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Evaluating the Effects of Variable Corn Seedling Emergence and Replanting Methods for Substandard Corn Stands

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Evaluating the effects of variable corn seedling emergence and replanting methods for substandard corn stands

By

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Evaluating the effects of variable corn seedling emergence and replanting methods for substandard corn stands

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Mississippi growers often have issues with corn seedling establishment due to saturated and cool soils, which can reduce productivity. Our first objective was to quantify yield reduction associated with variable emergence. Four patterns simulating various extent of affected plants and four different emergence delays were hand planted uniformly at a standard population. Plants were closely monitored to document emergence variability. Growth stages were measured three separate ways to identify the best field method to characterize stand variability. Data suggest there were yield disadvantages associated with emergence variability. Another objective was to evaluate practical replanting methods for Mid-South corn growers. Treatments included four populations planted at a normal time and replant interval. Two different series of treatments were imposed to evaluate the productivity of intra-planting seed in a partial stand. Corn grain yield was 11% greater when replanting in a clean seedbed, compared to all intra-planted treatments.

DEDICATION

I would like to dedicate this work to my parents, Kevin and Sue Pettit, to my irreplaceable sisters, Jennifer and Valerie, and to my loving girlfriend, Candice. Without their love and support, none of this work would have been possible. Thank you.

> "Be strong and of a good courage, fear not, nor be afraid of them: for the Lord thy God, he it is that doth go with thee; he will not fail thee, nor forsake thee."
>
> Deuteronomy 31:6

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CHAPTER I

INTRODUCTION

Corn (*Zea mays* L.) acreage has more than doubled since 2007 in Mississippi, making it a vital part of the state's agricultural economy (USDA-NASS, 2015). Although corn acreage has significantly increased, weather conditions dictating planting time have remained similar. Rainy weather is common in the Mid-South during this earlier planting window and often leads to planting in wet conditions and may result in non-uniform emergence. Therefore, research efforts to improve regional corn production are needed, especially for limitations unique to southern climates and cropping systems.

Corn tends to be more productive when planted early (Bruns & Abbas, 2006; Lauer, 2001). However, corn seedling establishment and development will likely suffer when planted early due to more adverse environmental conditions, compared to later planting in the spring. Cool soil temperatures minimize corn seed germination rate, which leads to issues with germination, emergence and early growth (Schneider & Gupta, 1985). Saturated soils, including flooded or ponded soils, can also have a negative impact on corn germination, emergence, and early growth (Drury et al., 1999). The Mid-South's climate involves high annual rainfall which tends to keep soil moisture extremely wet during the spring, which can significantly restrict timely planting, and hamper seedling emergence and development critical to corn productivity.

Corn is known to be very responsive to plant density, uniform spacing and synchronous development. Corn's morphology and growth habit largely dictate why corn is responsive to plant density, uniform spacing and development. Corn is a tall plant grown at a relatively low plant population compared to other row crops. Typically, there is one fruit-bearing ear per plant, unlike other row crops such as soybean (*Glycine max*) and cotton (*Gossypium hirsutum*) which will branch and produce numerous fruit all over the plant, thereby better compensating for lower populations (Hollis, 2014). Achieving uniform plant spacing helps assure plants have comparable access to vital resources, including light, water and nutrients (Staggenborg et al., 2004). Corn possesses a determinate growth habit, where growth proceeds systematically through vegetative, then subsequently reproductive stages at a rate dictated by heat unit accumulation (Hoeft et al., 2000). Therefore, if a corn stand acquires a developmental disparity, that effect is permanent and cannot be restored during the remainder of the season.

While there has been some research on stand assessment in corn (Nafziger, 1991; Nielsen, 2001) little research considers developmental disparity and other forms of stress, which are known to limit plant competitiveness. Therefore, this research intends to quantify limitations associated with variable seedling growth and develop methods to quantify those concerns. These results can be assimilated into better guidelines for making corn replant decisions and strengthen justification for avoiding these limitations proactively.

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CHAPTER II

EVALUATING EFFECTS OF VARIABLE CORN SEEDLING EMERGENCE

Introduction

In Mississippi, the naturally abundant spring rainfall often limits corn planting progress and often delays seedling germination and development. According to USDA-NASS (2017), there was an average of 36.6 suitable days for fieldwork in 2015 and 2016 during the months of March, April and May. This often leads to challenging conditions for corn seedling germination and development, ensuing an increased occurrence of poor corn stands. Although corn is an incredibly productive plant generally possessing high seedling vigor, variable emergence will substantially limit corn yield potential. Environmental and management factors that may potentially affect the timing and success of corn seedling establishment are variable moisture in the seed zone, uneven depth of planting, soil compaction, soil temperature differences, or plant residue directly above seed placement (Ford and Hicks, 1992). A corn seedling's initial development is greatly affected by the soil characteristics (Copeland and McDonald, 2001; Cutforth et al., 1985; Nielson and Pepper, 1990). Soil properties such as porosity, water-holding capacity and aeration may be unfavorable for seed germination and emergence for some fields. However, in some fields these soil properties may provide an excellent growing medium and even buffer the effects of adverse weather conditions. Waterlogged soils have been shown to inhibit corn seed germination (VanToai et al., 1998). A prolonged period of saturated soil can reduce germination and emergence due to the lack of oxygen, which will limit a plants ability to photosynthesize.

Temperature is the independent variable determining plant growth rate and development (Dwyer and Stewart, 1986). Cool temperatures will slow corn development. Soil temperature affects the rate of corn emergence (Willis et al., 1957; Alessi and Power, 1971; Iremiren and Milbourn, 1979). Research has shown that corn seedlings will germinate at a minimum soil temperature of 10°C; however, the optimum temperature is 30°C, and a maximum of 40°C (Warrington and Kanemasu, 1983). Accumulation of heat units or growing degree days (GDD) is a reliable method commonly used to predict corn development. GDD's are calculated by subtracting the corn's threshold temperature of 50 °F (10 °C) from the average daily air temperature. Corn also has an upper temperature threshold (30 °C), above which plant growth does not increase. Al-Darby and Lowery (1987) found that lower soil temperatures associated with conservation tillage delayed corn growth and development. Bollero et al. (1996) found that warmer early-season soil temperatures linearly increased corn yield by 0.14 Mg ha^{-1} $°C^{-1}$. The presence of elevated levels of crop residues have been the main source responsible for cool soil temperatures in no-till systems (Kaspar et al., 1990; Swan et al., 1987).

Corn seedlings grown in the Mid-South often emerge at various times, especially when exposed to adverse weather during germination and establishment. This variable emergence creates corn plant growth disparity which persists throughout the growing season. Earlier emerging plants are typically larger with more developed root systems compared to later emerging plants. Late emerging plants have more difficulty competing for sunlight, moisture and nutrients with neighboring plants. When growth disparity is extreme, and competition is severe, late-developing plants may produce little to no grain and may serve as weeds in the field (Nielsen, 2001; Maddonni and Otegui, 2004). Uniform plant growth and development is closely associated with higher yields (Glenn and Daynard, 1974). Nielsen’s (2001) research has shown that yield losses can easily be as much as 441 to 945 kg ha^{-1} due to uneven seedling emergence or uneven within-row plant spacing. Uneven seedling emergence quite often stunts plant development and diminishes grain yield, with prior emerged plants unable to fully compensate for lower yield of the later emerging plants (Nielsen, 2001). However, Nafziger (1991) found some yield compensation by normal plants may occur when grown next to a late emerged plant. A study conducted by Liu et al. (2004) found that plants with a two-leaf emergence delay reduced grain yield 35%, and plants with a four-leaf delay reduced grain yield 72% compared to the plants with no emergence delay. The neighboring plant yield increase was only 2 to 7%, not large enough to compensate for the loss in the study by Liu et al. (2004).

Corn is also extremely sensitive to plant spacing, crowded plants similar to late-emerging plants will produce small ears and spindly stalks due to intense competition for light, water and nutrients. However, Johnson and Mulvaney (1980) found higher yield losses when within-row plant spacing variability occurred as large gaps rather than smaller gaps, and yield losses were somewhat greater under low than under high plant populations. While fields with uneven plant spacing have unique problems, no single factor is responsible for differences among fields for stand establishment. Thus, a combination of the environmental and planting factors previously mentioned collectively influence corn stand establishment.

The first objective of this research is to 1) Evaluate the effects of non-uniform seedling emergence on corn development and productivity. The first objective is designed to quantify the negative effect of corn emergence variability compared to uniform emergence. Various treatments differing in extent and developmental disparity will be evaluated in field trials. The second objective of this research is to 2) Identify a practical method for characterizing late-emerging corn plants commonly found in fields which possess developmental disparity. Therefore, farmers, crop consultants and other agricultural professionals can correlate their practical issue in the future with research results documenting losses. The results from each objective can be integrated into better strategies for evaluating corn stands and making replant decisions.

Materials and Methods

Field experiments were grown in 2015 and 2016 at the Mississippi State University R.R. Foil Plant Science Research Center (33.472305° -88.784068°) located near Starkville, MS. Corn was grown in both irrigated and rain fed culture in separate locations each year. Corn was grown in rain fed culture in 2015 and 2016 and in irrigated culture in 2016 on a Leeper silty clay loam soil (Fine, smectitic, nonacid, thermic Vertic Epiaquepts) (USDA-NRCS Soil Survey Division, 2016). Corn was grown in irrigated culture in 2015 on a Marietta fine sandy loam (Fine-loamy, siliceous, active, thermic

Fluvaquentic Eutrudepts) (USDA-NRCS Soil Survey Division, 2016) soil. The previous crop for the irrigated and rain fed studies in 2015 and 2016 was soybean. Soil samples were collected for analysis and fertilizer was applied according to the soil test recommendations for each year and location. Nitrogen (N) was applied at recommended rates for corn grown for either rain fed or irrigated culture. Nitrogen was applied in two subsequent or split applications to reduce losses associated with our high rainfall environment. The nitrogen source applied was liquid UAN solution and was injected in the soil with a coulter-knife equipped applicator approximately 20-cm from each row. The first application of N was applied to plants at the V2 to V3 leaf growth stage. The second N application was applied at the V5 to V7 leaf stage. Weed competition was controlled using an application of Glyphosate (Roundup PowerMax™, Monsanto Company, St. Louis, MO) and Atrazine, Mesotrione, S-Metolachlor (Lexar® EZ, Syngenta Crop Protection, Greensboro, NC) at recommended labeled rates for glyphosate resistant corn. Corn was grown on raised beds which were prepared in the fall using a 6 row one trip plow (KBH Corporation, Clarksdale, MS) preceding planting. A spike-tooth hand garden rake was used prior to planting to smooth the top of the raised bed, if necessary.

The experimental design was a randomized complete block design with 4 replications. The treatment design was an augmented factorial. The factorial portion of the treatment design is a 4 x 4 x 4 (location, 4 levels; delay, 4 levels; and pattern, 4 levels), for a total of 64 combinations. This is augmented by a control at each of the 4 locations; giving a grand total of 68 combinations. Dekalb (Monsanto, St. Louis, MO)

’DKC67-72’ corn hybrid was grown in all experiments. Each plot consisted of three rows 3.048 m long with row spacing of 97 cm. Corn was hand planted and grown at a consistent plant density of 67,900 plants ha^{-1} for all treatments. To achieve equal spacing, a 335-cm nylon rope was marked every 15.24 cm to ensure equivalent distance between individual plants. Corn was planted within the normal planting dates for Mississippi, and experimental planting dates are listed in Table 2.2.

One treatment variable implemented in this study was four various levels of emergence or growth disparity. In order to create the plant growth disparity treatments desired, seeds were planted individually at four different intervals subsequent to the initial planting. The four emergence intervals were intended to be established by planting seeds two, four, six and eight days after initial planting. The specific delay intervals for each treatment may vary by location or year because rainfall often dictated when treatments could be successfully established. A hand-planting device was constructed using a 1.27 cm metal dial 20 cm in length and a metal washer fixed at 3.81 cm to ensure even depth for each seed. For the delayed plants, colored flags corresponding to a specific delay were placed at the time of the initial planting to mark the location of treatments to be planted at a later date.

Four different treatment patterns were also implemented to establish a broad range representing real issues encountered in production corn fields exposed to undesirable growing conditions. The four patterns consisted of either 1, 2, 3 or 4 delayed plants bordered by two normal plants on each side. These respective patterns are repeated over the length of each given plot (Figure 2.1).

Seedling corn plants were closely monitored so we could develop methodology to characterize variable emergence. Plant growth and development was measured using three different methods from emergence until the most substantial delay treatment attained V3 growth stage. Plant growth disparity was measured using three methods: leaf collar method, the droopy leaf method (DLM), and total plant height. The leaf collar method determines leaf stage in corn by counting the number of fully emerged leaves on a plant with visible leaf collars, beginning with the lowermost, short, rounded-tip true leaf and ending with the uppermost leaf with a visible leaf collar (Abendroth et al., 2011). The "Droopy" Leaf Method (DLM) stages plants based on the number of leaves emerged with at least 40 to 50 percent of their leaf area exposed and the tip of the uppermost counted leaf pointing down (USDA-Federal Crop Insurance Corporation, 2010). Total plant height was taken by measuring from the soil surface to the arch of the uppermost leaf that is more than 50% emerged (Hager and Sprague, 2002). Tassel dates were recorded for normal plants and delayed plants within each plot.

After corn tasseled and vegetative growth was complete, plant characteristics were measured including stalk diameter of the widest point below the first node, plant height, and ear height. After grain reached physiological maturity and suitable moisture, individual ears were hand harvested (Figure 2.2). The treatment row was the only row harvested in 2015. In 2016, ears from the adjacent row were also harvested to confirm whether compensation occurred in adjacent rows. In 2015, ears were air-dried in a forced air dryer at approximately 60°C for approximately 48 hours until they reached suitable moisture for storage. In 2016, grain did not require supplemental drying. Ear yield components, including number of kernel rows and number of kernels per row were measured prior to shelling grain. The ears were then mechanically shelled in an Ear Corn Sheller ECS-11AC by Almaco©. Grain weights were measured for each experimental treatment. Grain moisture and test weight were measured using a Perten AM 5200-A Certified Grain Moisture Tester (Perten Instruments AB, Hägersten, Sweden). Grain weights were measured and adjusted to the standard corn moisture content of 15.5% to calculate grain yield. Average kernel weight for 250 seeds were also measured.

Statistical analyses of the data were analyzed with the GLIMMIX procedure in SAS 9.4 (SAS Institute, Inc., Cary, NC). Comparisons of treatments were made by calculating Least Square Means (LSMEANS), standard error (STDERR) and the probability of difference (PDIFF) between treatment means. A protected LSD ($p \leq 0.05$) was used in mean comparisons.

Results and Discussion

Individual Ear Data

Analysis of variance were performed on grain yields from individual plants and showed there was no interaction between locations, years, delay and pattern. Thus, grain yield data from individual plants was combined across locations and years. There were no significant difference in grain yield between the control and adjacent control plants, therefore the adjacent control grain yields were not included in further analyses. Also, there were no significant difference in grain yield for late or late middle plants, therefore, they were combined, and yields were calculated. There was no interactions between delay and pattern; however, main effects of delay and pattern were both significant.

An analysis was performed to determine how four different increasing emergence delays affect grain yield compared to uniform emergence. The control treatment, which possessed uniform emergence, produced a grain yield of 12,824 kg ha^{-1}. Increasing emergence delay significantly reduced corn grain yield associated with delay 2 (10,492 kg ha^{-1}), delay 3 (9,108 kg ha^{-1}) and delay 4 (6,774 kg ha^{-1}). Thus, emergence delay and variability may cause significant corn yield loss, regardless of whether the stands possess similar and acceptable plant density. These findings are similar to the study conducted by Liu et al. (2004), who found that plants with a two-leaf emergence delay reduced grain yield 35%, and plants with a four-leaf delay reduced grain yield 72% compared to the plants with no emergence delay. Thus, in a corn replant decision, the yield reductions associated with emergence variability in corn should be considered and these plants should not be counted as normal emerging plants. Figure 2.3 illustrates yield loss of individual corn plants with varying degree of emergence delay using the corresponding t grouping (α=0.05).

An analysis was performed to determine how four planting delay emergence patterns affect grain yield compared to uniform emergence. Compared to the grain yield of the control, each pattern significantly reduced grain yield. Treatment patterns which possessed multiple adjacent delayed plants produced higher yields, compared to a solitary delayed plant bordered by two normal plants. The grain yield for the treatment plant, which possessed an emergence delay, in each pattern was: pattern 1 (8,111 kg ha^{-1}), pattern 2 (9,164 kg ha^{-1}), pattern 3 (10,031 kg ha^{-1}) and pattern 4 (10,527 kg ha^{-1}). The reason more delayed plants could achieve higher yields may be because of less competition in neighboring plants with the same delay in emergence. This indicates interplant competition is more severe when there is a substantial growth disparity amongst adjacent plants. Figure 2.4 illustrates the significant differences for mean grain yields between control plants and delayed plants among the treatment pattern using the corresponding t grouping ($\alpha=0.05$).

Cumulative Yields

Cumulative yields are defined in this study as all plants within any treatment row. This includes normal plants and those representing an emergence delay and treatment pattern. Analysis of variance of cumulative grain yields showed there was no interaction between location, years, delay and pattern. Thus, cumulative corn grain yield data was combined across locations and years. Further analysis of variance reported there was no interaction between delay and pattern; however, delay was significant. Treatment patterns did not significantly affect cumulative yields. Cumulative grain yields of the four delayed treatments were compared to the control or uniform stand. The control or uniform stand produced a yield of 12,824 kg ha^{-1}. Increasing emergence delay significantly reduced corn grain yield associated with delay 1 by 5% (12,164 kg ha^{-1}), delay 2 by 6% (12,049 kg ha^{-1}), delay 3 by 11% (11,430 kg ha^{-1}) and delay 4 by 18% (10,487 kg ha^{-1}). Therefore, emergence delay reduced cumulative corn grain yields and should be accounted for when making replant decisions. Currently, the living corn plant population is what corn growers use to make the replant decision. Regional research shows a 14% yield loss associated with a 29% plant density reduction compared to an optimal plant density of 83,980 plants per hectare (Kelley, 2014). However, our results show that it is also important to account for emergence disparity when assessing marginal corn stands and making replant decisions, since this study documents corn grain yield reduction up to 18% resulting from emergence delay. These yield reductions associated with emergence delay are greater than (Nafziger et al., 1991) who found delayed emergence decreased yields by approximately 6% after 10-12 days and by approximately 12% after three weeks. However, Nafziger's research classifies delayed emergence treatments by the number of days planting was delayed, which does not provide a practical measurement for assessing emergence delay in the field. Figure 2.5 illustrates the significant differences for cumulative grain yields between control and delayed emergence treatments using the corresponding t grouping ($\alpha=0.05$).

Evaluating Methods to Characterize Emergence Variability

Emergence variability was assessed by analyzing measurable growth differences between normal or control plants, and those plants with a delayed emergence treatment imposed. For the total plant height method, percentage of height reduction was calculated by subtracting the mean height of delayed plants in each delay from the mean height of control plants. For the two-leaf staging methods, differences for the V-stage and droopy leaf methods were calculated by subtracting the mean stage of delayed plants from the mean stage of control plants.

The first method we evaluated to potentially characterize emergence variability used plant height. Total plant heights were measured beginning soon after emergence to evaluate how well this method would characterize corn physiological differences in emergence disparity. An issue associated with using plant height to characterize emergence variability is that the rate of plant growth or height increases as corn growth stage increases. Therefore, to minimize the variability associated with this method, we analyzed corn height measurements collected in a concise (7-10 day) time period, before V6 growth stage. Data are reported based on the amount of GDD50 delay for each treatment after initial planting. Increasing emergence delay significantly increased mean total plant height reduction (%). Mean total plant height reduction ranges from 20% to 83% for emergence delay ranging from 50 to 250 GDD50's. However, there was considerable variability among plant height results representing similar delay treatments. For example, height reductions fluctuate up to 19% among similar GDD50's (Table 2.4).

Mean growth stage difference was analyzed for the V-stage method compared to the Droopy Leaf method after all delayed plants reached emergence. Analyses of emergence or growth disparity are based on GDD50 delay after initial planting. Growth disparity measured with these methods are not influenced by time, and thus, are inherently more consistent and reliable, compared to the height method. Growth stage differences will not change over time since corn possesses a determinant growth habit. Increasing emergence delay significantly increased growth disparity measured with both the V-stage method and the Droopy Leaf method. For the V-stage method, mean growth stage differences ranged from 0.25 to 3.31 leaves for emergence delay ranging from 39 to

255 GDD50’s (Table 2.5). For the Droopy leaf method, mean growth stage differences ranged from 0.44 to 4.45 leaves for emergence delay ranging from 39 to 255 GDD50’s (Table 2.5). Plant growth disparities are nearly always greater and thus, more practical or valuable, when measured using the Droopy leaf growth staging method, compared to the V-stage method. The only issue with using a growth staging method, is their precision is limited by the intervals associated with corn leaf growth and development. This research shows the Droopy Leaf method is the most practical method to characterize corn developmental disparity. Prior research (Nielsen, 2001; Nafziger, 1991) that evaluates emergence delay in corn did not associate delayed emergence results with growth differences.

Since we have identified a practical method to characterize corn developmental disparity, we can now integrate these results with yield data to better assess effects of emergence variability and help make replant decisions. Delayed corn seedling emergence significantly reduced cumulative corn grain yield as well as leaf difference, however, pattern did not have a significant effect. Grain yield reduction of 5% was documented for delay corresponding with emergence disparity measured with the Droopy leaf method of 1 leaf stage less than the control. Also, an 11% grain yield reduction was documented for delay corresponding with emergence disparity measured with the Droopy leaf method of 2 leaf stages less than the control. Grain yield reduction up to 18% was documented for emergence delay of 3 stages or more measured with the Droopy Leaf Method.

Stalk Diameter, Overall Plant Height, Ear Height

The stalk diameters of control, adjacent control and delayed plants were compared to determine the effects of delayed emergence and treatment pattern. There was no significant interaction for location, delay or pattern. Thus, data was combined across locations and years. There were no significant differences for the stalk diameters of control plants versus adjacent control plants, therefore they were not included in further analysis. There was no significant interaction for delay and pattern. However, delay and pattern were both statistically significant when comparing stalk diameters.

Stalk diameters were measured to evaluate the effects of delayed emergence and treatment pattern. The mean stalk diameter of the control plants was 20.98 mm, which was statistically greater than the delayed plants in the four delayed treatments as well as the four treatment patterns. Mean stalk diameter for delay 1 (18.98 mm) was significantly greater than delay 2 (16.85 mm). Mean stalk diameter for delay 2 was significantly greater than delay 3 (15.51 mm). Mean stalk diameter for delay 3 was significantly greater than delay 4 (14.05 mm). These smaller stalk sizes for plants delayed in emergence are the result of the enhanced competition for water, light and nutrients. Smaller stalk sizes also confirm yield competition of individual plants, when increasing emergence delay reduced stalk diameter and grain yield. Table 2.6 illustrates the significant differences for stalk diameters among treatment delays using the corresponding t grouping (α=0.05).

Mean stalk diameter for pattern 1 (15.48 mm) was significantly less than pattern 3 (16.71 mm) and pattern 4 (17.00 mm). Mean stalk diameter for pattern 2 (16.21 mm) were significantly less than pattern 3 (16.71 mm). Mean stalk diameter for pattern 3 (16.71 mm) were significantly less than pattern 4 (17.00 mm). Smaller stalk sizes also correlate with the individual yield results, where fewer adjacent late plants bordered by normal plants reduced stalk diameter and grain yield more substantially. Table 2.7 illustrates the significant differences for stalk diameters among treatment patterns using the corresponding t grouping (α=0.05).

Plant heights were measured to evaluate the effects of delayed emergence and treatment pattern. There was no significant interaction for location, delay, or pattern. Thus, plant height data was combined across location and years. There was no interaction between delay and pattern; however, delay and pattern were each significant. The plant height of the control was 2.44 m. Mean plant height for delay 4 (2.19 m) was significantly less than the three other delayed treatments and the control (Table 2.8). Mean plant height for delayed plants in pattern 1 (2.26 m) and pattern 2 (2.27 m) were significantly reduced compared to the control and pattern 3 (2.34 m) and pattern 4 (2.35 m). These results are similar to the yield results, where pattern 1 and pattern 2 both produced lower yields compared to the control. This yield reduction likely resulted from shading, where taller plants will have a competitive advantage for capturing sunlight used for photosynthesis, and ultimately grain production. Table 2.9 illustrates the significant differences for mean plant heights among treatment patterns using the corresponding t grouping (α=0.05).

Ear heights were also compared across treatments to evaluate the effects of delayed emergence on final ear height. There were reported no significant interactions for location, delay, or pattern. Also, there was no interaction between delay and pattern. Pattern or delay did not significantly influence ear height. Thus, delayed emergence had no impact on ear height.

Yield Components

Yield components were also compared across treatments to further evaluate potential effect of delayed emergence or treatment pattern. There are five yield components for corn; plants per acre, ears per plant, kernel rows per ear, kernels per row, and kernel weight. Plants per acre was fixed for this study. Ears per plant typically do not change unless there is a significant reduction in plant density, thus this component is not covered in this study. Initial analysis of two yield components (kernel rows per ear, kernels per row) did not indicate any interaction among locations, years, delay or pattern, therefore all locations and years were combined. Further analysis of yield components (kernel rows per ear, kernels per row,) showed delay as significant, but pattern and the delay by pattern interaction were not significant. Thus, results are reported for the yield components (kernel rows per ear, kernels per row,) for the delay factor. The control had a mean kernel rows per ear of 14.99 rows. The kernel rows per ear for the control was significantly higher than delay 3 (13.87 rows) and delay 4 (12.85 rows). Table 2.10 illustrates the significant differences for kernel rows per ear among treatment delays using the corresponding t grouping ($\alpha=0.05$). The control produced 35.45 kernels per row. The control produced more kernels per row compared to delay 3 (28.63 kernels) and delay 4 (24.69 kernels). Table 2.11 illustrates the significant differences for mean kernels per row among treatment delays using the corresponding t grouping (α=0.05).

There was no interaction between location, delay, or pattern for corn kernel weights, or other yield components. Thus, data was combined across location and years. There was no interaction between delay and pattern; however, delay was significant. Also, pattern was not significant. Thus, data is reported for the emergence delay for kernel weight comparisons. The control produced a kernel weight of 85.94 grams per 250 kernels. Kernel weight for the control was significantly higher than the kernel weight for delay 3 (81.38 g), and delay 4 (78.06 g). These results are similar to the data above for delay 3 and delay 4, as kernel weight, kernel rows per ear and cumulative grain yield are significantly reduced compared to the control. This data confirms the yield results that show a decrease in yield, kernel weight, kernel rows per ear and kernels per row as emergence delay progresses beyond a 2-leaf difference measured by the Droopy leaf method compared the control. Table 2.12 illustrates the significant differences for mean plant heights among treatment delays using the corresponding t grouping (α=0.05).

Conclusions

This research shows how much growth disparity reduced corn grain yield. An increase in emergence delay significantly reduced cumulative grain yield 660 kg ha^{-1} to 2,337 kg ha^{-1}. We believe it is important to integrate these results with yield data for this data to be useful.

This research also shows how to characterize emergence disparity and relate these visible differences to grain yield. Although the plant height method can measure subtle differences in plant height, there was considerable variability in results over time and years. This variability likely results from increasing plant growth rate over time. Therefore, the plant height method has inherent flaws which limit its ability to consistently characterize corn growth disparity within a stand. Plant growth disparities are nearly always greater and thus, more practical or valuable, when measured using the Droopy leaf growth staging method, compared to the V-stage method.

Our research results showed corn emergence disparity of 1 droopy leaf stage reduced yield approximately 5%. Emergence disparity of 2 droopy leaf stages reduced grain yield 11%. Emergence disparity of 3 droopy leaf stages reduced grain yield 18%. This level of reduction is similar to research that shows a 14% yield loss associated with a 29% plant density reduction compared to an optimal density of 83,980 plants per hectare (Kelley, 2014). Therefore, growers and consultants should also account for emergence disparity when assessing marginal corn stands and making replant decisions.

Several plant parameters and yield components confirm emergence disparity creates interplant competition which reduces grain yield. The stalk diameters of control plants were significantly larger than delayed plants, which confirm earlier emerging plants are more competitive compared to later-emerging plants. This yield reduction likely results from shading, where taller plants will have a competitive advantage for capturing sunlight used for photosynthesis, and ultimately grain production. The yield component results also show a decrease in yield, kernel weight, kernel rows per ear and kernels per row as emergence delay is approximately 2 leaf differences from the control using the Droopy leaf method.

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Table 2.1 Treatment structure used in the delayed emergence experiment evaluated at Starkville in 2015 and 2016.

Delayed Emergence Experiment				
Treatment	Delay	Pattern	Est. (GDD50) from initial*	% Plants Delayed
1	CK	CK	0	0
2	1	1	50	33
3	1	2	50	50
4	1	3	50	60
5	1	4	50	67
6	2	1	100	33
7	2	2	100	50
8	2	3	100	60
9	2	4	100	67
10	3	1	150	33
11	3	2	150	50
12	3	3	150	60
13	3	4	150	67
14	4	1	200	33
15	4	2	200	50
16	4	3	200	60
17	4	4	200	67

*Growing degree-days after initial planting

*Delay values 1, 2, 3 and 4 are approximately 50, 100, 150, or 200 GDD's after the CK.

*Pattern values 1, 2, 3 and 4 are levels of amount of delayed plants per row

Table 2.2 Dates of corn planting and hand grain harvest for the delayed emergence experiments in 2015 and 2016.

Location	Year	Planting date(GDD50) *					
		Initial	Delay 1	Delay 2	Delay 3	Delay 4	Grain harvest
Irrigated	2015	1-May	3-May (44)	5-May (85)	7-May (132)	9-May (184)	8-Sept
	2016	28-Apr	5-May (141)	7-May (168)	9-May (206)	11-May (255)	15-Sept
Rain fed	2015	4-May	6-May (63)	8-May (114)	10-May (167)	12-May (216)	17-Sept
	2016	18-Apr	20-Apr (46)	23-Apr (100)	26-Apr (160)	28-Apr (205)	2-Sept

*GDD50 growing degree-days after initial planting.

*2016 Irrigated location delays were postponed due to excessive rainfall.

Table 2.3 Growth stages of plants in the delayed emergence experiment at all locations for 2015 and 2016 when growth characteristics were measured.

Year	**Location**	**4-5 Days after Emergence**			**6-10 Days after Emergence**		
		V-stage Range	Droopy Leaf Range	Height Range mm	V-stage Range	Droopy Leaf Range	Height Range mm
2016	Irrigated	V1-V4	1-6	0.64-22.86	V3-V6	3-8	7.62-35.56
2016	Rain-fed	V1-V3	1-4	1.27-17.78	V1-V4	2-6	5.08-25.40
2015	Irrigated	V1-V4	1-5	2.54-22.86	V2-V5	3-7	10.16-30.48
2015	Rain-fed	V1-V3	1-5	2.54-20.32	V2-V4	3-6	10.16-27.94
All		V1-V4	1-6	0.64-22.86	V1-V6	2-8	5.08-35.56

Table 2.4 Mean growth characteristic differences of the total plant height method for each delay for 7-10 days after all delayed plants reached emergence.

Year	Location	Delay	GDD50	Mean % Height Reduction	Mean % Height Reduction
2015	Irrigated	1	39	19%	20%
2016	Rain-Fed	1	46	26%	
2015	Rain-Fed	1	58	16%	
2015	Irrigated	2	77	30%	40%
2016	Rain-Fed	2	100	46%	
2015	Rain-Fed	2	105	35%	
2015	Irrigated	3	120	49%	
2016	Irrigated	1	141	48%	58%
2015	Rain-Fed	3	154	57%	
2016	Rain-Fed	3	160	61%	
2016	Irrigated	2	168	57%	
2015	Irrigated	4	168	67%	
2015	Rain-Fed	4	199	70%	70%
2016	Rain-Fed	4	205	76%	
2016	Irrigated	3	206	65%	
2016	Irrigated	4	255	83%	83%

Table 2.5 Mean growth differences comparing the V-stage method and Droopy Leaf Method after all delayed plants reached emergence.

Year	**Location**	**Delay**	**GDD**	**Mean V-stage Difference**	**Mean Droopy Leaf Difference**
2015	Irrigated	1	39	0.33	0.44
2016	Rain-Fed	1	46	0.57	0.54
2015	Rain-Fed	1	58	0.25	0.63
2015	Irrigated	2	77	1.00	1.33
2016	Rain-Fed	2	100	1.14	1.34
2015	Rain-Fed	2	105	1.00	1.38
2015	Irrigated	3	120	1.67	2.00
2016	Irrigated	1	141	1.86	2.26
2015	Rain-Fed	3	154	1.63	2.13
2016	Rain-Fed	3	160	2.12	2.28
2016	Irrigated	2	168	2.29	2.94
2015	Irrigated	4	168	2.17	2.56
2015	Rain-Fed	4	199	2.06	2.63
2016	Rain-Fed	4	205	2.41	3.03
2016	Irrigated	3	206	2.50	3.60
2016	Irrigated	4	255	3.31	4.45

Table 2.6 Effect of emergence delay on corn stalk diameter (mm).

DELAY	STALK DIA. (MM)	T-GROUP
CONTROL	20.98	A
1	18.98	B
2	16.85	C
3	15.51	D
4	14.05	E

Stalk diameters within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 2.7 Effect of treatment pattern on corn plant stalk diameters (mm).

PATTERN	STALK DIA. (MM)	T-GROUP
CONTROL	20.98	A
1	15.48	C
2	16.21	BC
3	16.71	B
4	17.00	B

Stalk diameters within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 2.8 Effect of emergence delay on corn plant height (m).

DELAY	PLANT HEIGHT (M)	T-GROUP
CONTROL	2.44	A
1	2.35	A
2	2.37	A
3	2.31	A
4	2.19	B

Plant heights within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 2.9 Effect of treatment pattern on corn plant height (m).

PATTERN	PLANT HEIGHT (M)	T-GROUP
CONTROL	2.44	A
1	2.26	B
2	2.27	B
3	2.34	AB
4	2.35	AB

Plant heights within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 2.10 Effect of emergence delay on yield component rows per ear.

Delay	Rows per ear	T-group
Control	14.99	A
1	14.89	A
2	14.30	AB
3	13.87	B
4	12.85	C

Rows per ear with the same letter are not significantly different (α =0.05).

Table 2.11 Effect of emergence delay on yield component kernels per row.

Delay	Kernels per row	T-group
Control	35.45	A
1	33.04	A
2	31.51	AB
3	28.63	B
4	24.69	C

Kernels per row with the same letter are not significantly different (α =0.05).

Table 2.12 Kernel weight response to emergence delay.

Delay	Kernel Weight for 250 kernels (g)	T-group
Control	85.94	A
1	82.63	AB
2	81.38	B
3	81.07	B
4	78.06	C

Kernel weights within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

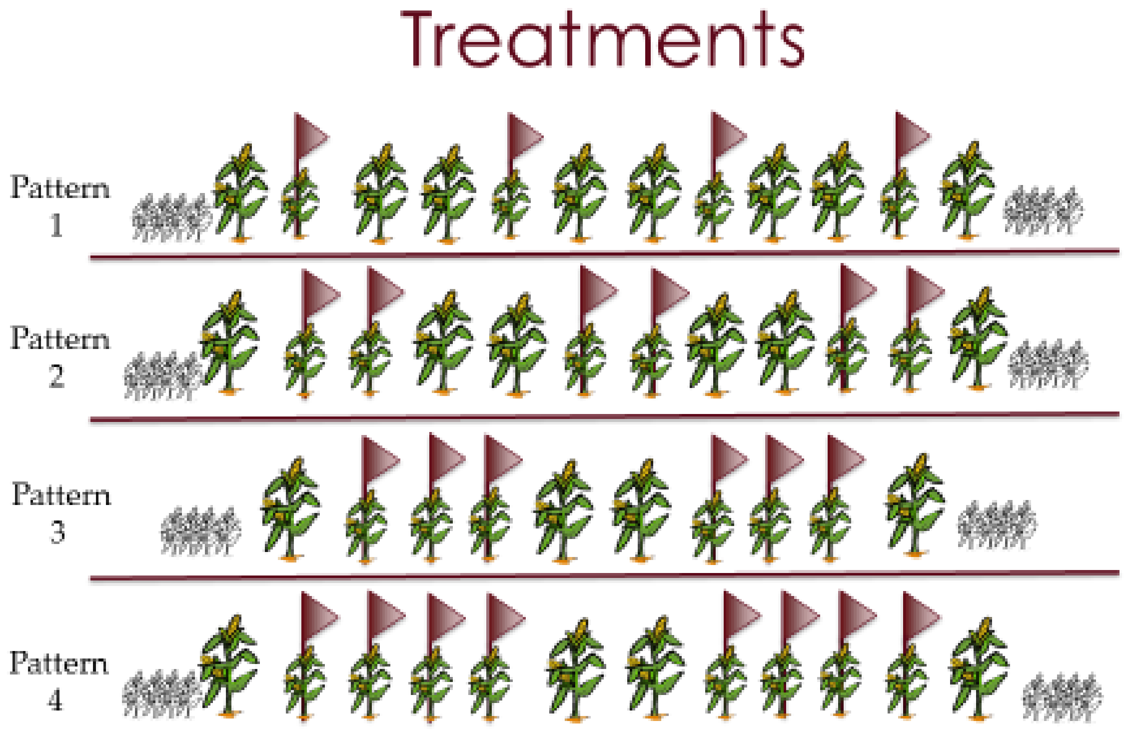
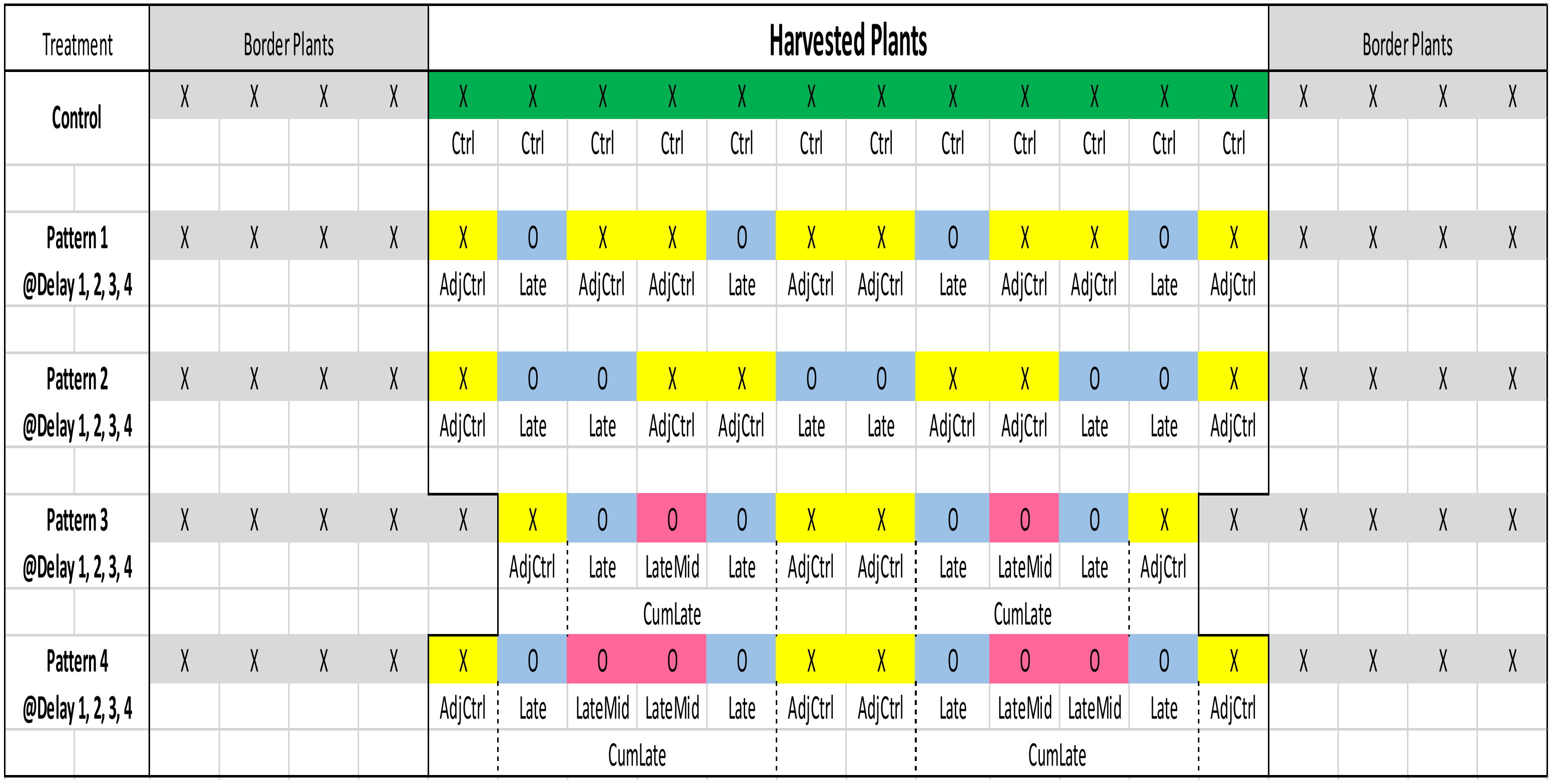


Figure 2.1 Planting design for the delayed emergence experiment at Starkville in 2015 and 2016

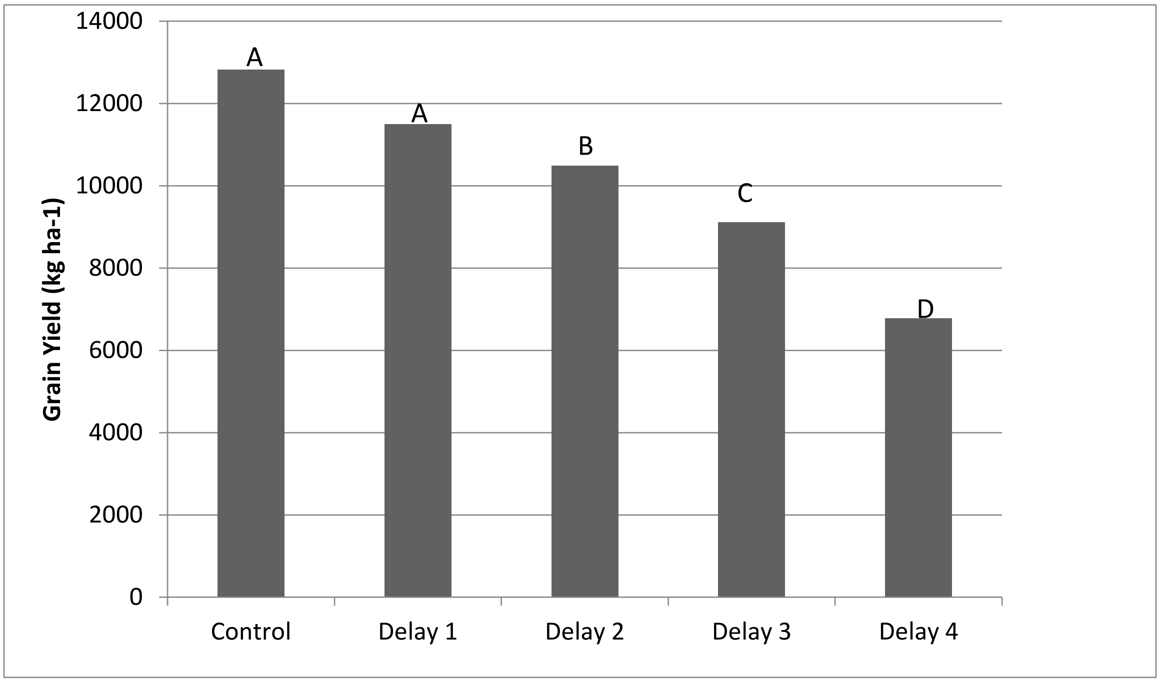
*Large plants and no flag represents initial plants
*Small plants with a flag represents delayed plants
*Small plants without a flag represents border plants



Treatment	Border Plants				Harvested Plants												Border Plants			
Control	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
					Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl	Ctrl				
Pattern 1	X	X	X	X	X	0	X	X	0	X	X	0	X	X	0	X	X	X	X	X
@Delay 1, 2, 3, 4					AdjCtrl	Late	AdjCtrl	AdjCtrl	Late	AdjCtrl	AdjCtrl	Late	AdjCtrl	AdjCtrl	Late	AdjCtrl				
Pattern 2	X	X	X	X	X	0	0	X	X	0	0	X	X	0	0	X	X	X	X	X
@Delay 1, 2, 3, 4					AdjCtrl	Late	Late	AdjCtrl	AdjCtrl	Late	Late	AdjCtrl	AdjCtrl	Late	Late	AdjCtrl				
Pattern 3	X	X	X	X	X	X	0	0	0	X	X	0	0	0	X	X	X	X	X	X
@Delay 1, 2, 3, 4						AdjCtrl	Late	LateMid	Late	AdjCtrl	AdjCtrl	Late	LateMid	Late	AdjCtrl					
								CumLate					CumLate							
Pattern 4	X	X	X	X	X	0	0	0	0	X	X	0	0	0	0	X	X	X	X	X
@Delay 1, 2, 3, 4					AdjCtrl	Late	LateMid	LateMid	Late	AdjCtrl	AdjCtrl	Late	LateMid	LateMid	Late	AdjCtrl				
						CumLate						CumLate								

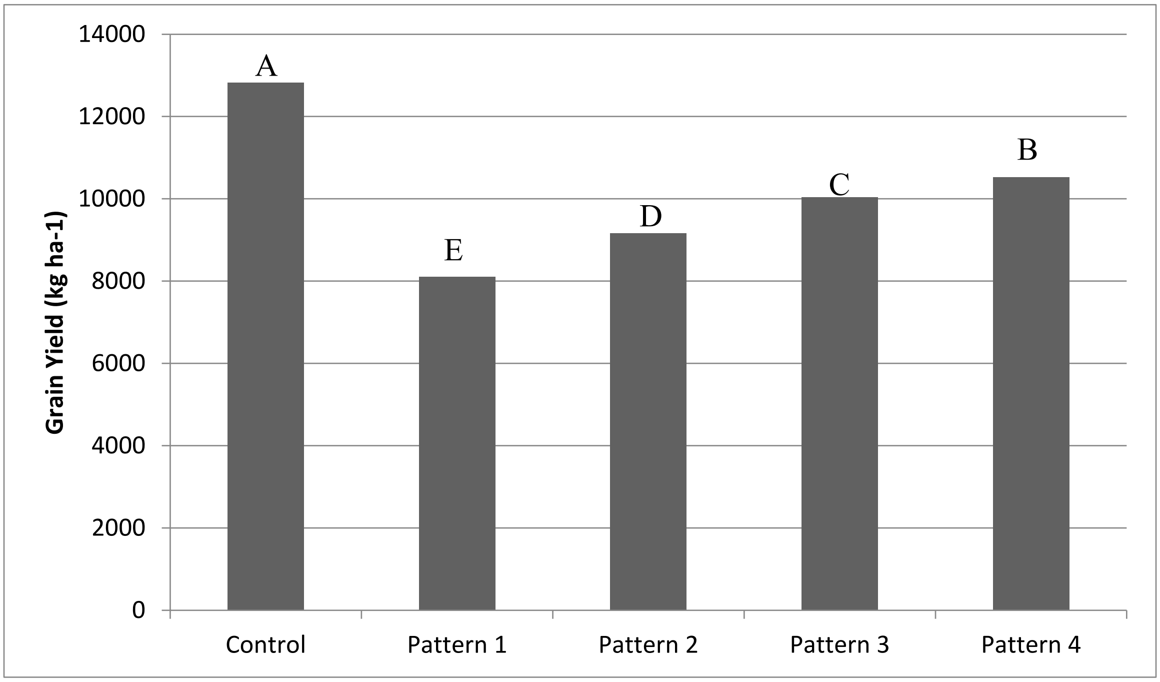
Figure 2.2 Harvest plan for the delayed emergence experiment in 2015 and 2016.

Figure 2.3 Individual plant corn grain yields as affected by delayed emergence treatments compared to a uniform control.



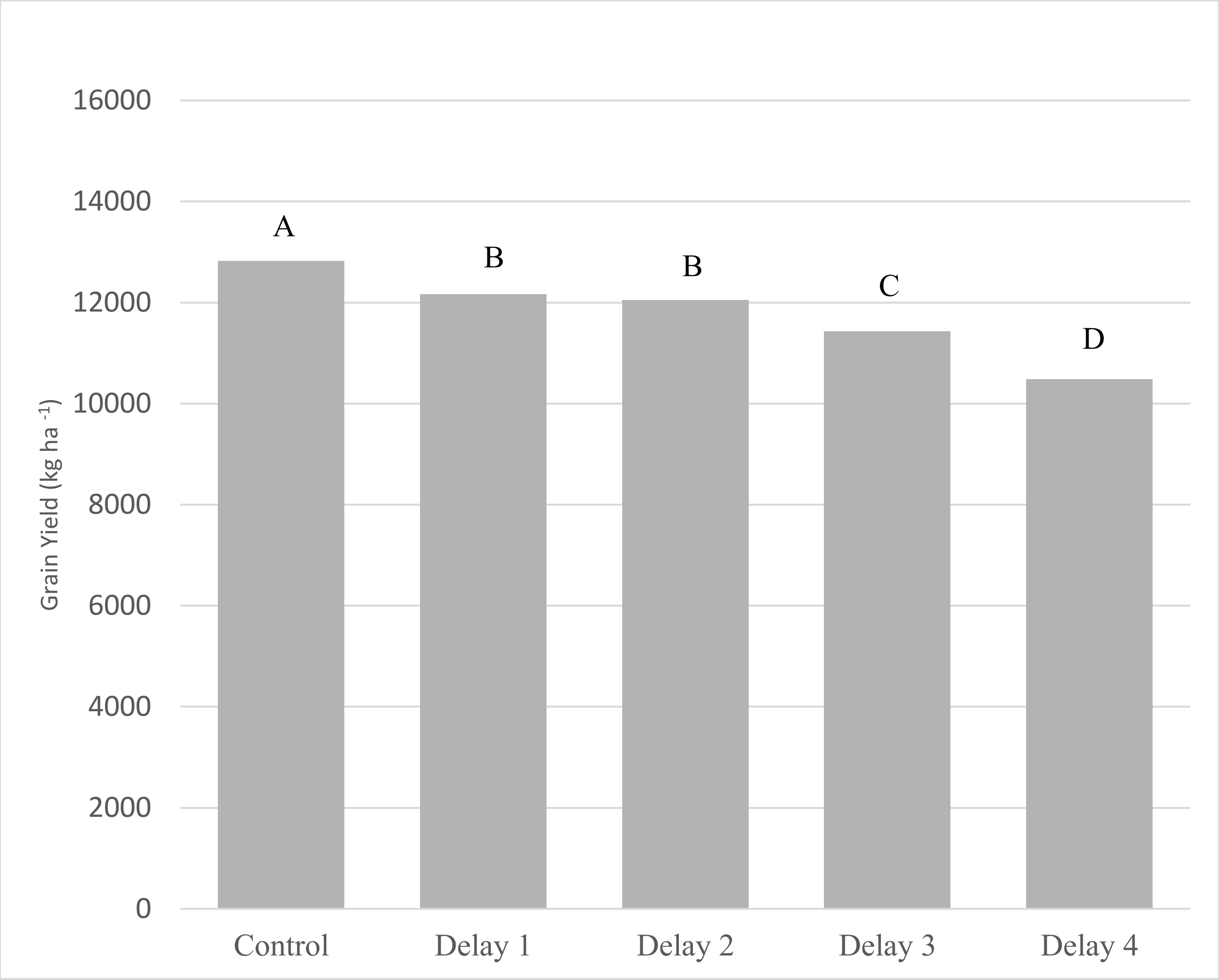
Grain yields with the same letter are not significantly different according to an LSD test (P = 0.05).

Figure 2.4 Individual plant corn grain yields as affected by treatment pattern compared to a uniform control.



Grain yields with the same letter are not significantly different according to an LSD test (P = 0.05).

Figure 2.5 The effect of delayed emergence on cumulative grain yields.



Cumulative grain yields with the same letter are not significantly different according to an LSD test (P = 0.05)

CHAPTER III

EVALUATING REPLANTING METHODS FOR SUBSTANDARD CORN STANDS

Introduction

Corn (*Zea mays L.*) producers in the Mid-South often experience frequent rainfall during the planting season. This abundant rainfall saturates soil, limiting days suitable for fieldwork, which delays or restricts planting (USDA-NASS, 2015). Saturated soil conditions after planting are often detrimental to corn seedling survival and growth in the Mid-South. Cool temperatures retard corn seedling growth and elevate risk associated with seedling pathogens, insect pests, nematodes and other factors known to inhibit seedling health and survival (Ford and Hicks 1992). These issues may reduce corn seedling survival or emergence variability enough to justify replanting the crop.

Mississippi growers normally grow corn on prepared, raised beds designed to minimize problems associated with early-season soil saturation. Removing an inadequate corn stand using tillage equipment is often used in regions where corn is not grown on raised beds. However, tillage will destroy raised beds and thus, is not generally a viable option to control a partial corn stand when replanting corn in the Mid-South. Therefore, producers are left with the option to keep the original stand, to replant into the existing stand, or to terminate the undesirable stand with specific herbicides and replant. Many Mid-South growers choose to replant directly into the poor stand because this is an easy, quick, and inexpensive remedy to their issue, compared to destroying the surviving plants.

Intra-planting corn into previously emerged partial stand will create a considerable developmental disparity between the two planting dates. Since corn possesses a determinate growth habit, corn surviving the initial planting will have a significant competitive advantage over the replanted corn to utilize nutrients, water and sunlight. Documentation of corn grain yield response to intra-planting a replant stand is very limited. With increased plant competition, corn plants likely respond by growing taller, which results in smaller-diameter stalks. Consequently, stalk lodging may increase, reducing grain yield. Shauck and Smeda et al. (2014) found competition with initial corn for light and nitrogen reduced replanted corn stalk diameter 8 to 30% relative to the number of plants surviving the initial planting. They reported yield losses of 7 to 58% when corn was intra-planted and concluded that this competition may be related to the availability of nitrogen. Nafziger et al. (1991) reported a 3-week delay in planting 25, 50, or 75% of the plant population in a row caused grain yield losses of 10, 20, and 22%, respectively. They also stated when 25% of the corn stand emerged 1.5 weeks late, yield losses were 6 to 8%. Terry et al. (2012) reported the percent yield contribution from an initial density of 20,000 plants ha^{-1} was 20% greater than the replant stand, showing the competitive advantage of initial corn compared to replanted corn, even at low initial corn densities. Thus, most scientists conclude that producers should destroy partial, inadequate corn stands, prior to replanting, rather than intra-planting into it. (Larson, 2009; Terry et al., 2012; Thompson and Steckel, 2007).

The objective of this research was: 1) to evaluate the productivity of different methods commonly used to replant corn grown in the Mid-South region. These methods include intra-planting into a substandard corn stands. Little research has been conducted to determine specific effects of initial corn on replanted corn. These results will potentially provide justification for implementing a strategy which may present specific management challenges and additional expenses, compared to alternative methods. Corn grown in the Mid-South is commonly grown on prepared, raised beds which restrict management options compared to traditional “Corn Belt” cropping systems.

Materials and Methods

Field experiments were grown at the Mississippi State University R.R. Foil Plant Science Research Center (33.472305° -88.784068°) located near Starkville, MS in 2015 and 2016, at the Black Belt Experiment Station (33.255454° -88.543330°) located near Brooksville, MS in 2015, and at the North Mississippi Research and Extension Center (34.166767° -88.738282°) located near Verona, MS in 2016. Trials were grown in irrigated and a rain fed culture in separate locations at MSU in 2015 and 2016. The Brooksville and Verona locations were both grown in rain fed environments. The 2015 and 2016 rain fed experiments at MSU were planted in Leeper silty clay loam soil (Fine, smectitic, nonacid, thermic Vertic Epiaquepts) (USDA-NRCS Soil Survey Division, 2016). The irrigated experiments were grown in Marietta fine sandy loam soil (Fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts) (USDA-NRCS Soil Survey Division, 2016). The Verona experiment was planted in Marietta loam soil (Fine loamy, siliceous, active, thermic Fluvaquentic) soil (USDA-NRCS Soil Survey Division, 2016). The Brooksville experiment was planted in Brooksville silty clay soil (Fine, smectitic, thermic, Aquic, Hapluderts). The previous crop grown at all locations was soybeans. Soil samples were collected for analyses and fertilizer was applied according to the soil test recommendations for each year and location. Nitrogen (N) was applied at recommended rates for corn grown for either dryland or irrigated culture. Nitrogen was applied in two subsequent or split applications to reduce losses associated with our high rainfall environment. The nitrogen source applied was liquid UAN solution and was injected in the soil with a coulter-knife equipped applicator approximately 20-cm from each row. The first application of N was applied to plants at the 2 to 3 leaf growth stage. The second N application was applied at the 5 to 7 leaf stage. The study grown at Verona had the first N application applied pre-plant. The second application of N was applied at the 2 to 3 leaf stage. A supplemental application of Zn was applied at Verona at a rate of 0.6946 Kg ha^{-1} at the 3 to 5 leaf stage using a CITRI-CHE® ZINC 10% Zn solution using a hooded sprayer. At the Brooksville and Starkville locations, weed competition was controlled using an application of Glyphosate (Roundup PowerMax™, Monsanto Company, St. Louis, MO) and Atrazine, Mesotrione, S-Metolachlor (Lexar® EZ, Syngenta Crop Protection, Greensboro, NC) at recommended labeled rates for glyphosate resistant corn. For the Verona location, weed competition was controlled using an application of Glyphosate (Roundup PowerMax™, Monsanto Company, St. Louis, MO), Dimethylamine salt of dicamba (Banvel®, BASF Corporation, Florham Park, NJ), Rimsulfuron and Thifensulfuron-methyl (DuPont™ Leadoff®, E. I. du Pont de Nemours and Company, Wilmington, DE) and tank mixed with an insecticide Cypermethrin (Battery® 2.5EC, Winfield Solutions, LLC, St. Paul, MN) at recommended label rates. In Starkville, corn was grown on raised beds which were prepared in the fall using a 6 row one trip plow (KBH Corporation, Clarksdale, MS) preceding planting. For the Brooksville study, corn was grown on a convention seedbed prepared using tillage. In Verona, corn was grown on raised beds which were prepared in the fall using a terratill (in-row-subsoil-bed-roller). The raised beds were lightly harrowed with a do-all immediately prior to the initial planting at all locations. Corn was planted 3.81 cm deep using a 4-row John Deere 7100 MaxEmerge vacuum planter (Deere and Co., Moline, IL). The replant was oriented approximately 10 cm from the center of the original row.

The experimental design for each site-year was a randomized complete block design with 4 replications. Dekalb (Monsanto, St. Louis, MO) DKC67-72 corn hybrid was grown in all experiments. Plots consisted of four 0.97 m rows 10.67 m in length. Treatments included a 100% population and three reduced populations planted at a normal and a replant interval. The reduced population treatments consist of 50, 25 and 12% of the desired plant density. Two different series of replanting methods were imposed to evaluate the productivity of intra-planting seed into a partial stand. One series of treatments were implemented to supplement the existing stand to achieve a 100% population. This series of treatments consisted of a 50% initial stand subsequently intra-planted with an additional 50%, a 25% initial stand subsequently intra-planted with an additional 75%, and a 12% initial stand subsequently intra-planted with an additional 88%. The other series of treatments were replanted with a 100% population regardless of the partial stand. This series of treatments consisted of 50%, 25%, and 12% initial stands each subsequently intra-planted with an additional 100% (Table 3.1). These replanting and intra-planting treatments were performed when the initial stands reached V2-V3 growth stage, consistent with the normal timing of a production replanting scenario. All plots were hand thinned to attain desired populations.

Treatments were added in 2016 to address whether plant spacing variability would affect corn productivity relative to these replanting methods. Two series of treatments were established to evaluate effects of uniform-spaced reduced populations, compared to similar plant density with variable plant spacing. Each series consisted of an initial stand of variable-spaced plants grown at 50%, 25%, and 12% of the optimal plant density. One series consists of these three variable-spaced densities planted at the initial planting with no intra-plant component. The other series consists of these three variable-spaced densities intra-planted with a full 100% population.

After corn tasseled and vegetative growth was complete, plant growth characteristics of each planting date were measured. Stalk diameter of the widest point below the first node above ground, overall plant height, and ear height from the soil surface was recorded. The middle two rows of each plot were harvested, and grain was shelled and weighed with a Kincaid 8-XP research plot combine (Kincaid Equipment Manufacturing, Haven, KS). Grain moisture and test weight were measured using a Perten AM 5200-A Certified Grain Moisture Tester (Perten Instruments AB, Hägersten, Sweden). Grain weights were measured and adjusted to the standard corn moisture content of 15.5% to calculate grain yield.

An economic analysis was also performed using data from this experiment to add real world value to this study. Grain yields from each year were used in conjunction with the prices of each of the following parameters; corn grain price, hybrid corn seed price, planting cost, and stand termination cost. The corn grain prices used to calculate gross revenue for each treatment in this study are \$3.63 per bushel for 2015 and \$3.21 per bushel for 2016. These are the average prices for #2 yellow corn delivered to Greenwood, MS during September 2015 and September 2016 (Mississippi Daily Grain Report). Seed price was based upon the hybrid planted, DEKALB DKC-67-72, which possessed Genuity® VT Double Pro® traits (Cry1A.105 + Cry2Ab2, Monsanto Company, St. Louis, MO). This corn also contained the Roundup Ready® 2 Technology (Monsanto Company, St. Louis, MO). This hybrid corn seed was treated with Acceleron insecticide seed treatment (Clothianidin (Poncho®) 500 (0.5 mg AI / seed), *Bacillus firmus* (VoTivo®)), Bayer CropScience, Research Triangle Park, NC) and fungicides Prothioconazole, Metalaxyl, and fluoxastrobin. Corn seed expense was applied to all 17 treatments for both planting intervals. Some seed companies may offer discounts for replanted corn; however, rates are not consistent, thus full seed expense was used throughout this analysis. An herbicide application is generally required terminate a failed corn stand in the Mid-South region of the U.S. where most corn is grown on raised beds. Using tillage to kill remaining plants in a failed stand is not a viable management option, because it would destroy the raised beds as well. The preferred herbicide to use for termination a failed stand of Roundup Ready® 2 corn is SelectMax®, Valent U.S.A Corporation applied 6 ounces per acre plus 0.25% Non-Ionic Surfactant. The stand termination herbicide application was broadcast applied with a 40-foot boom attached to a tractor. The stand termination cost was only used for the four replant treatments. Seed price, planting cost, herbicide application cost, herbicide price, and surfactant price were obtained from the 2016 Delta Planning Budgets (MSU Department of Agricultural Economics Budget Report 2015–05, October 2015) and 2017 Delta Planning Budgets

(MSU Department of Agricultural Economics Budget Report 2016–05, October 2016). Cost estimates for a reseeding rate of 34,000 seeds in 2015 are shown in Table 3.2, with cost estimates for a reseeding rate of 34,000 seeds in 2016 shown in Table 3.3. The reseeding rate of 34,000 seeds was chosen for worst case scenario, replanting a full stand at full price. In some cases, the replanted stand may not be planted at the full rate, which are not listed in Table 3.2 or Table 3.3. Thus, for reduced replant seeding rates, simply multiply seed cost per thousand seeds times the rate used. The relative costs that compose the total replanting expense are herbicide cost, surfactant cost, the herbicide application, planting cost and seed cost. The total replant costs are the combination of all five variables. The five variables are listed in Table 3.2 for 2015 and Table 3.3 for 2016.

Statistical analyses of the data were analyzed with the General Linear Model (GLM) procedure in SAS 9.4 (SAS Institute, Inc., Cary, NC). Location was considered as a random effect while treatment was considered a fixed effect. Comparisons of treatments were made by calculating Least Square Means (LSMEANS), standard error (STDERR) and the probability of difference (PDIFF) between treatment means. A protected LSD ($p \leq 0.05$) was used in mean comparisons.

Results and Discussion

Grain Yield

An analysis of corn grain yields was performed to evaluate various corn replanting methods. Initial analysis indicated no significant difference across environment, year and treatment. Thus, data was combined across locations and years for subsequent analyses. The Brooksville location suffered drought and poor growing conditions, thus it was not included in this analysis.

The 100% initial or control stand produced 11,326 kg ha^{-1}. The similar 100% treatment planted at the replanting interval achieved a mean grain yield of 11,116 kg ha^{-1}. The analysis showed the yield of the 100% replant stand was statistically greater than the six intra-planting treatments (Table 3.4). There were no significant yield differences among the six intra-planting treatments, or two different intra-planting methods. Thus, neither of the two intra-planting methods, an initial stand supplemented with a replant to achieve a 100% stand, proved to be more productive than the other compared to an initial stand replanted with a 100% stand. Intra-planting reduced corn yield by a mean of 11% or range of 8-13%, compared to replanting a full stand. These results indicate that a grower should completely terminate a substandard stand prior to replanting, rather than intra-plant into any remaining live corn plants. This finding is like those by Terry et al. (2012) and Nafziger et al. (1991).

Corn grain yield was significantly reduced for the three sub-optimal plant populations ranging from 12% to 50% of the desired plant density. However, corn did demonstrate some ability to compensate grain yield, relative to the degree of stand reduction. The 50% initial density produced 77% of the grain yield compared to the 100% initial density (Table 3.4), considerably higher than found by Farnham (2001). The 25% initial density treatment produced 54% of the grain yield compared to the control. The 12% initial density treatment produced 30% of the yield compared to the control.

In 2016, six additional treatments were added to evaluate if random plant spacing affected corn agronomic performance when grown at low plant density, compared to uniform spacing. Treatments consisting of 50%, 25%, and 12% uniform plant density were evaluated, compared to similar plant densities consisting of randomly-spaced plants.

The analysis did not indicate any statistical difference among similar treatments with random spacing compared to uniform-spaced plants (Table 3.5).

Economic Analysis

An economic analysis was also performed to determine how replanting methods affect the final returns of investment. There was no significant interaction between environment, year and treatment. Thus, data was combined across locations and years. The Brooksville location suffered drought and poor growing conditions, thus it was not included in the economic analysis. The Budget Report for 2015 and 2016 from the Mississippi State University Agricultural Economics department (Corn Planning Budgets, 2015; Corn Planning Budgets, 2016) was used in determining the final returns of investment.

The 100% replant treatment produced a mean net return of $883.25 per hectare. Intra-planting treatments generally produced net returns less than the 100% replant. Two of the intra-planted treatments supplemented to achieve a 100% stand (50% + 50% and 12% + 88%) produced returns statistically similar to the 100% replant treatment. However, the other intra-planted treatment supplemented to achieve 100% stand suffered a significant economic loss ($101.91 per hectare) compared to replanting. All three of the intra-planted treatments supplemented with a 100% replant produced significant negative returns. While the yields were similar for both intra-planting methods, seed cost had a significant impact on net returns. Considerable seed expense was saved for intra-planted treatments which were supplemented to achieve a 100% stand, compared to replanting with a 100% stand. However, intra-planting to achieve a 100% stand still reduced economic return for one of the treatments comprising this replanting method. Therefore, when replanting is justified, the most practical method a grower can employ, is to completely terminate a substandard stand prior to replanting, rather than intra-plant into any remaining live corn plants. The mean net returns ha^{-1} of all treatments is shown in (Table 3.6).

Plant Characteristics

An analysis was performed to compare stalk diameters of corn planted during the initial planting and replanted later. Analysis indicated no significant difference across location, year, and treatment. Therefore, data is presented for all locations and years collectively for stalk diameters. Larger stalk diameters were found on the corn grown at low plant density (25 or 12% stands). This compensation is expected when corn is grown at far sub-optimal plant densities, when plants have abundant space and resources available. Conversely, intra-planting significantly stunted smaller stalk diameters of the replanted corn. This is because the remaining plants from the initial stand are 3-4 growth stages more advanced, compared to the replanted corn. Thus, intra-planted plants have an extreme competitive disadvantage relative to the remaining plants from the initial stand. Table 3.7 illustrates mean stalk diameters (mm) for each treatment and the statistical significance.

Additional data was measured to compare final plant heights (m) of the initial corn and the replanted corn. Analysis indicated no significant difference across location, year and treatment; therefore, data was combined across locations and years. Initial plants tended to be taller, compared to the replanted corn. The shortest corn was found on the replanted corn intra-planted into substandard initial stands. Corn replanted into a clean seedbed was taller than all intra-planted treatments Thus, intra-planting significantly stunted final plant height compared to replanting into a clean seed bed. Table 3.8 illustrates mean plant heights (m) for each treatment and the statistical significance.

Conclusions

This research suggests that if a stand of corn is not adequate and needs to be replanted, growers should kill any remaining plants prior to replanting corn. Replanting corn into a clean seedbed was 11% more productive than intra-planting into an existing stand. Our evaluation of two different intra-planting methods, differing in seeding rate, produced no significant grain yield difference between the two methods. Intra-planted corn was less productive than normal stands likely due to significant competition resulting from a 3-4 leaf stage development disparity. This conclusion is supported by results showing reduced stalk diameters and plant height for intra-planted treatments, compared to normal stands. These results reiterate the importance of terminating substandard initial stands, when replanting is necessary.

Table 3.1 Description of replanting method treatments used in irrigated replant experiments 2015 and 2016.

Corn Replant Experiment

		Treatment	Initial Density (%)	Replant Density (%)
			-----plants ha^{-1}-----	
No Intra-Planting	Normal Interval	100	83,951	n/a
		50	41,975	n/a
		25	20,988	n/a
		12	10,494	n/a
	Replant Interval	100	n/a	83,951
		50	n/a	41,975
		25	n/a	20,988
		12	n/a	10,494
Intra-Planted	Supplemental	50+50	41,975(50)	41,975(50)
		25+75	20,988(25)	62,963(75)
		12+88	10,494(12)	73,457(88)
	Full replant	50+100	41,975(50)	83,951(100)
		25+100	20,988(25)	83,951(100)
		12+100	10,494(12)	83,951(100)

Table 3.2 2015 Replant Cost Calculation for Replanting with an 84,000 ha-reseeding rate.

Item	Unit	Price	Quantity Used	$ per ha
Select Max	liter	26.10	0.438	11.43
Surfactant	liter	11.31	0.234	2.65
Herbicide Application	hectare	8.47	1	8.47
Planter	hectare	23.54	1	23.54
Seed	thousand	3.27	84	274.68
Total				320.77

Table 3.3 2016 Replant Cost Calculation for Replanting with an 84,000 ha-reseeding rate.

Item	Unit	Price	Quantity Used	$ per ha
Select Max	liter	31.68	0.438	13.88
Surfactant	liter	7.80	0.234	1.82
Herbicide Application	hectare	8.27	1	8.27
Planter	hectare	23.34	1	23.34
Seed	thousand	3.89	84	326.76
Total				374.07

Table 3.4 Corn grain yield as affected by initial plant stand and replanting method in 2015 and 2016 at all locations.

Initial	**Replant**	**Yield**	***Yield reduction to control (100% initial)**	**Yield reduction to 100% Replant**
--------% plant stand--------		kg ha^{-1}-T-group		
100	0	11326 A		
50	0	8719 C	23%	
25	0	6082 D	46%	
12	0	3356 E	70%	
50	50	9851 B	13%	11%
25	75	9646 B	15%	13%
12	88	10193 B	10%	8%
50	100	9861 B	13%	11%
25	100	9699 B	14%	12%
12	100	10079 B	11%	9%
0	100	11116 A	2%	
0	50	8566 C	24%	
0	25	5961 D	47%	
0	12	3336 E	71%	

Means within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 3.5 Corn grain yield as affected by randomly-spaced assorted plants compared to uniform -spaced plants in 2016 at all locations.

Treatment	Yield --kg ha^{-1}—	T - Group
Evenly Spaced		
50% initial	8602	B
25% initial	6243	C
12% initial	3825	D
Random Spaced		
50% initial	8463	B
25% initial	5801	C
12% initial	2915	D
Evenly Spaced		
50% initial + 100% replant	9655	A
25% initial + 100% replant	9410	AB
12% initial + 100% replant	10104	A
Randomly Spaced		
50% initial + 100% replant	9676	A
25% initial + 100% replant	9710	A
12% initial + 100% replant	9732	A

Means within a column followed by the same letter are not significantly different according to an LSD test ($P = 0.05$).

Table 3.6 Mean Net Return ha^{-1} of all treatments at all locations in 2015 and 2016.

TREATMENT	INITIAL	REPLANT	NET RETURN
	--------% plant stand--------		\$ ha^{-1}
1	100	0	1,236.49 A
2	50	0	887.40 B
3	25	0	533.98 F
4	12	0	168.44 H
5	50	50	879.81 B
6	25	75	781.34 CD
7	12	88	816.50 BC
8	50	100	743.55 D
9	25	100	722.72 D
10	12	100	770.21 CD
11	0	100	883.25 B
12	0	50	613.56 E
13	0	25	402.98 G
14	0	12	88.33 I

Means within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 3.7 Analysis results comparing stalk diameters (mm) of initial corn and replanted corn for all locations in 2015 and 2016.

Plant	Treatment	Initial %	Replant %	Stalk Dia. (mm)	t GROUP
Initial	1	100	0	20.1763	G
Initial	2	50	0	23.8044	EF
Initial	3	25	0	27.3084	ABC
Initial	4	12	0	28.9322	A
Initial	5	50	50	23.5247	F
Replant	5	50	50	10.8256	I
Initial	6	25	75	26.5472	BCD
Replant	6	25	75	12.7556	I
Initial	7	12	88	27.53	AB
Replant	7	12	88	14.755	H
Initial	8	50	100	23.8928	EF
Replant	8	50	100	10.8178	J
Initial	9	25	100	25.83	CD
Replant	9	25	100	12.6184	I
Initial	10	12	100	27.7887	AB
Replant	10	12	100	14.8222	H
Replant	11	0	100	19.7347	G
Replant	12	0	50	23.8838	EF
Replant	13	0	25	25.2888	DE
Replant	14	0	12	26.7547	BCD

Stalk diameters within a column followed by the same letter are not significantly different according to an LSD test (P = 0.05).

Table 3.8 Analysis results comparing final plant heights (m) of initial corn and replanted corn for all locations in 2015 and 2016.

Plant	Treatment	Initial %	Replant %	Height (m)	t GROUP
Initial	1	100	0	2.4506	ABCD
Initial	2	50	0	2.4873	A
Initial	3	25	0	2.4075	ABCD
Initial	4	12	0	2.3463	CDEF
Initial	5	50	50	2.4467	ABCD
Replant	5	50	50	2.0772	I
Initial	6	25	75	2.4058	ABCD
Replant	6	25	75	2.176	GHI
Initial	7	12	88	2.3406	DEF
Replant	7	12	88	2.235	FGH
Initial	8	50	100	2.4603	ABC
Replant	8	50	100	2.0766	I
Initial	9	25	100	2.3706	BCDE
Replant	9	25	100	2.1477	HI
Initial	10	12	100	2.3548	CDE
Replant	10	12	100	2.2684	EFG
Replant	11	0	100	2.5193	A
Replant	12	0	50	2.4831	AB
Replant	13	0	25	2.4261	ABCD
Replant	14	0	12	2.368	BCDE

Plant heights within a column followed by the same letter are not significantly different according to an LSD test ($P = 0.05$).

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APPENDIX A

STATISTICAL ANALYSIS REFERENCES TO TABLES

Table A.1 ANOVA for the effect of main effects on corn stalk diameter (mm).

SOV	Df	F	*P* > F
Location	2	74.02	<.0001
Delay	3	16.98	0.0003
Location*Delay	6	0.34	0.9157
Pattern	3	10.80	<.0001
Location*Pattern	6	2.71	0.0137
Delay*Pattern	9	2.02	0.0555
Location*Delay*Pattern	18	1.62	0.0516

* Significant at (p≤0.05)

Table A.2 ANOVA for the effect of main effects on corn plant height (m).

SOV	Df	F	*P* > F
Location	2	356.38	<.0001
Delay	3	13.45	<.0001
Location*Delay	6	2.45	0.0245
Pattern	3	6.64	0.0002
Location*Pattern	6	3.66	0.0015
Delay*Pattern	9	2.23	0.0593
Location*Delay*Pattern	18	1.49	0.0873

* Significant at (p≤0.05)

Table A.3 ANOVA for the effect of emergence delay on yield component rows per ear.

SOV	Df	F	*P* > F
Location	3	24.06	<.0001
Delay	3	31.13	<.0001
Location*Delay	9	3.71	0.0001
Pattern	3	5.00	0.0018
Location*Pattern	9	2.37	0.0115
Delay*Pattern	9	3.23	0.1006
Location*Delay*Pattern	27	1.19	0.2251

* Significant at (p≤0.05)

Table A.4 ANOVA for the effect of emergence delay on yield component kernels per row.

SOV	Df	F	*P* > F
Location	3	236.75	<.0001
Delay	3	93.51	<.0001
Location*Delay	9	7.68	<.0001
Pattern	3	27.88	<.0001
Location*Pattern	9	3.9	<.0001
Delay*Pattern	9	2.23	0.0577
Location*Delay*Pattern	27	2.27	0.2002

* Significant at ($p \leq 0.05$)

Table A.5 ANOVA for the kernel weight response to emergence delay.

SOV	Df	F	*P* > F
Location	3	134.39	<.0001
Delay	3	3.84	0.0096
Location*Delay	9	5.60	<.0001
Pattern	3	1.49	0.2154
Location*Pattern	9	1.04	0.4063
Delay*Pattern	9	0.29	0.9784
Location*Delay*Pattern	27	1.42	0.0789

* Significant at ($p \leq 0.05$)

Table A.6 ANOVA for corn grain yields as affected by main effects compared to a uniform control.

SOV	Df	F	*P* > F
Location	2	162.27	<.0001
Delay	3	46.41	<.0001
Location*Delay	6	2.20	0.0421
Pattern	3	12.32	<.0001
Location*Pattern	6	1.02	0.4141
Delay*Pattern	9	1.80	0.0663
Location*Delay*Pattern	18	0.74	0.7703

* Significant at ($p \leq 0.05$)

Table A.7 ANOVA for the effect of delayed emergence on cumulative grain yields.

SOV	Df	F	*P* > F
Con_vs_Trt	1	19.85	<.0001
Con_vs_Trt*Location	6	19.48	<.0001
Con_vs_Trt*Delay	3	29.62	<.0001
Con_vs_Trt*Pattern	3	1.35	0.2569
Con_*Loca*Delay*Pattern	27	0.48	0.9863

* Significant at ($p \leq 0.05$)

Table A.8 ANOVA for corn grain yield as affected by initial plant stand and replanting method.

SOV	Df	F	*P* > F
Environment	1	218.94	<.0001
Year	1	9.33	0.0025
Environment*Year	1	4.33	0.0386
Treatment	13	171.83	<.0001
Environment*Treatment	13	2.39	0.0051
Year*Treatment	13	1.90	0.0308
Environ*Year*Treatment	13	1.00	0.4559

* Significant at ($p \leq 0.05$)

Table A.9 ANOVA for corn grain yield as affected by randomly-spaced assorted plants compared to uniform- spaced plants.

SOV	Df	F	*P* > F
Environment	1	175.31	<.0001
Treatment	19	78.78	<.0001
Environment*Treatment	19	2.33	0.0520

* Significant at (p≤0.05)

Table A.10 ANOVA for mean net return ha-1 of all treatments.

SOV	Df	F	*P* > F
Environment	1	92.10	<.0001
Year	1	133.32	<.0001
Environment*Year	1	0.53	0.4661
Treatment	13	134.33	<.0001
Environment*Treatment	13	1.98	0.0235
Year*Treatment	13	4.32	<.0001
Environ*Year*Treatment	13	0.95	0.4986

* Significant at (p≤0.05)

Table A.11 ANOVA for comparing stalk diameters (mm) of initial corn and replanted corn.

SOV	Df	F	*P* > F
Location	1	0.65	0.4211
Treatment	13	90.38	<.0001
Location*Treatment	13	1.39	0.1626
Plant	1	1492.85	<.0001
Location*Plant	1	3.50	0.0621
Treatment*Plant	5	0.28	0.9228
Location*Treatment*Plant	5	0.70	0.6237

* Significant at (p≤0.05)

Table A.12 ANOVA for comparing final plant heights (m) of initial corn and replanted corn.

SOV	Df	F	*P* > F
Location	1	51.32	<.0001
Treatment	13	11.51	<.0001
Location*Treatment	13	0.14	0.9999
Plant	1	83.71	<.0001
Location*Plant	1	11.91	0.0006
Treatment*Plant	5	5.74	<.0001
Location*Treatment*Plant	5	0.18	0.9687

* Significant at ($p \leq 0.05$)