr>
</tbody>
</table>

Data were analyzed using Statistical Analysis Software (SAS, Version 9.3), including the general linear model procedure (PROC GLM) with $\alpha=0.10$ (SAS, 2012). For significant regressions, predicted values for the two target plant populations (74 000 and 111 000 plants ha$^{-1}$) were calculated and reported. Significant regressions occurred for a number of physiological variables as well as grain yield components.
Chapter 3: Results

Physiological Response of Corn to Narrow Rows and Plant Population

Most data reported in the following results section of text are in the form of figures and mostly include regressions that are statistically significant. All data, whether significant or not can be accessed in the Appendix section of this thesis.

Stalk Diameter/Plant Measurements

Actual stands were variable, but plant-to-plant spacing decreased as plant population increased (Figure 3.2), which was expected. Plant-to-plant spacing was about 43% greater in twin rows than in 76-cm rows, as expected.

In each year, a hybrid by row width interaction occurred for stalk diameter. Stalk diameter in 2011 decreased as plant population increased for three out of six hybrids (Figure 3.3 through Figure 3.5) in 76-cm row widths and two out of six hybrids in twin rows (Figure 3.3 and Figure 3.6). In 2012, stalk diameter decreased as plant population increased for P1480HR in the 76 cm rows (Figure 3.8) and DKC66-96 (Figure 3.7), P1480HR (Figure 3.8), and 33D44 (Figure 3.9) in twin rows. When compared to 2012, average stalk diameters were smaller in 2011. The stalk diameter in 2011 in the lower target plant population ranged from 18 to 20 mm compared to 16 to 17 mm at 111 000 plants ha\(^{-1}\). In 2012, target populations of 74 000 and 111 000 plants ha\(^{-1}\) had stalk diameters of 22 to 23 mm, and 19 to 21 mm, respectively.
**Plant Height**

Plant height of hybrids P1480HR and A6533VT3 decreased 8 and 10 cm, respectively as target populations increased in 2011 across both row widths (Figure 3.10). Plant population had no effect on plant height for the remaining four hybrids in 2011 (Table A-4) or any of the hybrids in 2012 (data not shown).

**Ear Height**

No interactions occurred between hybrids and row widths for ear height. Increased plant population increased ear height for A6632VT3 in 2011 and DKC62-97 in 2012 by 7 to 13%, respectively (Table A-5). Plant height in these two cases was not affected (Table A-4). Plant population had no effect on ear height for the majority of hybrids each year and row width had no effect on ear height (Table A-5).

**Kernels Per Ear**

Kernels per ear (KPE) in 2011 decreased as plant population increased for hybrids DKC62-97 and P1480HR at both row widths (Figure 3.11). KPE averaged across all hybrids in 2011 decreased as plant population increased in 76-cm and twin rows (Figure 3.12). However, KPE decreased at a slower rate for twin rows. When moving from the lower target population to the higher target population, predicted KPE decreased by 24 and 16% for 76-cm and twin rows, respectively. In 2012, for DKC66-96 (Figure 3.13) and DKC62-97 (Figure 3.14) in twin rows, KPE decreased as plant population increased. Plant population had no effect on KPE for four hybrids in 2011 and ten of the hybrid by row width comparisons in 2012.
Kernel Row Number

Kernel row number (KRN) across plant populations was not consistent from year to year for hybrids or row widths, and only eight of the 24 comparisons (looking at both 2011 and 2012) resulted in significant regressions. Increasing plant population decreased KRN for DKC66-96 in twin rows in 2011 (Figure 3.15), P1480HR in twin rows (Figure 3.16), 33D49 in 76-cm rows (Figure 3.17), and A6533VT3 and A6632VT3 in 76-cm rows (Figure 3.18 and Figure 3.19). In 2012, plant population did not affect KRN for any hybrid in 76-cm rows (Table A-9). For twin rows, KRN decreased as plant population increased for hybrids DKC62-97 (Figure 3.20) and P1480HR (Figure 3.21), while KRN increased as plant population increased for A6533VT3 (Figure 3.22).

In 2011, moving from the low target population to the high target population changed predicted KRN by -1.5 to -0.3 for the negative regressions. In 2012, the two negative regressions changed predicted KRN by about -1.3, while the positive regression (A6533VT3 in twin rows) increased KRN from 8.7 to 14.0.

Ear Length

In 2011, ear length decreased as plant population increased for all hybrids except A6632VT3 (Figure 3.23 through Figure 3.25). In 2012, ear length decreased as plant population increased in twin rows for DKC66-96 (Figure 3.26) and in both row widths for P1480HR (Figure 3.27). In 2011 and 2012, hybrid P1480HR had the longest ear in both the low and high target plant populations as compared to the other hybrids with significant regressions. Predicted ear lengths tended to be longer in the low target plant populations ranging from 17 to 19 cm in 2011 and 15 to 17 cm in 2012, compared to a
range of 14 to 16 cm in 2011 and 13 to 15 cm in 2012, of predicted ear length in the high target populations.

**Tip-back**

Regressions for plant population effect on tip-back were significant for four of the six hybrids in 2011 and only one of the six hybrids in 2012. None of the hybrids resulted in significant tip-back both years (Table A-12). In all of the significant regressions, increasing plant population increased the length of tip-back (Figure 3.28, Figure 3.29, Figure 3.30 and Figure 3.31). Moving from the low target population to the high target population increased predicted tip-back by about 0.1 to 0.5 cm.

**Kernel Weight**

Kernel weight (KW) for hybrids 33D49 and A6632VT3 decreased as plant population increased in 2011 (Figure 3.32). None of the treatments significantly affected KW in 2012. Row width had no effect on KW either year.

**Anthesis-Silking Intervals**

Only two ASI regressions were significant for both years of the study. The predicted ASI in 2011 for 33D49 and P1480HR approached zero (-0.2 to 0.01 and -1.2 to -0.7 d, respectively) as plant population increased (Figure 3.33). These ASI ranges likely did not influence pollination or yield. Measuring ASI was a key in this study and for the majority of comparisons, row width and plant population did not influence ASI. In 2011, both A6533VT3 and A6632VT3 did not reach 50% anthesis during the 17-d sampling period, and in 2012, A6632VT3 did not reach 50% anthesis during the 22-d sampling
period, implying highly variable ASI values. Yet, both hybrids were high-yielding, which will be addressed later.

**Light Interception**

Predicted light interception (LI) at V8 ranged from 59.4 to 78.9% and was not affected by row width. In 2011, LI increased as plant population increased for DKC66-96 (Figure 3.34), 1480HR (Figure 3.35), 33D49 (Figure 3.36), and A6533VT3 (Figure 3.37). In the low target plant populations, predicted light interception ranged from 60 to 70% with the highest percentage occurring in 2012 in hybrid A6533VT3 (Figure 3.37), and the lowest percentage occurring in 2011 in hybrid P1480HR (Figure 3.35). In the high target plant populations, predicted light interception had a higher range from 69 to 79%, with the highest percentage occurring in 2012 in hybrids 33D44 (Figure 3.36) and A6533VT3 (Figure 3.37), and the lowest percentage occurring in 2011 in hybrid DKC66-96 (Figure 3.34). In 2012, LI increased as plant population increased for DKC66-96 (Figure 3.34), 33D49 (Figure 3.36), and A6533VT3 (Figure 3.37). The highest rate of increase between predicted LI, moving from the low target population to the high target population, occurred for 33D44 in 2012 (Figure 3.36).

**Field Studies – Yield**

Although hybrid and row width did not interact in 2011, both factors were significant on grain yield. Predicted yield increased as plant population increased, in both row widths (Figure 3.38). Predicted yields increased at a greater rate for twin rows and predicted yields were greater for twin rows than 76-cm rows at all populations in 2011 (Table A-16). Only three hybrids, DKC66-96, DKC62-97, and 33D49, revealed an increase in yield as plant population increased in 2011 (Table A-17). Of those three
hybrids, yields increased at the greatest rate for DKC66-96. No treatments had a significant effect on grain yield in 2012 (numeric yield values for 2012 can be found in Table A-18 and Table A-19, however, ASI was compared to grain yield in both 2011 (Figure 3.39) and 2012, with a significant and negative trend in 2012 (Figure 3.40). In 2011, the range in ASI from -6 to 1 d most likely would not influence pollination or yield, however, in 2012 the ASI range from -3 to 7 d likely reduced pollination and yield.
Figure 3.1: (A) Monthly rainfall data during the growing seasons in 2011 and 2012. (B) Monthly temperature data during the growing seasons in 2011 and 2012. (C) Weather data during the 17 day anthesis-silking interval period in 2011. (D) Weather data during the 22 day anthesis-silking interval period in 2012.
Figure 3.2: Mean plant-to-plant spacing (cm) of 20 consecutive plants in twin and 76 cm row widths for six hybrids in 2011 and 2012 as a function of plant population.

![Plot of plant-to-plant spacing](image1)

Figure 3.3: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid DKC62-97 in 2011 as a function of plant population.

![Plot of stalk diameter](image2)
Figure 3.4: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid DKC66-96 in 2011 as a function of plant population.

![Graph for DKC 66-96, 2011]

*Linear (76-cm Rows)*

\[ y = -6.7 \times 10^{-5}x + 24.0 \]

\[ R^2 = 0.78 \]

\[ p = 0.02 \]

*Twin*

\[ y = -4.6 \times 10^{-5}x + 23.1 \]

\[ R^2 = 0.26 \]

\[ p = 0.30 \]

Figure 3.5: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid P1480HR in 2011 as a function of plant population.

![Graph for P1480HR, 2011]

*Linear (76-cm Rows)*

\[ y = -8.7 \times 10^{-5}x + 25.7 \]

\[ R^2 = 0.78 \]

\[ p = 0.02 \]

*Twin*

\[ y = -1.1 \times 10^{-4}x + 28.0 \]

\[ R^2 = 0.51 \]

\[ p = 0.11 \]
Figure 3.6: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid A6533VT3 in 2011 as a function of plant population.

Figure 3.7: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid DKC66-96 in 2012 as a function of plant population.
Figure 3.8: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid P1480HR in 2012 as a function of plant population.

Figure 3.9: Mean stalk diameter (mm) for 20 consecutive plants in twin and 76 cm row widths for hybrid 33D44 in 2012 as a function of plant population.
Figure 3.10: Mean plant height (cm) of 20 consecutive plants in 76 cm and twin row widths for hybrids P1480HR and A6533VT3 in 2011 as a function of plant population.

Figure 3.11: Mean kernels per ear (KPE) for 20 consecutive plants for hybrids P1480HR and DKC62-97 in 2011 as a function of plant population.
Figure 3.12: Mean kernels per ear (KPE) for 20 consecutive plants in 76 cm and twin row widths in 2011 as a function of plant population.

Figure 3.13: Mean kernels per ear (KPE) for 20 consecutive plants in twin row widths for hybrid DKC66-96 in 2012 as a function of plant population.
Figure 3.14: Mean kernels per ear (KPE) for 20 consecutive plants in twin row widths for hybrid DKC62-97 in 2012 as a function of plant population.

![Graph showing the relationship between kernels per ear and plant population for DKC62-97 in 2012.]

**DKC62-97, 2012**

![Graph showing the relationship between kernels per ear and plant population for DKC62-97 in 2012.]

Figure 3.15: Mean kernel row number per ear (KRN) for 20 consecutive for hybrid DKC66-96 in twin rows in 2011 as a function of plant population.

![Graph showing the relationship between kernel row number per ear and plant population for DKC66-96 in 2011.]

**DKC66-96, 2011**

![Graph showing the relationship between kernel row number per ear and plant population for DKC66-96 in 2011.]

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Figure 3.16: Mean kernel row number per ear (KRN) for 20 consecutive plants in twin rows for hybrid P1480HR in 2011 as a function of plant population.

P1480HR, 2011

\[ y = -3.9 \times 10^{-5}x + 18.9 \]
\[ R^2 = 0.75 \]
\[ p = 0.02 \]

Figure 3.17: Mean kernel row number per ear (KRN) for 20 consecutive plants in 76-cm rows for hybrid 33D49 in 2011 as a function of plant population.

33D49, 2011

\[ y = -1.4 \times 10^{-5}x + 15.9 \]
\[ R^2 = 0.75 \]
\[ p = 0.03 \]
Figure 3.18: Mean kernel row number per ear (KRN) for 20 consecutive plants in 76-cm rows for hybrid A6533VT3 in 2011 as a function of plant population.

Figure 3.19: Mean kernel row number per ear (KRN) for 20 consecutive plants in 76-cm rows for hybrid A6632VT3 in 2011 as a function of plant population.
Figure 3.20: Mean kernel row number per ear (KRN) for 20 consecutive plants in twin rows for hybrid DKC62-97 in 2012 as a function of plant population.

**DKC62-97, 2012**

![Graph showing the relationship between plant population and mean kernel row number per ear for DKC62-97 in 2012.](image)

- **Twin**
  - \( y = -3.1E-4x + 17.2 \)
  - \( R^2 = 0.64 \)
  - \( p = 0.06 \)

Figure 3.21: Mean kernel row number per ear (KRN) for 20 consecutive plants in twin rows for hybrid P1480HR in 2012 as a function of plant population.

**P1480HR, 2012**

![Graph showing the relationship between plant population and mean kernel row number per ear for P1480HR in 2012.](image)

- **Twin**
  - \( y = -4.2E-5x + 18.5 \)
  - \( R^2 = 0.91 \)
  - \( p = 0.003 \)
Figure 3.22: Mean kernel row number per ear (KRN) for 20 consecutive plants in twin rows for hybrid A6533VT3 in 2012 as a function of plant population.

Figure 3.23: Mean ear length (cm) for 20 consecutive plants for hybrids DKC62-97 and DKC66-96 in 2011 as a function of plant population.
Figure 3.24: Mean ear length (cm) for 20 consecutive plants for hybrids P1480HR and 33D49 in 2011 as a function of plant population.

![Graph showing ear length vs. plant population for P1480HR and 33D49 hybrid plants in 2011.](image)

- **P1480HR**: $y = -7.4E-5x - 24.2$, $R^2 = 0.88$, $p < 0.0001$
- **33D49**: $y = -5.5E-5x - 21.7$, $R^2 = 0.79$, $p = 0.0001$

Figure 3.25: Mean ear length (cm) for 20 consecutive plants for hybrids A6533VT3 in 2011 as a function of plant population.

![Graph showing ear length vs. plant population for A6533VT3 hybrid plants in 2011.](image)

- **A6533VT3**: $y = -8.0E-5x - 23.1$, $R^2 = 0.46$, $p = 0.01$
Figure 3.26: Mean ear length (cm) for 20 consecutive plants in twin row widths for hybrid DKC66-96 in 2012 as a function of plant population.

Figure 3.27: Mean ear length (cm) for 20 consecutive plants in 76 cm and twin row widths for hybrid P1480HR in 2012 as a function of plant population.
Figure 3.28: Mean ear tip-back (cm) for 20 consecutive plants for hybrid DKC62-97 in 2011 as a function of plant population.

![Diagram](image1)

Figure 3.29: Mean ear tip-back (cm) for 20 consecutive plants for hybrids 33D49 and 33D44 in 2011 and 2012, respectively as a function of plant population.

![Diagram](image2)
Figure 3.30: Mean ear tip-back (cm) for 20 consecutive plants for hybrid A6533VT3 in 2011 as a function of plant population.

Figure 3.31: Mean ear tip-back (cm) for 20 consecutive plants for hybrid A6632VT3 in 2011 as a function of plant population.
Figure 3.32: Mean kernel weight seed\(^{-1}\) (kg) for 20 consecutive plants for hybrids 33D49 and A6632VT3 in 2011 as a function of plant population.

![Graph showing the relationship between kernel weight and plant population for 33D49 and A6632VT3.](image)

- **33D49**
  - Linear equation: \(y = -4.0 \times 10^{-10}x + 2.6 \times 10^{-4}\)
  - \(R^2 = 0.35\)
  - \(p = 0.04\)

- **A6632VT3**
  - Linear equation: \(y = -7.2 \times 10^{-10}x + 2.9 \times 10^{-10}\)
  - \(R^2 = 0.36\)
  - \(p = 0.04\)

Figure 3.33: Mean anthesis-silking interval (days) for 20 consecutive plants for hybrids 33D49 and P1480HR in 2011 as a function of plant population.

![Graph showing the relationship between anthesis-silking interval and plant population for 33D49 and P1480HR.](image)

- **33D49**
  - Linear equation: \(y = 7.0 \times 10^{-6}x + 0.76\)
  - \(R^2 = 0.26\)
  - \(p = 0.09\)

- **P1480HR**
  - Linear equation: \(y = 1.5 \times 10^{-5}x + 2.3\)
  - \(R^2 = 0.60\)
  - \(p = 0.003\)
Figure 3.34: Mean light interception (%) for hybrid DKC66-96 in 2011 and 2012 as a function of plant population.

Figure 3.35: Mean light interception (%) for hybrid P1480HR in 2011 as a function of plant population.
Figure 3.36: Mean light interception (%) for hybrids 33D49 and 33D44 in 2011 and 2012, respectively as a function of plant population.

Figure 3.37: Mean light interception (%) for hybrid A6533VT3 in 2011 and 2012 as a function of plant population.
Figure 3.38: Mean grain yield (Mg ha\(^{-1}\)) harvested from 20 consecutive plants per experimental unit in 76 cm and twin row widths for six hybrids 2011 as a function of plant population.

![Grain Yield, 2011](image)

Figure 3.39: Anthesis-silking interval (days) average for the plot vs. grain yield (Mg ha\(^{-1}\)) in 2011.

![ASI vs GY, 2011](image)
Figure 3.40: Anthesis-silking interval (days) average for the plot vs. grain yield (Mg ha\(^{-1}\)) in 2012.

\[ r = -0.37674 \]
\[ p = 0.0033 \]
Chapter 4: Discussion and Conclusions

Field Studies

Weather conditions differed greatly over the two years (Figure 3.1) and those differences impacted the physiological response of corn to row width and population. The weather in 2011 was more favorable for crop growth and yield compared with the weather in 2012. Hollinger and Changnon (1993) stated that the effect of weather on crops has always been the main source of year-to-year variability in yields. Year was significant in the majority of parameters studied and analyzed. There was also a large amount of variation in hybrid response to weather and the treatments. Grain yield in 2011 increased as plant population increased when averaged across all hybrids in both 76-cm rows and twin rows (Figure 3.38). The greatest yields in 2011 occurred in twin rows, however, plant population did not affect grain yield for either row width or any of the six hybrids in 2012 (data not shown).

The ASI may explain some yield difference in 2012, but not in 2011. ASI did not affect grain yield in 2011 (p-value = 0.14, Figure 3.39), but an increasing ASI decreased grain yield in 2012 (Figure 3.40). In 2011, pollen shed occurred in a range from 6 d before to 1 d after silking which likely did not hinder pollination (Borrás et al., 2007). However, in 2012, pollen shed occurred from 3 d before silking to about 7 d after silking. A delay in silking by 5 to 7 d after first pollen drop likely would reduce pollination and yield. However, in 2011, both AgriGold hybrids did not reach 50% anthesis during the monitoring period, yet had yields comparable to other hybrids (Table A-18). For these hybrids, ASI was not an accurate measurement of stress tolerance or determinant of grain yield.
Light interception at V8 growth stages varied each year as well and may partially explain some of the yield differences. For all significant regressions in 2011, an increase in plant population increased light interception (Figure 3.34 through Figure 3.37). Row width did not affect light interception in either year of the study. Stewart et al., (2003) suggested that the IPAR influences canopy photosynthesis and yield. IPAR may have been more influential in 2011 when water was available and may explain, in part, the yield increases in 2011. The lack of water in 2012 likely overwhelmed any effect of IPAR.

The greater yields in twin rows in 2011 can be explained in part by kernel number per ear. Plant population reduced kernels per ear for two hybrids (DKC62-97 and P1480HR) and for both row widths in 2011 (Figure 3.11 and Figure 3.12, respectively). However, kernel counts were reduced less in twin rows than in 76-cm rows, which contributed to more total kernels per hectare for twin rows.

Six hybrids were evaluated in this study. Several of these hybrids were listed as a flex type ear, implying that as population increased, kernel number, ear length and kernel rows per ear will decrease. Other hybrids were listed as a fixed ear type, where kernel number, ear length and kernel rows per ear would change little to increasing plant population. However, observations in this study indicate that the expression of a “flex-type” ear may not be consistent from year to year.

In 2011, the hybrids that appeared to be a flex type were DKC62-97 and P1480HR. Increasing plant population decreased ear length for both hybrids in 2011 (Figure 3.23 and Figure 3.24) and decreased kernel rows per ear for P1480HR in twin
rows (Figure 3.16). However, plant population did not affect kernel rows per ear for P1480HR in 76-cm rows or DKC62-97 in either row width (Table A-9). In 2011, increased plant population reduced kernel number per ear for both hybrids (Figure 3.11), indicative of a flex-ear type. In 2012, increasing plant population decreased kernel number for DKC62-97 in twin rows (Figure 3.14), but had no effect on kernel number for DKC62-97 in 76-cm rows or P1480HR (Table A-8). Ear length decreased with increasing plant population in that same year in both row spacings for P1480HR only (Figure 3.27), and row number per ear decreased in twin rows only for both hybrids (Figure 3.20 and Figure 3.21). When comparing the behavior of the flex ear type hybrids in each year individually, for all grain yield components measures, the response was generally the same to increasing plant population (for significant regressions). However, from one year to the next each hybrid did not respond the same and there were inconsistencies among row spacings from one year to the next. Increased plant population in 2011 increased DKC62-97 grain yield but had no effect on the yield of 1480HR (Table A-17). So, while both hybrids exhibited some characteristics of a flex-ear hybrid, those characteristics did not necessarily explain yield.

In 2011, increased plant populations increased DKC66-96 yield (Figure 3.38 and Table A-17) in both row widths, but had no effect on KPE (Table A-6). Increased plant population reduced ear length in 2011 (Figure 3.23), but the lack of effect of plant population on KPE may explain why yield increased as plant population increased.

As plant population increased in 2011, kernel weights decreased for hybrids 33D49 and A6632VT3 (Figure 3.32) and did not affect kernel weight for the other four hybrids (Table A-13).
For all significant regressions in 2011 (hybrids DKC62-97, 33D49, A6533VT3, and A6632VT3), tip-back length increased as plant population increased (Figure 3.28 through Figure 3.31). Studies support the idea that tip-back increases as the amount of stress incident upon the corn plant increases (Below et al., 2009). The increased stress of the higher plant population was likely the reason for the increased length of tip-back, but it did not cause enough kernel loss to be detrimental to grain yield.

For all significant regressions, stalk diameter decreased as plant population increased (Figure 3.3 through Figure 3.9). While lodging was not observed to be consistent with any treatment in this study, decreased stalk diameters can increase the potential for lodging (Rutger and Crowder, 1967).

Row width did not influence ear height or plant height in this study. Increasing plant population decreased the plant height of only two hybrids one season (Figure 3.10) and increased the ear height of one hybrid (A6632VT3) in 2011 and one hybrid (DKC62-97) in 2012 (Table A-5). A study by Denmead and Shaw (1960) found that cases where soil moisture was present during the vegetative stage of growth, stalk height was reduced. This was likely not the case for this study in 2011, since moisture during vegetative growth was more than adequate.

**Conclusion**

The weather each year greatly influenced yield and corn physiological response to plant population and row widths. Grain yield was affected by treatments in 2011 only. Increased plant populations increased yields for both DeKalb brand hybrids and 33D49 in 2011. When averaged across hybrids, yields in 2011 were greater in twin rows. Increased
population increased the ASI in 2011 only for the Pioneer hybrids and had no effect on ASI for the other four hybrids. Row width in 2011 did not influence ASI. However, ASI did not influence yield in 2011, probably because the range in ASI values were not great enough to affect pollination. For significant regressions in 2011, kernels per ear, kernel row number, and ear length decreased as plant population increased.

The 2012 growing season was much more stressful, especially during the ASI. There was no population or row width effect on yield in 2012. When regressions were significant, ear length, kernel row number and kernels per ear were reduced. In 2012, increased ASI values decreased yield, in part because silking was delayed up to 7 d after male anthesis.

When row width influenced yields in 2011, the twin rows resulted in the greatest yields. There was not an interaction between row width and plant population, suggesting that in the parameters tested, plant population would influence yield equally in twin and 76-cm rows. The severe stress of 2012 overwhelmed the treatments and twin rows did not appear to reduce this stress.
### Appendix:

Table A-2: Predicted stalk diameter response to plant population for 2011 and 2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Row Spacing</th>
<th>Equation</th>
<th>R²</th>
<th>P-Value</th>
<th>Target Populations, plants ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>76 cm</td>
<td>y= -0.000066596x + 23.96371</td>
<td>0.78</td>
<td>0.02</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000046492x + 23.08735</td>
<td>0.26</td>
<td>0.30</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>76 cm</td>
<td>y= -0.000026336x + 19.61569</td>
<td>0.57</td>
<td>0.08</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000079687x + 26.07662</td>
<td>0.66</td>
<td>0.05</td>
<td>20.2</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>76 cm</td>
<td>y= -0.000087308x + 25.72460</td>
<td>0.78</td>
<td>0.02</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000114623x + 27.98157</td>
<td>0.51</td>
<td>0.11</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>76 cm</td>
<td>y= -0.000032516x + 20.15667</td>
<td>0.45</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000045229x + 21.36842</td>
<td>0.17</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>76 cm</td>
<td>y= -0.000030550x + 19.84464</td>
<td>0.35</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000086954x + 25.99031</td>
<td>0.68</td>
<td>0.04</td>
<td>19.6</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>76 cm</td>
<td>y= -0.000009880x + 18.16915</td>
<td>0.07</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000058050x + 22.99036</td>
<td>0.40</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>DKC66-96</td>
<td>76 cm</td>
<td>y= -0.000050965x + 26.06505</td>
<td>0.53</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000057324x + 27.47738</td>
<td>0.94</td>
<td>0.002</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>76 cm</td>
<td>y= -0.000027179x + 24.64681</td>
<td>0.13</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000069435x + 28.34792</td>
<td>0.51</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>76 cm</td>
<td>y= -0.000068125x + 28.11521</td>
<td>0.82</td>
<td>0.01</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000074417x + 27.74490</td>
<td>0.62</td>
<td>0.06</td>
<td>22.2</td>
</tr>
<tr>
<td></td>
<td>33D44</td>
<td>76 cm</td>
<td>y= -0.000040263x + 24.34257</td>
<td>0.26</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>76 cm</td>
<td>y= -0.000002323x + 22.50667</td>
<td>0.00</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000005806x + 19.07500</td>
<td>0.02</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>76 cm</td>
<td>y= -0.000064736x + 26.68298</td>
<td>0.30</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000005806x + 19.07500</td>
<td>0.02</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>76 cm</td>
<td>y= -0.000064736x + 26.68298</td>
<td>0.30</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000026963x + 20.93333</td>
<td>0.31</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>
Table A-3: Predicted plant-to-plant spacing response to plant population.

<table>
<thead>
<tr>
<th>Years</th>
<th>Row Spacing</th>
<th>Equation</th>
<th>R²</th>
<th>P-value</th>
<th>Target Populations, plants ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>y=</td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td>2011 &amp; 2012</td>
<td>76 cm</td>
<td>-0.00013494x + 28.04824</td>
<td>0.3640</td>
<td>&lt;0.0001</td>
<td>111 000</td>
</tr>
<tr>
<td></td>
<td>Twin</td>
<td>-0.00020710x + 47.20209</td>
<td>0.47</td>
<td>&lt;0.0001</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predicted Plant-to-Plant Spacing (cm)</td>
<td></td>
<td></td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>31.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24.2</td>
</tr>
</tbody>
</table>
Table A-4: Predicted plant height response to plant population.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Equation</th>
<th>$R^2$</th>
<th>p-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>$y = -0.000124609x + 253.734$</td>
<td>0.15</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>$y = 0.000019577x + 245.119$</td>
<td>0.01</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>$y = -0.000212385x + 275.063$</td>
<td>0.39</td>
<td>0.03</td>
<td>259</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>$y = -0.000077847x + 272.153$</td>
<td>0.036</td>
<td>0.55</td>
<td>259</td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>$y = -0.000269931x + 278.943$</td>
<td>0.38</td>
<td>0.03</td>
<td>259</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>$y = 0.000027191x + 234.257$</td>
<td>0.01</td>
<td>0.80</td>
<td>249</td>
</tr>
</tbody>
</table>

Predicted Plant Height (cm)
Table A-5: Predicted ear height response to plant population.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Equation</th>
<th>$R^2$</th>
<th>p-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>y=</td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>0.000056666x + 103.488</td>
<td>0.11</td>
<td>0.29</td>
<td>111 000</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>0.000117322x + 116.529</td>
<td>0.18</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>0.000032409x + 119.343</td>
<td>0.02</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>-0.000012886x + 130.597</td>
<td>0.003</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>0.000065392x + 114.123</td>
<td>0.09</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>0.000191022x + 83.632</td>
<td>0.29</td>
<td><strong>0.07</strong></td>
<td>98</td>
</tr>
<tr>
<td>2012</td>
<td>DKC66-96</td>
<td>-0.000055407x + 108.667</td>
<td>0.04</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>0.000203846x + 99.900</td>
<td>0.44</td>
<td><strong>0.02</strong></td>
<td>141</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>-0.000104891x + 117.439</td>
<td>0.04</td>
<td>0.55</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>33D44</td>
<td>-0.000089202x + 109.367</td>
<td>0.11</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>0.000178122x + 83.609</td>
<td>0.19</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>0.000051381x + 87.830</td>
<td>0.02</td>
<td>0.67</td>
<td></td>
</tr>
</tbody>
</table>
Table A-6: Predicted kernels per ear response to plant population across all row widths.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Equation</th>
<th>$R^2$</th>
<th>P-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>$y = -0.004376957x + 1026.33$</td>
<td>0.05</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>$y = -0.004359619x + 1009.80$</td>
<td>0.14</td>
<td>0.08</td>
<td>687</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>$y = -0.006146331x + 1365.36$</td>
<td>0.14</td>
<td>0.07</td>
<td>911</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>$y = -0.003111135x + 979.40$</td>
<td>0.03</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>$y = -0.003531708x + 1060.83$</td>
<td>0.05</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>$y = -0.003500597x + 1060.71$</td>
<td>0.02</td>
<td>0.57</td>
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</tr>
</tbody>
</table>
Table A-7: Predicted kernels per ear response to plant population across all hybrids.

<table>
<thead>
<tr>
<th>Year</th>
<th>Row Spacing</th>
<th>Equation</th>
<th>$R^2$</th>
<th>P-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>y=</td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td>2011</td>
<td>76 cm</td>
<td>-0.004906256x+1124.27</td>
<td>0.58</td>
<td>&lt;0.0001</td>
<td>761</td>
</tr>
<tr>
<td></td>
<td>Twin</td>
<td>-0.003377186x+1037.93</td>
<td>0.31</td>
<td>0.001</td>
<td>788</td>
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</table>
### Table A-8: Predicted kernels per ear response in 2012 to plant population.

<table>
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<th>Year</th>
<th>Hybrid</th>
<th>Row Spacing</th>
<th>Equation</th>
<th>R²</th>
<th>P-value</th>
<th>Target Populations, plants ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Predicted Kernels ear⁻¹</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>DKC66-96</td>
<td>76 cm</td>
<td>( y = -0.004385162x + 645.09201 )</td>
<td>0.37</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>( y = -0.001786712x + 561.22969 )</td>
<td>0.86</td>
<td>0.01</td>
<td>429</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>76 cm</td>
<td>( y = -0.002500354x + 573.18671 )</td>
<td>0.43</td>
<td>0.16</td>
<td>363</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>( y = -0.003714563x + 664.43529 )</td>
<td>0.59</td>
<td>0.07</td>
<td>252</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>76 cm</td>
<td>( y = -0.00236523x + 641.34585 )</td>
<td>0.45</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>( y = -0.004750983x + 741.24712 )</td>
<td>0.50</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33D44</td>
<td>76 cm</td>
<td>( y = -0.003555430x + 721.67266 )</td>
<td>0.37</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>Twin</td>
<td>( y = -0.00666370x + 466.74112 )</td>
<td>0.05</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>76 cm</td>
<td>( y = -0.003699378x + 689.42833 )</td>
<td>0.17</td>
<td>0.42</td>
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<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>( y = 0.000920918x + 106.92229 )</td>
<td>0.01</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>76 cm</td>
<td>( y = -0.006429718x + 886.87525 )</td>
<td>0.52</td>
<td>0.11</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>( y = 0.004254638x + 83.24386 )</td>
<td>0.17</td>
<td>0.41</td>
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</tr>
</tbody>
</table>
Table A-9: Predicted kernel row number per ear response to plant population.

<table>
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<tr>
<th>Year</th>
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<th>Row Spacing</th>
<th>Equation</th>
<th>R²</th>
<th>p-value</th>
<th>Target Populations, plants ha⁻¹</th>
</tr>
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<tbody>
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<td>Predicted Row Number</td>
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<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>76 cm</td>
<td>-0.000018313x + 18.5904</td>
<td>0.50</td>
<td>0.12</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000019179x + 19.2370</td>
<td>0.58</td>
<td>0.08</td>
<td>17.8</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>76 cm</td>
<td>-0.000012998x + 16.0832</td>
<td>0.47</td>
<td>0.13</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000007851x + 16.354</td>
<td>0.36</td>
<td>0.21</td>
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<tr>
<td></td>
<td>P1480HR</td>
<td>76 cm</td>
<td>-0.000007883x + 16.0320</td>
<td>0.28</td>
<td>0.28</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.0000039642x + 18.9409</td>
<td>0.75</td>
<td>0.02</td>
<td>16.0</td>
</tr>
<tr>
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<td>33D49</td>
<td>76 cm</td>
<td>-0.000014385x + 15.8957</td>
<td>0.75</td>
<td>0.03</td>
<td>14.8</td>
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<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000008312x + 15.4147</td>
<td>0.25</td>
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<td>A6533VT3</td>
<td>76 cm</td>
<td>-0.000007314x + 15.5004</td>
<td>0.66</td>
<td>0.05</td>
<td>15.0</td>
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<td>Twin</td>
<td>0.000003089x + 14.4174</td>
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<td>0.68</td>
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<td>A6632VT3</td>
<td>76 cm</td>
<td>-0.000009429x + 15.8998</td>
<td>0.90</td>
<td>0.004</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.00000497x + 15.2836</td>
<td>0.00</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>DKC66-96</td>
<td>76 cm</td>
<td>-0.000063051x + 20.5967</td>
<td>0.41</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000014831x + 18.3369</td>
<td>0.35</td>
<td>0.22</td>
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<tr>
<td></td>
<td>DKC62-97</td>
<td>76 cm</td>
<td>-0.000002081x + 16.57953</td>
<td>0.24</td>
<td>0.33</td>
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<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000030539x + 17.19404</td>
<td>0.64</td>
<td>0.06</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>76 cm</td>
<td>-0.000016546x + 16.27694</td>
<td>0.44</td>
<td>0.15</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000042209x + 18.46288</td>
<td>0.91</td>
<td>0.003</td>
<td>15.3</td>
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<tr>
<td></td>
<td>33D44</td>
<td>76 cm</td>
<td>-0.000011964x + 15.38515</td>
<td>0.09</td>
<td>0.56</td>
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</tr>
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<td></td>
<td>Twin</td>
<td>-0.000006976x + 14.95083</td>
<td>0.14</td>
<td>0.47</td>
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<td></td>
<td>A6533VT3</td>
<td>76 cm</td>
<td>0.000030652x + 13.17241</td>
<td>0.43</td>
<td>0.16</td>
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<tr>
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<td></td>
<td>Twin</td>
<td>0.000014126x - 2.00012</td>
<td>0.69</td>
<td>0.04</td>
<td>8.7</td>
</tr>
<tr>
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<td>A6632VT3</td>
<td>76 cm</td>
<td>-0.0000151942x + 27.01348</td>
<td>0.49</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twin</td>
<td>-0.000016929x + 15.43388</td>
<td>0.03</td>
<td>0.74</td>
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</table>
Table A-10: Predicted ear length response to plant population 2011.

<table>
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<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Equation</th>
<th>$R^2$</th>
<th>p-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
<th>Predicted Ear Length (cm)</th>
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</tr>
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<td></td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>-0.00008492x + 23.32462</td>
<td>0.83</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td></td>
<td>DKC62-97</td>
<td>-0.00009617x + 25.54318</td>
<td>0.46</td>
<td>0.02</td>
<td>17.0</td>
<td>13.9</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>-0.00007420x + 24.19072</td>
<td>0.88</td>
<td>&lt;0.0001</td>
<td>18.7</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>-0.00005522x + 21.68549</td>
<td>0.79</td>
<td>0.0001</td>
<td>17.6</td>
<td>15.6</td>
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<tr>
<td></td>
<td>A6533VT3</td>
<td>-0.00008034x + 23.06822</td>
<td>0.46</td>
<td>0.01</td>
<td>17.1</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>-0.00004304x + 20.15815</td>
<td>0.11</td>
<td>0.283</td>
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Table A-11: Predicted ear length response to plant population 2012.

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<th>Hybrid</th>
<th>Row Spacing</th>
<th>Equation</th>
<th>R²</th>
<th>p-value</th>
<th>Target Populations, plants ha⁻¹</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2012</td>
<td>DKC66-96</td>
<td>76 cm</td>
<td>-0.00008850x+ 18.30573</td>
<td>0.27</td>
<td>0.29</td>
<td>14.6</td>
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<tr>
<td></td>
<td>Twin</td>
<td></td>
<td>-0.0000532x+ 18.40232</td>
<td>0.89</td>
<td>0.005</td>
<td>17.1</td>
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<td>DKC62-97</td>
<td>76 cm</td>
<td>-0.00006385x+ 18.78295</td>
<td>0.49</td>
<td>0.12</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>Twin</td>
<td></td>
<td>-0.00008274x+ 20.15044</td>
<td>0.37</td>
<td>0.20</td>
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</tr>
<tr>
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<td>P1480HR</td>
<td>76 cm</td>
<td>-0.00005360x+ 21.06847</td>
<td>0.74</td>
<td>0.03</td>
<td>14.6</td>
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<tr>
<td></td>
<td>Twin</td>
<td></td>
<td>-0.00005360x+ 21.06847</td>
<td>0.74</td>
<td>0.03</td>
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<tr>
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<td>33D44</td>
<td>76 cm</td>
<td>-0.00007012x+ 20.44357</td>
<td>0.49</td>
<td>0.12</td>
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</tr>
<tr>
<td></td>
<td>Twin</td>
<td></td>
<td>-0.00007012x+ 20.44357</td>
<td>0.49</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>76 cm</td>
<td>-0.00006026x+ 18.43513</td>
<td>0.08</td>
<td>0.58</td>
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</tr>
<tr>
<td></td>
<td>Twin</td>
<td></td>
<td>-0.00006026x+ 18.43513</td>
<td>0.08</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>76 cm</td>
<td>-0.00002092x+ 14.84894</td>
<td>0.04</td>
<td>0.69</td>
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</tr>
<tr>
<td></td>
<td>Twin</td>
<td></td>
<td>-0.00002092x+ 14.84894</td>
<td>0.04</td>
<td>0.69</td>
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Table A-12: Predicted tip-back response to plant population.

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<th>Equation</th>
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<th>p-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
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<td>74 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>$y=0.00000713x+0.22111$</td>
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<td>0.17</td>
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<td>DKC62-97</td>
<td>$0.00000307x+0.19134$</td>
<td>0.26</td>
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<td>P1480HR</td>
<td>$0.0000836x+0.38170$</td>
<td>0.18</td>
<td>0.17</td>
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<tr>
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<td>33D49</td>
<td>$0.00000579x+0.13885$</td>
<td>0.34</td>
<td>0.0448</td>
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<td>$0.00001030x-0.16829$</td>
<td>0.55</td>
<td>0.01</td>
<td>0.9</td>
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<td>A6632VT3</td>
<td>$0.00001348x-0.32646$</td>
<td>0.69</td>
<td>0.001</td>
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<td>2012</td>
<td>DKC66-96</td>
<td>$0.0000294x+0.69794$</td>
<td>0.07</td>
<td>0.41</td>
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<tr>
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<td>$-0.00000477x+1.58161$</td>
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<td>0.38</td>
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<td>$-0.0000317x+1.41240$</td>
<td>0.11</td>
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<td>0.0467</td>
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<td>A6533VT3</td>
<td>$0.0000281x+0.64645$</td>
<td>0.02</td>
<td>0.63</td>
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<td>$-0.0000460x+1.48591$</td>
<td>0.05</td>
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Table A-13: Predicted kernel weight seed\(^{-1}\) response to plant population.

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<th>Equation</th>
<th>R(^2)</th>
<th>p-value</th>
<th>Target Populations, plants ha(^{-1})</th>
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<tbody>
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<td></td>
<td></td>
<td>y=</td>
<td></td>
<td></td>
<td>Predicted Weight Seed(^{-1}) (kg)</td>
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<tr>
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<td>DKC66-96</td>
<td>-1.6695E-10x+2.99E-4</td>
<td>0.02</td>
<td>0.69</td>
<td>74 000</td>
</tr>
<tr>
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<td>DKC62-97</td>
<td>2.4158E-10x+2.55E-4</td>
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<td>0.50</td>
<td>111 000</td>
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<td>P1480HR</td>
<td>-8.3697E-11x+2.06E-4</td>
<td>0.01</td>
<td>0.77</td>
<td>2.33E-4</td>
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<td>-4.0467E-10x+2.63E-4</td>
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<td>0.04</td>
<td>2.18E-4</td>
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<td>0.11</td>
<td>2.36E-4</td>
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<td>-7.2203E-10X+2.89E-4</td>
<td>0.36</td>
<td>0.04</td>
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Table A-14: Predicted ASI response to plant population.

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<th>Equation</th>
<th>R²</th>
<th>p-value</th>
<th>Target Populations, plants ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td>74 000</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2011†</td>
<td>DKC66-96</td>
<td>76 cm and twin</td>
<td>y= 0.00002202x-4.64432 × 10⁻³ + 0.0000942x-2.99696 × 10⁻³ + 0.0000697x-0.75879 × 10⁻³</td>
<td>0.16</td>
<td>0.20</td>
<td></td>
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<tr>
<td></td>
<td>DKC62-97</td>
<td>Twin</td>
<td>0.00000942x-2.99696 × 10⁻³ + 0.0000697x-0.75879 × 10⁻³</td>
<td>0.08</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>Twin</td>
<td>0.000001494x-2.31953 × 10⁻³ + 0.000121441x-5.10463 × 10⁻³ + 0.000087229x-4.42517 × 10⁻³</td>
<td>0.60</td>
<td>0.003</td>
<td>-1.2</td>
</tr>
<tr>
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<td>P1480HR</td>
<td>Twin</td>
<td>3.359856E-9x²-0.000650093x+28.58313 × 10⁻³ + 3.35020E-10x²+ 0.000025317x-1.64534 × 10⁻³</td>
<td>0.73</td>
<td>0.14</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>Twin</td>
<td>5.71871E-10x²-0.000036088x + 0.10348 × 10⁻³ + 3.60397E-10x²-0.000055842x + 2.11016 × 10⁻³</td>
<td>0.14</td>
<td>0.80</td>
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</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>Twin</td>
<td>2.236647E-9x²-0.000563768x+37.45750 × 10⁻³ + 2.36647E-9x²-0.000563768x+37.45750 × 10⁻³</td>
<td>0.53</td>
<td>0.33</td>
<td></td>
</tr>
</tbody>
</table>

†A6533VT3 and A6632VT3 did not reach 50% anthesis in 17 d period, thus they are not reported.
†A6632VT3 did not reach 50% anthesis in 22 d period, thus they are not reported.
Table A-15: Predicted light interception response to plant population.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Equation</th>
<th>$R^2$</th>
<th>p-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>111 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>$y = 0.00022395x + 44.06650$</td>
<td>0.35</td>
<td>0.04</td>
<td>60.6</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>$y = 0.00015471x + 60.15146$</td>
<td>0.16</td>
<td>0.20</td>
<td>68.9</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>$y = 0.00030077x + 37.10879$</td>
<td>0.29</td>
<td>0.07</td>
<td>59.4</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>$y = 0.0035417x + 33.50870$</td>
<td>0.55</td>
<td>0.0061</td>
<td>59.7</td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>$y = 0.00022258x + 44.75000$</td>
<td>0.37</td>
<td>0.04</td>
<td>61.2</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>$y = 0.00014003x + 49.65426$</td>
<td>0.23</td>
<td>0.114</td>
<td>69.5</td>
</tr>
<tr>
<td>2012</td>
<td>DKC66-96</td>
<td>$y = 0.00032206x + 41.72140$</td>
<td>0.52</td>
<td>0.008</td>
<td>65.6</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>$y = 0.00009173x + 64.70168$</td>
<td>0.06</td>
<td>0.43</td>
<td>77.5</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>$y = 0.00009848x + 59.41898$</td>
<td>0.15</td>
<td>0.21</td>
<td>60.7</td>
</tr>
<tr>
<td></td>
<td>33D44</td>
<td>$y = 0.00049160x + 24.32852$</td>
<td>0.71</td>
<td>0.0006</td>
<td>78.9</td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>$y = 0.00024549x + 51.60127$</td>
<td>0.44</td>
<td>0.02</td>
<td>78.9</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>$y = 0.00017194x + 43.04820$</td>
<td>0.17</td>
<td>0.188</td>
<td>78.9</td>
</tr>
</tbody>
</table>
Table A-16: Predicted grain yield response to plant population in 2011.

<table>
<thead>
<tr>
<th>Year</th>
<th>Row Spacing</th>
<th>Equation</th>
<th>$R^2$</th>
<th>P-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$y=0.00003801x+13.9$</td>
<td>0.2257</td>
<td>0.0034</td>
<td>16.7</td>
</tr>
<tr>
<td>2011</td>
<td>76 cm</td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
</tr>
<tr>
<td></td>
<td>Twin</td>
<td>$y=0.00006498+14.2$</td>
<td>0.29</td>
<td>0.0007</td>
<td>19.0</td>
</tr>
</tbody>
</table>
Table A-17: Predicted grain yield response to plant population in 2011.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Equation</th>
<th>$R^2$</th>
<th>P-value</th>
<th>Target Populations, plants ha$^{-1}$</th>
<th>Predicted Yield, Mg ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74 000</td>
<td>111 000</td>
</tr>
<tr>
<td>2011</td>
<td>DKC66-96</td>
<td>$y=0.00007552x+12.4$</td>
<td>0.40</td>
<td>0.03</td>
<td>18.0</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>DKC62-97</td>
<td>$y=0.0006372x+13.0$</td>
<td>0.48</td>
<td>0.01</td>
<td>17.7</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>$y=0.0001149x+16.9$</td>
<td>0.02</td>
<td>0.65</td>
<td>17.8</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>$y=0.0005020x+12.9$</td>
<td>0.41</td>
<td>0.03</td>
<td>16.6</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>$y=0.0005661x+14.6$</td>
<td>0.18</td>
<td>0.17</td>
<td>18.8</td>
<td>20.9</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>$y=0.0000625x+18.6$</td>
<td>0.002</td>
<td>0.89</td>
<td>19.1</td>
<td>19.3</td>
</tr>
</tbody>
</table>
Table A-18: Average grain yield (Mg ha\(^{-1}\)) for each hybrid in 2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hybrid</th>
<th>Grain Yield, Mg ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DKC66-96</td>
<td>13.2</td>
</tr>
<tr>
<td>2012</td>
<td>DKC62-97</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>P1480HR</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td>33D49</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td>A6533VT3</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>A6632VT3</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Table A-19: Average grain yield (Mg ha\(^{-1}\)) for each row width in 2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>Row Spacing</th>
<th>Grain yield, Mg ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>76 cm</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td>Twin</td>
<td>12.4</td>
</tr>
</tbody>
</table>
References


VITA

The author, Chelsea Clay McFarland, was born on August 17, 1989 in Mt. Sterling, KY to Kenneth Todd and Lisa Bishop McFarland. She graduated with distinction from Bourbon County High School in 2007 and attended Eastern Kentucky University where she graduated Summa Cum Laude in 2011 with a Bachelor of Science degree in Horticulture and a minor in general biology. She furthered her educational career by beginning graduate school at the University of Kentucky in 2011 pursuing a Master of Science degree in Plant and Soil Science, where she will graduate in May 2013. During her time in college, Chelsea has served as state reporter for the Kentucky FFA Association, been selected as a New Century Farmer by the National FFA Organization, received her American FFA degree, achieved alumna status with Alpha Gamma Delta Fraternity, and attended and participated in two years of oral poster presentations through the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. Her future plans include seeking a career where she can implement her passion of serving farmers in an agricultural, specifically agronomic, capacity.

Chelsea Clay McFarland

April 27, 2013
(Date)