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Evaluation of Row Patterns for Mid-South Corn Production Systems

Tyson T. Poulsen

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Evaluation of row patterns for Mid-South corn production systems

By

Tyson T Poulsen

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Masters of Science
in Agronomy
in the Department of Plant and Soil Sciences

Mississippi State, Mississippi

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2018

Evaluation of row patterns for Mid-South corn production systems

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Row patterns affected irrigated corn productivity when grown in the Mid-South region of the United States. Narrow (76 cm) row spacing increased grain yield 8% when compared to traditional wide (96-102 cm) row spacing. Twin rows (20-25 cm spacing) in a wide (96-102 cm) row pattern, produced similar grain yield as a traditional wide single row. At a normal plant density of 79,040 ha⁻¹, traditional wide rows yielded 10.51 Mg ha⁻¹, twin wide rows yielded 10.34 Mg ha⁻¹, and the narrow rows yielded 11.33 Mg ha⁻¹. Growing corn at various plant densities did not affect corn grain yield response to various row patterns. As a comparison the traditional wide rows and twin rows were similar in their yield, and the narrow rows performed better. Corn grain yields for the traditional 96-102 cm wide single rows were 11.20 Mg ha⁻¹, wide 96-102 cm twin rows yielded 11.22 Mg ha⁻¹, and narrow 76 cm rows produced 12.07 Mg ha⁻¹. Row pattern had no effect on corn plant height, photosynthetically active radiation (PAR), leaf area index (LAI), SPAD, stalk diameter, and plant lodging in either study.

DEDICATION

I want to dedicate this to my ever beautiful, supportive wife for the many long hours and difficult times she spent raising our family during this phase of our lives. Shalie, I love you so very much. To my wonderful, patient, persistent boys and my beautiful daughter who have been so supportive through the years of learning and struggle. Thank you and I love you. To my parents and my in-laws thank you for your love and support.

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CHAPTER I

INTRODUCTION

Mississippi has experienced a dramatic increase in corn plantings during the last decade, where corn and soybean has displaced traditional cotton plantings. In The New York Times (2009) O. A. Cleveland, a Professor Emeritus of Agricultural Economics at Mississippi State University, is quoted saying, “Globalization has dethroned King Cotton without question, not only in Mississippi, but throughout the South and the United States.” Globalization is the process of global economic incorporation enabled by lower costs and lower barriers for movements in capital and goods. There has been a decline in the profitability of cotton production relative to corn and soybeans. As the price differential has increased, there has been a wholesale switch in row crop production in Mississippi. In 1996 there were 453 thousand hectares planted to cotton, 255 thousand hectares of corn, and 730 thousand hectares of soybeans. In 2012, there were 235 thousand hectares planted to cotton, 340 thousand hectares of corn, and 862 thousand hectares of soybean (NASS Mississippi Publication and Press Release, 2013).

As corn and soybean plantings increase through the Mid-South region of the United States, crop production practices need to be evaluated. Traditionally in Mississippi and the Mid-South region of the United States, row crop production practices have generally been based on cotton production. Cotton is typically grown in a wide row, 96 to 102 cm, and the rows are planted on top of raised beds. The row width or distance

between crop rows was originally determined by the width of horses used for drawing mechanical cultivators to control weeds prior to the 1940's and row width was generally 100 to 112 cm (Olson and Sander, 1988).

Weeds were a major production limitation in row crop production and mechanical cultivation between the rows allowed for the best control. Early corn production through the Corn Belt commonly planted corn in individual hills spaced 107 x 107 cm apart in rows at planting rates of two to four plants per hill or 17,600 to 35,100 plants ha⁻¹ (Bryan et al, 1940). This hill pattern facilitated cultivation in perpendicular directions to accomplish more complete weed control. Herbicide development greatly reduced the need for mechanical cultivation, and resulted in the development of narrower row width equipment to improve crop productivity.

As corn productivity has improved equipment advances have enabled narrower planting, cultivating, and harvesting. Thus, corn growers have increasingly adopted narrow row plantings (76 cm and 51 cm) (Stickler, 1964). Through the Mid-South, adoption of narrow rows has been limited. This has been due to cotton being the primary row crop grown in the South. Wide rows remain in cotton growing regions because cotton harvesting equipment is only suitable for wide rows. Spindle harvesters were designed to initially only work in rows that were 96-102 cm wide (Williford, 1992), thus, the lack of narrow row adoption is largely a result of cotton production practices.

Growers also commonly use raised beds for row crop production in the Mid-South region of the United States to alleviate soil saturation. The Mid-South region of the United States receives high amounts of rain fall each year, compared to Corn Belt region of the United States. In Mississippi, the yearly average rainfall is 147 cm. Raised beds

may improve water drainage following heavy rainfall during the spring. Combined with drainage, raised beds promote warmer soil temperatures earlier in the spring. Hatfield et al. (1998) concluded that the warmer soil temperatures associated with raised beds promotes rapid emergence and establishment of the crop where the crop is planted on top ridge. Raised beds may also facilitate earlier planting, which is well-documented to generally improve corn productivity by avoiding late-season heat and drought stress (Bruns, 2006).

Row spacing is important in affecting plant spacing geometry. Plants use light, nutrients, and water for plant growth and development. Reducing row width allows for more uniform, equal spacing of plants. Improving plant spacing increases productivity resulting from less plant competition for nutrients, light, and water (Olson and Sander, 1988).

Increases in corn yield will be important to meet the demands of the future. This research was conducted to evaluate different row patterns which may improve corn productivity in Mississippi and other southern states where traditional wide-rows are common.

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CHAPTER II

LITERATURE REVIEW

Effects of Row Spacing on Plant Growth and Productivity

Row spacing affects plant distribution within the field. Producers can alter the plant spacing geometry of the crop by manipulating planter row spacing (Sojka et al., 1988). Light, nutrients, and water are essential for plant growth and development. Hence, competition can be detrimental to the plants if any of the three are limited. Plants that are spaced equally from each other, have a comparable availability for these needed resources and should be more productive (Olson and Sander, 1988).

Research generally documents considerable crop productivity improvement in many locations over the last 40 years due to narrower rows providing lower interplant competition for nutrients, water, and solar radiation. Yao and Shaw (1964) found that when comparing 107, 81, and 53 cm rows in Iowa, yields were highest with narrow 53 cm rows and attributed this to greater energy capture in the narrow rows. Brown et al. (1970) noted that narrow 51 cm rows were more productive than wide 102 cm rows at comparable populations and indicated that there was greater interplant competition in the wide 102 cm rows. Stivers et al. (1971) showed narrow 76 cm rows were 4-5% more productive compared to wide 102 cm rows in Indiana. It was determined that at the narrower row spacing, plant spacing was more equidistant and this showed higher soil shading and reduced soil moisture loss due to evaporation. Cardwell (1982) reviewed and

summarized 50 years of Minnesota corn production and found that grain yield increased with decreasing row width. Although results varied over time and across experiments, overall grain yield increased 4% as a result of reducing row width from 107 cm to 90 cm. Porter et al. (1997) found ultra-narrow row width of 51 or 25 cm increased productivity 7% compared to 76 cm rows, regardless of plant population and attributed this to less interplant competition within the row. Similarly, Widdicome and Thelen (2002) found narrow 56 cm and 38 cm rows increased productivity 2 to 4% compared to 76 cm rows and determined that the inter-plant competition was reduced in narrow rows. The plants in the narrow rows increased utilization efficiency of nutrients, water, and solar radiation. Likewise, Shapiro and Wortmann (2006) reported 4% yield improvement for narrow 51 cm, compared to 76 cm rows in northeast Nebraska and attributed the improvement in narrowing row spacing to improved nutrient uptake.

Reducing row width and improving plant spacing uniformity is a way to improve yield and solar energy capture. In a comparison of conventional 107 cm row spacing and equidistant planting (the same difference between rows and between the plants within the row) Hoff and Mederski (1960) show that equidistant planting increased the mean yield of corn by $.3 \text{ Mg ha}^{-1}$. This increase is attributed to a more uniform distribution of solar radiation within the plant canopy. Yao and Shaw's (1964) evaluation of radiation interception showed as row spacing decreased the net radiation ratio also decreased. The net radiation ratio was developed by measuring radiation 1 meter above the canopy and 15 cm above the soil surface. Solar radiation is a finite resource and by reducing row width, plants have more uniform spacing within the row and have greater potential of intercepting and utilizing energy (Yao and Shaw, 1964). This improved distribution

creates a more efficient use of the energy by the upper and lower plant leaves improving growth development and yield capability (Karlen et al., 1987).

Narrow rows have resulted in more consistent maize yield increases throughout the northern Corn Belt due to greater light interception. Paszkiewicz (1997) reviewed 84 university and industry studies across the United States and found more response to narrow rows, (<76 cm) in regions north of 43° N latitude. In this area, the yield advantage of the narrower rows was 8% higher than the 76 cm rows. Solar radiation is lower in these northern regions during critical ear development and a closer planting arrangement captures more of the available light during this critical time (Butzen and Paszkiewicz, 2008).

Narrower row spacing does not always lead to improved yields. Increases in corn grain yields are not consistent across all locations or environments. In Iowa, Farnham (2001) found yields were greater in 76 cm rows compared to 38 cm rows when evaluating one hybrid and four plant populations (59,000, 69,000, 79,000, and 89,000 plants ha⁻¹). In a review of narrow row research throughout the United States, Lee (2006) shows some of the inconsistency of narrow row yield advantage. In Texas there was no yield change when comparing 102 cm rows to 51 cm rows and in South Carolina there was no yield change when comparing 96 cm rows to 48 cm rows. In the review, Lee (2006) concluded that south of approximately 43°N latitude narrow rows rarely increase corn yields. This trend is reasonable because southern regions of the United States have a longer growing season and more favorable temperatures for vegetative growth than the northern United States. Warmer temperatures, coupled with later maturity corn hybrids, encourages more leaf area development when corn is grown in Southern latitudes.

Therefore, Southern corn is less responsive to narrow rows because it will not affect plant-light relations as much as when grown further north.

A somewhat recent modification of narrow row spacing is the implementation of twin rows. Twin row production is an alternative row pattern that provides a way to improve plant distribution at similar plant populations as single rows (Karlen et al., 1987). Twin rows are two adjacent rows planted in close proximity typically based upon a traditional row width. Twin row production has emerged as an option to attain the benefits of narrow rows while reducing financial drawbacks of equipment change normally needed when changing from a traditional planting system to a narrower row system (Karlen et al., 1987). Twin row production requires minimal increase in capital investment for equipment by allowing producers to utilize much of the same equipment designed for conventional row production system (Bruns et al., 2012). This system may attempt to alternate or stagger adjacent plants across rows to further improve plant distribution.

Corn productivity has generally increased in twin row planting patterns, likely due to improved plant spacing. The improved plant spacing offered by twin row planting patterns often enhances yield (Ottman and Welch, 1989; Jeschke, 2010). Karlen et al. (1987) evaluated nine different hybrids in 76 cm row and 76 cm twin rows. Results indicate stem diameter and weight, and leaf area and weight were significantly greater for twin row plants than in the single rows. Those vegetative growth benefits resulted in significantly greater grain yield for twin row when averaged for the nine hybrids. The single row pattern yielded 11.0 Mg ha^{-1} and the twin row pattern yielded 11.3 Mg ha^{-1} .

This yield increase is attributed to improving plant distribution and decreasing plant competition for light, water and nutrients (Karlen et al., 1987).

Improved plant distribution attributed with a twin-row system does not always increase productivity or profitability. Bruns et al. (2012) showed no significant differences in overall grain yield when comparing single 102 cm rows and 102 cm twin rows for a single hybrid at four plant populations. Kratochvil and Taylor (2005) evaluated four hybrids that represented differences in relative maturity, ear flex, and leaf architecture grown at six plant populations and found no significant differences in grain yield between twin row plantings at 76 cm and single row plantings at 76 cm. (Sorensen et al., 2006; Buehring et al., 2003). Ottman and Welch (1989) suggest that row patterns influence total radiation intercepted by the crop as well as the distribution of solar radiation within the crop canopy, but found no significant differences in interception of solar radiation between twin and single rows and no significant difference in yield. Karlen et al. (1987) reported that greater than 98% of photosynthetically active radiation (PAR) was intercepted with a plant population of 86,000 plants ha⁻¹ regardless of row configuration. This occurred even though leaf area was greater for twin row plants than for single row plants. The limited amount of difference in interception of solar radiation between twin and single row plants may also be attributed to the corn plants' ability to modify its leaf architecture in response to the environment. In Argentina, Maddonni et al. (2002) showed that some hybrids can re-orient their leaves based on red and far red light ratios during early vegetative growth in response to neighboring plants. Increased interception of solar radiation during early growth may increase plant size; however, the plant cannot store photosynthate for use during pollination and grain fill. This may be one

reason why increased early season interception of solar radiation does not translate into increased yield for twin row production.

Limited research has been conducted in the Mid-south region of the United States to evaluate different row patterns for corn production. In Mississippi, Bruns and Abbas (2005) found no yield difference when comparing 102 cm rows to 76 cm rows. Overall, there has been little evaluation of the optimal row width and population for corn production in the Mid-South as it pertains to wide rows >76 cm compared to narrow 76 cm rows under irrigation.

Effect of Plant Density on Corn Productivity

Corn productivity has steadily increased over time, due in part to genetic improvements which have allowed the use of higher plant densities or populations. Higher plant densities increase the ability to produce greater grain yield on a unit area basis. Modern hybrids planted at higher populations produce approximately the same amount of grain per plant as was produced by older hybrids at lower populations (Duvick, 2005). Stickler and Laude (1960) reported that a plant population of 25,800 to 38,700 plants ha⁻¹ produced the greatest corn yield in Kansas. In an irrigated environment, Stickler (1964) found the highest yield for corn occurred when planted at populations of 49,400 to 59,300 plants ha⁻¹. Lutz et al. (1971) found similar results in Virginia where 49,000 to 62,000 plants ha⁻¹ produced the highest corn grain yield. In Minnesota, Porter et al. (1997) found the greatest yield at populations of 86,400 or 98,800 plants ha⁻¹. Likewise, in Michigan the greatest yield was found at a plant population of 90,000 plants ha⁻¹ (Widdicombe and Thelen, 2002). In New York, Cox (1996) reported that a 90,000 plants ha⁻¹ population improved dry matter and yield by 5% compared a

medium population of 67,500 plants ha⁻¹ and a 15% increase in comparison to 45,000 plants ha⁻¹.

Higher plant population improves the corn canopy's ability to capture energy. As plant population is increased, more leaves are present to capture light leading to greater leaf area index (LAI), which increases interception of photosynthetically active radiation (PAR) by the corn canopy (Tollenaar and Aguilera, 1992). Cox (1996) reported a 40% increase in LAI at the high population of 90,000 plants ha⁻¹ from mid-vegetative to early grain fill in comparison to the low population of 45,000 plants ha⁻¹. This LAI increase happens even though per plant biomass has been reported to decrease 40 to 60% at high plant population (Maddonni and Otegui, 2004). At higher plant populations, the corn canopy absorbs photosynthetically active radiation more efficiently, which during grain filling contributes to higher yields (Tollenaar and Aguilera, 1992).

Improved ability to capture energy from sunlight enhances energy production for the corn plant. Subedi et al. (2006) looked at a leafier hybrid, and a conventional hybrid at three different plant populations. For comparison chlorophyll was measured at two different growth stages, V12 and R1, with a SPAD chlorophyll meter. The SPAD chlorophyll meter measured the chlorophyll present in the plant leaves and the values given indicate the relative amount of chlorophyll present in the leaves. The higher the SPAD value the higher the chlorophyll content in that sample. The SPAD readings identified the leafier hybrid as always having a lower chlorophyll reading when compared to the conventional hybrid. In addition, the highest plant population for both hybrids exhibited the lowest SPAD chlorophyll value when compared to the other populations for each hybrid. Boomsma et al. (2009) found similar results in Indiana when comparing two

hybrids and three populations. The SPAD readings were always lower in the higher populations. At a higher plant population a decrease in chlorophyll concentration per plant is observed, but at the same time there is an increase of photosynthetically active radiation (PAR) capture by the canopy. Increased PAR values indicates that more light is captured by the canopy and less passes through to reach the ground. Subedi et al. (2006) recorded that at the higher population there was an increase in leaf area index (LAI), and PAR for both hybrids. Despite the differences in the leaf architecture of the leafier hybrid and the conventional hybrid, there was no significant difference between the hybrids in the percentage of PAR intercepted by the canopy. This indicates that each hybrid, regardless of leaf architecture, is efficient in absorbing PAR.

Increased population can potentially limit corn grain yield after the rate exceeds optimum density. The typical yield response curve is quadratic showing yield increase up to a certain population, and then no further gain. This type of response curve is common under higher yielding conditions.

Limiting factors are accentuated as plant population is increased. As plants are placed closer together the individual competition between plants is increased for light, nutrients, and water. This competition impacts yield due to the increased crowding and after an optimal population is surpassed yields tend to level off (Paszkievicz and Butzen, 2007). Breeding efforts have substantially improved corn yield potential over time by improving corn yield response to increased plant density (Cox. 1996). For example, hybrids have improved stress tolerance associated with crowding with increased resistance to root lodging and stalk lodging. In conjunction hybrids have improved tolerance to environmental stress, such as heat and drought (Duvick, 2005).

Increasing plant population to maximize yield may create other corn production issues. When plant populations are increased the potential for lodging is increased. There are two types of lodging of corn plants, stalk lodging and root lodging. Stalk lodging is defined as the stalk breaks or collapses below the ear. Root lodging occurs when the entire plant falls over because the roots cannot support the weight. Both of these types of lodging can limit the ability of a combine to gather ears and impede harvest progress. Harvest loss has the potential to nullify yield improvement associated with high plant population (Olson and Sander, 1988). Pedersen and Lauer (2002) found high plant population increased the lodging potential, particularly stalk lodging. Corn plants were 13% taller with plant populations of 90,000 or 120,000 plants ha⁻¹ when compared to 30,000 plant ha⁻¹, which increases lodging potential of corn grown at higher plant populations due to the extra height and stress on the stalk when exposed to adverse environmental conditions (Maddonni et al., 2001).

Effect of Genetics on Plant Productivity

In addition to improved management practices, the dramatic increase in corn yield over history can be attributed to improved plant breeding (Cardwell, 1982; Duvick, 2005). Improved plant breeding over time has selected for superior tolerances to environmental stresses (Paszkiwicz and Butzen, 2007). As hybrids continue to develop, they exhibit improved resistance to root and stalk lodging and, better tolerance to abiotic and biotic stresses (Duvick, 2005). Plant breeders have continued to develop hybrids that are more tolerant to higher plant density, potentially increasing productivity and yield stability (Duvick and Cassman, 1999; Tollenaar and Lee, 2002).

Hybrid development necessitates the importance of evaluating performance in different crop management systems as cultural systems evolve. Research has shown the effect hybrids and row spacing to be inconsistent on productivity. Karlen et al. (1987) showed early maturity hybrids were more productive for twin row production in South Carolina. Widdicombe and Thelen (2002) reported no difference in six hybrids, with differing maturity used across multiple row spacings. Farnham (2001) evaluated six hybrids with varying maturity and found that the later maturing hybrids tended to perform better than narrower row spacing while the earlier maturing hybrids did better in wider row systems. One early maturing hybrid yielded significantly (7%) better at 76 cm spacing than it did at 38 cm spacing when averaged across six locations and three years. Similarly, one late maturing hybrid yielded significantly (2%) better at narrower row spacing when averaged across locations and years.

In consideration of these effects on corn production, it was necessary to evaluate different row spacings for corn production in the Mid-South.

Objectives

The first objective of this research was to determine if row spacing significantly influenced corn productivity. Specifically, corn was grown with three different row patterns (conventional wide rows of 96-102 cm, wide twin rows (rows 20-25 cm apart on 96-102 cm centers), and “narrow” single 76 cm rows) under irrigated culture at an optimal plant population to determine the effect of row spacing on yield in the Mid-South. Evaluation of plant morphology responses to row pattern happened by measuring plant height, photosynthetically active radiation (PAR), leaf area index (LAI), SPAD chlorophyll, stalk diameter, and lodging. The second objective was to evaluate how plant density affected corn response to row patterns. Specific measurements that aided the evaluating of plant densities effect on the corn response within the row pattern included yield, plant height, PAR, LAI, SPAD chlorophyll, stalk diameter, and lodging.

Hypotheses

- Narrow rows and twin rows will likely increase overall corn grain yield due to improved plant spacing and a reduction in competition. PAR and LAI should also be increased during reproductive growth, as well as early season interception of solar radiation. Stalk diameter will likely be increased and lodging may be reduced.
- As plant densities are increased, the grain yield will increase regardless of row patterns. Corn grain productivity may improve in narrow and twin row patterns, compared to traditional 96-102cm row pattern, due to improved plant spacing.

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CHAPTER III

MATERIALS AND METHODS

Field Descriptions

Field research studies were conducted from 2010 thru 2012 at the R.R. Foil Plant Science Research Center at Mississippi State University (Starkville, Mississippi 33.454844, -88.7886639) and at the Delta Research and Extension Center at Stoneville, Mississippi (33.424005, -90.9151014). Soil textures in the Starkville fields included Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts), Marietta fine sandy loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts), Mantachie loam (fine-loamy, siliceous, active, acid, thermic Fluventic Endoaquepts), and Savannah fine sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Fragiudults). The soils for the Stoneville location included Beulah very fine sandy loam (coarse-loamy, mixed, active, thermic Typic Dystrudepts) and Dowling soils (very-fine, smectitic, nonacid, thermic Vertic Endoaquepts). These locations represent areas where corn is grown in Mississippi.

Row Spacing Study

A field study was conducted from 2010-2012 to evaluate the effect of row pattern on corn productivity. Plots were arranged in randomized complete blocks with split-plot design using four replicates. Plot dimensions were four rows wide by 12.2 m long. Three

row spacing systems (narrow, 76 cm row spacing; traditional wide, 96-102 cm row spacing of single rows; and twin rows, spaced 20-25 cm apart in a wide 96-102 cm row pattern) on a single bed comprised main plots and four contrasting hybrids (Terral REV28HR29, DEKALB DKC68-05, Pioneer 31G96, and Pioneer P1184HR) were included as sub plots. Hybrids evaluated were selected based upon superior grain yield performance in University Hybrid Trials. Terral REV28HR29 is a medium tall, late maturing (117-119 day), semi-flex ear hybrid that historically responds well to increased population. DEKALB DKC68-05 is a shorter hybrid with a thinner canopy that is late maturing (118 day). It is a, semi-flex ear hybrid that has shown some positive response to increasing populations. Pioneer 31G96 is a tall, late maturing (116 day), flex ear hybrid with a strong ability to compensate for varying plant populations by changing ear size. Pioneer P1148HR is a tall, early maturing (111 day), fixed ear hybrid that has a relatively strong yield correlation to increasing plant populations. Pioneer 31G96 was discontinued in 2012 and thus replaced that year with Pioneer 1615HR which represented similar traits. Furthermore, Pioneer P1184HR had limited availability and was replaced with Pioneer P1184YHR in 2012. This hybrid had an additional biotechnology trait of YieldGard corn borer gene and was released as a genetic isolate. All plots were over-seeded and hand thinned to a plant density of 79,040 plants ha⁻¹ at the three leaf corn growth stage (V3).

Row Spacing plus Population Study

A second study at the same locations was conducted in 2011 and 2012 to evaluate the potential effects of plant population on corn productivity when grown in various row patterns. Plots were arranged in randomized complete blocks with split-plot design using

four replicates. Plot dimensions were four rows wide by 12.2 m long. Main plot consisted of row spacing (narrow, 76 cm row spacing; traditional wide, 96-102 cm row spacing of single rows; and twin rows spaced 20-25 cm apart in a wide 96-102 cm row pattern) subplots consisted of each population (61,750, 74,100, 86,450, and 98,800 plants ha⁻¹) of the individual hybrid (Pioneer 31G96 (replaced by Pioneer 1615HR in 2012). The hybrids used were Pioneer 31G96, a tall, late maturing (116 day), flex ear hybrid with strong ability to compensate for varying plant populations by changing ear size. Pioneer P1184HR is a tall, early maturing (111 day), fixed ear hybrid that has a relatively strong yield correlation to increasing plant populations. However, Pioneer 31G96 was discontinued in 2012 and thus replaced with Pioneer 1615HR which represented similar traits. Furthermore, Pioneer P1184HR was replaced with Pioneer P1184YHR in 2012, with an additional biotechnology trait of YieldGard corn borer gene was released as a genetic isolate. Plots were over seeded and hand-thinned at the three leaf corn growth stage (V3).

Plot Preparation and Planting

Site preparation and crop and soil management throughout each year was performed according to Mississippi State University Extension recommendations. Fertility requirements were determined from University recommendations derived from soil samples collected in fields at each location. Primary tillage followed by a bedding operation were performed each fall to prepare raised beds common in the Mid-South region of the United States for row crop production. A herbicide application of Gramoxone was applied in the spring prior to any field work, to kill winter weed growth. Also in the spring, raised beds were reformed that settled and where inadequate to plant

on if needed. Just prior to planting, the top portion of the beds were leveled and firmed with a “do all”. This tillage implement levels the top portion of the raised bed to facilitate subsequent planter performance.

Different planters were used to implement the three row-pattern treatments. At the Stoneville location the wide single rows were planted with a John Deere MaxEmerge 7100 (John Deere Co., Moline, IL) with rows spaced 102 cm apart. The twin rows were planted with a Monosem Twin-Plus (Monosem, Inc., Edwardsville, KS) with rows spaced 102 cm rows apart with the twin rows spaced 20 cm. The narrow rows were planted with a Monosem NG Plus hydraulic drive with single rows spaced 76 cm apart. Similar planters were generally used at the MSU R.R. Foil Plant Science Research Center. However, the wide-row patterns system planted on were based upon 96 cm rows, instead of 102 cm. The twin-row Monosem NG hydraulic drive planter used at Starkville had twin rows spaced 25 cm apart from the center of the row.

Field plots were planted in Stoneville on April 6, 2010, April 7 & 8, 2011, and April 10 & 12, 2012. The Starkville location was planted on April 15, 2010, May 12, 2011 and April 24, 2012. At each location, the plots were seeded at 5 cm depth and planter down pressure was similarly adjusted to optimize performance relative to field conditions. Studies were replanted in 2011 at Starkville because of stand failure in the initial planting.

The corn was grown using irrigated culture at both study locations. Supplemental water was applied when soil moisture became limited using furrow irrigation. Weeds were controlled using atrazine and metolachlor tank-mixed with glyphosate and applied when the corn was V3 to V5 growth stage.

In-Season Data Collection

Photosynthetically Active Radiation (PAR), Leaf Area Index (LAI), and plant height were taken multiple times during the season. PAR is the measurement of the amount of solar radiation in the wavelength range from 400 to 700 nanometers available for photosynthesis. LAI is the area of leaf exposed to incoming solar radiation in relation to unit of area on the soil surface.

Measurements of PAR, LAI, and plant height were taken at V8 (eight leaves fully emerged with leaf collar present), V11 (eleven leaves fully emerged with leaf collar present) and tasseling (VT) growth stages to track development of the canopy within each treatment. Multiple growth stages were chosen for the purpose of documenting potential trends or interactions between treatments. The critical growth stage for these measurements to occur is tasseling (VT). At the tassel stage, plants have reached full height, vegetative development is essentially complete and the plant is progressing to the reproductive phases of growth. Measuring PAR and LAI at this stage should give insight regarding light interception throughout reproductive development. PAR and LAI measurements were collected using an AccuPAR LP-80 Ceptometer (Decagon Devices, Pullman, WA).

In 2010, PAR, LAI, and plant height were also measured at the V10 (ten leaves fully emerged with leaf collar present) and VT growth stages. In 2011 and 2012, these measurements were taken at V8, V11, and VT only. Plant height measurements were taken at the upper most leaf collar where it connected to the stalk. The growth stage measurements changed in 2011 to incorporate an earlier growth stage and the

developmental stage timing and measurement timing did not correlate. For purpose of consistency 2012 measurements were conducted at the same growth stages as in 2011.

During the VT growth stage measurements, chlorophyll content was measured using a SPAD chlorophyll meter (Konica Minolta, Hong Kong) for each plot. The SPAD meter uses emitted light to calculate the SPAD value, which corresponds to the amount of chlorophyll present in the leaf. SPAD readings were collected from the midpoint of the leaf, and around the midpoint of the midrib and margin of the ear leaves of 10 plants per plot to compute a mean (Chapman and Barreto, 1997).

After physiological maturity, and prior to harvest, the basal stalk diameter was measured along with individual counts for stalk and root lodging. Basal stalk diameter was measured on the first internode above the brace roots, at the widest point in the center of the internode, on 10 plants in the middle of the center two rows in each plot with electronic caliper. Root and stalk lodging were also measured as a percentage of total plants. Lodging data were collected from the two center plot rows. Plants were recorded as root lodged if the stalk was $>45^\circ$ from vertical, and stalk lodged if the stalk was bent or broken below the ear.

Plot Harvest

Grain yield was obtained by harvesting the two center rows of each four row plot, in both locations. The Stoneville location was harvested with a two-row Model K2 Gleaner combine adapted for small plot research harvest with on-board weighing system. The Starkville locations were harvested with a Massey Ferguson 8XP (Massey Ferguson, Agco Company, Duluth, GA) two-row plot combine and weighed. Grain subsamples were collected for all locations and plots, and used to determine moisture and test weight.

Moisture and test weight were measured using a DICKEY-John GAC2100 AGRI (DICKEY-John Corporation, Auburn, IL). Grain yield was adjusted to standard moisture of 155 g kg⁻¹ (15.5 %). Grain harvest was on August 30, 2010, September 1, 2011, and August 28, 2012 in Stoneville and on August 25, 2010, September 13, 2011, and September 10, 2012 in Starkville.

Statistical Analysis

Data were statistically analyzed using SAS 9.3 (SAS Institute Inc., Cary, NC). The PROC GLIMMIX procedure was performed for all analyses and to separate means. Effects were considered significant when $P \leq 0.05$. The statistical analyses performed for this study showed no interactions between years, locations, and treatments. Therefore, all of the data was pooled across years and locations for analyses.

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CHAPTER IV
RESULTS AND DISCUSSION

Row Pattern Effects on Corn Productivity

Analysis of variance were performed and showed there was no interaction between locations, years, and treatments. Thus, data was combined across locations and years for all subsequent analyses. Further analysis indicated row pattern affected corn grain yield. Narrow (76 cm) row spacing significantly increased corn grain yield (7.8%) when compared to the traditional wide (96-102 cm) row spacing. Corn grown in twin rows (20-25 cm spacing) in a wide (96-102 cm) row pattern, produced similar grain yield as a traditional wide (96-102 cm) single row. Corn grown in the traditional wide rows yielded 10.51 Mg ha⁻¹, the twin rows yielded 10.34 Mg ha⁻¹, and the narrow rows yielded 11.33 Mg ha⁻¹ (Figure 1.1).

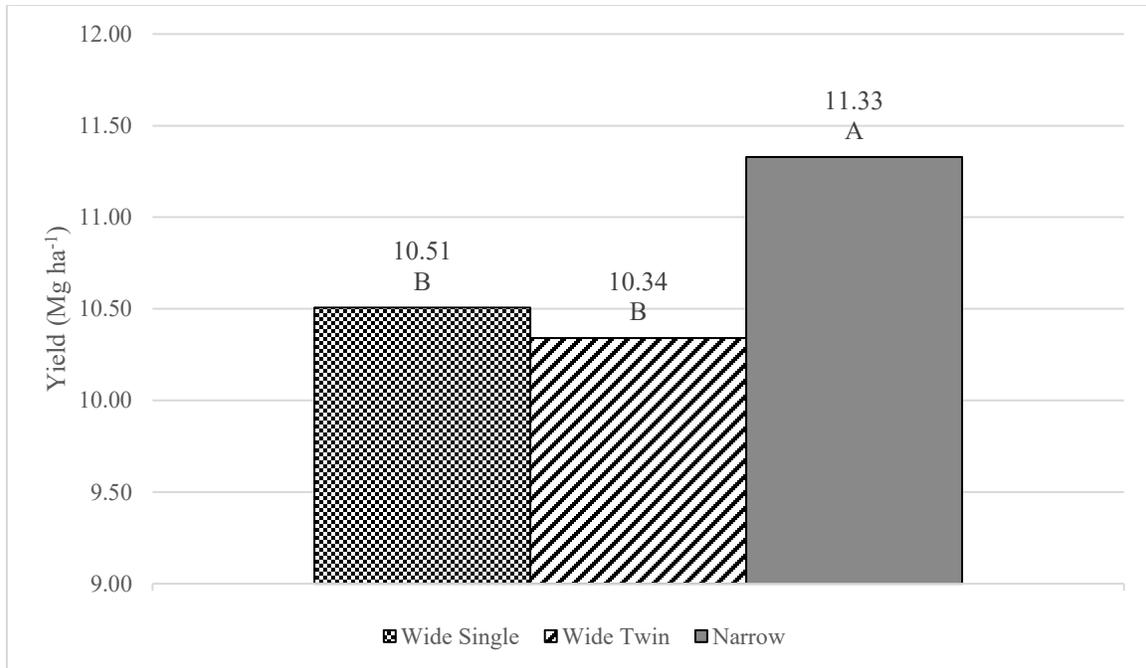


Figure 1.1 Corn yield response to wide-single row, wide twin-row, and narrow row patterns grown in irrigated culture during 2010 and 2011. Values represented with the same letter are not significantly different ($P < 0.05$).

This yield increase in the narrow row system is similar to Strivers et al. (1971) who found 76 cm rows performed 4-5% better than the wide 102 cm rows. Narrow row spacing increases grain yield likely due to improved plant spacing geometry which reduces competition by neighboring plants. Traditional wide single-row and the twin row patterns produced grain yield results similar to Bruns et al. (2012). Bruns et al. (2012) found no difference in grain yield for corn grown on single 102 cm rows and twin rows, spaced 15 to 25 cm apart, on 102 cm row spacing.

Row pattern did not effect PAR, LAI, and plant height measured at VT. Row pattern PAR values ranged from 99.44 to 99.58% of light intercepted and LAI ranged from 4.08 to 4.19 m^2m^{-2} . LAI values above $> 4 m^2m^{-2}$ for corn at silking are considered to

be above the critical value for light interception in corn production (Maddonni and Otegui, 1996). Light interception is a non-limiting factor for the row pattern treatments.

Other unmeasured factors may have limited potential improvements associated with twin row pattern, compared to a traditional wide row pattern. An example of this would be off-center row alignment on the bed, placing one of the twin rows close to the edge of the raised bed. This may restrict germination, successful emergence and seedling establishment, and subsequent root development. Heavy rainfall can also erode the side of the beds, further inhibiting normal plant development. These are a few things to consider for future studies including twin row patterns.

The hybrids used in this study were selected to evaluate whether different hybrid traits or characteristics would affect corn productivity response to various row patterns. Average yields from highest to lowest were: Dekalb DKC68-05 (11.36 Mg ha⁻¹), followed by Pioneer 31G96 (10.75 Mg ha⁻¹), and Pioneer P1184HR (10.72 Mg ha⁻¹), and

Terral REV28HR29 (10.07 Mg ha⁻¹).

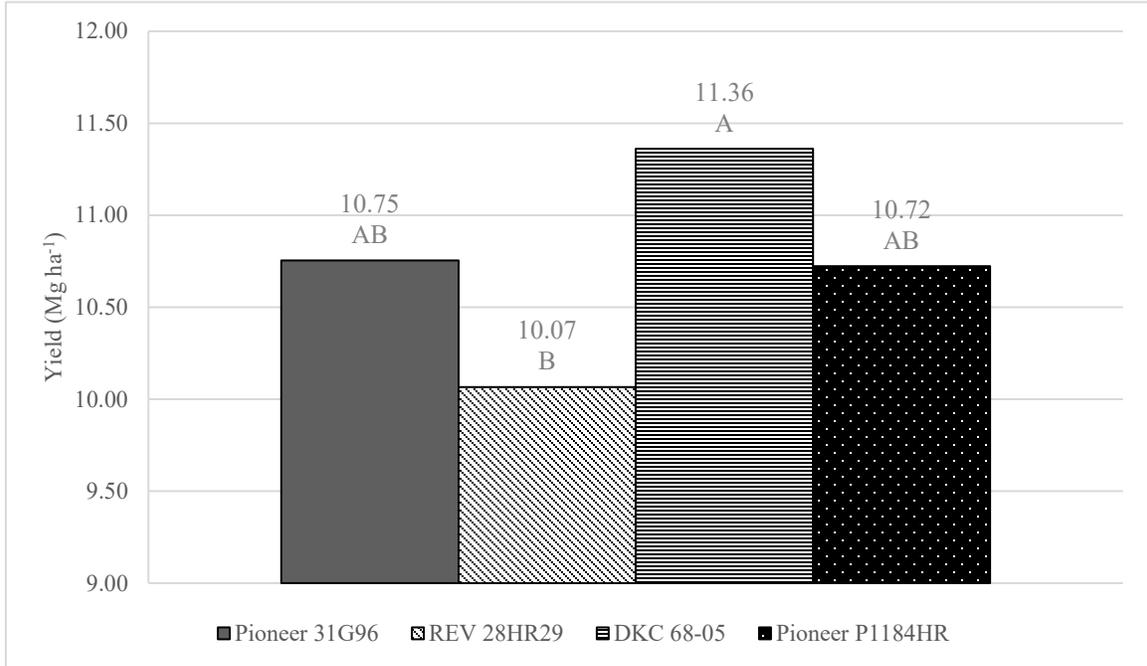


Figure 1.2 Hybrid yield response at 79,040 plants ha⁻¹ averaged across years and locations. Values represented with the same letter are not significantly different (P<0.05)

The only differences among hybrid grain yields were found between Dekalb DKC68-05 and Terral REV28HR29. Each hybrid regardless of ear type, flex, semi-flex, and fixed, yielded well when grown at the 79,040 plants ha⁻¹ plant density.

Measurements of plant height, PAR, and LAI found differences only in plant height for the hybrids. Plant height showed differences between the tallest hybrids (Pioneer 31G96, 244.87 cm; Terral REV28HR29, 244.14 cm), and the shortest (Dekalb DKC68-05, 222.38 cm). The PAR and LAI values revealed that the individual hybrids were not different in regards to light interception. LAI values ranged from 3.76 to 4.31 showing leaf canopy was acceptable for light interception.

Plant parameter measurements of SPAD chlorophyll, stalk diameter, and plant lodging vary among the hybrids represented in the row pattern study. The SPAD chlorophyll meter data revealed that all four hybrids exhibited similar chlorophyll amounts across the study. From the measurements taken and values shown for LAI to be within a normal range, it can be concluded that plant growth was not limited by light interception. Stalk diameter for Pioneer 31G96 and Terral REV28HR29 were larger at 23.1 mm than Pioneer 1184HR and Dekalb DKC68-05 21.9 mm. The Pioneer 31G96 and Terral REV28HR29 are taller, late maturing hybrids. Lodging counts were collected from each treatment within the study. Hybrids did not differ in stalk lodging, but there was a significant difference in root lodging between hybrids. Pioneer 31G96 had more root lodging averaging 4.75 (5.4%) lodged plants per plot, while the other hybrids averaged less than 1% root lodging. Pioneer 31G96 root lodging was observed in all row pattern treatments and has not affected by any one row pattern. The hybrids chosen for this study proved to be very well suited for the environment where they were grown.

In conclusion, narrow rows improved corn grain yield 7.8% compared to the traditional wide-single row pattern. However, row pattern had no effect on plant height, PAR, LAI, SPAD, stalk diameter, and plant lodging. A twin row planting pattern failed to produce higher grain yield than the traditional single row pattern. Failure of the twin row pattern to produce higher yield might be attributed to plant developmental issues associated with poor or off-center alignment of rows grown on raised beds. Twin-row planting patterns may lead to uneven corn seedling emergence, increased compaction of root zone near the edge of the bed, and more soil erosion from raised beds, compared to traditional single-row patterns.

Evaluation of Plant Population Effects on Row Patterns

The second study was established to evaluate whether plant population affected corn response to various row patterns. There was no significant plant population by row pattern interaction for corn grain yield. Since there was no interaction, grain yield data were pooled and averaged over all populations for each row pattern.

Corn productivity was influenced by various row pattern treatments evaluated in this study. Narrow 76 cm row pattern increased grain yield 7.8% compared to the traditional wide single 96-102 cm row pattern. Twin rows 20-25 cm spaced in a wide 96-102 cm row pattern were no more productive than the traditional wide single row. Corn grain yields for the traditional 96-102 cm wide single rows was 11.20 Mg ha⁻¹, wide 96-102 cm twin rows yielded 11.22 Mg ha⁻¹, and narrow 76 cm rows produced 12.07 Mg ha⁻¹. (Figure 1.3).

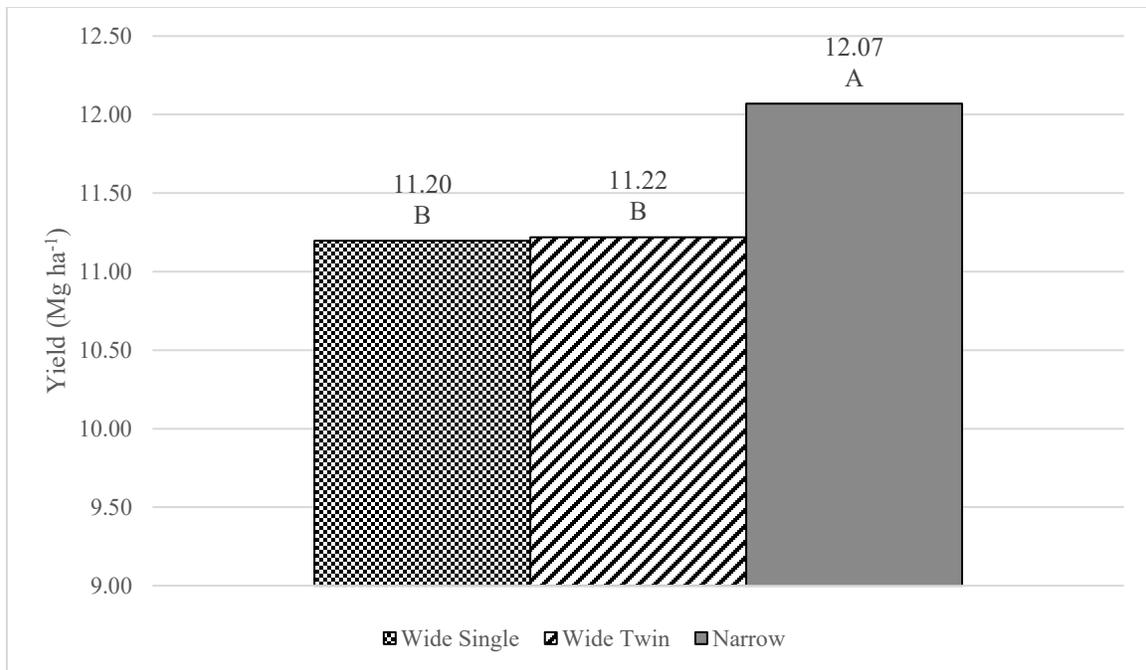


Figure 1.3 Yield response to row patterns averaged across four populations, locations, hybrids, and years. Values represented with the same letter are not significantly different ($P < 0.05$)

Similar grain yield results have been found by Strivers et al. (1971) who found 76 cm rows performed 4-5% better than the wide 102 cm rows. Furthermore, others have found no corn yield improvement for twin-rows, compared to single row patterns (Bruns et al. (2012), Sorensen et al. (2006), and Buehring et al. (2003)). The lack of yield improvement for the twin row pattern may be associated with various issues including off-center alignment of plants grown on a raised bed, compaction or erosion of raised beds, and seed depth disparity creating seedling emergence and developmental disparity.

Narrower row patterns improve the plant spacing geometry and decrease competition from neighboring plants for water, nutrients, and light interception. Row pattern did not affect light interception measured as PAR, and LAI. PAR values for various row patterns were normal and ranged from 99.31-99.95%, and LAI values ranged

between 4.30 and 4.57. Row pattern did not affect plant height measured at VT growth stage. Plant height were measured at the upper most leaf collar where the leaf connects to the stalk at the VT growth stage and heights ranged from 238.68-248.56 cm across all row pattern treatments.

Row pattern did effect chlorophyll content in corn ear leaves. Chlorophyll value was measured at the VT growth stage with a SPAD chlorophyll meter. The SPAD meter uses emitted light to calculate the SPAD value, which corresponds to the amount of chlorophyll present in the leaf. The traditional single row pattern produced a statistically lower value of 56.4 compared to the other two row pattern treatments which had a value of 57.6. These values are similar to Sunderman et al. (1997) who determined the SPAD values of 57.9 ± 4.5 at the start of silking provided adequate nitrogen levels corresponding with non-limiting growth factors.

Plant densities evaluated in this study represent a range of low to high populations for corn agronomic culture in this region. Plant density did affect yield in this study. The lowest plant density of 61,750 plants ha⁻¹ yielded 10.93 Mg ha⁻¹ while the 74,100 plants ha⁻¹ density yielded 11.25 Mg ha⁻¹ (Figure 1.4). These two lower populations produced similar grain yield. Higher plant density produced higher corn grain yields. Corn grown at 86,450 plants ha⁻¹ produced 11.93 Mg ha⁻¹, and 98,800 plants ha⁻¹ produced 11.87 Mg ha⁻¹ (Figure 1.4). These results showed a typical response where corn yield increases with

increasing plant densities until a point where yield reaches plateau.

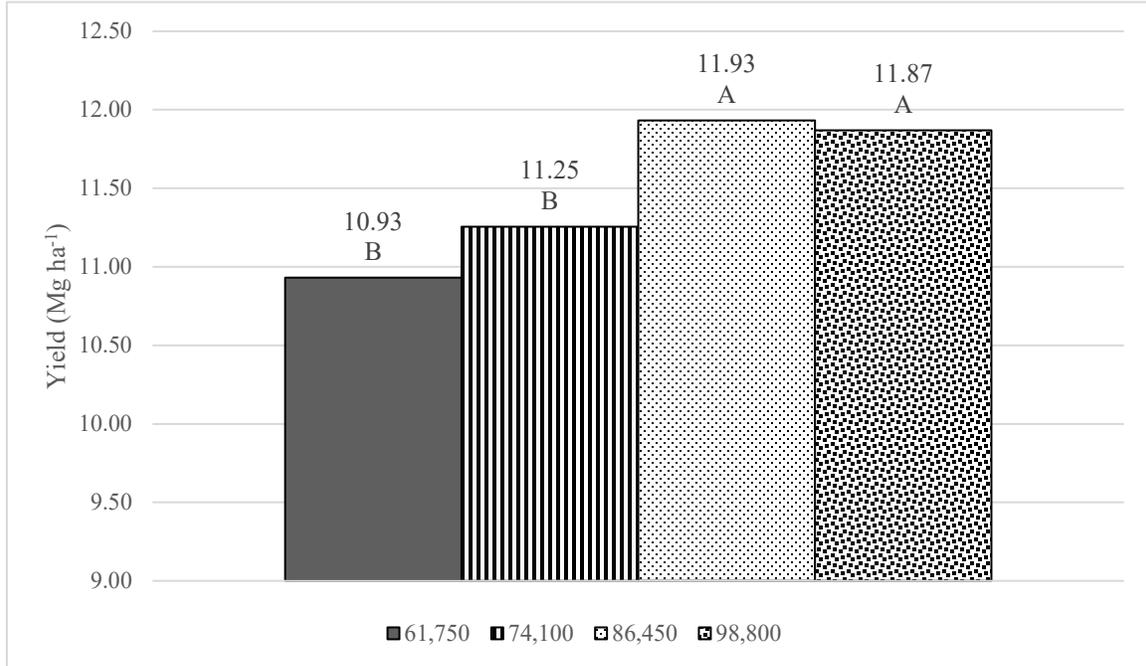


Figure 1.4 Yield response at four different plant populations averaged across years, hybrids, and locations. Mean separations determined by P value of < 0.05.

The optimal population in this study is 86,450 plants ha⁻¹.

Stalk diameters and lodging counts were conducted for evaluation of row patterns, hybrids, and population treatments. Row pattern and plant density had no effect on stalk diameter and lodging. Stalk diameter measurements were taken at the widest point on the first internode above the brace roots. Stalk and root lodging were both measured. Stalk lodging was defined as where the stalk was bent or broken below the ear, and root lodging is where the stalk is leaning past a >45° angle. The analyses showed only hybrid significantly affected stalk diameter, and stalk lodging. Row pattern and plant density had no effect on stalk diameters, or lodging of corn plants.

Conclusions

Narrow (76cm) row pattern improved corn grain yield 8% compared to the traditional wide row pattern. These results are similar to Stivers et al. (1971) who found a 4% increase moving from 102cm row to 76cm row. Results indicated that there was no corn grain yield difference between a wide twin-row pattern and a traditional wide single-row pattern, which was unexpected. These results are similar to Buehring et al. (2003) where they found no benefit between the twin-rows at 96cm and wide single 96cm rows.

We suspect that twin-row productivity did not improve primarily due to growing corn on a raised bed culture. Raised beds are commonly used in this region to alleviate soil saturation associated with abundant spring rainfall. Planting twin-rows on a bed require each row to inherently be positioned near each edge of a bed. This positioning could likely limit root distribution and efficiency for a lateral rooted crop, such as corn. Furthermore, intense spring rainfall may erode soil, especially on the sides of the beds.

Soil erosion could reduce coverage over the seed, leading to uneven seedling emergence or expose the roots. Also, any misalignment of the planter on the bed will create seedling emergence disparity and hinder root development.

Row pattern proved to have no effect on plant measurements of PAR, LAI, plant height, stalk diameter, and lodging. Plant density will not affect corn grain yield response to various row patterns. Therefore, corn grain yield response to row patterns was very similar in each study.

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APPENDIX A
STATISTIC TABLES

Table A.1 Test of fixed effects of yield, stalk diameter, stalk lodging, root lodging and SPAD across Row Patterns (RP), Hybrid (H) and all interactions.

Source of Variation	Yield	Stalk Diameter	Stalk Lodging	Root Lodging	SPAD
	Prob. >F value				
Row Pattern RP)	0.015	0.043	0.35	0.15	0.93
Hybrid (H)	0.013	0.00	0.14	0.0005	0.87
RP x H	0.80	0.85	0.65	0.29	0.99

†Note: A P value of <0.05 indicates significant effect or interactions

Table A.2 Test of fixed effects of height, photosynthetically active radiation (PAR), and leaf area index (LAI) across Row Patterns (RP), Hybrid (H) and all interactions at growth stages of tasseling.

Source of Variation	Height	PAR	LAI
	Prob. > F value		
	VT	VT	VT
Row Pattern (RP)	0.84	0.97	0.85
Hybrid (H)	0.004	0.72	0.14
RP X H	0.99	0.85	0.96

†Note: A P value of <0.05 indicates significant effect or interactions

Table A.3 Test of fixed effects of yield, stalk diameter, stalk lodging, and SPAD across Row Patterns (RP), Hybrid (H), Density (D), and all interactions.

Source of Variation	Yield	Stalk Diameter	Stalk Lodging	SPAD
Prob. >F value				
Row Pattern (RP)	0.003	0.77	0.90	0.02
Hybrid (H)	.0001	0.65	0.04	.0001
Plant Density (D)	.0001	0.84	0.92	.0001
RP x H	0.08	0.42	0.41	0.43
RP x D	0.85	0.40	0.93	0.88
D x H	0.25	0.47	0.76	0.58
RP x H x D	0.42	0.41	0.44	0.90

†Note: A P value of <0.05 indicates significant effect or interactions

Table A.4 Fixed effects of height, photosynthetically active radiation (PAR), and leaf area index (LAI) across Row Patterns (RP), Density (D), Hybrid (H) and all interactions at the growth stage of tasseling.

Source of Variation	Height	PAR	LAI
	Prob. > F value		
	VT	VT	VT
Row Pattern (RP)	0.16	0.09	0.16
Plant Density (D)	0.89	0.0001	0.0001
Hybrid (H)	0.0001	0.0001	0.0001
RP X D	0.66	0.89	0.85
RP X H	0.98	0.11	0.16
D X H	0.78	0.96	0.75

†Note: A P value of <0.05 indicates significant effect or interactions

Table A.5 Measured effect of Density on height, photosynthetically active radiation (PAR), and leaf area index (LAI), averaged across Row Patterns (RP), Hybrid (H), location and years at the growth stage of tasseling.

Source of Variation	Height (cm)	PAR (%)	LAI
	Prob. > F value		
	VT	VT	VT
61,750	245.87 A	99.01 B	4.08 C
74,100	242.29 A	99.20 B	4.18 C
86,450	242.98 A	99.92 A	4.64 B
98,800	244.58 A	99.96 A	4.94 A

†Note: LS-Means followed by same letter are not significant at P value of <0.05.

Table A.6 Measured Row Pattern effect on height, photosynthetically active radiation (PAR), and leaf area index (LAI) averaged across Density (D), Hybrid (H), location and years at the growth stage of tasseling.

Source of Variation	Height (cm)	PAR (%)	LAI
	Prob. > F value		
	VT	VT	VT
Wide Single	238.68 A	99.31 B	4.30 A
Twin	248.56 A	99.81 AB	4.49 A
Narrow	244.53 A	99.95 A	4.57 A

†Note: LS-Means followed by same letter are not significant at P value of <0.05.