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TWIN AND NARROW ROW WIDTH EFFECTS ON CORN (ZEA MAYS L.) YIELD AND WEED MANAGEMENT

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TWIN AND NARROW ROW WIDTH EFFECTS ON CORN (*ZEA MAYS* L.) YIELD AND WEED MANAGEMENT

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

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Major: Crop Science

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ABSTRACT OF THESIS

TWIN AND NARROW ROW WIDTH EFFECTS ON CORN (*ZEA MAYS* L.) YIELD AND WEED MANAGEMENT

Corn or maize (*Zea mays* L.) has been grown in North America for many centuries, and an increase in corn production will continue to be needed. Agriculture producers must meet the demands of feeding and providing for an increasing population of people. In order to meet those needs, different production practices are being investigated as a way to increase grain yield.

Field plots were conducted across the state of Kentucky in 2011 and 2012 to evaluate the interaction between hybrid, row width, and plant density on corn yield. The primary objectives were to test if 1) narrower rows increase grain yield, 2) higher plant densities increase yield in narrow and twin rows, and 3) the interactions among all factors. Three hybrids were evaluated in three row widths (76, 38 cm or twin) at target densities ranging from 74 000 to 124 000 plants ha^{-1}. Interactions between hybrid, row width, and plant density occurred; however, effects on grain yield and plant physiological characteristics were small and variable across all environments. Plant density had the greatest impact on IPAR and grain yield.

Field trials were conducted near Lexington and Princeton, Kentucky in 2011 and 2012 to evaluate the effects of row width on different weed management treatments in corn. The objectives were to 1) evaluate five weed management methods in three row widths (76, 38 cm or twin) and 2) estimate the effect of these practices on corn yield. Herbicides used within each weed management strategy included the residual herbicide S-metholachlor + atrazine (1.4 + 1.8 kg/ha) applied preemergence (PRE) and/or glyphosate (0.86 kg/ha) postemergence (POST). Weed management treatments consisted of a PRE only, PRE followed by POST, POST only, POST + PRE, and an untreated control. Row spacing had little effect on weed suppression and control except for two cases. In general, PRE followed by POST and POST + Residual treatments controlled weeds better compared to PRE only and POST only treatments. Corn yields were higher when a herbicide was used compared to applying no herbicide application.

KEYWORDS: Row spacing, Plant Density, Corn Hybrids, Weed Management, Herbicide Application Timing

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Preface

Agriculture producers are continually under pressure to meet the demands of feeding and providing for an increasing population of people. For decades a producer's main goal has been to increase yields and to gain a profit, and when commodity prices were low, most producers minimized inputs. Producers must double their yields in the next 30 years in a sustainable manner to meet government regulations and population increases. Corn or maize (*Zea mays* L.) has been grown in North America for many centuries, and an increase in corn production will continue to be needed. Recent alterations in row spacing are being examined as a means of increasing grain yield in corn. Field experiments have been conducted that show moderate yield increases when row spacing was less than 76 cm. Corn row spacing in Kentucky has decreased from about 102 cm in the early 1900's to about 76 cm currently. During this period, plant densities have also increased from about 30 000 plants ha^{-1} to around 67 000 plants ha^{-1}. More plants within a row should increase plant-to-plant competition. By reducing row widths, the plant-to-plant competition should be reduced and yields may increase. Some suggest that twin rows give the best chance of increasing yield while still using the same production practices and equipment. However, results from experiments evaluating narrow and twin rows throughout the United States have been variable, and do not justify that yield always increases under narrow row spacing systems.

Chapter 1: Hybrid, Row Spacing, and Plant Density Interactions

Introduction

Hybrid Corn

Since the 1930's corn yields have been increasing and even more dramatically in the past 30 years (Duvick, 2005). Numerous factors are responsible for these improvements, but three are thought to be the primary source of the increase. The three are improved technological and production practices as well as crop genetic improvements. While continually perfecting production practices is a key factor, nearly 60% of the increase in corn yields since the 1930's is due to the introduction of corn hybrids (Lee and Tollenaar, 2007). The crossing of open pollinated corn inbred lines produced hybrids and as acceptance of hybrids increased, grain yields on farms did as well. This gave rise to the current development of large commercial corn seed industry. The most notable history of seed commercialization is from the seed company Pioneer Hi-Bred International where they introduced their ERA hybrids (Lee and Tollenar, 2007). Since that time seed companies have continued to develop, but have consolidated into a few major seed production companies of today.

Over the years, modern hybrids have been selected primarily for their increase in yield. As a result, corn yields have consistently increased nearly 75 kg ha^{-1} $year^{-1}$ (Lee and Tollenaar, 2007). Today, over 90% of the corn acres grown in the U.S. use hybrid or transgenic corn seed hybrids (Egli, 2008). Selection of corn seed has been based on dominating performance, but other physiological components and transgenic traits have also contributed to the increase in yield. The components selected for or incorporated into these new hybrids have included greater tolerances to abiotic and biotic stress (Boomsma et al., 2009). New hybrids have been genetically altered to be resistant to detrimental insects, reducing the need for foliar insecticide sprays. The genetically altering of hybrids to tolerate certain herbicides, such as glyphosate, has improved weed control and promoted minimal tillage and no-tillage practices. Abiotic stresses such as weather conditions and increased fertilizer rates have also been selected for over time (Duvick, 2005). Changes that have occurred through selection and plant breeding specifically to the corn plant include plant height, plants that have longer seed fill, delayed leaf senescence, more upright leaves, tassel size, lodging, number of ears, and kernel number per ear (Egli, 2008). Proper selection of all these physiological characteristics combined continues to improve corn production and increase grain yield.

Row Spacing

As mechanization and production practices have improved, farmers have decreased row widths of corn from 100 cm to 76 cm in most of Kentucky and throughout the U.S. cornbelt. With the importance of producers maximizing the use of their inputs and also increasing profit, all aspects of the production system are always being evaluated. Crop genetics are still important, but they have to work well within the overall production system. Some research suggests that reducing row spacing to less than 76 cm provides improved crop growth and increased yield. Porter et al. (1997) reported yield advantages when narrowing corn row spacing from 76 to 51 and 38 cm. Nielsen (1988) also increased grain yield when corn was grown in 38 cm rows. Widdicombe and Thelen (2002) found that narrowing row width from 76 to 56 and 38 cm increased grain yield by 2 and 4%, respectively. This research also showed no interaction between hybrid and row spacing, meaning that corn hybrids will not perform better in one row spacing over another. However, there is variability in the results of planting narrow row corn.

Other research, has not observed a yield advantage for narrow rows, especially when field conditions are not consistent or optimal. In Minnesota, research comparing hybrid maturity and row spacing configuration showed no benefit of reducing plant row width, regardless of the hypothesis that early maturing hybrids could take advantage of more leaf area in high plant densities (Coulter and Van Roekel, 2012). It was found that current row widths in the Northern Corn Belt are probably near their optimum spacing; however, plant densities of 84 500 to 108 700 plants ha^{-1} increased yield to a maximum of 10.9 Mg ha^{-1}. Vyn et al. (2012) also reported no significant increase in corn grain yield in twin rows versus single rows over a three year experiment in Indiana. The theoretical benefit of narrow row corn is in the interaction between row spacing and plant density. However, most research has not observed interactions between row width and plant density. Farnham (2001) reported no increase in grain yield in 38-cm rows over 76-cm rows, but observed a yield increase from increased plant density. Vyn et al. (2012) also reported no interaction between the row spacing and plant density, but observed yield increases from increased pant density.

Research also suggests that narrow-row corn increases yield due to better nutrient, water and light use as well as improved weed control (Sharratt and McWilliams, 2005). Corn plants grown in narrow rows influenced the leaf and canopy architecture of the plant. Due to the change in architecture, plants were able to intercept and absorb more light per unit leaf area which increased photosynthesis in C4 plants. Intercepted photosynthetically active radiation

(IPAR) was measured in these systems and provided similar results. Vyn et al. (2012) determined that narrow or twin rows increased IPAR up to 22% but only when taken at corn growth stage V8. Differences recorded were not significant when measured closer to anthesis. By this stage, yield is determined by whether or not the plant is intercepting enough sunlight. As long as IPAR is greater than 95%, no additional benefit in yield occurred. In this study full light interception was achieved in both systems. Narrow rows increased yields when 95% IPAR was not achieved in the Northern Corn Belt where short-season hybrids were used. In northern latitudes, short- season hybrids are typically smaller plants with more upright leaves. IPAR in narrow row corn might also improve in situations where plants have experienced stress throughout the growing season. It is possible that these smaller and stressed plants are not intercepting enough radiation to maximize their crop growth or yield potential. Reducing the row width might solve these problems and improve intercepted solar radiation. Results are still inconclusive as most research shows no benefit. Coulter and Van Roekel (2012) in Minnesota observed no increase in IPAR with reducing row width. However, later maturity hybrids had greater IPAR values than earlier maturity hybrids.

Corn grown in narrow rows use water and nutrients more efficiently than corn grown in 76 cm rows. Narrow rows improve the uniformity between plants in the field, which improves the use of water and nutrients (Sharratt and McWilliams, 2005). Sharratt and McWilliams (2005) reported 57 cm and 38 cm row corn increased root densities, reduced soil water evaporation, and reduced soil temperatures. The combination of reducing soil water evaporation and reduced soil temperatures suggest that corn grown in narrow rows can utilize space, water and nutrients better than corn grown in 76 cm rows. Twin row corn planter manufacturers argue that more equidistant roots are the key for improved crop growth (Great Plains Manufacturing, Salina, KS). Increasing plant density would increase root competition for water and nutrients as they come in contact with one another. Spreading those roots out over the area has potential for less crop stress. Lodging and poor stalk quality has also been observed when plant densities have increased or when rows are decreased. Although, much of these issues of lodging are attributed to certain environmental stresses. Plant densities and row spacing only tend to make lodging more of an issue.

Plant Density

Since hybrid corn was introduced, plant densities have increased to obtain maximum yield. Boomsma et. al (2009) concluded in a review that further yield gains can be achieved at even higher plant densities given optimal field and nutrient conditions. The authors summarized studies that observed the highest yields gained were those with corn densities at 104,000 plants ha^{-1}, when nitrogen was not limiting. This has also been the trend ever since the Green Revolution. As our corn hybrids have been bred to increase yield they have also been selected to withstand certain stresses including intense crowding between plants.

In recent research conducted in Minnesota by Coulter and Van Roekel (2012) over three years, planting density significantly impacted corn yield regardless of row spacing. Early maturity hybrids grown in southern Minnesota obtained a maximum yield of 12.5 Mg ha^{-1} in planting densities ranging from 81,700 to 107,900 plants ha^{-1}. They proposed that highest yields will be achieved with higher plant densities especially with later maturity hybrids, which is consistent with the findings by Porter et al. (1997). Increased plant density inconsistently increased in another study, where maximum yields were achieved at 81 000 plants ha^{-1} for one site year (Vyn et al., 2012). Widdicombe and Thelen (2002) observed that row spacing did not have an effect or interaction on grain yield in Michigan. However, higher plant densities significantly increased grain yield. The maximum target density of 90,000 plants ha^{-1} resulted in maximum yields (11.6 Mg ha^{-1}) but the extension of trend lines predicted greater yields at even greater plant densities (Widdicombe and Thelen, 2002). Research in Iowa reported a 6.9% increase in grain yield when plant density was increased from 59,000 to 89,000 plants ha^{-1} (Farnham, 2001).

Increasing corn planting density also creates other areas of interest as to how the plant responds with increasing yield. Some hybrid corn breeders and crop physiologists rank or rate corn hybrids as having a flex ear type or fixed ear type. Fixed ear length and size will remain unchanged (or change very little) with changes in plant density or environmental stress (Pioneer Hi-Bred International, 2009). Flex ear length and size will adjust with changes in plant density or environmental stress (Pioneer Hi-Bred International, 2009). Some speculate that a fixed ear type could result in better yields at higher plant densities than a flex ear type.

Objectives

The objectives of this study were to 1) determine if narrow row corn increases grain yield compared to corn grown in 76-cm row widths; 2) determine if higher plant densities are needed in narrow rows to increase yield; and 3) determine if there are interactions among hybrids, row spacings, and plant densities.

Materials and Methods

Field experiments were conducted at Princeton, Larue County and Lexington, Kentucky in 2011 and 2012 to evaluate the effect of different hybrids, row spacings, and plant densities on corn yield. The soil types at these experiment locations in 2011 were Crider silt loam (fine-silty, mixed, mesic Typic Paleudalfs), Nicholson silt loam (fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs), and Loradale silt loam (fine, mixed, mesic Typic Argiudolls), respectively (USDA-NRCS, 2012). In 2012 the soil types were Crider silt loam, Nolin silt loam (fine-silty, mixed, active, mesic Dystric Fluventic Eutrudepts), and Loradale silt loam respectively for the three locations (USDA-NRCS, 2012). The previous crops for these locations both years were soybean at Larue County and Lexington and wheat at Princeton.

Field Production

Soil fertility and pH were adjusted according to the University of Kentucky soil recommendations and 224 kg ha^{-1} of nitrogen (N) was applied at each location, which was in excess of the university recommendations. Princeton and Lexington were no-tilled while Larue County was minimal-tilled. Minimal-tillage at about a 5 cm depth occurred one week prior to planting each year at Larue County using a Great Plains Turbo Till model 4000TT (Great Plains Manufacturing, Salina, KS). The spring months of 2011 were abnormally wet (Table 1.1), delaying seeding until 11 May, 11 May and 9 May for Princeton, Larue County and Lexington, respectively. Corn was seeded 3 April, 10 April, and 23 April 2012 at Princeton, Larue County and Lexington, respectively. A custom-engineered John Deere 7000 series (Deere & Co., Moline, IL) planter, with Precision Planting (Tremont, IL) metering units and Martin Row Cleaners (Elkton, KY) set on float mode was used to place seeds at a target depth of 4 cm. This planter was designed by adding four additional planter units to the rear capable of planting multiple row widths and a modified transmission allowing for variable seeding rates.

Low-pressure drip irrigation was used at Lexington as needed each year. As noted before, 2011 was abnormally wet in the spring and adequate rainfall was received throughout the growing season (Table 1.1). No irrigation was applied at Lexington in 2011. In 2012, the growing season began with timely rain events, but a severe drought and high temperatures were in place by the first of July. The Lexington location was drip irrigated (Table 1.1), but after the end of the season it was evident that we did not apply sufficient irrigation.

Experimental Design and Data Analysis

Treatments were arranged in a randomized complete block split-split design replicated three times. The main plots were three hybrids; marketed as AgriGold 6533 VT3 (A6533VT3), DeKalb 62-97 (DKC62-97), and Pioneer 1480 HR (P1480HR). The split plots were three row spacings; 76, 38 cm, and twin (20 cm rows on 76 cm centers). The split-split plots were planting density with target densities of 74 000, 86 000, 99 000, and 111 000 plants ha^{-1}. An additional planting density was added to the Lexington location in 2012 with a target density of 124 000 plants ha^{-1}. Each split-split plot was 3 meters wide by 9 meters in length and consisted of either four rows in 76 cm row width or eight rows in a 38-cm or twin row spacing. Data were analyzed using PROC GLM in SAS (Statistical Analysis Program, version 9.3). Site year was treated as fixed. Treatment means were separated with a protected least significant difference at $\alpha = 0.10$.

Measurements

Plant stand counts were taken early in the season at each location to determine if target densities were achieved (Table 1.2, 1.3). Stand counts were taken by counting the number of plants present in 3 m sections of the center, left single row of the 76-cm row spacing; and 3-m sections of the center, left two rows of the 38 cm and twin rows of each plot at all locations.

Intercepted photosynthetically active radiation (IPAR) was measured at growth stage V8 (Andrade et al., 2002) at the soil level and at growth stage VT/R1 at ear height. IPAR was measured using a Licor Quantum Sensor and a Licor datalogger (Lincoln, NE) placed with the sensor perpendicular to the row at three locations per plot. IPAR was also measured in full sunlight at the end of each plot to determine the IPAR for that plot. Measurements were taken on clear days with full sunlight between 1000 and 1400 hours nearest the Zenith of the sun.

Stalk diameter was measured at Lexington for all treatments in both 2011 and 2012. Measurements were taken using electronic digital calipers. Measurements were taken on five consecutive plants in a row between the first and second visible nodes of the plant. Stalk diameter for the five plants were then averaged together for a stalk diameter per plot.

Corn grain from the entire plot length within the center two rows (76-cm rows) or four rows (38-cm and twin rows) was harvested with a Wintersteiger Delta small plot harvester (Salt Lake City, UT) equipped with a Harvest Master grain weight system that measured weight, moisture and test weight (Juniper Systems Inc., Utah). Harvest occurred 16 September, 16 September and 30 September, for Princeton, Larue County, and Lexington, respectively in 2011.

Results from Princeton were not analyzed due large variability in yield data. Harvest in 2012 occurred 13 September and 8 October in Larue County and Lexington. Princeton was abandoned early in 2012 due to poor stands, and was not harvested. Grain yields collected were adjusted to 150 g kg^{-1} grain moisture and converted to field scale yields.

Subsamples of grain at Lexington both years were taken from the yield harvested. Subsamples were then dried to constant moisture concentrations and weighed to determine individual kernel size. Individual kernel size was calculated by counting 200 kernels from each subsample, weighing the total, and then converting to individual kernel size.

Results and Discussion

Climate Conditions

Climate conditions for the two experimental years were much different from one another. In 2011, rainfall was above average April through June (Table 1.1). Temperatures in 2011 were close to the 30 year average for both Larue County and Lexington. Due to the high amounts of rainfall experienced in the spring, planting was delayed across all locations in 2011. In 2012, Kentucky experienced a drought and extreme heat stress late in the growing season. Rainfall amounts were consistent with 30 year averages, but several weeks during pollination received little or no rain. Average temperatures were also in line with the 30 year average; however, there were a number of days during pollination of corn that temperatures were in excess of 35 C. These two seasonal factors in 2012 resulted in poor pollination, which contributed to significant reductions in grain yield.

Plant Stand Counts

Plant density stand counts increased as target densities increased across all row widths. Densities were planted higher than target plant densities based on the planter configuration. Since a finger pickup planter was used, exact planting density could not be obtained and the most closely matched planter configurations were used. Different row spacings also required different planting configurations and therefore variations in plant stand counts were observed (Table 1.2, 1.3).

Intercepted Photosynthetic Active Radiation (IPAR)

Intercepted photosynthetically active radiation (IPAR) at growth stage VT/R1 was significantly affected by plant density for both years and across all locations. Hybrid interacted with plant density for IPAR. Certain hybrids tested at specific locations resulted in greater IPAR.

At Lexington 2011, significant interactions for IPAR at the base of the dominant ear occurred between hybrid, row spacing, and plant density (Table 1.4). Row spacing had no effect on IPAR for P1480HR for the 86 000 and 99 000 densities (Table 1.5). This is consistent with results observed by Vyn et al. (2012) as well as Coulter and Van Roekel (2012). They observed no difference in IPAR when measured during anthesis. However, in this IPAR of 76 cm rows at the 74 000 density was greater than twin rows. P1480HR also had the highest IPAR in 38 cm rows compared to 76 cm rows for the 111 000 target density. No differences in row spacing were observed for DKC62-97. For A6533VT3, IPAR was greater in 76-cm rows compared with 38 cm rows at 99 000 plants ha^{-1}. Overall, target density had the largest impact on light interception. As plant density increased, IPAR also increased. The IPAR for target densities 99 and 111 000 plants ha^{-1} were significantly greater than 74 and 86 000 plants ha^{-1} (Table 1.5).

In 2012, IPAR was again significantly altered by plant density. Interactions between location and hybrid were observed as well (Table 1.6). Location significantly affected IPAR and interacted with hybrids at VT/R1. In 2012, plant density had the greatest impact on IPAR, with IPAR increasing as plant density increased (Table 1.9). This data is consistent with 2011 observations and with other narrow row corn research (Coulter and Van Roekel 2012). Specific hybrids at each location also interacted differently and significantly increased or reduced light interception. Hybrid P1480HR consistently resulted in the lowest IPAR at both environments, while A6533VT3 consistently had the highest IPAR. Hybrid P1480HR has upright leaves and the lower IPAR values were expected. Hybrids A6533VT3 and D62-97 in Lexington were significantly different from those observed in Larue County (Table 1.8), which most likely was attributed to the irrigation used at Lexington.

In 2012, an additional plant density of 124 000 plants ha^{-1} was included in the test. The analyses combined across years omitted this density (Table 1.6), but an analysis for 2012 only included the Lexington and the additional plant density of 124 000 plants ha^{-1} (Table 1.7). Again, as plant density increased, IPAR increased (Table 1.9). Row spacing had no effect on intercepted radiation in 2012, which is not consistent with some studies (Coulter and Van Roekel, 2012). While IPAR has a direct relationship to yield potential, high IPAR values do not always guarantee high yields. In 2012, other stress factors contributed to the low yields compared to 2011.

Stalk Diameter

Stalk diameter measurements were consistent with previous research showing that as plant densities increase, stalk diameter decreased. The hypothesis was that by reducing the row widths under high planting densities, plant-to-plant spacing would increase and approach a more even distribution than higher plant densities in wider rows. This improved distribution should produce stronger, larger stalks and increase yield.

Stalk diameter means for the two years of this study were significantly different from one another. In 2011, hybrid, row width and density interacted, but there were no interactions in 2012 (Table 1.10). In most comparisons in 2011, stalk diameter decreased as plant density increased (Table 1.11). There were significant differences in stalk diameter for DKC62-97 in 76-cm and twin rows, and P1480HR in twin rows. For hybrid DKC62-97 at 86 000 plants ha^{-1}, stalk diameter was larger for the 76 cm than twin rows. At 99 000 plants ha^{-1}, DKC62-97 stalk diameter was larger in 38-cm rows than 76-cm rows, as expected. P1480HR stalk diameters were largest for twin rows at 74 000 and 86 000 plants ha^{-1}. At 111 000 plants ha^{-1}, P1480HR stalk diameters were largest in 38-cm rows. Although some differences were not significant, the largest stalk diameters were observed at the lower densities for P1480HR. In 2012, only row width and plant density each affected stalk diameter separately.

The hypothesis that row spacing would have a significant effect on stalk diameter was correct; as plants in twin and 38-cm rows generally had a larger stalk diameter compared to the 76-cm row spacing at similar densities (Figure 1.1). As expected, greater densities generally decreased stalk diameters (Figure 1.2). These trends were similar when the additional plant density of 124 000 plants ha^{-1} was analyzed in 2012. There were no differences observed in lodging or stalk quality at harvest (data not shown).

Grain yield

Significant interactions were observed across years and locations for grain yield (Table 1.12). Yields in 2012 were much lower and more variable than yields in 2011 due to poor pollination resulting from the hot, dry weather in 2012. Therefore, yields were analyzed separately by year. In 2011, location significantly effected grain yield (Table 1.12). Lexington grain yield means were greater than those in Larue County. Interactions were also observed between hybrid, row spacing, and plant density.

At Larue County 2011, subtle differences were observed in grain yields as a result of reducing row widths (Table 1.13). In general, yields at Larue County 2011 were greater in corn grown in 38-cm and twin rows than corn in 76-cm rows (Table 1.13). For Larue County 2011, significant differences in yield among row width occurred for: A6533VT3 at 99 000 plants ha^{-1} (where yields in 38-cm rows were greater than yields in 76-cm rows), DKC62-97 at 99 000 plants ha^{-1} (where yields in 76-cm rows were greater than yields in 38-cm rows) and DKC62-97 at 111 000 plants ha^{-1}(where yields in twin rows were greater than yields in 76-cm rows); and P1480HR at 74 000 plants^{-1} (where yields in 38-cm rows were greater than yields in 76-cm rows) and 99 000 plants ha^{-1} (where yields in twin rows were greater than yields in 38-cm rows) (Table 1.13). The results of this are conclusive with research by Nielsen (1988) and Widdicombe and Thelen (2002) where corn grown in 38 cm increased grain yield. However, row width effect was still inconsistent, but narrow rows generally resulted in greater yields. The greatest yield for A6533VT3 (16.0 Mg ha^{-1}) occurred in 38-cm rows at 99 000 plants ha^{-1}. The greatest yield for DKC62-97 (16.1 Mg ha^{-1}) occurred in twin rows at 111 000 plants ha^{-1}. For P1480HR, yields were greatest in 38-cm rows at 74 000 plants^{-1} (14.1 Mg ha^{-1}).

At Lexington 2011, few significant differences in yield were observed among row spacings. Significant differences observed in row width occurred for: A6533VT3 at 74 000 plants ha^{-1} (yields in twin rows were greater than yields in 76-cm rows), A6533VT3 at 111 000 plants ha^{-1} (yields in 38-cm rows were greater than yields in 76-cm rows), and DKC62-97 at 111 000 plants ha^{-1} (yields in 76-cm rows were greater than yields in either narrow row) (Table 1.14). The greatest yields for A6533VT3 (18.8 Mg ha^{-1}) occurred in 38-cm rows at 111 000 plants ha^{-1}. The greatest yield for DKC62-97 (18.0 Mg ha^{-1}) occurred in 76-cm rows at 111 000 plants ha^{-1}. Compared to Farnham (2001), there was one case where 38-cm rows out yielded 76-cm rows, but also increased as plant density increased. This research also agrees with the results of Vyn et al. (2012) where increasing plant density increased grain yield.

In 2012 interactions between location and hybrid, and location and plant density were significant for grain yield (Table 1.15). The extra plant density, (124 000 plants ha^{-1}) was removed at Lexington for this analysis. Row spacing did not influence grain yield in 2012. Grain yield in 2012 was less than 3.2 and 6.6 Mg ha^{-1} for Larue County and Lexington, respectively. At Larue County 2012, A6533VT3 yielded more than DKC62-97 or P1480HR (Table 1.16) and yields were not significantly different among hybrids at Lexington, despite using irrigation.

Each location in 2012 resulted in no difference in grain yield based on row spacing (Table 1.15). At Larue County 2012, the lowest densities (74 and 86 000 plants ha^{-1}) provided the maximum grain yields (Table 1.17). At Lexington 2012, maximum yields were obtained at 99 000 plants ha^{-1} (6.8 Mg ha^{-1}) and were similar to yields at the lower plant densities but 8% greater than yields at the higher plant densities.

Kernel Weights

Kernel weights were only measured at Lexington and years were significantly different (Table 1.18). In 2011 hybrid and row spacing interacted with each other but no other differences were observed. In 2012, density and hybrid were the only factors that significantly changed individual kernel weight. Individual kernel weights in 2011 interacted differently for specific hybrid and row spacing combinations (Table 1.19). In 2011, A6533VT3 kernel weights were greatest in twin rows (318 mg kernel^{-1}), while kernel weights for DKC62-97 was greatest in 76-cm rows (318 mg kernel^{-1}) and least in 38-cm rows (Table 1.19). For P1480HR in 2011, kernel weights were not affected by row width. The 2011 kernel weights for DKC 62-97 in 76-cm rows were greater than the other two hybrids, but kernel weights among hybrids were similar at 38-cm and twin rows. For 2012, both hybrid and density independently had significant effects on individual kernel weights. Kernel weights averaged across row width for DKC62-97 were largest compared with the other two hybrids (Table 1.20, Figure 1.3). Conversely, P1480HR had the smallest average seed size of all the hybrids tested. Plant density also changed average kernel weights (Table 1.21, Figure 1.4). It was expected that as plant density was increased, individual kernel weights would be reduced as a result of inter-row competition between plants. Kernel weight declined from 74 000 to 111 000 plants ha^{-1} (Table 1.21, Figure 1.4), but kernel weight for 124 000 plants ha^{-1} (301 mg kernel^{-1}) was similar to the kernel weight at 74 000 and 86 000 plants ha^{-1} (305 and 300 mg kernel^{-1}, respectively).

Summary

Results of this study indicate that IPAR (measured at the base of the ear at VT/R1) was affected by hybrid and plant density, but normally not by row width. Differences in plant leaf architecture resulted in greater or less IPAR. Hybrid P1480HR had very upright leaves compared to A6533VT3 and DKC62-97. In 2011, the highest IPAR percentage for P1480HR (with upright leaves) was observed in 38-cm row spacings in the highest plant density. The largest increase for IPAR in 2012 was observed when plant densities increased. Thus, higher plant densities could result in higher yield potential. However, results of this study show that high IPAR values do not always result in high yields. Other stress factors also contributed to grain yields.

Stalk diameter measurements demonstrated what was anticipated in our hypothesis, where higher plant densities generally decrease stalk diameter and narrow rows generally increase stalk diameter at a given density. As plants are spaced further apart in narrow rows they reduced inter-plant competition for water and nutrients. In 2011, row spacing affected all hybrids in given plant densities. Generally stalk diameter was greatest in 38-cm rows. But these observations were not consistent. In 2012, row width 38-cm resulted in the largest stalk diameter and 76-cm rows had the smallest stalk diameter.

Grain yield was affected by hybrid, row spacing, and density interactions. In 2011, at Larue County, yields were increased in 38-cm and twin rows. A6533VT3 yields observed for 38-cm and twin rows were 14 and 8% higher than 76 cm rows at 99 000 plants ha^{-1}. Yields were also greater at 99 000 and 111 000 plants ha^{-1} in twin rows for DKC62-97. At Lexington 2011 the largest increase in grain yields were observed when plant densities changed. Plant density was the only treatment that effected grain yield in 2012. At Larue County the two lower densities and at Lexington the three lowest densities resulted in the greatest grain yield.

Row width effect on kernel weight was different for each hybrid in 2011. For A6533VT3, the largest kernel weight occurred in the twin rows; for DKC62-97, the largest kernel weight occurred in 76-cm rows; and for P1480HR, row width did not affect kernel weight. In 2012, kernel weights were significantly different from one another but grain yield was not. Kernel weights were largest for DKC62-97 and the smallest for P1480HR. Plant density also had a significant effect on kernel weights. Although not consistent, most kernel weights observed decreased as plant densities increased.

Based on these results, producers may consider narrowing row widths and increasing plant densities in order to increase yield potential. Both row spacing and plant density had significant effects on grain yield and plant physiological traits in select environments. In a few instances, grain yield increased when row widths were reduced or plant densities increased. However, results were variable and inconsistent and often interactions between hybrid, row spacing, and plant density occurred. When significant differences occurred, narrow rows generally resulted in greater yields. Reducing row widths and increasing plant density may not be justifiable unless planting conditions are optimum. More consistent long term studies may be needed to further investigate the relationship between row spacing and plant density.

Table 1.1. Weather conditions during the growing season †‡

	Larue	Lexington	30-yr Normal	Lexington	Larue	Lexington	30-yr Normal	Lexington
2011	------------- Rainfall, cm ------------			Irrigation, cm	------------- Mean Temperature, C -----------			Days ≥ 35 C
Apr	37.3	31.4	10.6	0	15.6	14.4	13.3	0
May	23.3	17.1	13.3	0	18.3	17.8	18.3	0
Jun	15.8	6.6	10.4	0	23.9	23.3	22.8	0
Jul	12.1	16.0	11.2	0	26.1	26.7	24.4	0
Aug	4.2	7.3	8.0	0	24.4	23.9	23.9	0
Sep	14.3	14.0	8.3	0	19.4	18.9	20.6	3
2012								
Apr	9.5	8.3	10.5	0	14.4	13.3	13.3	0
May	10.9	10.2	13.1	0	21.1	20.6	18.3	0
Jun	7.9	6.2	10.4	4.1	22.8	22.8	22.8	3
Jul	12.2	6.4	11.1	19.6	27.2	27.2	24.4	11
Aug	4.7	4.3	8.0	16.3	23.9	23.3	23.9	0
Sep	17.7	16.3	8.7	0	19.4	19.4	20.6	0

† Larue County had a weather station placed at research site.

‡ Data from the weather station located at Spindletop Research Farm, University of Kentucky.

Table 1.2. Effects of Hybrid, Row Spacing and Density on plant stand counts, 2011.

Location	Hybrid	Row Width	Target Density (plants ha^{-1})				
			74 000	**86 000**	**99 000**	**111 000**	**LSD**
			Actual Density, plants ha^{-1}				
Larue County	**A6533VT3**	76	93 200	84 600	101 900	94 700	10 400
		38	77 500	87 500	106 200	113 300	9 200
		Twin	83 200	89 000	100 400	113 300	10 200
		LSD	33 800	9 986	5 900	23 600	
	DKC62-97	76	73 200	87 500	100 400	120 500	5 000
		38	80 300	88 900	88 900	114 800	17 500
		Twin	84 600	86 100	103 300	114 800	12 200
		LSD	6 600	9 700	14 300	2 500	
	P1480HR	76	78 900	87 500	100 400	107 600	8 100
		38	77 500	86 100	99 000	106 200	5 600
		Twin	80 300	84 600	101 900	116 200	10 400
		LSD	6 100	14 700	8 700	3 900	
Lexington	**A6533VT3**	76	73 200	84 600	93 200	127 700	15 300
		38	78 900	96 100	99 000	99 000	10 500
		Twin	71 700	87 500	99 000	113 300	11 800
		LSD	9 700	23 000	14 600	6 100	
	DKC62-97	76	68 900	87 500	103 300	111 900	4 400
		38	70 300	96 100	96 100	99 000	19 000
		Twin	70 300	90 400	96 100	106 200	12 300
		LSD	21 300	8 500	6 600	28 000	

Table 1.3. Effects of Hybrid, Row Spacing and Density on plant stand counts, 2012.

Location	Hybrid	Row Width	Target Density (plants ha^{-1})					
			74 000	**86 000**	**99 000**	**111 000**	**124 000**	**LSD**
			Actual Density, plants ha^{-1}					
Larue County	**A6533VT3**	76	88 900	81 800	90 400	97 600	---	32 500
		38	91 800	106 200	73 200	88 900	---	17 500
		Twin	67 400	78 900	76 000	104 700	---	15 300
		LSD	26 400	17 800	43 100	34 600		
	DKC62-97	76	78 900	90 400	88 900	96 100	---	34 800
		38	99 000	94 700	91 800	86 100	---	23 700
		Twin	90 400	91 800	86 100	96 100	---	26 200
		LSD	36 400	17 200	12 200	44 100		
	P1480HR	76	91 800	73 200	93 200	84 600	---	35 800
		38	80 300	90 400	83 200	96 100	---	26 000
		Twin	73 200	86 100	87 500	100 400	---	12 800
		LSD	25 600	21 000	20 000	20 000		
Lexington	**A6533VT3**	76	66 000	76 000	93 200	106 200	109 000	27 900
		38	68 900	83 200	94 700	103 300	120 500	11 800
		Twin	81 800	94 700	97 600	110 500	127 700	11 300
		LSD	17 700	22 700	25 00	24 600	26 700	
	DKC62-97	76	63 100	73 200	97 600	119 100	114 800	18 200
		38	68 900	84 600	94 700	106 200	109 000	11 100
		Twin	71 700	80 300	88 900	104 700	127 700	13 400
		LSD	15 500	18 000	6 600	8 500	25 000	
	P1480HR	76	73 200	81 800	93 200	110 500	124 800	12 200
		38	76 000	88 900	86 100	103 300	132 000	9 200
		Twin	74 600	93 200	91 800	97 600	113 300	14 600
		LSD	6 100	9 000	14 300	18 300	18 100	

Table 1.4. ANOVA for IPAR at the base of the dominant ear VT/R1 at Lexington 2011

Source	DF	P value
Rep	2	<.0001
Hyb	2	0.0023
Rep*Hyb	4	0.6991
Row	2	0.1012
Hyb*Row	4	0.0332
Rep*Row(Hyb)	12	0.0515
Pop	3	<.0001
Hyb*Pop	6	0.1407
Row*Pop	6	0.5838
Hyb*Row*Pop	12	0.0712

Table 1.5. IPAR at the base of the dominant ear at VT/R1 at Lexington, 2011

Hybrid	**Row Width**	**Target Density (plants ha^{-1})**				
		74 000	**86 000**	**99 000**	**111 000**	**LSD**
		IPAR, %				
A6533VT3	76	73	75	91	81	12
	38	74	84	86	88	12
	Twin	83	81	89	91	7
	LSD	10	12	3	16	
DKC62-97	76	78	84	79	81	6
	38	82	80	88	86	5
	Twin	85	88	83	90	6
	LSD	8	9	10	10	
P1480HR	76	81	78	84	79	5
	38	78	75	80	83	11
	Twin	67	79	83	80	12
	LSD	14	12	5	4	

Table 1.6. ANOVA for IPAR in 2012

Source	DF	P value
Location	1	0.0568
Rep (Location)	4	<.0001
Hyb	2	<.0001
Location*Hyb	2	0.0041
Rep*Hyb (Location)	8	0.2127
Row	2	0.6075
Location*Row	2	0.7230
Hyb*Row	4	0.7904
Rep*Row (Hyb)	12	0.2770
Pop	3	0.0084
Location*Pop	3	0.9471
Hyb*Pop	6	0.2695
Row*Pop	6	0.4465
Hyb*Row*Pop	12	0.8489
Location*Hyb*Pop	6	02728
Location*Row*Pop	6	0.6755
Location*Hyb*Row*Pop	16	0.7966

Table 1.7. ANOVA for IPAR 2012 by Location with 124 000 plants ha^{-1}

	Larue County		Lexington	
Source	DF	P value	DF	P value
Rep	2	0.0011	2	<.0001
Hyb	2	0.0011	2	<.0001
Rep*Hyb	4	0.1764	4	0.2070
Row	2	0.4437	2	0.9540
Hyb*Row	4	0.4400	4	0.9085
Rep*Row (Hyb)	12	0.4647	12	0.7420
Pop	3	0.1210	4	0.0066
Hyb*Pop	6	0.1226	8	0.6148
Row*Pop	6	0.4086	8	0.8678
Hyb*Row*Pop	12	0.5004	16	0.9793

Table 1.8. IPAR Interactions between Location and Hybrid in 2012

Location	**Hybrid**			
	A6533VT3	**DKC62-97**	**P1480HR**	**LSD**
		IPAR, % †		
Larue	66	58	59	4
Lexington	72	63	56	4
LSD	5	4	4	

† IPAR was measured at the base of the dominant ear during VT/R1 growth stage.

Table 1.9. IPAR by Plant Density, 2012

Target Density (plants ha^{-1})	Larue	Lexington
	IPAR, % †	
74 000	58	60
86 000	62	65
99 000	60	63
111 000	65	67
124 000	---	70
LSD	4	4

† IPAR was measured at the base of the dominant ear during VT/R1 growth stage.

Table 1.10. ANOVA for Stalk Diameter at Lexington

	2011		2012	
Source	DF	P value	DF	P value
Rep	2	0.7305	2	<.0001
Hyb	2	0.1283	2	<.0001
Rep*Hyb	4	0.8745	4	0.8260
Row	2	0.0559	2	<.0001
Hyb*Row	4	0.0295	4	0.4530
Rep*Row (Hyb)	12	0.1926	12	0.2406
Pop	3	0.0046	4	<.0001
Hyb*Pop	6	0.1270	8	0.9101
Row*Pop	6	0.2344	8	0.5676
Hyb*Row*Pop	12	0.0246	16	0.5962

Table 1.11. Stalk Diameter at Lexington, 2011

Hybrid	Row Width	Target Density (plants ha^{-1})				
		74 000	86 000	99 000	111 000	LSD
		Stalk Diameter, mm				
A6533VT3	76	19.2	18.3	19.3	17.8	3.3
	38	20	19.7	18	21.1	2.7
	Twin	18	18.2	18.2	18.5	2.3
	LSD	3.7	1.7	2.4	4.4	
DKC62-97	76	20.1	19.7	16.4	17.7	2
	38	21.3	19.1	20.5	17.7	2.6
	Twin	21.4	18.6	18.7	18	2.2
	LSD	2.4	1.1	2.7	2.9	
P1480HR	76	20.7	18.1	19.6	17	2.8
	38	19.7	17.1	18.6	21.6	2.7
	Twin	21.5	21.7	20.3	19.5	2.3
	LSD	1.8	3.2	2.5	4.3	

Figure 1.1. Stalk diameter means averaged across hybrid and plant density, 2012

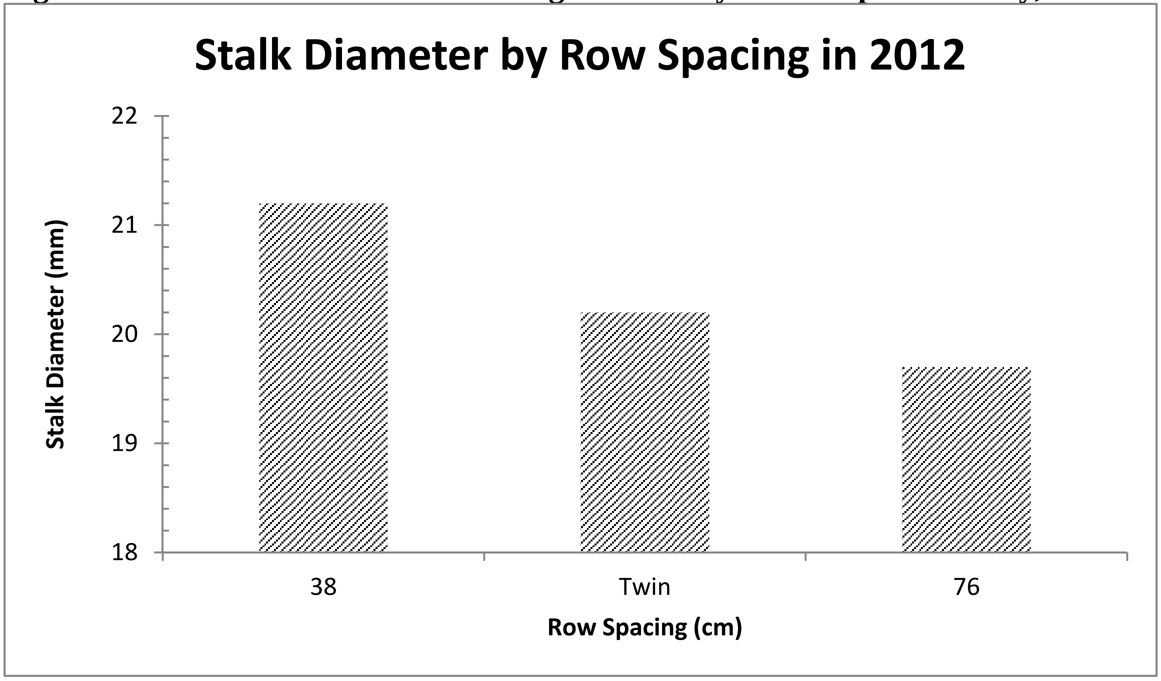


Figure 1.2. Stalk diameter means averaged across hybrid and row spacing, 2012

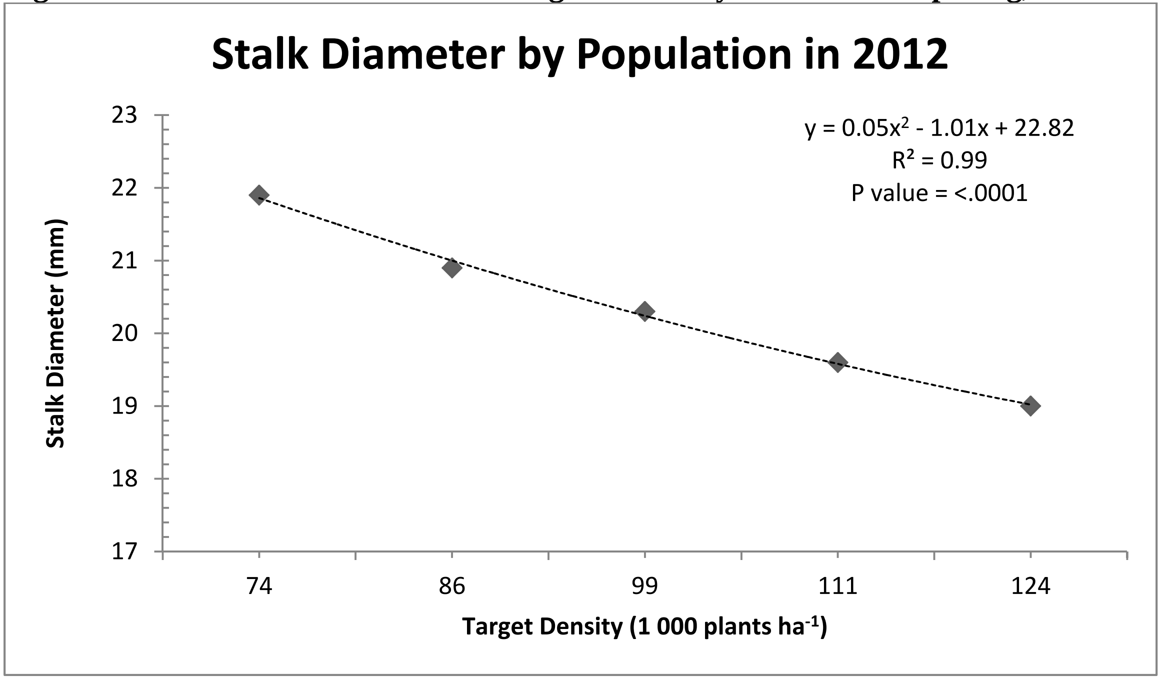


Table 1.12. ANOVA for grain yield, 2011

Source	**DF**	**P value**
Location	1	<.0001
Rep (Location)	4	<.0001
Hyb	2	<.0001
Location*Hyb	1	0.5562
Rep*Hyb (Location)	6	<.0001
Row	2	0.0237
Location*Row	2	0.0177
Hyb*Row	4	0.0661
Rep*Row (Hyb)	12	0.1041
Pop	3	0.0181
Location*Pop	3	0.0005
Hyb*Pop	6	<.0001
Row*Pop	6	0.3460
Hyb*Row*Pop	12	0.0555
Location*Hyb*Pop	3	0.8183
Location*Row*Pop	6	0.2593
Location*Hyb*Row*Pop	8	0.2343

Table 1.13. Mean grain yield (Mg ha^{-1}) interactions, Larue County 2011

Hybrid	Row Width	Target Density (plants ha^{-1})				
		74 000	86 000	99 000	111 000	LSD
		Grain Yield, Mg ha^{-1}				
A6533VT3	76	13.7	14.7	13.7	13.4	2.5
	38	14.2	15.1	16.0	14.8	1.5
	Twin	15.1	14.4	14.9	15.6	1.9
	LSD	2.1	1.6	1.9	2.8	
DKC62-97	76	13.6	14.3	15.2	13.5	1.1
	38	13.2	13.7	13.5	14.1	2.1
	Twin	13.9	14.4	14.8	16.1	1.8
	LSD	2.1	1.3	1.5	1.9	
P1480HR	76	11.4	12.2	11.5	10.3	1.9
	38	14.1	13.2	9.5	10.3	2.8
	Twin	12.1	13.7	12.2	10.9	1.6
	LSD	2.6	1.4	2.5	2.5	

Table 1.14. Mean grain yield (Mg ha^{-1}) interactions, Lexington 2011

Hybrid	Row Width	Target Density (plants ha^{-1})				
		74 000	**86 000**	**99 000**	**111 000**	**LSD**
		Grain Yield, Mg ha^{-1}				
A6533VT3	76	15.5	16.5	18.0	16.4	1.1
	38	16.3	17.7	17.7	18.8	1.2
	Twin	16.7	16.4	17.7	17.0	1.6
	LSD	0.7	3.5	2.3	1.9	
DKC62-97	76	14.8	16.7	16.6	18.0	0.8
	38	15.9	16.7	16.9	16.8	1.4
	Twin	15.3	16.2	16.7	16.4	1.1
	LSD	1.3	1.0	2.1	1.1	

Table 1.15. ANOVA for grain yield, 2012

Source	DF	P value
Location	1	<.0001
Rep (Location)	4	<.0001
Hyb	2	0.2035
Location*Hyb	2	0.0308
Rep*Hyb (Location)	8	0.0173
Row	2	0.3374
Location*Row	2	0.3534
Hyb*Row	4	0.5832
Rep*Row (Hyb)	12	0.8174
Pop	4	0.2247
Location*Pop	3	0.0478
Hyb*Pop	8	0.2151
Row*Pop	8	0.4843
Hyb*Row*Pop	16	0.5429
Location*Hyb*Pop	6	0.1643
Location*Row*Pop	6	0.1132
Location*Hyb*Row*Pop	16	0.4552

Table 1.16. Mean grain yield (Mg ha^{-1}) for hybrid at each location, 2012

Hybrid	Larue County	Lexington	LSD
	Grain Yield, Mg ha^{-1}		
A6533VT3	3.1	6.2	0.9
DKC62-97	2.0	6.5	0.5
P1480HR	2.2	6.2	0.6
LSD	0.6	0.8	

Table 1.17. Mean grain yield (Mg ha^{-1}) for plant density at each location, 2012

Target Density (plants ha^{-1})	Larue County	Lexington	LSD
	Grain Yield, Mg ha^{-1}		
74 000	2.9	6.4	1.0
86 000	2.7	6.3	0.6
99 000	1.7	6.8	0.6
111 000	2.3	5.8	1.1
124 000	---	5.9	
LSD	0.7	0.9	

Table 1.18. ANOVA for seed weight (mg kernel^{-1}) at Lexington

	2011		2012	
Source	DF	P value	DF	P value
Rep	2	<.0001	2	0.3332
Hyb	2	0.1248	2	<.0001
Rep*Hyb	4	<.0001	4	0.0615
Row	2	0.4700	2	0.1984
Hyb*Row	4	0.0881	4	0.4703
Rep*Row (Hyb)	12	0.3012	12	0.5811
Pop	3	0.4186	4	0.0594
Hyb*Pop	6	0.5706	8	0.8847
Row*Pop	6	0.2364	8	0.9554
Hyb*Row*Pop	12	0.1517	16	0.5248

Table 1.19. Mean individual kernel weights (mg kernel^{-1}) at Lexington 2011.

Hybrid	Row Width, cm			
	76	38	Twin	LSD
	Kernel Weight, mg kernel^{-1}			
A6533VT3	305	308	318	13
DKC62-97	323	311	318	8
P1480HR	314	314	309	10
LSD	9	8	14	

Table 1.20. Mean individual kernel weights (mg kernel^{-1}) at Lexington 2012 by hybrid.

Hybrid	Kernel Weight, mg kernel^{-1}
A6533VT3	302
DKC62-97	332
P1480HR	263
LSD	6

Table 1.21. Mean individual kernel weights (mg kernel^{-1}) at Lexington 2012 by plant density.

Target Density (plants ha^{-1})	Kernel Weight, mg kernel^{-1}
74 000	305
86 000	300
99 000	295
111 000	293
124 000	301
LSD	7

Figure 1.3. Mean individual kernel weights (mg kernel^{-1}) at Lexington 2012, by hybrid.

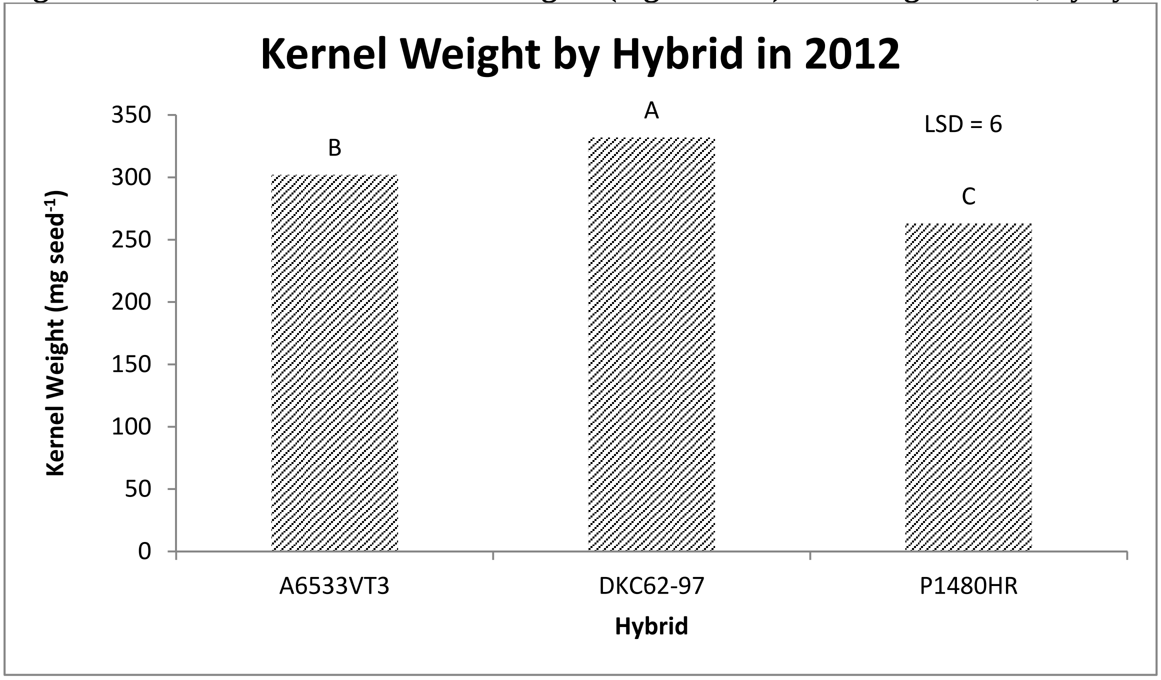
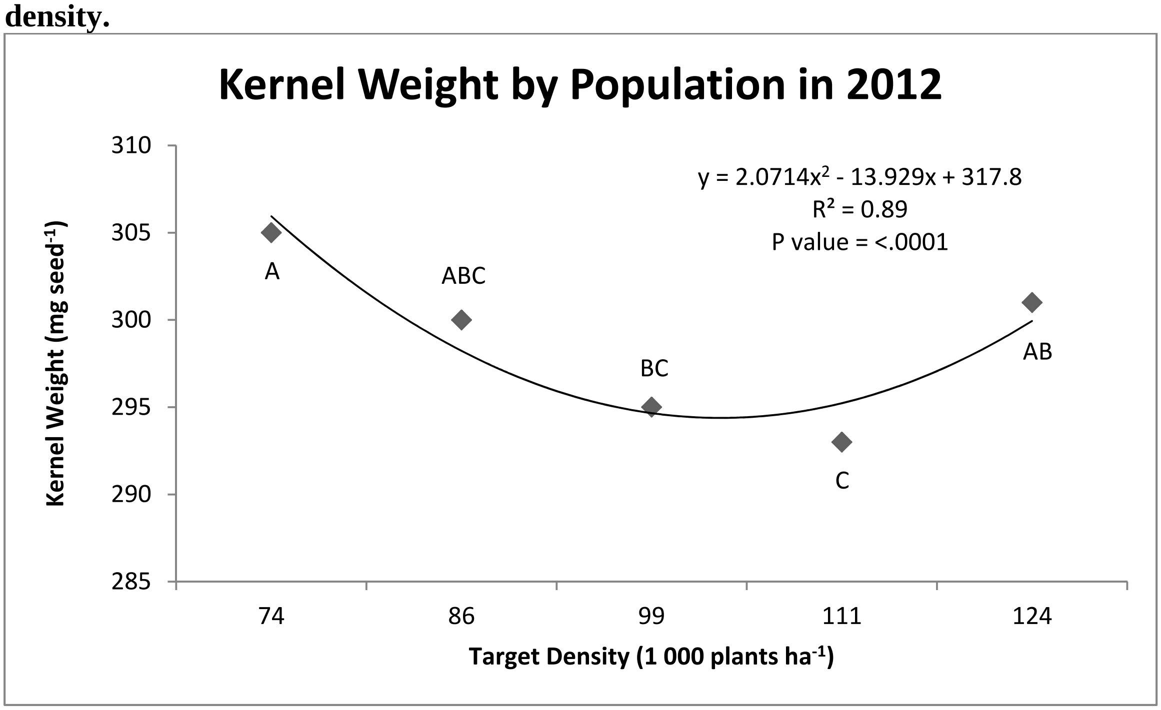


Figure 1.4. Mean individual kernel weights (mg kernel^{-1}) at Lexington 2012, by plant density.



Chapter 2: Weed Management Strategies in Different Row Spacings

Introduction

One of the possible benefits obtained from planting narrow row corn is better late season weed control. Corn planted in narrow rows has been reported to alter weed pressure in the field (Teasdale, 1995). As corn is planted closer together in narrow rows, the corn canopy closes faster early in the growing season. After canopy closure there is less light reaching the soil surface which prevents weed germination or growth. Teasdale (1995) found that reducing corn row widths has the potential to decrease the amount of herbicides required to control weeds. Research conducted at Minnesota, illustrated weed control benefits of reducing row spacing from 76 to 51 cm (Johnson and Hoverstad, 2002). However, the density of certain weed species increased as postemergence (POST) herbicide application was delayed. There was also row spacing by herbicide interactions in this study when narrow-row corn had higher weed densities when a late POST application was used. Apparently by the time of herbicide application, the corn in 51-cm rows was shading more of the soil than 76-cm rows and inadequate herbicide reached the weeds (Johnson and Hoverstad, 2002). The 51 cm rows used in this study may be too narrow to efficiently apply POST herbicides, which is why twin row systems may be better. Murphy et al. (1996) also observed that narrow rows (50 cm) significantly reduced late season weed pressure in Ontario, Canada. In addition, light transmittance to weeds was significantly less in narrow rows compared to wide rows all three years tested (Murphy et al., 1996). Weed control aside, narrower row widths are thought to produce a yield benefit. There are also other valuable reasons for reducing corn row widths, including but not limited to corn plant morphology characteristics, planting density, and water and nutrients. In order to obtain the yield benefits of narrow rows everything within the production system must work together.

Whether narrow row corn systems are being used or not, it is important that proper herbicide programs are used at the critical time of weed removal (Norsworthy and Oliveira, 2004). If herbicides are applied within this critical period, reductions in grain yield will not be as evident. Herbicide resistant hybrids have made it possible for many different herbicide programs to be used without harming the crop. Herbicide applications are made based on the corn growth stage or the size of the weeds present. In a research study conducted at Minnesota from 2007 to 2009, Lindsey et al. (2012) studied the effects of different herbicide programs on weed control. Their results showed that significant differences in weed control were not observed between glyphosate and glufosinate herbicide applications. However, in 2009 results showed that common lambsquarters (*Chenopodium album* L.) control was 5% better with an early application POST program than a late application POST program. Frequently, an early POST herbicide application was better (5%) than later applications. In addition, soil residual herbicides followed by a sequential POST application consistently gave greater than 95% weed control (Lindsey et al., 2012).

Similar herbicide timing techniques are also being used in narrow row corn production systems. Research conducted in South Carolina determined that row spacing did not change the effect that herbicide timing had on weed suppression (Norsworthy and Oliveira, 2004). Based on weed removal timing, a single POST herbicide application could be made during the season without significant yield losses (Northworthy and Oliveira, 2004). However, all of herbicide timing is was dependent upon the weed species, weed density and the weed seed bank in the soil. When weed densities are high, early preemergence (PRE) herbicide applications should be made followed by a POST application.

Moderate decreases in weed density were observed when twin row corn was used in Missouri (Nelson, 2007). However, the results were not significant. Herbicide timing based on weed size made the largest difference. Early POST herbicide applications did not have the residual activity required to last throughout the season. Dalley et al. (2004) also reported that in narrow row corn systems, grain yield was greatest when weeds were controlled before they reached 5-cm in height. If narrow row corn production is going to be used to increase grain yield, a single herbicide application may be possible. However, that application may be required earlier in the season for narrow-row corn systems. Also, if an application is made early in the season, a residual herbicide may also be needed to maintain weed suppression. A study conducted in Texas showed consistently better weed control for multiple species when glufosinate (no residual activity) and atrazine (residual activity) combinations were used (Jones et al., 2001). Across multiple species, POST with residual applied herbicides consistently provided the greatest weed control as well as the lowest weed density in studies conducted in Ohio, Illinois, and Indiana (Young et al., 2011). Unlike soybean, faster and complete canopy closure in corn may not always be observed due to the growth characteristics of the plant. Therefore, when changing corn production to narrow row spacings, it is important not to compromise weed control.

Objectives

The objectives of this research were to 1) evaluate various herbicide timings in corn when planted in wide (76 cm), narrow (38 cm) and twin rows (20-cm twins on 76-cm centers) crop spacings; and 2) estimate the effect of crop row width and weed management method on corn yield.

Materials and Methods

Field Production

Field experiments were conducted at Princeton and Lexington, Kentucky in 2011 and 2012 to determine the effect row spacing and weed management systems had on season-long weed control and grain yield. These experiments evaluated five different weed management systems in corn planted with three different row spacings. The soil types at Princeton and Lexington were a Crider silt loam (fine-silty, mixed, mesic Typic Paleudalfs) and Loradale silt loam (fine, mixed, mesic Typic Argiudolls), respectively (USDA-NRCS, 2012). Soil fertility and pH were adjusted according to the University of Kentucky soil recommendations and nitrogen (N) was applied at a rate of 224 kg ha^{-1} at each location. This N rate was higher than the recommended rate for these soil types to ensure the N would not be a limiting factor. The previous crop for both of these two locations was soybean in 2011. In 2012, this study was planted corn after corn in Lexington due to crop rotation constraints.

Experimental Design and Data Analysis

The statistical design was a split-plot replicated four times in randomized complete blocks. The main plots were one of three row spacings; wide, narrow or twin. Split-plots were five different herbicide weed management systems (Table 2.1) that consisted of 1) PRE only (S-metolachlor + atrazine), 2) PRE fb POST (S-metolachlor + atrazine followed by glyphosate), 3) POST only (glyphosate), 4) EPOST + Residual (glyphosate + S-metolachlor + atrazine), and 5) an untreated control. Each split-plot was 3 meters wide by 12 meters in length and consisted of either four rows in a standard 76 cm row width or eight rows in a 38-cm or twin row spacing.

Corn was planted 11 May and 9 May 2011 at Princeton and Lexington, respectively. In 2012, corn was planted 3 April and 23 April for Princeton and Lexington, respectively. At Princeton, the experimental area was conventionally tilled prior to planting both years. At Lexington the study area was no-tilled with glyphosate applied across the entire experiment area for control of existing vegetation before planting. All plots were planted at a density of 74 000 plants ha^{-1}. Corn was planted using a custom engineered John Deere 7000 series finger pickup planter. This planter included four additional planter units in the rear capable of planting multiple row widths. The planter was adjusted to achieve a planting depth of approximately 4 cm.

Herbicides were applied by hand using a compressed CO_2 backpack sprayer and a 3-m wide spray boom. Spray nozzles were TeeJet 8003 spray tips spaced 51 cm used to deliver a target spray volume of 187 L ha^{-1}. PRE herbicide applications were made immediately after planting (Table 2.2). In 2011, EPOST + Residual applications were made at approximately corn growth stage V4 (6 June and 3 June at Princeton and Lexington, respectively). In 2012, EPOST + Residual applications were made at approximately corn growth stage V5 (11 May and 23 May at Princeton and Lexington, respectively). In 2011, POST applications for POST only and PRE fb POST were made at corn growth stage V7 (10 June 2011 at both Princeton and Lexington). In 2012, POST applications for POST only and PRE fb POST were made at corn growth stage V7 (16 May and 4 June at Princeton and Lexington 2012, respectively).

Measurements

Stand counts of corn were taken early in the season at both locations. Stand counts were taken by counting the number of plants present in 3 m sections of the center, left single row of the wide rows; and 3 m sections of the center, left two rows of the narrow and twin rows of each plot at all locations. Corn plant density was not part of the experiment being tested, and therefore, stand counts were only taken to make sure densities were consistent across the entire study.

Weed densities were measured 22 June and 20 June, in 2011 at Princeton and Lexington, respectively. In 2012, weed densities were counted 6 June and 20 June at Princeton and Lexington, respectively. Individual weed species in an area of 3.0 by 0.76 m (2.3m^2 or 25ft^2) were counted in each plot.

Control of individual weed species in each plot was determined on a visual scale of 0 to 100 percent with 0 representing no control and 100 being complete control. Visual ratings were taken 22 June and 20 June at Princeton and Lexington, respectively, in 2011. Visual ratings were taken 6 June and 20 June in 2012 at Princeton and Lexington, respectively.

Individual weeds present at Princeton in 2011 were johnsongrass (*Sorghum halepense* L.), smooth pigweed (*Amaranthus hybridus* L.), ivyleaf morningglory (*Ipomoea hederacea* L.), and honeyvine milkweed (*Ampelamus albidus* Michx.). Individual weed species present at Lexington in 2011 were smooth pigweed, ladysthumb (*Polygonum persicaria* L.), common lambsquarters (*Chenopodium album* L.), and horseweed (*Conyza canadensis* L.). Weeds observed at Princeton in 2012 were ivyleaf morningglory, yellow nutsedge (*Cyperus esculentus* L.), honeyvine milkweed, johnsongrass, smooth pigweed, and common lambsquarters. Weeds assessed at Lexington in 2012 were smooth pigweed, common lambsquarters, honeyvine milkweed, ivyleaf morningglory, yellow nutsedge, and ladysthumb. Canada thistle (*Cirsium arvense* L.) was also assessed at Lexington in 2012 based on the general density of the weed and given a rating of low, medium, or high (data not reported).

Intercepted photosynthetically active radiation (IPAR) was measured at growth stage V8 (Andrade et al., 2002) at the soil surface. IPAR was measured using a Licor Quantum Sensor and a Licor datalogger (Lincoln, NE) placed with the sensor perpendicular to the row at three locations per plot. IPAR was also measured in full sunlight at the end of each plot to determine the IPAR for that plot. Measurements were taken on clear days with full sunlight between 1000 and 1400 hours nearest the Zenith of the sun. Although this was not a major measurement taken in this study, results of one year have been included.

Grain yield was taken at the end of the season to determine the effect of weed pressure relative to the weed management system used and row spacing on yield. The center two rows (wide) or four rows (narrow and twin rows) were harvested with a small plot harvester (Wintersteiger Delta) equipped with a grain weight system that measured weight and moisture (Harvest Master, Juniper Systems Inc., Utah). Harvest occurred 16 September and 28 September in 2011 for Princeton and Lexington, respectively. In 2012, corn was harvested 29 August and 4 October for Princeton and Lexington. Grain yields were collected and adjusted to 15% grain moisture and then converted to final yields.

Data was analyzed using PROC GLM in SAS (Statistical Analysis Program, version 9.3). Individual weed count data was square root transformed prior to analysis to account for treatments with small weed densities. Weed densities means are reported for a 10 m^2 area. Visual control ratings were arc sine transformed due to the range of percent values recorded. Differences of significance of main plots and subplots were based on the analysis of variance. Individual treatment means were then separated by Fischer's Protected LSD at the 5% level of probability, unless otherwise noted.

Results and Discussion

With the diversity of weed species each year at both locations, results were analyzed separately by year and location. The hypothesis was that by reducing corn row widths weed densities would be suppressed and emergence of weeds reduced later in the season.

Weed Density

At Princeton in 2011 and 2012, no significant interactions between row spacing and herbicide treatment were observed among the densities of individual weed species present (Table 2.3). Row spacing had no effect on the weed density. Therefore, weed densities averaged across herbicide treatments were not reduced when corn was planted in narrow or twin rows relative to wide rows. Weed densities when averaged across row spacings at Princeton in 2011 were: 11, 1, 0, and 4 plants 10m^{-2} for johnsongrass, smooth pigweed, ivyleaf morningglory, and honeyvine milkweed; respectively. Weed densities when averaged across row spacings at Princeton in 2012 were: 0, 11, 14, 20, 0, and 119 plants 10m^{-2} for johnsongrass, smooth pigweed, ivyleaf morningglory, honeyvine milkweed, common lambsquarters, and yellow nutsedge; respectively.

While row spacing had no effect on weed densities at Princeton both experiment years, the herbicide treatments evaluated did have an effect on some weed species present (Table 2.4). Typically all herbicide treatments reduced weed density compared to the untreated control, but this response also depended on the weed species. For example, johnsongrass density was significantly reduced in 2011 at Princeton by all herbicide applications, except for the PRE only treatment which resulted in similar johnsongrass densities as the untreated control (Table 2.4). This was probably the result of the PRE only herbicides not lasting throughout the entire growing season and johnsongrass emergence by and seed. High johnsongrass densities were also the result of where densities were measured within the plot, as rhizome johnsongrass tends to cluster. Johnsongrass densities were much lower at this location in 2012 resulting in no difference among treatments. Except for honeyvine milkweed, densities of smooth pigweed and ivvyleaf morningglory at Princeton were reduced by herbicide treatments compared to the untreated control in 2011. Honeyvine milkweed is a perennial dicot. For Princeton 2011, the most effective herbicide timing for johnsongrass, smooth pigweed and ivyleaf morningglory was POST only and EPOST + Residual. Smooth pigweed and common lambsquarters densities in 2012 at Princeton were also reduced when a herbicide treatment was used compared to the untreated control. The lowest numerical values for smooth pigweed density occurred with PRE only and PRE fb POST.

No interactions between row spacing and herbicide treatment were observed at the Lexington location in 2011. No differences in weed densities occurred among row spacings at the 5% level of significance (Table 2.5). However, at P-values <0.10, ladysthumb and common lambsquarters indicated a difference in row spacing. At this level, ladythumb and common lambsquarters densities were significantly lower in narrow and twin rows compared to wide rows. Weed densities when averaged across row spacings at Lexington in 2011 were: 30, 5, 11, and 1 plants $10m^{-2}$ for smooth pigweed, ladysthumb, common lambsquarters, and marestail; respectively. Weed densities when averaged across row spacings at Lexington in 2012 were: 0, 1, 9, and 3 plants $10m^{-2}$ for ladysthumb, common lambsquarters, honeyvine milkweed, and ivyleaf morningglory; respectively. At Lexington 2012, interactions were observed between row spacing and herbicide treatment for smooth pigweed and yellow nutsedge. Herbicide treatment effect was significant for all weeds measured at Lexington in 2011, and for smooth pigweed and common lambsquarters in 2012.

Since two-way interactions were observed between row spacing and herbicide treatment for smooth pigweed and yellow nutsedge at Lexington 2012, data was analyzed separately by row spacing and by herbicide treatment (Table 2.6). Smooth pigweed densities in the untreated control were greater in wide rows (108 plants 10 m^{-2}) than narrow rows (15 plants 10 m^{-2}), but did not differ from twin rows (40 plants 10 m^{-2}). Smooth pigweed densities were not different among row widths within each herbicide treatment. Whereas, herbicide treatments within each row width greatly reduced smooth pigweed densities. Yellow nutsedge densities were very low for all row widths and herbicide treatment combinations (11 or fewer plants 10 m^{-2}) and there were no difference in density across row widths for any herbicide treatment. Weed densities within the twin-row spacing were significantly greater for the POST only treatment in twin rows compared to other treatments.

Differences observed among herbicide treatments varied among weed species at Lexington 2011 (Table 2.7). With smooth pigweed, all herbicide treatments reduced weed densities compared to the untreated control. The PRE only treatment resulted in higher smooth pigweed densities than POST treatments, but was significantly less than the untreated control density. Ladysthumb density was reduced most by PRE fb POST and EPOST + Residual treatments relative to the POST only treatment. Common lambsquarters densities were reduced by POST treatments. Lowest marestail densities occurred with PRE only, PRE fb POST, and EPOST + Residual applications. For Lexington 2011, the PRE fb POST and EPOST + Residual treatments were the most consistent at reducing weed densities. For Lexington 2012, ladysthumb densities were low and herbicide treatment did not affect densities. All herbicide treatments significantly reduced common lambsquarters densities. Honeyvine milkweed and ivyleaf morningglory densities were not affected by herbicide treatments, but densities for each species were highly variable. For all weed species at Lexington 2012, the most consistent herbicide treatments were PRE fb POST and EPOST + Residual. Interactions observed with smooth pigweed and yellow nutsedge at Lexington 2012 were reported in Table 2.6.

Visual Weed Control Ratings

The untreated control was removed from analysis for percent visual control evaluations of treatments. There were no interactions observed between row spacing and herbicide treatment for visual weed control ratings at Princeton in 2011 and 2012 (Table 2.8). Herbicide treatment improved visual weed control in 2011 for johnsongrass and overall weed control evaluated 6 June and for the preharvest rating taken prior to grain harvest. Row spacing was not significant. In 2012, herbicide treatment significantly affected visual control of all weed species except yellow nutsedge and smooth pigweed.

Visual weed control was not affected by row width for most weed species at Princeton 2011. However, ivyleaf morningglory was controlled better in 76 cm rows than in twin rows (Table 2.9). No differences were observed between row spacings at Princeton 2012 except for overall visual control (Table 2.9), where wide rows were superior to narrow rows.

Johnsongrass was controlled less using the PRE only treatment compared to all other herbicide treatment systems (Table 2.10). Across all row spacings, S-metolachlor + atrazine applied PRE did not have the residual efficiency to control late-season flushes of johnsongrass. All other herbicide treatments effectively controlled johnsongrass greater than 89%. Herbicide treatments did not affect visual control ratings of other weed species. The overall ratings taken early season and taken preharvest were less for the PRE treatments. These overall ratings were influenced by johnsongrass. PRE only herbicide treatments were the least effective at providing season-long weed control. PRE followed by POST glyphosate and POST glyphosate plus residual herbicide treatments visually provided the best overall weed control at the Princeton location in 2011. Herbicide treatment generally had significant effects on mean visual control ratings except yellow nutsedge and smooth pigweed at Princeton 2012 (Table 2.10). The PRE only resulted in the lowest overall ratings for the other weed species evaluated. For visual ratings with significant differences, PRE fb POST or EPOST + Residual resulted in the highest ratings.

Row spacing and herbicide treatment did not interact for visual weed control at Lexington in 2011 and 2012 (Table 2.11). Row spacing was significant for smooth pigweed and common lambsquarters at Lexington 2011. Smooth pigweed was visually controlled better by narrow and twin rows compared to wide rows (Table 2.12). Common lambsquarters visual control was better in narrow rows compared with wide rows. Treatment also significantly affected visual control of weed species and overall weed control early in the season and at preharvest (Table 2.11). At Lexington 2012 row spacing did not affect weed control, but herbicide treatment was significant for smooth pigweed, overall early season and at preharvest.

When combined across row spacings, visual weed control results for the overall rating at early season were greatest in the PRE, PRE fb POST, and EPOST + Residual treatments compared to the POST only treatment at Lexington 2011 (Table 2.13). Effectiveness of herbicide treatments were different for various weed species. Smooth pigweed and common lambsquarters control was greater in the PRE fb POST and the EPOST + Residual treatments compared to other treatments. Ladysthumbs control was the least effective when a POST only herbicide application was made compared to a EPOST + Residual. Marestail control was best with PRE and PRE fb POST treatments. Once marestail was established, post applications were less effective at suppressing growth and preventing weed branching. Herbicide treatment also had significant effects on overall early season weed control and at preharvest at Lexington 2012 (Table 2.13). PRE only resulted in the least amount of weed control (74 and 73% for early season and preharvest, respectively) compared to other treatments. Smooth pigweed visual control was also significantly less using the PRE only treatment compared to all other treatments. Honeyvine milkweed control was best achieved with POST herbicide treatments which contained glyphosate. Herbicide treatments had no effect on ladysthumb and marestail at Lexington 2011 and no effect on ladysthumb, common lambsquarters, ivyleaf morningglory, or yellow nutsedge at Lexington 2012.

Intercepted Photosynthetic Active Radiation (IPAR)

Intercepted photosynthetic active radiation (IPAR) at growth stage V8 was affected by row spacing in Lexington 2011 (Table 2.14). Narrow and twin row spacings significantly increased IPAR compared to wide rows, with twin rows providing the largest IPAR (45%) (Table 2.15). Since narrow and twin row spacings intercepted more sunlight, less sunlight reached the soil level and less sunlight was available to weeds earlier in the growing season. The potential for quicker canopy closure in narrow and twin rows early in the season could provide better full season weed control.

Grain Yield

Since year and location interacted for grain yield, mean grain yields were separated by year and location for further analysis. At Lexington in 2011, no interactions between herbicide treatments and row spacing were observed relative to grain yield (Table 2.16). However, at Princeton 2011 interactions between row spacing and herbicide treatment occurred at the 0.10 level of significance. The effect of row spacing at Princeton could be due to the highly significant effect replication had on grain yield. Whereas, at Lexington, only treatment influenced grain yield at $P < 0.05$.

At Princeton 2011, interactions between row spacing and herbicide treatment showed that PRE fb POST and POST only resulted in better yields for wide and twin rows compared with narrow rows (Table 2.17). Row width did not affect yields in EPOST + Residual and the untreated control. Within the wide and twin rows, PRE fb POST and POST only resulted in greater yields than the PRE only and untreated control. No significant difference in grain yield was observed between the PRE only and untreated control within each row spacing. The presence of rhizome johnsongrass late in the season in the PRE only may have impacted grain yield. The untreated control resulted in lowest grain yield at Lexington 2011 compared to treatments that received a weed management practice. No differences in yield were observed among herbicide treatments (Table 2.18).

No interactions between spacing and treatment were observed at Princeton 2012; however, interactions were observed between replication and spacing (Table 2.19). Yields were much lower in the fourth replication compared to the other three replications. As a result replication four was removed from analysis means to give a more accurate representation of the overall treatment. Treatment also had a significant effect on grain yield. Both spacing and treatment had an effect on grain yield at Lexington 2012.

All herbicide treatments resulted in greater yields than the untreated control at Princeton 2012 (Table 2.20). As expected, the untreated control produced the lowest yield compared to herbicide treatments. The PRE fb POST resulted in the greatest numerical yield (7.2 Mg ha^{-1}), which was similar to the yield for the PRE only and greater than the yields for POST only and EPOST + Residual. Since interactions occurred between row spacing and herbicide treatment for grain yield at Lexington 2012, row spacing and herbicide treatments were analyzed separately (Table 2.21). The PRE only treatment resulted in greater yields for wide rows compared to twin row spacings. Both PRE fb POST and POST only resulted in greatest yields for wide rows. For the EPOST + Residual, yields in twin rows and wide rows were similar, both of which were greater than narrow rows. It is possible that better herbicide coverage was achieved in wide and twin rows than in narrow rows at Lexington 2012, but no differences in visual weed control were detected among row widths. Yields at Lexington 2012, were extremely depressed (less than 4.0 Mg ha^{-1}) for all comparisons likely due to a drier growing season. Grain yields in 38-cm were numerically less than yields in wide and twin rows for most herbicide treatments. Either herbicide coverage was less, but we did not detect differences in weed densities with counts or visual ratings, or factors other than weed management affected yields in narrow rows.

Summary

In general, the results of these studies indicated that row spacing had little effect on weed densities, weed control ratings or grain yield, but control of some weed species was improved. It was hypothesized that row spacing would significantly reduce weed pressure late in the growing season. Certain broadleaf weeds at Lexington both years showed greater weed densities in corn grown in wide rows compared to narrow rows. Occasionally narrow or twin rows provided better visual control overall compared to wide rows.

Weed management treatments evaluated in this study showed an effect on weed densities, weed control ratings and grain yield. In circumstances where herbicide weed management treatments were used, weed densities in general were reduced compared to the untreated control. In some cases (eg. johnsongrass), the PRE only treatment resulted in similar weed densities to the untreated control. In general, PRE only resulted in the lowest weed control of any of the herbicide treatments. Conversely, PRE fb POST and EPOST + Residual treatments often provided better weed control compared to other treatments.

As was expected, grain yield was reduced by the untreated control compared to all other herbicide treatments in all environments. As long as a weed management method included a herbicide, grain yield was improved. Narrow and twin rows did not increase grain yield, contrary to other reports (Johnson and Hoverstad, 2002). However, interactions between row spacing and herbicide treatment occurred with higher yields in wide and twin rows for the PRE fb POST and POST only applications compared with narrow rows.

Based on the results of this study, producers may not observe a weed control advantage in corn when reducing row widths. Although in some cases, specific weed species were controlled better in narrow or twin rows compared to wide rows. Weed control can be difficult to assess when weeds are distributed randomly in the field. However, a herbicide treatment should always be used in corn to control weeds. PRE fb POST and EPOST + Residual herbicide treatments control weeds better than relying on a PRE only or POST only application. Herbicide treatments should also be used as an overall part of the production system in corn to reach maximum yield potential.

Table 2.1. Application treatments

Treatment Number	**Treatment Abbreviation §**	**Product Name**	**Product Rate**	**Chemical Name**	**Rate (kg ae or ai/ha)**
1	PRE only	Bicep II Magnum †	4.7 kg/ha (2 qt/A)	S-metolachlor +	1.5
				atrazine	1.8
2	PRE fb POST	Bicep II Magnum fb	4.7 kg/ha (2 qt/A)	S-metolachlor +	1.5
				atrazine	1.8
		Roundup Powermax ‡	1.54 kg/ha (22 oz/A)	glyphosate	0.84
3	POST only	Roundup Powermax	1.54 kg/ha (22 oz/A)	glyphosate	0.84
4	EPOST + Residual	Roundup Powermax +	1.54 kg/ha (22 oz/A)	glyphosate	0.84
		Bicep II Magnum	4.7 kg/ha (2 qt/A)	S-metolachlor +	1.5
				atrazine	1.8
5	Untreated Control	---	---	---	---

† Bicep II Magnum marketed by Syngenta (Greensboro, NC).
‡ Roundup Powermax marketed by Monsanto (St. Louis, MO).
§ Abbreviations: fb – followed by, PRE – preemergence, POST – postemergence, EPOST – early postemergence

Table 2.2 Planting, herbicide treatments, weed measurements, and harvest dates.

Practice	Herbicide Timing	Princeton 2011	Lexington 2011	Princeton 2012	Lexington 2012
Planting Dates	---	11 May	9 May	3 Apr	23 Apr
Herbicide Treatments					
PRE only	PRE	11 May	9 May	3 Apr	23 Apr
PRE fb POST	PRE	11 May	9 May	3 Apr	23 Apr
	POST	10 Jun	10 Jun	16 May	4 Jun
POST only	POST	10 Jun	10 Jun	16 May	4 June
EPOST + Residual	EPOST	6 Jun	3 Jun	11 May	23 May
Weed Density and Visual Ratings	---	22 Jun	20 Jun	6 Jun	20 Jun
Harvest Dates	---	16 Sep	28 Sep	29 Sep	4 Oct

Table 2.3. ANOVA for weed densities at Princeton in 2011 and 2012. †

Year	Source	DF	Johnsongrass	Smooth Pigweed	Ivyleaf Morningglory	Honeyvine Milkweed	Common Lambsquarters	Yellow Nutsedge
			----------------------	----------------------	---------------------- P value	----------------------	----------------------	----------------------
2011	Rep	3	0.1380	0.6864	0.3112	0.7717	---‡	---‡
	Spacing	2	0.7036	0.9817	0.2396	0.9730	---	---
	Rep*Spacing	6	0.0938	0.3040	0.5177	0.2553	---	---
	Trt	4	<.0001	0.0014	0.0135	0.6953	---	---
	Spacing*Trt	8	0.5400	1.0000	0.1964	0.6343	---	---
2012	Rep	3	0.1314	0.0366	0.0001	0.0090	0.1509	<.0001
	Spacing	2	0.6107	0.2437	0.3791	0.4585	0.5753	0.8404
	Rep*Spacing	6	0.8041	0.7796	0.4245	0.9313	0.7580	0.3305
	Trt	4	0.5645	<.0001	0.5358	0.5249	0.1357	0.9350
	Spacing*Trt	8	0.3704	0.9021	0.5728	0.0969	0.8020	0.5435

† Weed densities measured 22 June 2011 and 6 June 2012.

‡ Weeds not present at this location.

Table 2.4. Mean weed densities at Princeton pooled across row widths. †

Year	Treatment	Johnsongrass	Smooth Pigweed	Ivyleaf Morningglory	Honeyvine Milkweed	Common Lambsquarters	Yellow Nutsedge
		--Weed Density 10 m^{-2} --					
2011	PRE only	24	0	0	2	---‡	---‡
	PRE fb POST	7	0	0	6	---	---
	POST only	1	0	0	4	---	---
	EPOST + Residual	0	0	0	5	---	---
	Untreated	21	3	1	2	---	---
	LSD (0.05)	11	2	1	NS		
2012	PRE only	0	0	14	29	0	108
	PRE fb POST	0	0	23	18	0	106
	POST only	0	5	14	24	0	119
	EPOST + Residual	0	4	16	14	0	130
	Untreated	0	43	3	17	1	131
	LSD (0.05)	NS	20	NS	NS	NS	NS

† Weed densities measured 22 June 2011 and 6 June 2012.

‡ Weeds not present at this location.

Table 2.5. **ANOVA for weed densities at Lexington in 2011 and 2012. †**

Year	Source	DF	Smooth Pigweed	Ladysthumb	Common Lambsquarters	Marestail	Honeyvine Milkweed	Ivyleaf Morningglory	Yellow Nutsedge
			----------------	----------------	----------------	P value	----------------	----------------	----------------
2011	Rep	3	0.0164	0.0125	0.4662	0.0010	---‡	---‡	---‡
	Spacing	2	0.7969	0.0860	0.0598	0.3987	---	---	---
	Rep*Spacing	6	0.7392	0.1496	0.1934	0.8058	---	---	---
	Trt	4	<.0001	0.0424	0.0009	0.0238	---	---	---
	Spacing*Trt	8	0.8437	0.6577	0.2323	0.9179	---	---	---
2012	Rep	3	0.0866	0.5176	0.6156	---‡	0.4370	0.0460	0.2068
	Spacing	2	0.0169	0.2361	0.5963	---	0.2688	0.7397	0.2327
	Rep*Spacing	6	0.6787	0.5975	0.3900	---	0.8094	0.2494	0.7600
	Trt	4	<.0001	0.5227	0.0215	---	0.7196	0.2064	0.1596
	Spacing*Trt	8	0.0422	0.5926	0.6417	---	0.0933	0.1661	0.0268

† Weed densities measured 20 June 2011 and 20 June 2012.

‡ Weeds not present at this location.

Table 2.6. Mean weed densities at Lexington 2012, interactions for smooth pigweed and yellow nutsedge. †

Weed Species	Treatment	Row Spacing (cm)			
		Wide (76)	Narrow (38)	Twin	LSD (0.05)
		---------------- Weed Density 10 m^{-2} ---------------			
Smooth Pigweed	PRE only	14	1	2	NS
	PRE fb POST	0	0	0	NS
	POST only	1	0	1	NS
	EPOST + Residual	0	0	0	NS
	Untreated	108	15	49	89
	LSD (0.05)	64	14	28	
Yellow Nutsedge	PRE only	3	0	0	NS
	PRE fb POST	1	0	0	NS
	POST only	0	0	11	NS
	EPOST + Residual	0	0	0	NS
	Untreated	0	0	0	NS
	LSD (0.05)	NS	NS	9	

† Weed densities measured 20 June 2011 and 20 June 2012.

Table 2.7. Mean weed densities at Lexington pooled across row widths. †

Year	Treatment	Smooth Pigweed	Ladysthumb	Common Lamsquarters	Marestail	Honeyvine Milkweed	Ivyleaf Morningglory
		------------------	------------------	Weed Density 10 m^{-2}	------------------	------------------	------------------
2011	PRE only	28	3	20	0	---‡	---‡
	PRE fb POST	0	0	0	0	---	---
	POST only	0	13	6	2	---	---
	EPOST + Residual	0	0	1	0	---	---
	Untreated	121	6	27	3	---	---
	LSD (0.05)	48	10	19	3		
2012	PRE only	---§	0	1	---‡	8	6
	PRE fb POST	---	0	0	---	9	1
	POST only	---	2	0	---	11	5
	EPOST + Residual	---	0	0	---	5	0
	Untreated	---	0	5	---	10	1
	LSD (0.05)		NS	3		NS	NS

† Weed densities measured 20 June 2011 and 20 June 2012.
‡ Weeds not present at this location.
§ Herbicide treatment by row width interaction occurred. Data presented in Table 2.6

Table 2.8. ANOVA for visual weed ratings at Princeton in 2011 and 2012. †

Year	Source	DF	Johnsongrass	Yellow Nutsedge	Smooth Pigweed	Ivyleaf Morningglory	Honeyvine Milkweed	Overall	Preharvest
			-- P value ---						
2011	Rep	3	0.6345	---‡	0.9043	0.1696	0.8559	0.7150	0.1519
	Spacing	2	0.9080	---	0.1397	0.0754	0.4727	0.5442	0.7308
	Rep*Spacing	6	0.3512	---	0.9779	0.2622	0.4513	0.6993	0.5480
	Trt	3	<.0001	---	0.3001	0.8718	0.6712	<.0001	<.0001
	Spacing*Trt	6	0.2171	---	0.7231	0.6116	0.9618	0.3285	0.2199
2012	Rep	3	0.3207	0.0002	0.1920	0.3243	0.0313	0.0171	0.5914
	Spacing	2	1.0000	0.3808	0.8465	0.5648	0.9995	0.0149	0.4880
	Rep*Spacing	6	0.5167	0.3781	0.8387	0.3606	0.9086	0.4770	0.3773
	Trt	3	0.0480	0.0907	0.5009	0.0370	0.0158	0.0002	0.0001
	Spacing*Trt	6	1.0000	0.4591	0.8571	0.1320	0.9967	0.0716	0.7884

† Weed densities measured 22 June 2011 and 6 June 2012.

‡ Weeds not present at this location.

Table 2.9. Mean visual control ratings at Princeton pooled across herbicide treatment. †

Year	Spacing (cm)	Johnsongrass	Yellow Nutsedge	Smooth Pigweed	Ivyleaf Morningglory	Honeyvine Milkweed	Overall	Preharvest
		-------------------	-------------------	-------------------	% control	-------------------	-------------------	-------------------
2011	Wide (76)	85	---‡	96	95	87	88	89
	Narrow (38)	84	---	100	91	90	89	87
	Twin	81	---	99	84	86	85	85
	LSD (0.05)	NS		NS	NS	NS	NS	NS
2012	Wide (76)	99	93	98	93	86	91	78
	Narrow (38)	99	84	97	89	83	81	80
	Twin	99	86	97	87	83	86	78
	LSD (0.05)	NS	NS	NS	NS	NS	7	NS

† Weed densities measured 22 June 2011 and 6 June 2012.

‡ Weeds not present at this location.

Table 2.10. Mean visual control ratings at Princeton pooled across row widths. †

Year	Treatment	Johnsongrass	Yellow Nutsedge	Smooth Pigweed	Ivyleaf Morningglory	Honeyvine Milkweed	Overall	Preharvest
		------------------	------------------	------------------	% control	------------------	------------------	------------------
2011	PRE only	58	---‡	98	89	88	68	65
	PRE fb POST	93	---	100	92	87	98	98
	POST only	93	---	96	88	86	88	91
	EPOST + Residual	89	---	99	92	91	97	94
	LSD (0.05)	9		NS	NS	NS	8	8
2012	PRE only	95	79	96	78	68	81	66
	PRE fb POST	100	93	98	94	88	90	93
	POST only	100	92	97	91	88	92	70
	EPOST + Residual	100	88	99	95	93	91	80
	LSD (0.05)	4	NS	NS	9	11	8	13

† Weed densities measured 22 June 2011 and 6 June 2012.
‡ Weeds not present at this location.

Table 2.11. ANOVA for visual control ratings at Lexington in 2011 and 2012. †

Year	Source	DF	SP §	LQ	CL	MT	HM	MG	YN	Overall	Preharvest
			---------- P value ----------								
2011	Rep	3	0.1470	0.0961	0.4937	0.2087	---‡	---‡	---‡	0.0252	0.0071
	Spacing	2	0.0190	0.2951	0.0044	0.6969	---	---	---	0.5475	0.1053
	Rep*Spacing	6	0.7526	0.9405	0.5637	0.9615	---	---	---	0.7234	0.8707
	Trt	3	0.0007	0.0637	<.0001	0.0858	---	---	---	<.0001	<.0001
	Spacing*Trt	6	0.3537	0.7972	0.0597	0.5325	---	---	---	0.6383	0.7439
2012	Rep	3	0.1144	0.4079	0.1141	---‡	0.3932	0.4104	0.4079	0.6278	0.1425
	Spacing	2	0.6517	0.3811	0.2196	---	0.3032	0.3544	0.3811	0.5847	0.5084
	Rep*Spacing	6	0.8768	0.4456	0.1741	---	0.9498	0.3369	0.4456	0.8979	0.4003
	Trt	3	0.0003	0.4079	0.3639	---	0.0696	0.7708	0.4079	0.0020	0.0010
	Spacing*Trt	6	0.1616	0.4456	0.1604	---	0.5375	0.1481	0.4456	0.7907	0.8278

† Weed densities measured 20 June 2011 and 20 June 2012.

‡ Weeds not present at this location.

§ Abbreviations: SP=Smooth Pigweed, LT=Ladysthumb, LQ=Common Lambsquarters, MT=Marestail, HM=Honeyvine Milkweed, MG= Ivyleaf Morningglory, YN=Yellow Nutsedge.

Table 2.12. Mean visual control ratings at Lexington pooled across herbicide treatment. †

Year	Row Spacing (cm)	SP §	LT	LQ	MT	HM	MG	YN	Overall	Preharvest
		-------------------	-------------------	-------------------	-------------------	% control	-------------------	-------------------	-------------------	-------------------
2011	Wide (76)	88	88	85	96	---‡	---‡	---‡	83	71
	Narrow (38)	98	94	98	99	---	---	---	86	86
	Twin	96	91	91	98	---	---	---	84	81
	LSD (0.05)	8	NS	7	NS				NS	NS
2012	Wide (76)	93	100	97	---‡	93	93	100	91	86
	Narrow (38)	96	98	99	---	88	99	100	93	90
	Twin	95	100	99	---	84	93	99	88	88
	LSD (0.05)	NS	NS	NS		NS	NS	NS	NS	NS

† Weed densities measured 20 June 2011 and 20 June 2012.

‡ Weeds not present at this location.

§ Abbreviations: SP=Smooth Pigweed, LT=Ladysthumb, LQ=Common Lambsquarters, MT=Marestail, HM=Honeyvine Milkweed, MG=Ivyleaf Morningglory, YN=Yellow Nutsedge.

Table 2.13. Mean visual control ratings at Lexington pooled across row widths. †

Year	Treatment	SP §	LT	LQ	MT	HM	MG	YN	Overall	Preharvest
		-- % control								--
2011	PRE only	83	86	82	99	---‡	---‡	---‡	87	68
	PRE fb POST	99	94	98	100	---	---	---	94	92
	POST only	92	86	85	93	---	---	---	63	63
	EPOST + Residual	100	98	100	98	---	---	---	93	94
	LSD (0.05)	9	NS	8	NS				10	15
2012	PRE only	84	100	98	---‡	75	92	100	74	73
	PRE fb POST	99	100	99	---	92	92	100	96	94
	POST only	98	98	98	---	91	98	98	93	94
	EPOST + Residual	98	100	100	---	97	98	100	98	89
	LSD (0.0.5)	7	NS	NS		NS	NS	NS	13	8

† Weed densities measured 20 June 2011 and 20 June 2012.

‡ Weeds not present at this location.

§ Abbreviations: SP=Smooth Pigweed, LT=Ladysthumb, LQ=Common Lambsquarters, MT=Marestail, HM=Honeyvine Milkweed, MG=Ivyleaf Morningglory, YN=Yellow Nutsedge.

Table 2.14. ANOVA for IPAR taken at soil surface at V8 in Lexington 2011

Source	DF	P value
Rep	3	0.0090
Spacing	2	<.0001
Rep*Spacing	6	0.0001
Trt	4	0.1067
Spacing*Trt	8	0.5354

Table 2.15. IPAR taken at soil surface at V8 in Lexington, 2011

Row Spacing (cm)	IPAR, %
Wide (76)	29
Narrow (38)	36
Twin	45
LSD (0.05)	5

Table 2.16. ANOVA for grain yield at Princeton and Lexington, 2011

		Princeton	**Lexington**
Source	DF	P value	P value
Rep	3	<.0001	0.5348
Spacing	2	0.0073	0.2132
Rep*Spacing	6	0.2070	0.7136
Trt	4	<.0001	0.0388
Spacing*Trt	8	0.0747	0.8443

Table 2.17. Mean grain yield (Mg ha^{-1}) at Princeton 2011

Treatment	Row Spacing (cm)			
	Wide (76)	Narrow (38)	Twin	LSD
		Grain Yield, Mg ha^{-1}		
PRE only	12.5	11.4	10.4	1.4
PRE fb POST	14.3	12.8	14.6	1.5
POST only	14.7	12.3	14.6	1.6
EPOST + Residual	13.8	14.0	14.7	1.2
Untreated	11.4	10.0	10.1	1.9
LSD (0.10)	1.5	1.8	1.1	

Table 2.18. Mean grain yield (Mg ha^{-1}) at Lexington 2011 pooled across row widths.

Treatment	Grain Yield, Mg ha^{-1}
PRE only	15.0
PRE fb POST	15.4
POST only	14.5
EPOST + Residual	14.3
Untreated	12.8
LSD (0.10)	1.4

Table 2.19. ANOVA for grain yield at Princeton and Lexington, 2012

		Princeton	Lexington
Source	DF	P value	P value
Rep	3	<.0001	<.0001
Spacing	2	0.2170	<.0001
Rep*Spacing	6	0.0024	0.0169
Trt	4	<.0001	0.0007
Spacing*Trt	8	0.1130	0.0240

Table 2.20. Mean grain yield (Mg ha^{-1}) at Princeton 2012 pooled across row widths.

Treatment	Grain Yield, Mg ha^{-1}
PRE only	6.6
PRE fb POST	7.2
POST only	6.5
EPOST + Residual	6.0
Untreated	5.2
LSD (0.10)	0.6

Table 2.21. Mean grain yield (Mg ha^{-1}) at Lexington 2012.

Treatment	Row Spacing (cm)			
	Wide (76)	Narrow (38)	Twin	LSD
	Grain Yield, Mg ha^{-1}			
PRE only	3.7	3.1	2.5	1.0
PRE fb POST	3.9	2.3	2.8	0.8
POST only	3.7	2.3	2.5	0.8
EPOST + Residual	3.1	2.4	3.3	0.8
Untreated	2.1	2.0	2.1	0.9
LSD (0.10)	0.6	0.9	0.5	

Appendix

Figure A1. IPAR and Yield Correlation at Larue County 2012.

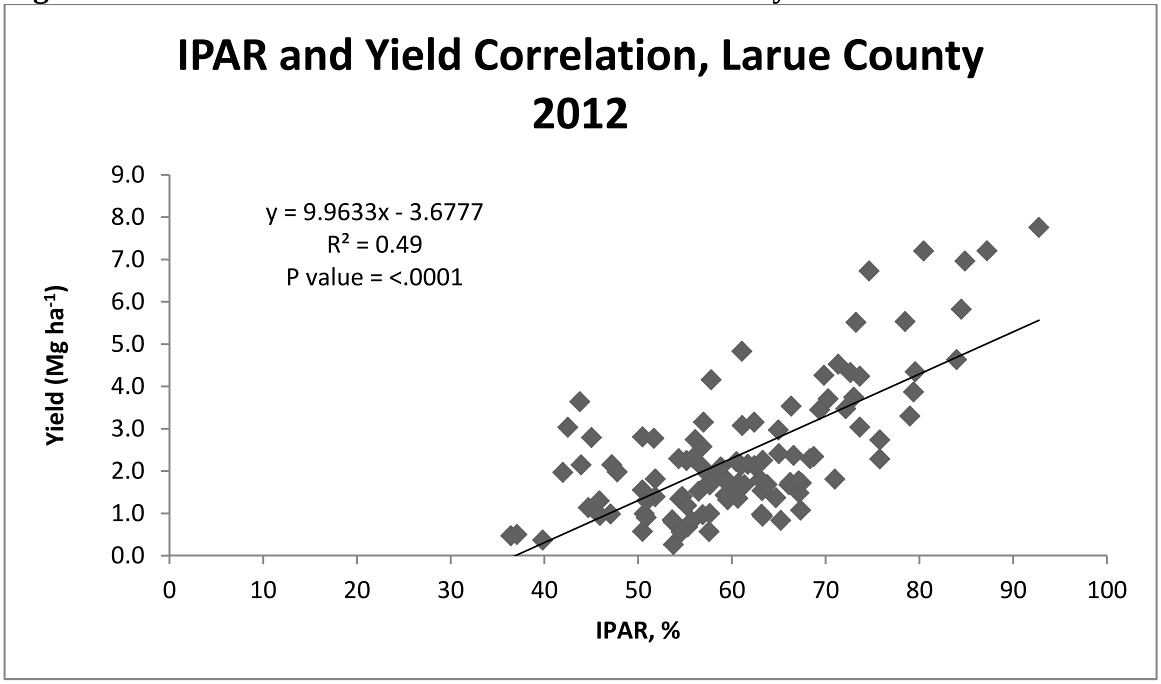


Figure A2. IPAR and Yield Correlation at Lexington 2012.

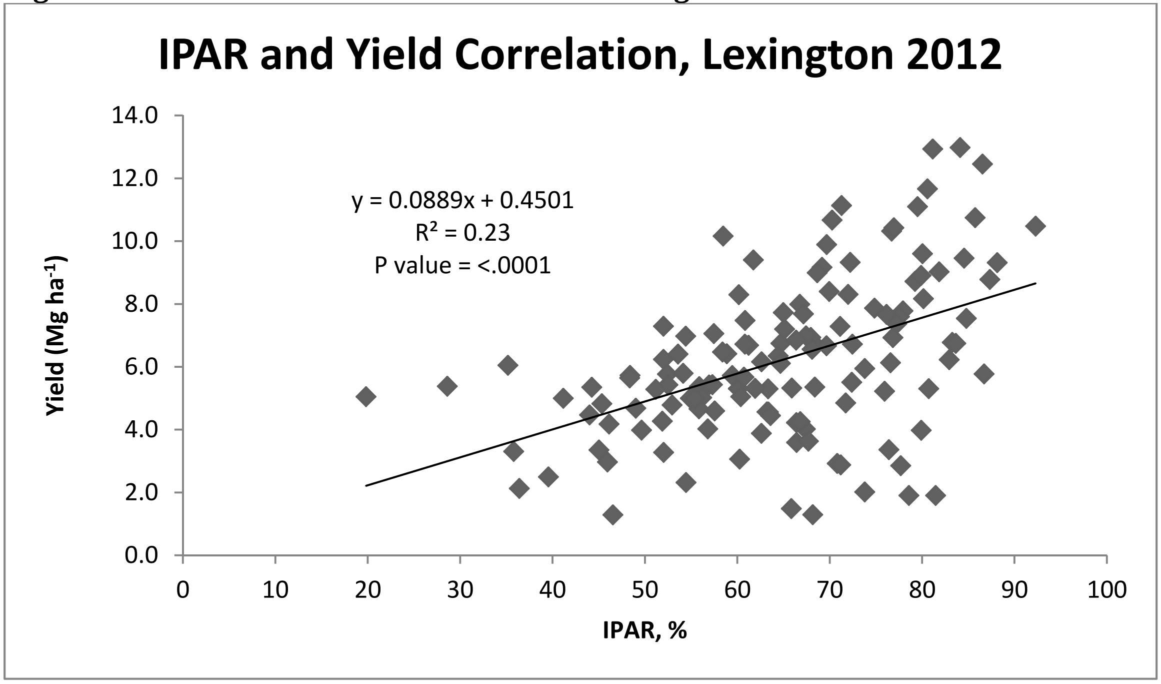


Figure A3. Mean grain yield (Mg ha^{-1}) Larue County 2011, A6533VT3

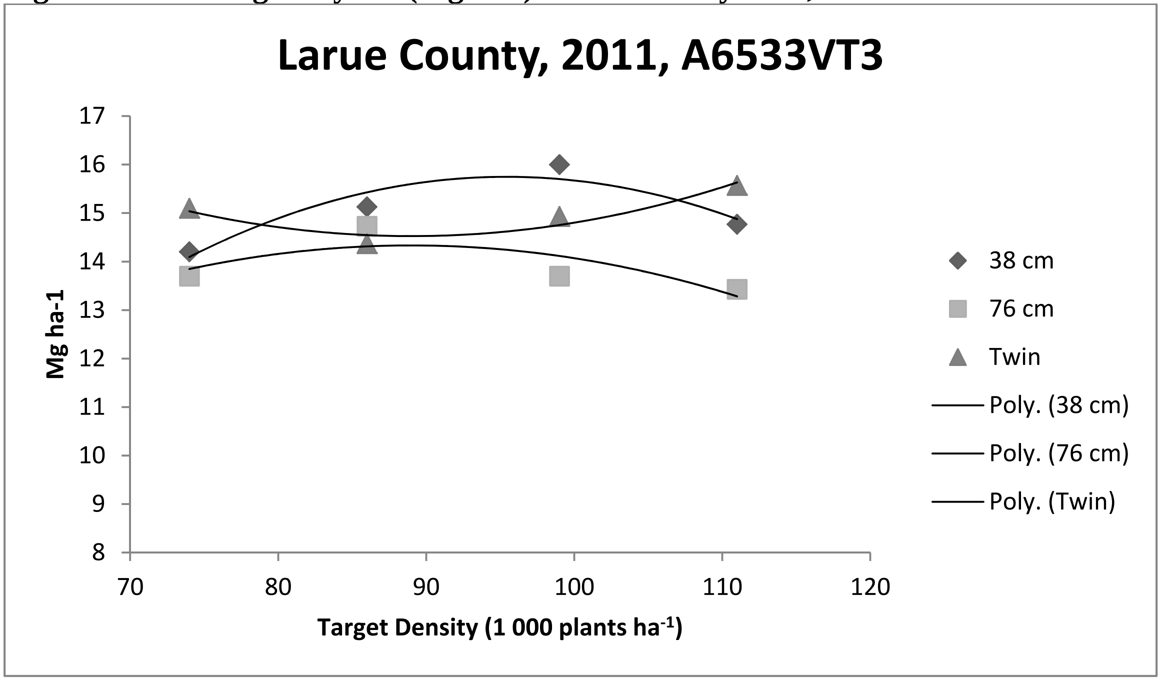


Figure A4. Mean grain yield (Mg ha^{-1}) Larue County 2011, DKC62-97

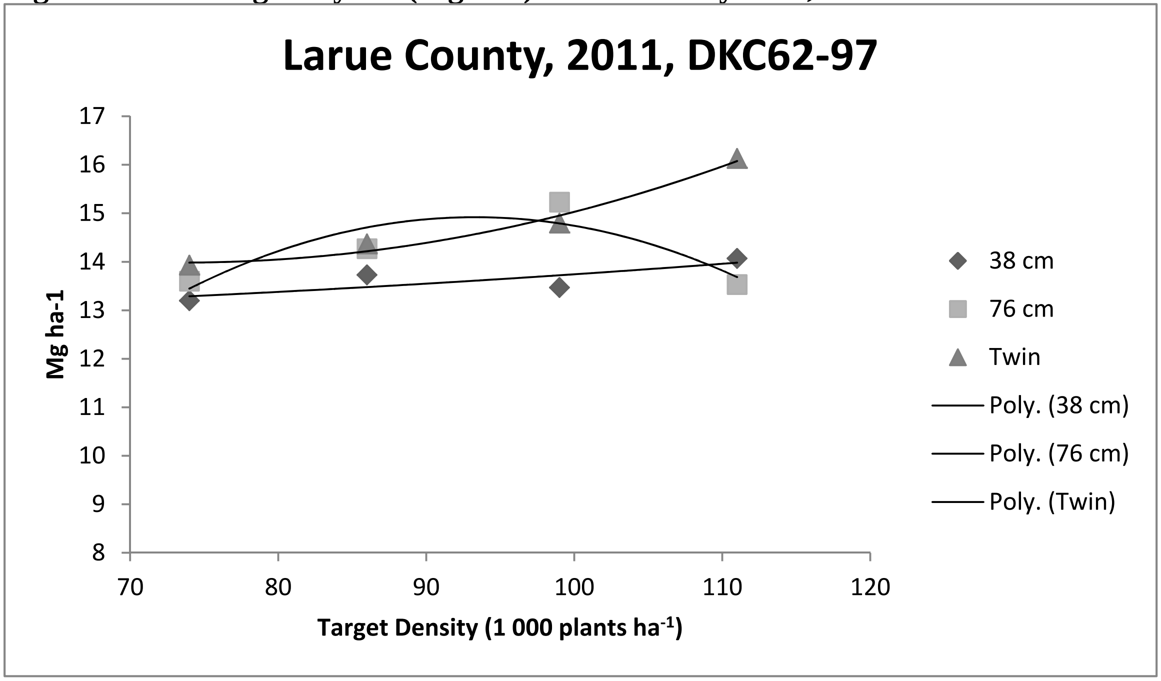


Figure A5. Mean grain yield (Mg ha^{-1}) Larue County 2011, P1480HR

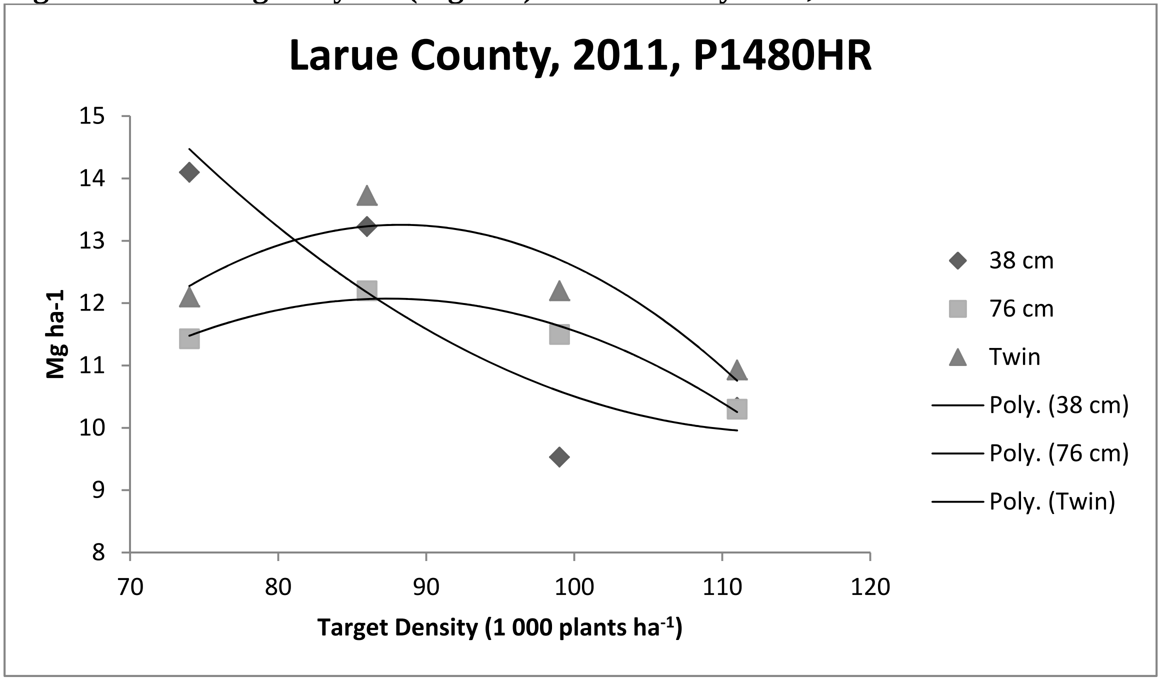


Figure A7. Mean grain yield (Mg ha^{-1}) Lexington 2011, A6533VT3

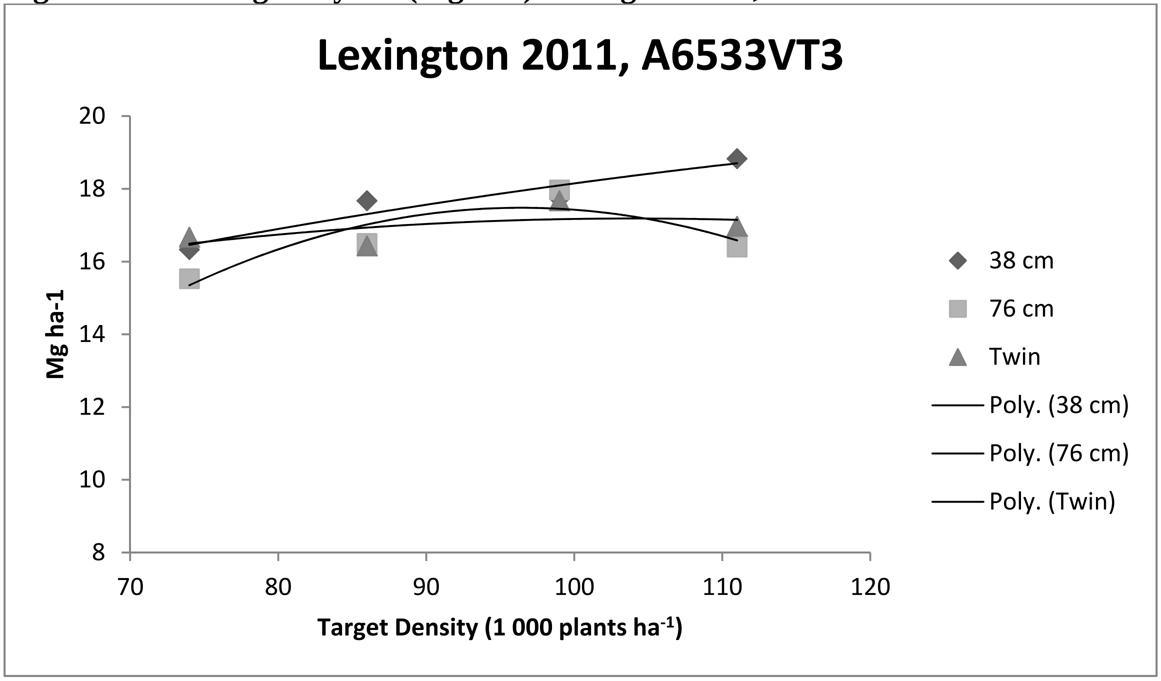
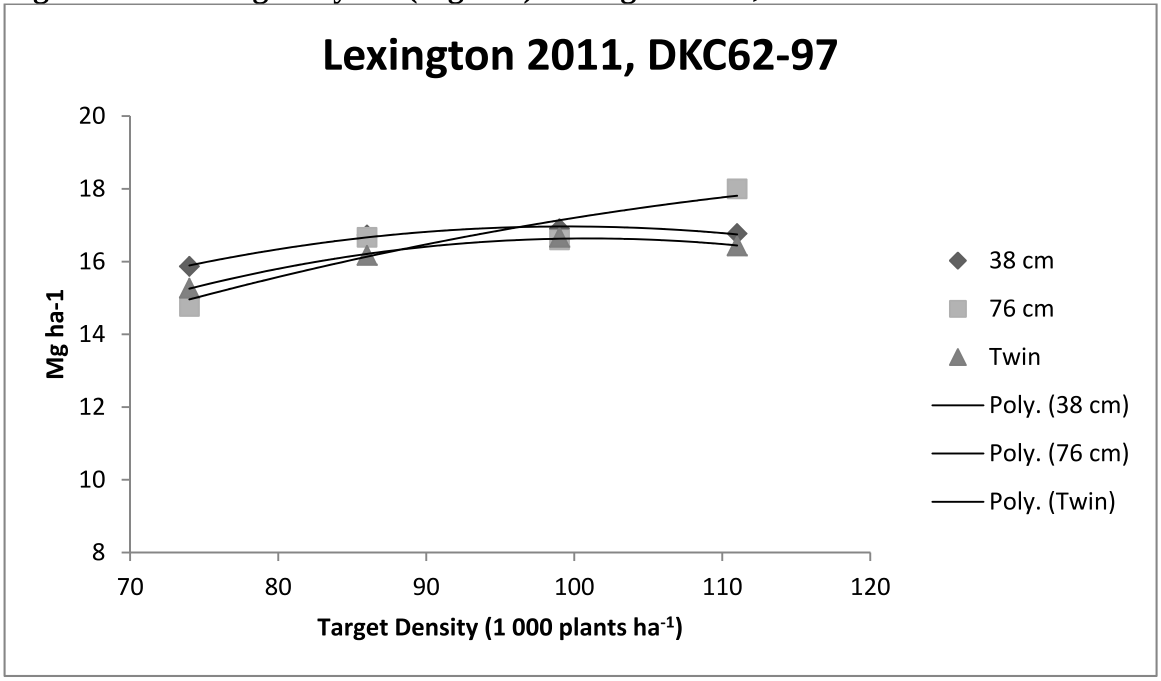


Figure A6. Mean grain yield (Mg ha^{-1}) Lexington 2011, DKC62-97



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Publications and Professional Presentations

North Central Weed Science Society Annual Meeting 2010
Presentation:
Sensitivity of Soybean and Tobacco to Aminopyralid in Soil
Grant A. Mackey *, Meghan E. Edwards, J.D. Green, W. W. Witt

ASA, CSSA, and SSSA Annual Meeting 2011
Presentation:
Row Width Effect on Corn Yield in Kentucky
Grant A. Mackey*, Chelsea McFarland and Chad Lee

North Central Weed Science Society Annual Meeting 2011
Presentation:
Impact of Row Spacing on Weed Management Strategies in Corn
Grant A. Mackey*, J.D. Green, Chad D. Lee, James R. Martin

ASA, CSSA, and SSSA Annual Meeting 2012
Presentation:
Row Width and Plant Population Effect on Corn Yield in Kentucky
Grant A. Mackey*, Chelsea McFarland and Chad Lee

Other Presentations

Franklin County Farm-City Field Day July 7, 2011
Speaker: Corn Production in Kentucky

UK College of Agriculture: Princeton, All Commodity Field Day July 21, 2011
Speaker: Narrow Row Corn Research

UK College of Agriculture: Princeton Corn & Soybean Field Day Aug. 9, 2012
Speaker: Narrow Row Corn Research

Bourbon County Field Day Sept. 18, 2012
Speaker: Discussion on corn research and crop outlook in 2012

Activities and Service

Congressional Visits Day: Washington D.C. March 28-29, 2012

Graduate student representative

Speaking to Senators and Representatives on behalf of ASA, CSSA, and SSSA for continual funding support of NSF

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Hardin County Farm Bureau Young Farmer committee
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