EVALUATION OF NARROW ROW SOYBEAN PRODUCTION AND TWIN-ROW PLANTER ERRORS FOR FURROW IRRIGATED SOYBEAN IN MISSISSIPPI

By

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

Mississippi State, Mississippi

May 2018

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Pages in Study 38

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The majority of irrigated soybean in Mississippi are planted on raised beds spaced 100 cm apart, in single row arrangement. Recently, there has been interest in growing soybean on narrower rows (< 100 cm), compared to the conventional wider rows, historically used for cotton production. Previous research indicates that narrower row spacing can provide advantages over wider arrangements including increased light interception through rapid canopy closure, improved weed control, and potentially greater seed yield. Furthermore, when using narrow row planting equipment, such as twin row planter, there is increased opportunity for planting errors. Therefore, the purpose of this study was to evaluate multiple row spacing choices for furrow irrigated soybean and to evaluate the effects of multiple twin-row planter errors in Mississippi.

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DEDICATION

First of all, I would like to thank God for providing undeserved opportunities throughout my life. Especially for my parents, Richard and Kathy. All that I am, or hope to be, I owe to my parents. Your teaching, guidance, protection and providence has led me to this point and will continue long after you're gone.

I've been fortunate with finding great friends, some before I can remember. I owe a lot to the Hydrick family, especially Tyler and Bobbi. Their kindness and generosity made my move to Mississippi a breeze. Family is not always blood.

My major advisor and dear friend, Dr. John Orlowski, holds wisdom far beyond his years. Thank you for your loyalty and many kindnesses through our time together. You have gone far beyond your call of duty, doing more than others expect, even after expected. Your success in life is inevitable.

ACKNOWLEDGEMENTS

A very special gratitude goes out to all Mississippi soybean producers and the Mississippi Soybean Promotion Board for graciously funding this research as well as my Master’s coursework at Mississippi State University. I am thankful for opportunities and lessons provided through my time in Mississippi. I feel honored to share a building and research station with world renowned scientists. Particularly to my graduate committee, thank you for the motivation and guidance in completing this life goal. Additionally, I could not have completed the magnitude of this research without the time dedicated by Hank Panton, Katelynn Carpenter, Jake Keith, Parker Harris and Hunter Sullivan. I am appreciative of the manuscript preparation advice from Drs. Larry Falconer and Gurpreet Kaar. Additionally, I would like to thank my fellow graduate students, especially Justin “Timmy” Smith and Kyle Lassiter for the countless stories while traveling between Stoneville and Starkville. And my office mate, Wilks Wood, for being my writing and SAS coach. And finally, I would not be writing this thesis without the opportunities provided by my friend and past advisor, Dr. Michele Reba.

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CHAPTER I

DEVELOPMENT OF A NARROW ROW PRODUCTION SYSTEM FOR FURROW IRRIGATED SOYBEAN IN MISSISSIPPI

Mississippi Soybean Production

Soybean [Glycine max (L.) Merr.] is the most abundant and consumed oilseed crop produced globally (Hymowitz, 2004). Soybean originated in China and were first planted in the United States in 1765 (N. Carolina Soybean Producers Association, Inc., 2014). Increased economic prosperity following World War 2 led to improved diets with greater meat consumption and increased demand for livestock feed. Soybeans are primarily used for livestock feed and also account for 35% of the world oilseed production (Wilcox, 2004). Soybean is currently the largest acreage row crop in Mississippi covering 826,000 ha in 2016 (National Agricultural Statistics Service, 2017). Current Mississippi production practices utilize the early soybean production system (ESPS) (Heatherly and Hodges, 1999). Planting shorter season maturity group IV and maturity group V cultivars in April or May compared to the more traditional practice of planting maturity group VI and maturity group VII later in the growing season has led to seed yield increases. Earlier planting helps to initiate reproductive development before the risk of mid-summer droughts and late-season insect pressure (Hoeft et al., 2000).

The Mississippi Delta has historically been a cotton producing region. Prior to mechanical cultivation with tractors, 100 cm row spacing were used to allow mules to move between rows for cultivation (Clark and Carpenter, 1992). Multi-row equipment was later developed that followed the standard 100 cm row spacing (Clark and Carpenter, 1992). Mississippi Cotton hectareage has declined by 89% while soybean hectareage has increased 96% from 1930 to 2017 (NASS, 2017). Despite the switch from cotton to soybean, a largely different crop type, the single 100 cm row spacing used is cotton is still the most prevalent type used in soybean production today. A state survey conducted in 2016 determined 42% of Mississippi soybean producers use a row spacing greater than 76 cm (MSPB, 2017), which is the most prevalent row spacing in other major soybean producing areas, particularly the Midwestern United States. Research from other U.S. soybean producing regions has shown consistent seed yield advantages for soybean produced in narrow rows (De Bruin and Pedersen, 2008; Taylor et al., 1982; Devlin et al., 1995; Elmore, 1998; Mickelson and Renner, 1997; Nelson and Renner, 1998; Swanton et al., 1998).

Light Interception and Seed Yield

Each unit of land is limited to a finite amount of sunlight, however, radiation use efficiency can be improved by modification of row spacing and seeding rate (Elgi, 1998). Maximizing the crops ability to capture solar radiation is necessary for maximizing seed yield (Shibles and Weber, 1966). Soybean seed yield is more closely correlated to seed number per unit area, as compared to seed weight. (Egli, 1998). Moreover, seed number is directly correlated to the amount of solar radiation intercepted by each unit of land (Egli, 1998; Gardner et al., 1985). Improved capture of solar radiation leads to greater dry matter accumulation (Gardener et al., 1985; Shibles and Weber, 1966). Greater dry-matter accumulation during vegetative growth and at pod set contributes to partitioning to reproductive structures (Andrade et al., 2002). Andrade et al. (2002) and Egli (1998) suggest that seed yield increases are closely related to increased solar radiation at physiological development stages known as pod set. Van Roekel et al., (2015) reports that any stress, including lack of light, during early reproductive growth stages (R1 to R5) that decreases biomass accumulation results in lesser seed yield due to increased pod abortion (Board and Harville, 1993; Egli, 1993; Egli, 1998; Board and Tan, 1995). Therefore, improvements of light interception during early reproductive stages result in greater pod set and less pod abortion under an ideal environment. Soybeans planted into narrow rows have been reported to develop full canopies earlier than those in wide rows (Heatherly, 1999; Shibles et al., 1974; Taylor et al., 1982). As the total plant population increases, each individual plant intercepts less solar radiation; however, the amount solar radiation intercepted by the crop community increases (Ethredge et al., 1989). Equidistant plant spacing is improved with narrow rows by reducing intraspecific competition for sunlight while increasing interception (Burnside and Colville, 1964; Shibles and Weber, 1966). Aside from intercepting more sunlight, the faster canopy closure of narrow rows can also reduce weeds, soil temperature, and soil evaporation. (Hoeft et al, 2000).

Another potential benefit of converting to narrow row spacing is weed suppression (Buhler and Hartzler 2004). Weeds compete with soybeans for sunlight, nutrients, and water (Hoeft et al., 2000; Buhler and Hartzler, 2004). The rapid canopy closure achieved by narrow row spacing can limit weed seed germination and growth (Yelverton and Coble, 1991). Weed seeds in a dormant state can be activated by environmental factors that are indirectly attributed to row spacing and seeding rate decisions. Temperature is a critical factor in weed seed germination. An unprotected soil that is exposed to variations in temperature (day to night) promotes germination, seedling growth and vigor in some plants (Guillemin et al., 2012; Baskin and Baskin, 1984; Baskin and Baskin, 1988). Similar to temperature, light quality is a critical factor that regulates seed germination and vigor in many weed species (Baskin and Baskin, 1988). Weed suppression in the presence of a complete soybean canopy is primarily a result of poor light quality (Schonbeck, 2015). Plants are naturally exposed to many wavelengths of light. Of which, red (622-780) and far-red (710-850) light are of most importance to this research. A complete canopy dilutes some portion of red light from reaching plants and soil below. Red light is preferred by plants, where far-red light is typically reflected or diluted as it penetrates the canopy (Kasperbauer, 1987). The lack of red light and abundance of far-red light reaching below a canopy serves as an environmental indicator of neighboring competition for plants and viable seed (Green-Tracewics et al., 2011). Development of herbicides and application technology provides producers an option to control weeds in a narrow row system, generally resulting in improved weed control compared to wide rows (Harder et al., 2007; Nice et al., 2001; Mickelson and Renner 1997; Dalley et al., 2004).

Seeding rate reduction is commonly used to reduce input costs. Seeding rates should be 20 to 40% greater for narrow row compared to wide row soybean (Bertram and Pedersen, 2004. Alternatively, Kratochvil et al. (2004) observed consistent seed yield when planting soybean at 20% less than the recommended seeding rate for 19 and 38 cm row spacing leading to profit of \$14 and \$28 ha^{-1} compared to the recommended rate. Bertram and Pedersen (2004) reported no seed yield loss when recommended seeding rates of 556,000, 432,000, and 309,000 seeds ha^{-1} were reduced by 20% at row spacings of 19, 38, and 76 cm, respectively. Oplinger and Philbrook (1992) found an interaction between row spacing and seeding rate where increased seeding rate led to increased seed yield in narrow compared to wide rows. A study by Cox and Cherney in 2011 found no interaction between row spacing and seeding rate.

Northern U.S.

Research from other soybean producing regions in the U.S. have shown yield advantages associated with narrow rows. Previous work by Harder et al. (2007) evaluated the effects of soybean row spacing and seeding rate on seed yield in Michigan during the 2004 and 2005. Treatments consisted of rows spacing of 19, 38, and 76 cm at seeding rates of 198,000, 296,000, and 445,000 plants ha^{-1}. Canopy closure measurements showed greater leaf area index (LAI) for row spacing of 19 and 38 cm compared to 76 cm. Rows spaced 19 and 38 cm had similar canopy development at each seeding rate. In addition, seeding rate had no effect on canopy development in 76 cm rows. Soybeans planted in 19 cm rows yielded 4% greater than those planted in 38 cm and 16% greater than in 72 cm.

A regional study was assembled in Ohio, Nebraska, Iowa and Indiana during 1994 and 1995 by Hammond et al. (2000) to determine if increased LAI associated with narrow row spacing can reduce yield loss from insect defoliation. Row spacings of 76 cm (wide), 38 cm (moderate) and 19 cm (narrow) were compared at seeding rates of 276,000, 294,000, and 325,000 plants ha^{-1}, respectively. Leaves were manually removed to imitate insect defoliation beginning at R3 growth stage at three treatment levels. Light interception was determined throughout the growing season by a LI-191 SA line quantum sensor (LI-COR Biosciences, Lincoln, NE). Seven of 28 situations in 1994 and 12 of the 28 situations in 1995 showed LAI variation with row width. Weak interaction between LAI, insect defoliation, and seed yield provides no necessitating evidence for varying insect treatment thresholds across row spacings. However, thresholds that are based on quantity of foliage feeding insects per unit area, instead of percent defoliation, would likely result in increased threshold for narrow rows.

Field experiments were conducted in Kansas to investigate optimum row spacing and seeding rates in historically low, medium, and high yield environments (Devlin et al, 1995). Eleven non-irrigated field studies were arranged to compare narrow (20 cm) and wide (76 cm) row spacing in combination with high and low seeding rates. Results showed that narrow rows behaved differently than wide rows at high seeding rates. Narrow rows resulted in greater seed yield than wide rows in historically high-yielding environments. Narrow rows in historically high yielding environments achieved greatest yield when combined with high seeding rates. Wide rows yielded greater than narrow rows with low seeding rates. Narrow rows yielded greater than wide rows at seeding rates $\geq$ 375,000 seeds ha^{-1}; however, wide rows yielded greater than narrow rows at $\leq$ 375,000 seeds ha^{-1}. Seeding rate effect on yield differed between historically medium and high yielding environments. Narrow and wide rows yielded similarly at 375,000 seeds ha^{-1}; however, wide rows yielded greater than narrow rows when combined with low seeding rate. Wide rows consistently yielding greater than narrow rows at all seeding rates in historically low yielding environments. Narrow rows yielded greater than wide rows at locations where adequate soil moisture was present during reproductive growth stages. Wide rows yielded greater than narrow rows where insufficient soil moisture was evident. Narrow row yield advantages could be consistently obtained in absence of drought during critical growth stages, such as under irrigated conditions in Mississippi.

Experiments were conducted by De Bruin and Pedersen (2008) to determine how row spacing affects seed yield and economic returns in Iowa. The 38 cm (narrow) and 76 cm (wide) row spacings were paired with seeding rates of 185,000, 309,000, 432,000, and 556,000 seeds ha^{-1}. Narrow row spacing yielded an average 248 kg ha^{-1} greater than wide rows. A budget analysis compared three farm sizes, possible corn-soybean rotation methods, production and equipment cost. Although narrow row adopters must initially acquire a split-row planter, potential economic gain outweighs the cost of additional equipment for the majority of farm sizes. Transition to narrow row spacing would only be economical on operations larger than 144 ha with at least 30% of land dedicated to soybean production.

Research in New York by Orlowski et al. (2012) investigated the effect of row spacing and seeding rate on soybean growth, seed yield, and economics. Field scale studies were conducted on two farms during 2011 and 2012. Treatments consisted of three row spacings (19, 38, and 76 cm) and two seeding rates (321,000 and 420,000 seeds ha^{-1}). Plant population data was collected at V2 growth stage. Light interception data was collected at R1. Seed samples and seed yield data were collected at harvest. Seed yield increased 160 kg ha^{-1} under conventional tillage when soybeans were planted by grain drill (19 cm row spacing and 420,000 seeds ha^{-1}) compared to the row crop planter (76 cm spacing and 321,000 seeds ha^{-1}). A partial budget approach evaluated the interaction between row spacing and seeding rate to determine the most economical planting method. Reduced seed cost was observed when using a row crop planter (76 cm row spacing and 310,000 seeds ha^{-1}) compared to planting with a grain drill (19 cm row spacing and 420,000 seeds ha^{-1}); however, cost of weed control with the row crop planter exceeded the grain drill. A budget analysis determined that grain drill costs can be offset by increased profit from yield increases when at least 250 ha of land is dedicated to soybean production.

Narrow row soybean production has been reported to provide seed yield advantages over conventional wide rows; however, the benefit of narrow rows can be inconsistent depending on environmental conditions and management practices. A three year Nebraskan study by Graterol et al. (1996) was conducted to determine if soybean planted in narrow (25 cm) and twin row (paired rows, 25 cm from each other, and 50 cm from other pairs) systems could provide seed yield advantage over wide (76 cm) row systems. Narrow and twin row seed yield was 6% and 8% greater than wide rows in site-years with adequate supply and ideal distribution of water. In a year without ideal supply and distribution of water, wide rows yielded 6% and 9% greater than twin and narrow rows, respectively. The study concluded that seed yield advantages are dependent on adequate soil-water availability during early reproductive growth.

Southern U.S.

Twin row production has gained popularity in recent years. Twin row planting consists of two rows spaced 19 cm apart planted on each bed, centered at 100 cm. A two-year survey was conducted in 2015 and 2016 that shows 22% of Mississippi soybean producers use the 100 cm twin row planting system (MSPB, 2017). Bruns (2011) conducted an experiment at two locations in Stoneville, MS on two differing soil types to determine if the increase equipment cost associated with the adoption of the twin-row planting configuration is economical for soybean producers in the region when utilizing the Early Soybean Production System. Furrow irrigated maturity group IV soybeans were planted in single and twin row arrangements at seeding rates of 200,000, 300,000, 400,000 and 500,000 seeds ha^{-1}. Twin row resulted in greater stand establishment at R4 than single row and seed yields were reduced as planting was delayed at all seeding rates and soil types. However, seed yields were greater at all planting dates and seeding rates with twin compared to single row. The increase in seed yield for the twin rows resulted in an increased profit of \$75.00 ha^{-1} based on 2010 soybean prices. This research suggests transition to a twin row system is a profitable option for operations with a large land base dedicated to soybean production.

Other southern U.S. studies have examined soybean row spacing. Bowers et al. (2000) conducted experiments in Texas, Louisiana, and Arkansas across multiple soil types from 1984 to 1997 to determine if narrow row spacing affects seed yield in the ESPS. A total of twenty-one experiments were conducted. Of which, seven tests compared row widths of 40 cm and 80 cm; six test compared row widths of 25, 50 and 75 cm; four tests compared row widths of 25, 50, and 100 cm; and three tests compared row widths of 25 and 100 cm. Maturity group III to IV indeterminate cultivars were planted. Narrow row spacing in certain environments produced greater seed weight. Conversely, some locations provided evidence that seeds have greater seed mass when grown in wider rows. At two locations the 80 cm row spacing showed an 8 and 9% seed yield increase over those produced in the 40 cm rows. Another location showed opposite results with 40 cm row spacing seed yielding 7% more than 80 cm.

The same authors also investigated the effects of various seeding rates on narrow rows in Louisiana (Bowers et al., 2000). They found seed yield advantages associated with row spacing could be confounded by planting population. Among a series of environments, narrow row spacing seed yield was equal or greater than that of wide row spacing. This study suggest that yield was optimized when using the ESPS and when row spacing was less than or equal to 40 cm.

Thompson et al. (2015) conducted experiments in Tennessee during 2005, 2006, and 2007 to determine how row spacing and seeding rate effect soybean seed yield and net returns. Maturity group IV and V soybean were each planted in 38 cm (narrow) and 76 cm (wide) row spacings at seeding rates between 60,000 and 180,000 seeds ha^{-1} and maturity group III between 247,000 and 590,000 seeds ha^{-1}. Results show that seed yield did not respond to seeding rate. Average seed yields for narrow rows were greater than wide rows in maturity group III (7%), maturity group IV (6%), and maturity group V (6%). A partial budget analysis was conducted to evaluate net return. Weather influenced seed yield and net return associated with the narrow row system. Net return and seed yield was consistently greater when precipitation was abundant during pod and seed development, similarly observed by Taylor (1980) and Alessi and Power (1982). Additionally, lower seeding rates resulted in greater economic return due to reduced seed costs. The results of this study (Thompson et al., 2015), similar to research at three locations in Kansas by Epler and Staggenborg (2008) in 2005 and 2006, suggests that narrow row seed yield advantages are dependent on environmental conditions. Precipitation was adequate and above average in 2005, but below average in 2006 for this region. Due to adequate rainfall in 2005, row spacing did not affect seed yield; however, seed yield was affected by plant population. Seed yield increases were associated with plant population increases up to plant populations of 198,000 seed ha^{-1} at all locations in 2005. Overall, seed yields were less in 2006 compared to 2005, likely due to inadequate precipitation. In 2006 there was a row spacing x location and location x plant population interaction, with greatest seed yield at plant populations occurring between 336,000-345,000 seed ha^{-1}. This study suggests that narrow row soybeans can achieve greater seed yield at lower plant populations in environments free of drought stress.

Studies were conducted by Heatherly et al., (2001) from 1994-1996 in Stoneville, Mississippi to determine the effect of pre- and post-emerge broadleaf and grass herbicides, used alone or in combination, on seed yield and weed cover from soybeans grown in 50 cm (narrow) and 100 cm (wide) row spacings. Treatments included (i.) pre- and post-emerge broadleaf control; (ii.) pre-emerge broadleaf, pre-emerge grass, and post-emerge broadleaf control; (iii.) post-emerge broadleaf control only; (iv.) post-emerge broadleaf and post-emerge grass control. Wide row weed management was less than narrow row when herbicides were band applied. In 1994, post-emerge broadleaf and post-emerge grass weed treatment resulted in the greatest cost to the producer, where the pre- and post-emerge broadleaf control option resulted in the least cost. In 1995 and 1996, the most expensive weed treatment was the pre-emerge broadleaf, pre-emerge grass and post-emerge broadleaf control, where the least expensive option was using only post-emergent broadleaf herbicides. Row spacing significantly affected weed cover at harvest in 1994 and 1995. Averaged weed cover at 1994 harvest for narrow rows was 2% compared to wide rows at 11%. Narrow rows yielded equal to or greater than wide rows in both irrigated and non-irrigated environments. Narrow row yielded greater than wide rows in 1994 and 1996. Average yields in 1994 for narrow and wide row were 3365 and 3075 kg ha^{-1}, respectively. Average yields in 1996 for narrow and wide row were 3225 and 2855 kg ha^{-1}, respectively. Average net return (all years) in non-irrigated trials was $22.00 ha^{-1} greater in narrow rows the wide rows. Average net return (all years) in irrigated trials was $31.00 ha^{-1} greater in narrow rows than wide rows.

Objective

Given the amount of previous research from around the United States suggesting potential seed yield advantages for narrow row soybean production systems under adequately watered conditions, the objective of this study is to compare three row spacing configurations for furrow irrigated soybean in Mississippi and evaluate the potential of a narrow row, raised bed, irrigated production system in Mississippi. It is hypothesized that planting soybean in narrow rows will increase seed yield for furrow irrigated soybean in Mississippi due to increased light interception resulting from faster rates of canopy closure. It is also hypothesized that it will be economically feasible for soybean producers to switch to a narrow row system.

Materials and Methods

Farmer-researcher partnerships were developed to conduct field-scale studies in 2016 and 2017 on farms in in the Mississippi River Delta in Mississippi. Study sites in 2016 were in Hollandale, MS (33^{o}12’ N, 90^{o}53’ W) and Stoneville, MS (33^{o}24’ N, 90^{o}53’ W). The Stoneville study site was used in both 2016 and 2017. The cooperating farmer in Hollandale sold his wide row planting equipment after the 2016 growing season, and therefore could not repeat the study in 2017. The variety planted in all site-years was Asgrow 4632 (Monsanto Co. St. Louis, MO). The predominant soil type for all locations is Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts), commonly used in cultivation of soybean in the Mississippi Delta. The preceding crop was soybean at each location in each site-year. Farmers performed all field operations including tillage, planting, chemical application and harvest according to Mississippi State University Extension Service recommendations. Sites were prepared with a disc-harrow and then raised beds were formed to facilitate furrow irrigation. Planting dates were 9 April at Stoneville and 10 May at Hollandale in 2016 and 8 April for Stoneville in 2017.

The experimental design was a randomized complete block in a split-plot arrangement with three replications at all site-years. The main plot was three row spacings (Figure 1.1), which consisted of Single row (one plant row on 100 cm spaced bed), Twin row (two paired plant rows separated by 20 cm on one bed spaced 100 cm) and narrow row (four plant row spaced 50 cm on 200 cm wide bed). The sub-plot factor were three seeding rates, 245,000, 345,000 and 445,000 seed ha^{-1}. The recommendation for maturity group IV soybean planted April to May in clay soil is 345,000 seeds ha^{-1} in Mississippi. Higher and lower seeding rates were included to determine if there was a potential interaction between row spacing and seeding rate. At the Stoneville site, the main plots measured 155 m in length and 8 m in width. At the Hollandale site, the main plots measured 450 m in length and 12 m in width.

Canopy closure was monitored from early vegetative growth to complete canopy closure using the Canopeo application (Patrignani and Ochsner, 2015), which processes above-canopy digital images to determine percent of green pixilation (leaf-ground ratio).

The camera was held at a constant height, angle and position above the canopy to ensure accurate and consistent data using a custom device built out of 2.5 cm diameter PVC pipe (Figure 1.2). Canopy closure data was collected weekly (weather and field conditions permitting) at each location until canopy closure measurement reached 95%. The entire length and widths of each plot were harvested using a plot combine (Model 2388, Case IH, Racine, WI) at Stoneville and entire plot harvested at Hollandale (Combine Info) to determine seed yield. Combines were equipped with yield monitors, however for accuracy and consistency, each subplot was weighed using a grain weigh cart (Grain-Weigh, Par-Kan Co., Silver Lake, IN). Seed samples were collected from each subplot at harvest and grain moisture was determined to adjust seed yield to 130 g kg^{-1} moisture.

Statistical analysis were performed with SAS using PROC MIXED (SAS Institute, Cary, NC). For the random effects mixed model, row spacing, seeding rate, and the row spacing x seeding rate interaction were considered fixed effects, while replication was considered a random effect. Degrees of freedom were calculated using the Kenward-Rogers method (Littell et al., 2006). Significance was assessed at $P \leq 0.05$ and means were separated using Fishers Protected LSD.

Economic analyses

The predominant row spacing used for soybean production in Mississippi is Single rows on a 100 cm wide bed. In order for a soybean producer to switch to a new row spacing that producer would be required to purchase a new planter. A partial budget approach was used to estimate the change in net annual profit from seed yield differences between the traditional Single row system and the Twin and narrow rows observed in this study to determine whether it would be economically justifiable to switch from a Single row system to either a Twin or narrow row system. Mississippi State soybean planning budgets were used to compare annual use, performance, repair, maintenance, and capital recovery cost based on initial purchase price of Single, Twin, and narrow row planters (Falconer et al., 2017). It was assumed that all new planting equipment purchased would be 12 m wide equipment which is the planter width for the vast majority of planters used in the Mississippi Delta. At each site-year, the average seed yield for each row spacing was multiplied by the two year average (2016, 2017) soybean price of \$0.361 kg^{-1} to determine the total revenue ha^{-1} (USDA, 2016; USDA, 2017). The annual cost ha^{-1} of the new planter was subtracted from the total revenue to complete the partial budget.

RESULTS

Environmental conditions differed somewhat between the 2016 and 2017 growing seasons. (Table 1.1). The 2016 growing season had more total precipitation than 2017 with precipitation totals of 111 and 97 cm for 2016 and 2017, respectively. However, rainfall distribution was markedly different between years, likely due to the unusual hurricane season. Overall, spring precipitation during the 2016 growing season was greater than the ten year average, while spring 2017 precipitation was less than the ten year average (TYA). March precipitation totals were 230% and 88% greater than the 10 year average in 2016 and 2017, respectively. Despite the above average spring rainfall in 2016 and the below average spring rainfall in 2017 planting occurred within the recommended planting window in both years. July and August precipitation during 2016 was 60% and 49% greater than the ten year average, respectfully. While July precipitation during 2017 was only 6% greater that the TYA, August precipitation reached a level 286% greater than the TYA. Precipitation in 2016 during July and

August was 60%, and 97% greater than the ten year average, respectively. Precipitation in 2017 during July and August was 5%, and 286% greater than the ten year average, respectively. Conversely, early fall precipitation was less than the ten year average in 2016 and 2017. September precipitation was 90% and 55% less in 2016 and 2017 compared to the ten year average, respectively.

Row spacing affected canopy closure at all site-years (Table 1.2). At Stoneville in 2016, soybean planted in narrow rows had greater canopy closure between 41 to 78 days after planting (DAP) compared to soybean planted in single and twin rows, which had similar patterns of canopy closure. (Figure 1.3). Approximately 60 days after planting (DAP) or R1 growth stage (Fehr and Caviness, 1977). Narrow rows reached 82% canopy closure compared to single and twins at 58% and 63%, respectively.

Twin rows developed canopy similarly to narrow rows at Hollandale in 2016, unlike results at Stoneville in 2016 where twins behaved similarly to single rows. Twins and narrow row treatments more rapidly developed a canopy, particularly early in the season, eventually closing the canopy, compared to singles which lagged, never fully developing a canopy (Figure 1.4). At approximately 50 DAP or R1 growth stage narrow and single had reached 76 and 73% canopy closure, respectively, compared to single row that had only reached 55% canopy development.

Canopy closure results at Stoneville in 2017 were similar to that found in Stoneville 2016, where narrow row canopy development rate exceeded that of single and Twin, which behaved similarly. At approximately 50 DAP or R1 growth stage narrow rows had reached 60% canopy development compared to single and twin which reached

38 and 41%, respectively (Figure 1.5). Soybean planted in twin rows were able to complete a full canopy in 2017 compared to the singles which did not.

Row spacing affected seed yield in all site-years, with a row spacing x seeding rate interaction occurring in Hollandale 2016 (Table 1.2). At Hollandale in 2016, soybean planted in single rows had decreased seed yield at the 445,000 seed ha^{-1} seeding rate compared to the other seeding rates while the 245,000 seed ha^{-1} seeding rate resulted in a 6% decrease in seed yield compared to the 445,000 seeds ha^{-1} seeding rate for soybean planted in twin rows (Figure 1.6). Despite the interaction between row spacing and seeding rate, the Mississippi recommended soybean seeding rate of 345,000 seeds ha^{-1} resulted in the greatest seed yield at all row spacings. Therefore, for the purposes of this manuscript we fill focus on the main effect of row spacing for Hollandale in 2016. Considering the main effect of row spacing, seed yield of soybean planted in single rows was decreased by 7% compared to soybean planted in both twin and narrow rows (Figure 1.6). The seed yield increase for soybean planted in narrow and twin rows over the single rows is likely due to increased rate of canopy closure and the resulting increased light interception by the soybean crop in twin and narrow rows (Figure 1.4).

The main effect of row spacing affected seed yield at Stoneville in 2016 (Table 1.2). Soybean planted in narrow rows had 11 and 13% greater seed yield than twin and single rows, respectively (Figure 1.6). Much like seed yield at Stoneville in 2016, Single and twin rows behaved similarly with regards to canopy closure. Soybean planted in single and twin row plantings had a similarly slower rate of canopy closure compared to narrow rows. Similar to Hollandale in 2016, the advantage of narrow rows over twin and single at Stoneville in 2016 could be explained by differences canopy closure rate (Figure 1.3).

Both row spacing and seeding rate affected soybean seed yield at Stoneville in 2017 (Table 1.2). When averaged across row spacings, soybean planted at 245,000 seeds ha^{-1} had ~7% decreased seed yield compared soybean planted at 345,000 and 445,000 seeds ha^{-1}. The main effect of row spacing also affected seed yield in Stoneville in 2017. Similar to Stoneville in 2016, soybean planted in narrow rows had 7% increased seed yield compared to single rows at Stoneville in 2017 (Figure 1.6). Narrow rows resulted in faster canopy closure than single and twin, which is similar to results of seed yield (Figure 1.5).

A partial budget analysis was conducted to enhance applicability for Mississippi soybean producers when making planter purchase decisions. The change in revenue for purchasing and operating a new twin and narrow row planter per year were compared to the cost of purchasing and operating a new single row planter based on seed yield data from this study. At Stoneville in 2016 the purchase and use of a twin row or narrow row planter resulted in a change in net change in revenue advantage of $21.57 and $261.64 ha^{-1} year^{-1} for purchasing a twin and narrow row planter, respectively, compared to a single row planter. Similar results were found in Hollandale in 2016 where a cost advantage of $99.74 and $118.16 ha^{-1} for twin and narrow planters, respectively, compared to purchasing a single row planter. Results were similar for Stoneville in 2017, where twin and narrow planters offered a cost advantage of $57.50 and $122.29, respectively, compared to the single row planter.

DISCUSSION

The results of this study support the findings of numerous other studies across the United States. Graterol, et al. (1996) observed where narrow and twin row soybean grown in a year with adequate precipitation offer seed yield advantages over single row soybean planting arrangements. Taylor (1980) reported a 17% seed yield advantage for narrow rows compared to single, which is similar to this study where there was a 10 to 13% seed yield advantage when planting soybean in narrow rows compared to single at every site-year. Bowers et al. (2000) found results similar to this study, where row spacings greater than 40 cm never resulted in greater seed yield than narrow rows (<40 cm). This research also indicates that narrow rows develop more rapid canopy closure compared to single in each site year. Changes in row spacing affects canopy formation rate, which determines total dry matter accumulation and seed yield (Andrade et al., 2002). The results of this study also suggest seed yield advantages in narrow rows closely relates to increased rate of canopy closure prior to critical periods for pod development.

The study locations used in this investigation received above average precipitation during the spring of 2016 and 2017. While seed yield was increased in this study, other researchers have reported that planting soybean in narrow rows could decrease seed yield in years where precipitation is limited during critical stages of soybean development (Zaffaroni and Schniter, 1989; Devlin et al., 1995; Elmore, 1998; Alessi and Power, 1982; Taylor, 1980). However, the ability to furrow irrigated in Mississippi would likely alleviate the effect of years of below average rainfall on narrow row production.

Soybean planted in Twin rows behaved differently between site-years. Twin row seed yield and canopy closure rate behaved similarly to single row at Stoneville in 2016 and 2017 while twin row seed yield and canopy closure rate behaved similarly to narrow rows in Hollandale in 2016. This could be a function of planting date between the two locations in 2016. The Stoneville site was in early April in both growing seasons while Hollandale was planted on in early May. It is possible that the increased early season light interception provided by the narrow row early in the growing season, when growth is normally slow, can result in increased seed yield later in the growing season. Multiple previous studies have reported that narrower row spacing can improve seed yield when planting later than optimum planting dates (Beatty et al., 1982; Boquet, 1990; Parker et al., 1981; Parvez et al., 1989). It has been reported that later than optimum planting dates can result in greater seed yield for narrow rows compared to when planted at the optimum planting date (Board et al., 1990; Boquet et al., 1982).

The economic analyses conducted in this study indicate that it would be economically beneficial for soybean producers in the Mississippi Delta to switch to either a twin row or narrow row system. We realize that a partial budgeting approach to economic analysis is rather simple and there are a number of other factors must be considered when switching to a narrow row system. When planting in narrow rows, the bed used to accommodate the rows is twice as wide as the beds used for single and twin row planting. Bedding equipment must either be altered, or new equipment purchased to accommodate the wider bed pattern. Also, for producers who grow soybean in rotation with either corn or cotton, there has been only limited research regarding growing corn in narrower rows, especially in the midsouthern United States and no information on narrow row cotton production. Ebelhar (2010) reported greater seed yield for twin-row planted corn compared to those planted in the conventional single row. Similarly, results from

Mackey et al. (2016) found twin row corn production resulted in greater seed yield than corn grown on 76 cm rows, however resulted in similar seed yield as narrow row (38 cm). Although some preliminary research suggests that narrow row corn can result in increased grain yield (Henry, unpublished data), producers in the midsouthern United States would likely be required to have 2 separate planters; a narrow row planter for soybeans and a more traditional wide row planter for corn and/or cotton. This would increase equipment costs and affect the profitability of switching to a narrow row system.

Finally, this study only investigated the effects of using a narrow row soybean production system on heavy clay soils in the Mississippi River Delta. The wide bed configuration necessary for narrow row production requires capillary action to move irrigation water from the irrigation furrow to the middle of the bed. On heavy-clay soils water movement is not problematic. However, on soils with much greater sand content, such as the sandy- and silt-loams also prevalent in the Mississippi River Delta, the narrow row system is likely not feasible under furrow irrigated conditions. Despite these potential limitations, the results of this study suggest that using a narrow row soybean production system can increase soybean seed yields. Under the right circumstances, Mississippi soybean producers should consider switching to a narrow row system.

Table 1.1 Monthly precipitation and average temperature measured at the Stoneville weather station during 2016 and 2017 compared to a 10 year average.

	Monthly Precipitation Totals (cm)		
Year/Month	2016	2017	10 year average
March	47	8	14
April	11	17	14
May	8	12	13
June	13	19	8
July	17	11	10
August	14	27	7
September	1	4	10
October	1	1	13
Total precipitation	**112 cm**	**99 cm**	**89 cm**

Table 1.2 ANOVA table representing seed yield for row spacing, seeding rate and the row spacing and seeding rate interaction at each site-year.

Effect	**Stoneville 2016**	**Stoneville 2017**	**Hollandale 2016**
Row Spacing (RS)	<0.0001	0.0100	< 0.0001
Seeding Rate (SR)	NS	0.0053	NS
RS x SR	NS	NS	0.0014

Table 1.3 Partial budget analysis used to determine potential revenue advantages when purchasing a Narrow and Twin row planter compared to a Single row planter.

Treatment	Kg ha^{-1}	Planter cost ($ kg^{-1}/year)	Soybean ($ kg^{-1})	Rev. ha^{-1}	Rev.-Planter cost	Advantage over Single ($ ha^{-1})
			Stoneville 2016			
Single	5090.8	19.60	0.361	1837.78	1818.18	-
Twin	5187.64	32.99	0.361	1872.74	1839.75	21.57
Narrow	5846.01	30.59	0.361	2110.41	2079.82	258.13
			Hollandale 2016			
Single	4371.23	19.60	0.361	1578.01	1558.42	-
Twin	4684.61	32.99	0.361	1691.14	1658.16	99.74
Narrow	4728.99	30.59	0.361	1707.17	1676.57	114.65
			Stoneville 2017			
Single	4584.41	19.60	0.361	1654.97	1635.38	-
Twin	4780.78	32.99	0.361	1725.86	1692.87	57.50
Narrow	4953.61	30.59	0.361	1788.25	1757.66	118.78

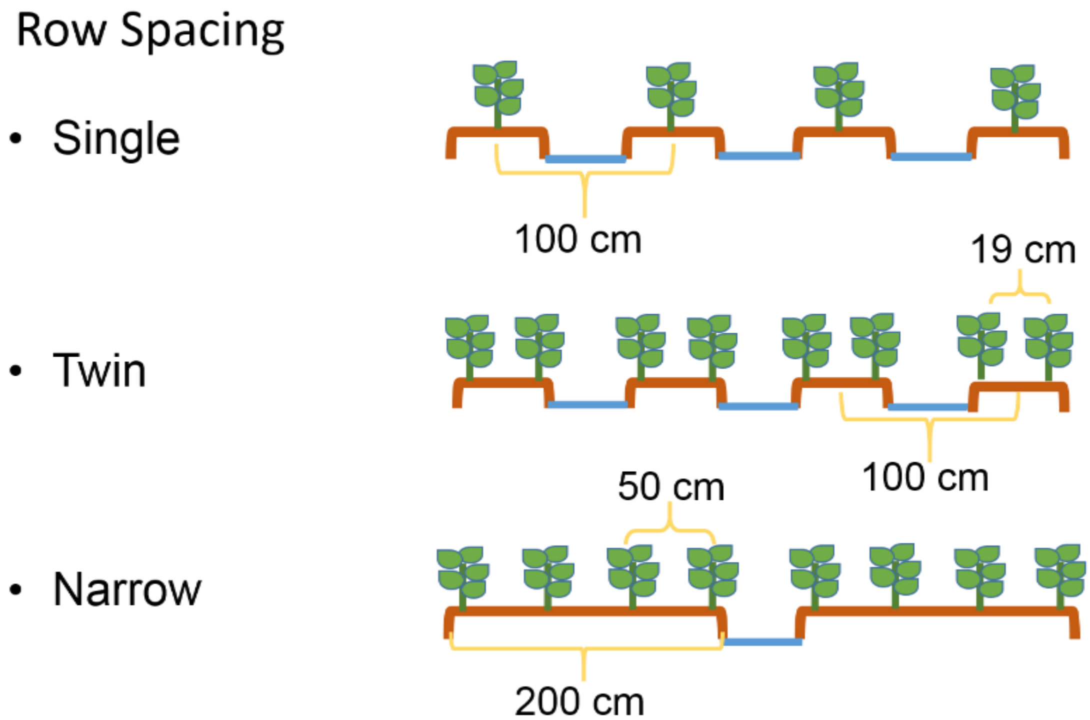

Figure 1.1 Visual representation of three row spacings which including single, twin, and narrow.

Figure 1.2 PVC structure which held camera at consistent position and height above crop canopy.

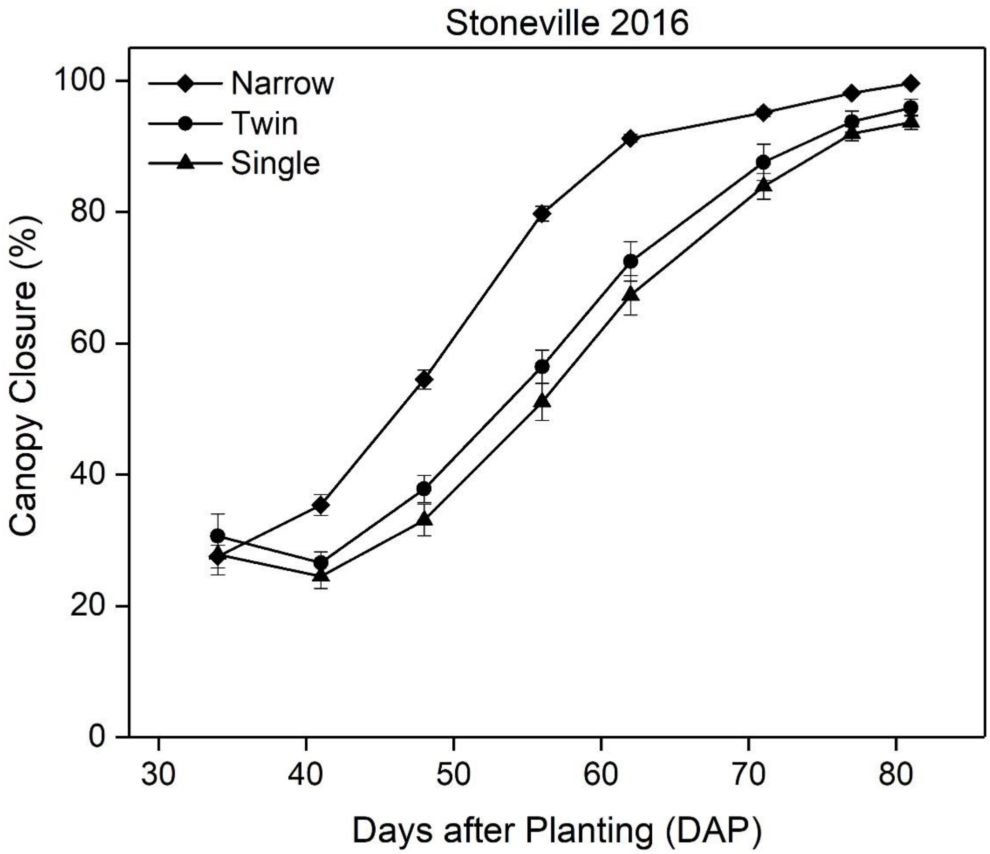

Figure 1.3 Canopy closure at multiple days after planting (DAP) for narrow, twin, and single row spacings for the Stoneville study location in 2016.

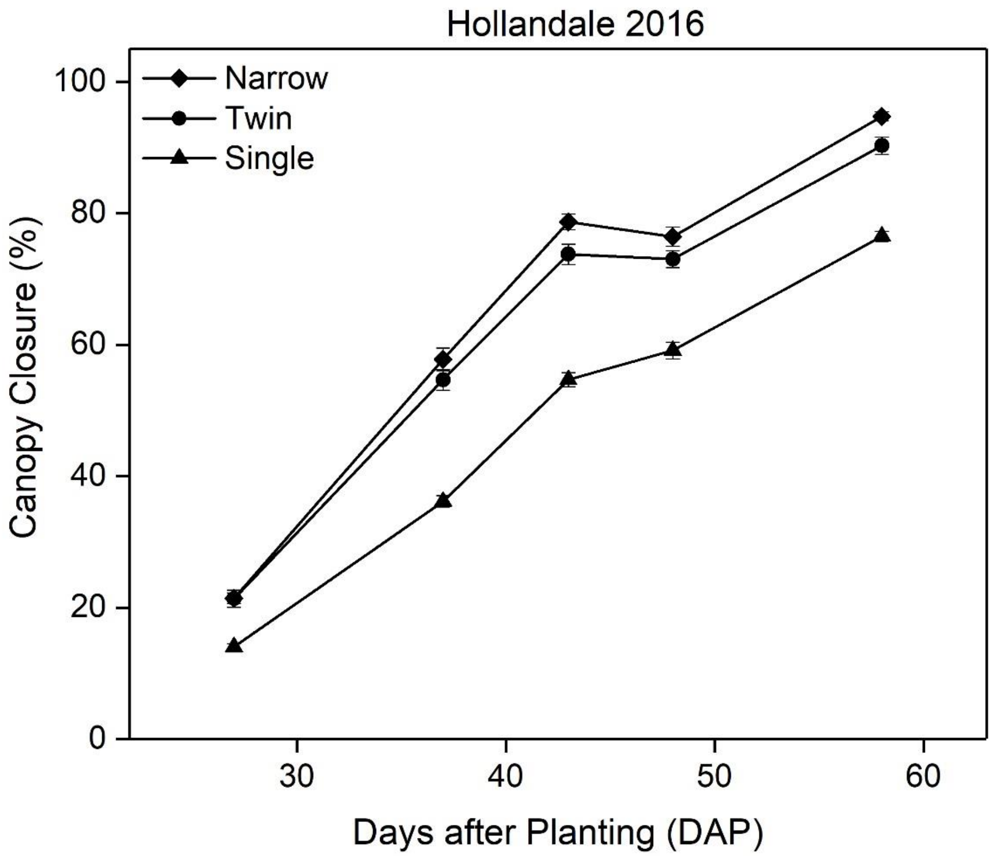

Figure 1.4 Canopy closure at multiple days after planting (DAP) for narrow, twin, and single row spacings for the Hollandale study location in 2016.

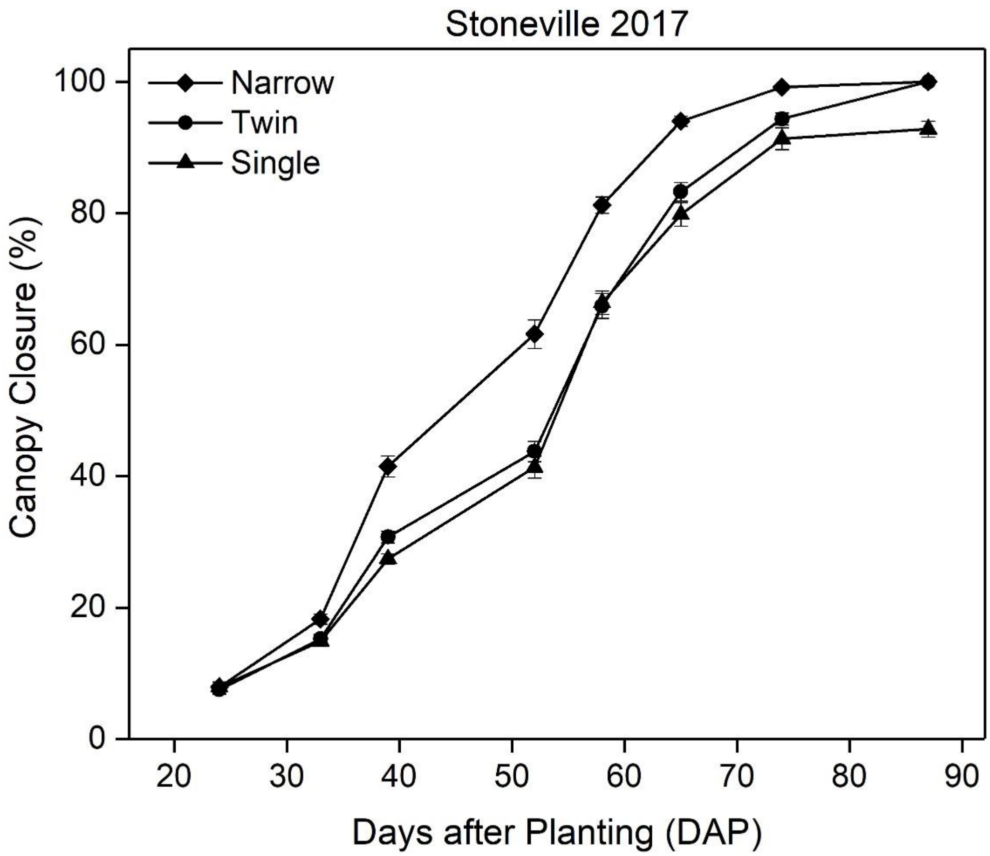

Figure 1.5 Canopy closure at multiple days after planting (DAP) for narrow, twin, and single row spacings for the Stoneville study location in 2017.

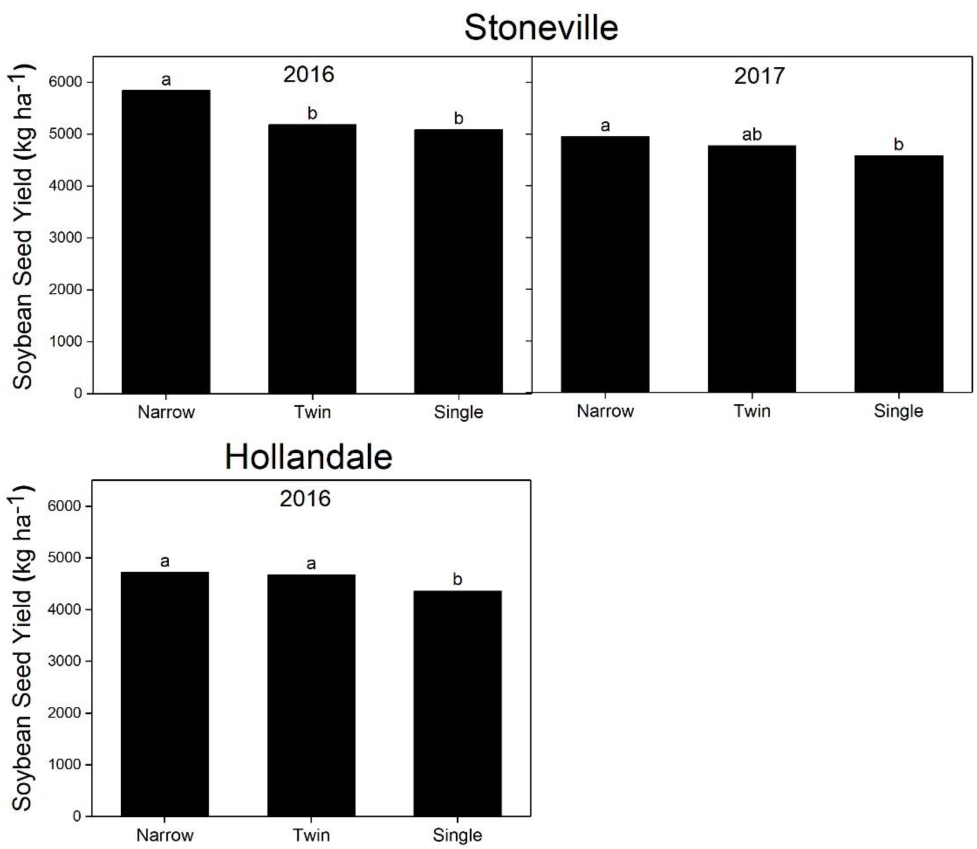

Figure 1.6 Seed yield for narrow, twin, and single row spacings at Stoneville in 2016 and 2017 and Hollandale in 2016.

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CHAPTER II

EVALUTATION OF PLANTER ERRRORS ASSOCIATED WITH TWIN ROW PRODUCTION

Introduction

There has been increased interest in the midsouthern United States in decreasing soybean row width from the traditional single rows planted on the traditional 100 cm rows. Bowers et al. (2000) concluded that soybeans grown in the mid-southern United States can be planted in rows spaced ≤ 40 cm to optimize seed yield. As a result, twin row planting has gained popularity among soybean producers in Mississippi and throughout much of the Mid-South (Bruns, 2011). Twin row planting has been shown to improve seed yield by means of increased seasonal radiation interception through earlier canopy closure, greater photosynthetic rate through increased leaf-area, improved nutrient uptake and water use-efficiency (Bellaloui et al., 2015). The twin row production system effectiveness is dependent on the availability of water (Jamieson et al., 1995), nutrients (Bellaloui et al., 2014), and temperature (Andrade et al., 2002). Twin row planters have twice the number of planting units as conventional single row planters, meaning that when planting twin rows, there is increased opportunity for malfunctions that can affect the planting pattern of the soybean crop in the field.

There is currently a lack of research regarding how various planting errors affect soybean seed yield and ultimately decisions about what to do with the soybean crop when planting errors do occur. Previous research has shown that decreased plant stands, which can be one consequence of a planter malfunction, can lead to decreased light interception and ultimately reduced seed yield (Conley et al., 2008). Because planter errors can affect the rate of canopy closure in a soybean crop, the economic impact of a planter error may vary by soil texture, as soil texture has been shown to affect soybean growth (Daddow and Warrington, 1983).

Soil texture is determined by particle diameter. Soils containing large amounts of fine particles (clay) will have lesser pore diameter compared to soils with coarse particles (sand/silt-loam). Bulk density is related to soil texture. As roots move through the soil, they displace soil particles, penetrating those with lesser diameter than the root tip. As soil bulk density increases, root growth is retarded because soil particle cannot be displaced as rapidly due to physical resistance. Clay soils will have greater penetration resistance at a lower bulk density compared to sandy or silt-loam soil due to particle size (Daddow and Warrington, 1983). Loamy soils promote faster growth and development under adequate moisture compared to clayey soils because water is more readily available to the plant (Heatherly, 2013). Similarly, the maturity of the soybean also has the opportunity to affect the extent to which a planting error can affect a soybean crop. A soybean with a shorter maturity potentially has less time to compensate for missing rows compared to those with a longer maturity because of reduced periods for leaf expansion and canopy development (Salmeron et al., 2015; Board et al., 1990).

Given the lack of research about the effect of planter errors on soybean yield, the purpose of this study is to determine the effect of multiple potential twin row planter errors on soybean canopy closure and seed yield across multiple maturity groups and on two highly different soil types commonly used to produce soybeans in Mississippi.

Materials and Methods

Experiments were established at two locations in Mississippi during the 2016 and 2017 growing seasons. One study was located at the Mississippi State University Delta Research and Extension Center in Stoneville, Mississippi. The soil type at this location was a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts). The second study site was located at the Monsanto Learning Center in Scott, Mississippi. The soil type at this location was a Commerce very fine sandy loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts). Both locations were conventionally tilled and planted on raised beds to facilitate furrow irrigation. Soybeans were planted in a twin row arrangement on raised beds spaced at 100 cm apart at a seeding rate of 345,000 seeds ha^{-1}.

The study was established as a randomized complete block in a split-plot arrangement. The main plot were four Asgrow (Monsanto Co. St. Louis, MO) soybean varieties of differing maturity; Asgrow 42X6 (4.2 relative maturity), Asgrow 47X6 (4.7 relative maturity), Asgrow 49X6 (4.9 relative maturity), and Asgrow 54X6 (5.4 relative maturity). The sub plots consisted of four potential planter errors that could be associated with the twin row planting system (Figure 2.1). These included a control (None) consisting of the full intended stand with two normal twin pairs within a row, one single row from a twin row pair missing (Single), one row of a twin row pair missing in two adjacent rows (Separate), and both twin rows within a row missing (Whole). Experimental plots measured 4 m (four-100 cm row) in width and 26 m in length. Study fields were managed according to Mississippi State University Extension Service recommendations.

Canopy closure was monitored from stand emergence to complete canopy closure using the Canopeo application (Patrignani and Ochsner, 2015), which can process above-canopy digital images to determine percent of green pixilation (leaf-ground ratio). The camera was held at a constant height, angle and position above the canopy to ensure accurate and consistent data using a custom device built out of 2.5 cm diameter PVC pipe. Canopy closure data was collected weekly (weather and field conditions permitting) at each location until canopy closure measurement reached 95%. Seed yield was determined at harvest with a plot combine (Wintersteiger, Inc., Salt Lake City, UT) as the entire length and width of each subplot was harvested and a seed yield and moisture were determined with a Harvest Master system (Harvest Master, Juniper Systems, Inc., Logan, UT). Seed yield was adjusted to 130 g kg^{-1} moisture.

Data were subjected to ANOVA using the PROC MIXED procedure in SAS (SAS Institute, Cary, NC). It was predetermined that each location would be analyzed separately due to the vastly different soil types which had noticeable effects on soybean growth. Maturity group, planter error and the maturity group x planter error interaction were considered fixed effects. Replication was considered a random effect. Level of significance was assessed at $P \leq 0.05$ for all analyses. Least square means were calculated and separated using PDMIX800 macro (Saxton, 1998) in SAS.

Economic analyses

To make data from this research more applicable to soybean production in Mississippi, a partial budget analysis was conducted to aid farmers with replant decisions when encountering a twin row planter error. When a planter error does occur, the management options are to keep the affected stand or terminate the affected stand and then replant. Seed yield loss associated with planter errors were compared to replanting costs to determine when replant could be economically feasible. Seed yield associated with each planting error was subtracted from the control to determine expected seed yield loss. The expected seed yield loss for each planter error was multiplied by the yearly average soybean price for the 2016 and 2017 marketing years, \$0.361 kg^{-1}. (USDA, 2016; USDA, 2017). The expected revenue loss due to reduced seed yield of each planter error was compared to the cost of stand termination and replanting using a negative calculated advantage. The termination and replant cost of \$214.52 ha^{-1} was determined using costs in the Mississippi State University soybean planning budgets and included cost estimates of the herbicide and herbicide application for removal of the existing stand and replant costs (labor, fuel, repair, maintenance), and replanted seed costs (Falconer et al., 2017). In addition to the two-year average soybean price, a sensitivity analysis was conducted to determine if replant was necessary at a range of soybean price points.

Results

Environmental condition differed between the 2016 to 2017 growing seasons (Table 2.1). The 2016 growing season had more total precipitation than 2017 with precipitation totals of 111 and 97 cm for 2016 and 2017, respectively. However, rainfall distribution was markedly different between years, likely due to the unusual hurricane season. Overall, spring precipitation during the 2016 growing season was greater than the ten year average, while spring 2017 precipitation was less than the ten year average (TYA). March precipitation totals were 230 and 88% greater than the 10 year average in 2016 and 2017, respectively. Despite the above average spring rainfall in 2016 and 2017, planting occurred within the recommended planting window in both years. July and August precipitation during 2016 was 60 and 49% greater than the TYA, respectfully. While July precipitation during 2017 was only 6% greater that the TYA, August precipitation reached a level 286% greater than the TYA. Precipitation in 2016 during July and August was 60%, and 97% greater than the TYA, respectively. Precipitation in 2017 during July and August was 5%, and 286% greater than the TYA, respectively. Excessive precipitation during these critical soybean development months was likely responsible for reduced seed yield in 2017 compared to 2016. Increased disease was noticed, but not recorded in 2017, likely due to excessive precipitation in during pod development. Conversely, early fall precipitation was less than the TYA in 2016 and 2017.

The main effect of maturity group affected seed yield at every site-year. This was largely due to the difference in yield potential between varieties that represented the maturity groups. We included multiple maturity groups in this study to evaluate if there was any interaction between maturity group and planter error. In three of the four site-years no interaction was observed and in the other site-year, it was apparent that the interaction was largely due to the large differences in yield between the soybean varieties. Maturity group 4.7 resulted in the greatest seed yield in each site-year followed by maturity groups 4.2, 4.9, 5.4 (descending order). Therefore, for clarity we will focus only on the main effect of planter error for all site years.

Clay Soil

A maturity group x planter error interaction occurred at Stoneville in 2016 (Table 2.2). Planter error treatments, None and Single, resulted in similar seed yields at each maturity group in 2016 and 2017. The main effect of planter error affected seed yield at both site-years (Table 2.2). There was no difference in seed yield between None and Single in 2016 (Figure 2.2). Like seed yield, None and Single resulted in similar canopy closure rate and trend. Plots with Whole rows missing resulted in 45% canopy closure at 50 days after planting (DAP) compared to 75 and 70% canopy closure with None and Single, respectively (Figure 2.3).

There was no difference in seed yield of plots with planter errors None, Single and Separate in 2017 (Figure 2.2). Similar to the relationship between seed yield and canopy closure during 2016, None, Single, and Separate behaved somewhat alike during canopy development, resulting in faster development than Whole. Plots with Whole rows missing resulted in 39% canopy closure at 50 DAP compared to 75, 68, and 52% for those with None, Single and Separate (Figure 2.4). Whole resulted in the lowest seed yield of all planter errors during both years. Results from Stoneville in 2016 and 2017 indicate that furrow irrigated twin row systems missing a Whole row on clay soil result in a slower rate of canopy development compared to all other planter error treatments. Furthermore, the reduced rate of canopy closure for treatments with a Whole row missing is likely the reason for observed reduction in seed yield during both years.

Based on the negative calculated advantage to replant it would not be economically feasible to replant a soybean crop exhibiting either Single or Separate planter error at any maturity group in 2016 and 2017. There is no negative calculated economic advantage to terminate and replant a crop exhibiting any planter error at all maturity groups in 2017 in Stoneville.

Based on the negative calculated advantage to replant it would not be economically feasible to replant a soybean crop exhibiting any planter error at Stoneville in 2016 or 2017 at the two-year average soybean price, \$0.361 kg^{-1}. (Table 2.3). A price sensitivity analysis was conducted to determine if there were negative calculated advantages at several soybean price points, including \$0.30, 0.35, 0.40 and 0.45 kg^{-1} (Table 2.4). This analysis found that at Stoneville in 2016 there would be a replant advantage of \$22.62 and \$52.26 for a soybean crop experiencing a Whole row missing at soybean prices of \$0.40 or \$0.45 kg^{-1}.

Sandy Soil

The main effect of planter error affected seed yield at Scott in both 2016 and 2017. Plots with a Whole row missing resulted in the lowest seed yield compared to all other planter errors. There were no difference in seed yield between planter errors where a Single row was missing and untreated plots. Additionally, there was no difference in seed yield between planter errors in Single and Separate plots in 2016. Much like seed yield, None, Single and Separate plots resulted in the greater rate of canopy closure, however Single and Separate behaved most alike (Figure 2.5). Plots which experienced Whole planter error resulted in the slowest rate of canopy closure. Yielding similarly, Single row missing and untreated plots resulted in ~7% and ~ 21% greater seed yield compared to when a Whole row was missing in 2016 and 2017, respectively. Additionally, Separate resulted in 9% greater seed yield than Whole in 2017. Generally, canopy closure occurred earlier in 2016 compared to 2017. Planter error None had achieved 98% canopy closure at 50 DAP in 2016 (Figure 2.5) compared to 58% at 50 DAP in 2017 (Figure 2.6). Single and Separate treatments resulted in 95 and 94% canopy closure at 50 DAP in 2016 compared to 48 and 36% in 2017. Like all treatments, Whole resulted in 77% canopy closure at 50 DAP in 2016 compared to 29% in 2017. Similar trends can also be found when comparing seed yield between the two years at Scott.

Based on the negative calculated advantage to replant it would not be economically feasible to replant a soybean crop exhibiting any planter error at Scott in 2016 based on the averaged 2016 and 2017 soybean price of \$0.361 kg^{-1} (Table 2.3). There would be an economic advantage of \$27.80 ha^{-1} to replant a soybean crop experiencing a Whole missing row in 2017. A price sensitivity analysis was conducted to determine if there were negative calculated advantages at several soybean price points, including \$0.30, 0.35, 0.40 and 0.45 kg^{-1} (Table 2.4). There is an economic advantage of \$20.41, \$53.98, and \$87.54 ha^{-1} in 2017 to replant a soybean crop experiencing a Whole row missing when soybean prices are \$0.35, 0.40, and 0.45 kg^{-1}, respectively.

Discussion

Lack of research dedicated to replant decisions when partial or Whole twin rows are missing has led to the interest of this research. This research is one of the first studies considering replant decisions with planter errors. Planter error affected seed yield at all site-years (Figure 2.2). Overall, seed yield was greater in 2016 compared to 2017 at both locations. Results show that across both soil types, the absence of both twin rows (Whole) resulted in greater seed yield loss compared to when one Single or two Separate rows were missing. Canopy closure measurements followed similar patterns as seed yield with Whole rows resulting in the slowest rate of canopy closure, while the untreated check (None) completed canopy closure faster than all planter errors at each site-year. Single and None resulted in similar patterns of canopy closure at Stoneville in 2016 and 2017. Conversely, canopy closure patterns of Single were most similar to Separate missing rows at Scott in 2016. This research indicates that soybeans can fill available space faster on silt-loam (Scott) compared to the clay (Stoneville); therefore, soil texture should be considered when making replant decisions. Moreover, a replant may only be warranted when missing both twins within a row. Furthermore, a replant decision was only warranted at high soybean price levels.

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Table 2.1 Monthly precipitation and average temperature measured at the Stoneville weather station during 2016 and 2017 compared to a 10 year average.

	Monthly Precipitation Totals (cm)		
Year/Month	2016	2017	10 year average
March	47	8	14
April	11	17	14
May	8	12	13
June	13	19	8
July	17	11	10
August	14	27	7
September	1	4	10
October	1	1	13
Total precipitation	**112 cm**	**99 cm**	**89 cm**

Table 2.2 ANOVA table representing seed yield for maturity group, planter error, and maturity group x planter error interaction at each site-year.

Effect	**Stoneville 2016**	**Stoneville 2017**	**Scott 2016**	**Scott 2017**
Maturity group (MG)	<0.0001	<0.0001	<0.0001	<0.0001
Planter error (PE)	<0.0001	<0.0001	0.0001	<0.0001
MG x PE	0.0135	NS	NS	NS

Table 2.3 A partial budget analysis was conducted at each site-year to compare change in revenue from the control (None) to each planter error based on the mean seed yield multiplied by the two-year (2016, 2017) average soybean price of \$0.361 kg-1 versus the cost of replanting each planter error.

Planter error	**Seed Yield ($kg\ ha^{-1}$)**	**Yield loss vs. check ($kg\ ha^{-1}$)**	**Soybean price (\$ kg^{-1})**	**Expected loss due to yield (\$ ha^{-1})**	**Replant Cost (\$ ha^{-1})**	**Advantage to replant (\$ ha^{-1})**
			Stoneville 2016			
None (check)	4471					
Single	4415	55.83	0.361	20.15	214.52	\$ 194.37
Separate	4319	151.44	0.361	54.67	214.52	\$ 159.85
Whole	3878	592.84	0.361	214.02	214.52	\$ 0.50
			Stoneville 2017			
None (check)	3928					
Single	3828	99.64	0.361	35.97	214.52	\$ 178.55
Separate	3869	58.64	0.361	21.17	214.52	\$ 193.35
Whole	3563	364.19	0.361	131.47	214.52	\$ 83.05
			Scott 2016			
None (check)	4582					
Single	4526	56.34	0.361	20.34	214.52	\$ 194.18
Separate	4415	166.77	0.361	60.20	214.52	\$ 154.32
Whole	4233	348.69	0.361	125.88	214.52	\$ 88.64
			Scott 2017			
None (check)	3669					
Single	3528	141.13	0.361	50.95	214.52	\$ 163.57
Separate	3311	357.26	0.361	128.97	214.52	\$ 85.55
Whole	2997	671.24	0.361	242.32	214.52	\$ (27.80)

Table 2.4 Price sensitivity analysis using table 2.3 to determine replant decisions when planter errors occur at a range of soybean prices at each site-year.

		Soybean price (kg^{-1})			
	Seed yield ($kg\ ha^{-1}$)	**$ 0.30**	**$ 0.35**	**$ 0.40**	**$ 0.45**
		Stoneville 2016			
None (check)	4471				
Single	4415	$ 197.77	$ 194.98	$ 192.19	$ 189.40
Separate	4319	$ 169.09	$ 161.52	$ 153.94	$ 146.37
Whole	3878	$ 36.67	$ 7.03	$ (22.62)	$ (52.26)
		Stoneville 2017			
None (check)	3928				
Single	3828	$ 184.63	$ 179.65	$ 174.67	$ 169.68
Separate	3869	$ 196.93	$ 194.00	$ 191.07	$ 188.13
Whole	3563	$ 105.26	$ 87.05	$ 68.84	$ 50.64
		Scott 2016			
None (check)	4582				
Single	4526	$ 197.62	$ 194.80	$ 191.99	$ 189.17
Separate	4415	$ 164.49	$ 156.15	$ 147.81	$ 139.48
Whole	4233	$ 109.91	$ 92.48	$ 75.04	$ 57.61
		Scott 2017			
None (check)	3669				
Single	3528	$ 172.18	$ 165.13	$ 158.07	$ 151.01
Separate	3311	$ 107.34	$ 89.48	$ 71.62	$ 53.75
Whole	2997	$ 13.15	$ (20.41)	$ (53.98)	$ (87.54)

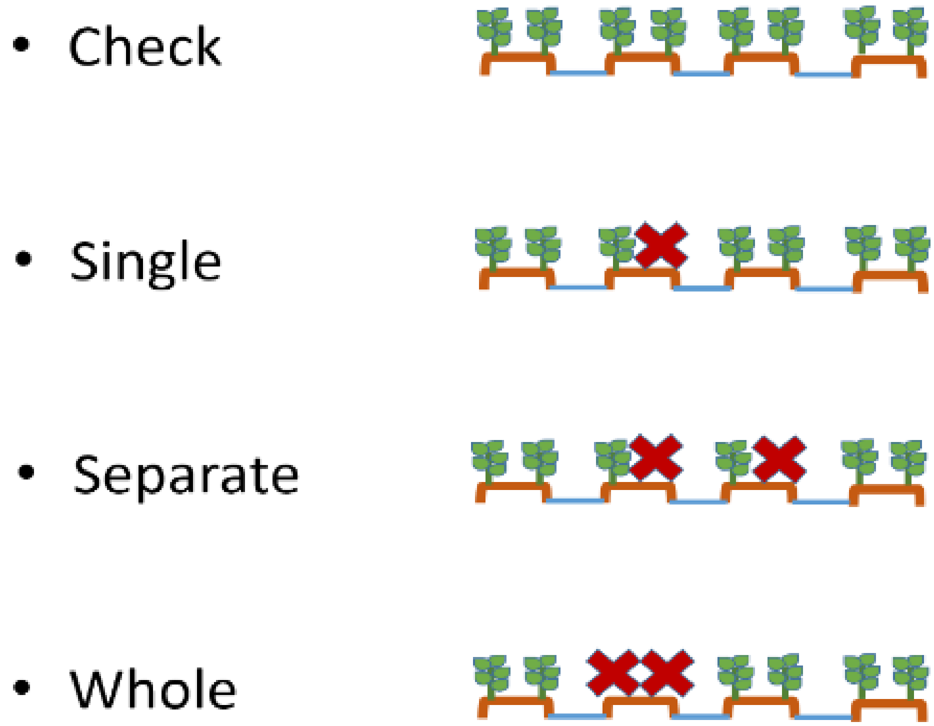

Figure 2.1 Visual representation of planter error treatments including an untreated check, one Single row missing, separate Single rows missing, and a Whole twin row missing.

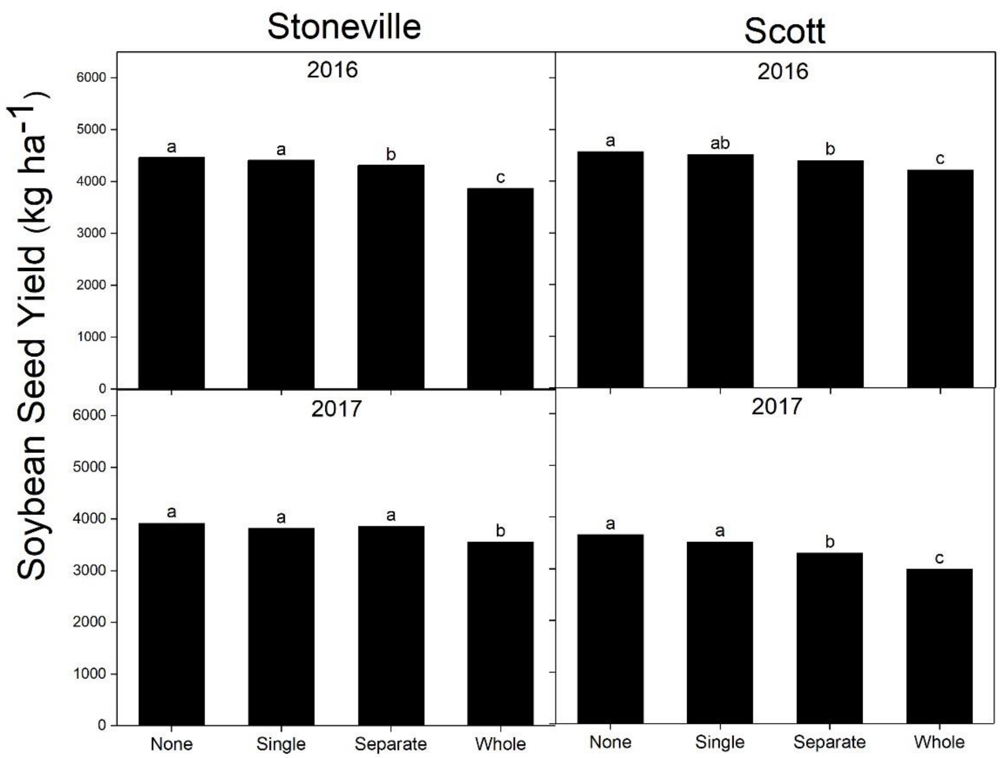

Figure 2.2 Comparison of seed yield by planter error at each site-year.

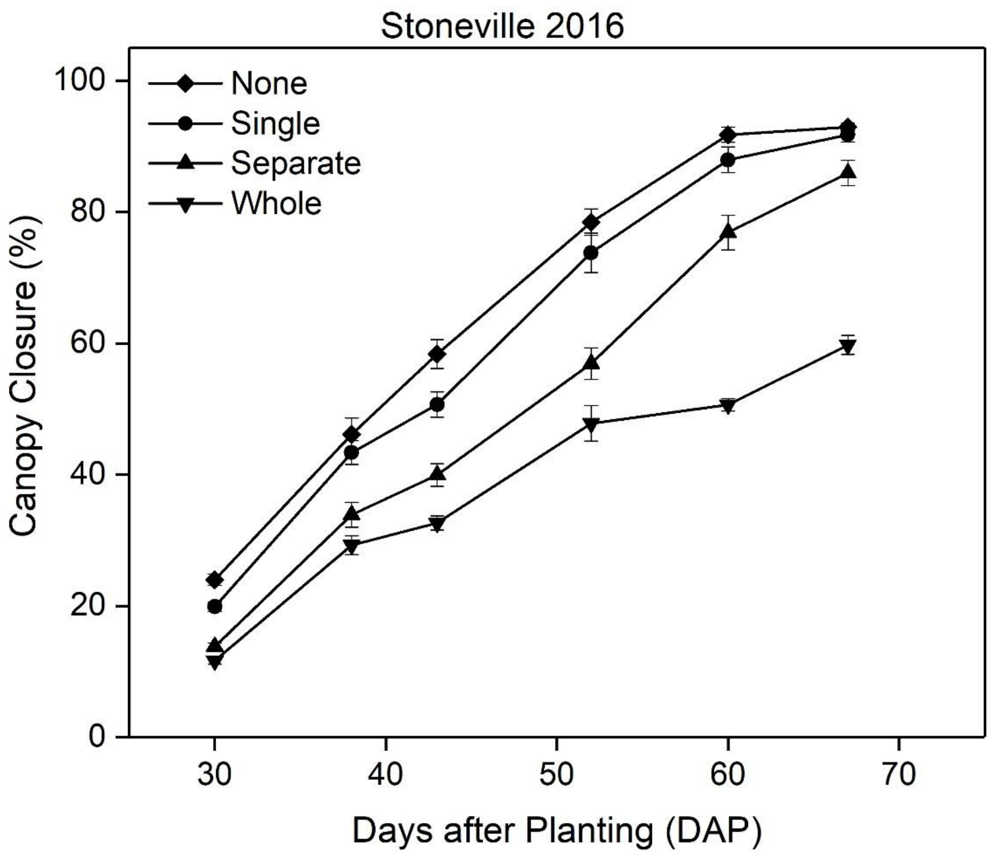

Figure 2.3 Canopy closure at multiple days after planting (DAP) for None, Single, Separate and Whole planter errors at the Stoneville study location in 2016.

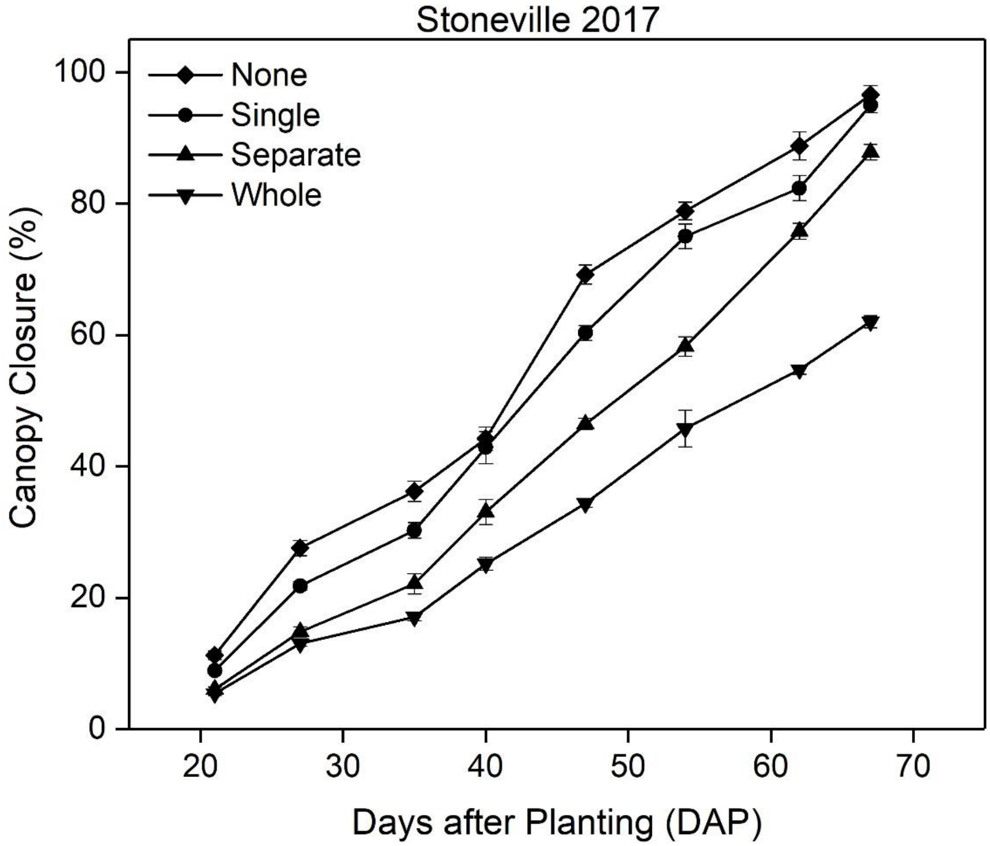

Figure 2.4 Canopy closure at multiple days after planting (DAP) for None, Single, Separate and Whole planter errors at the Stoneville study location in 2017.

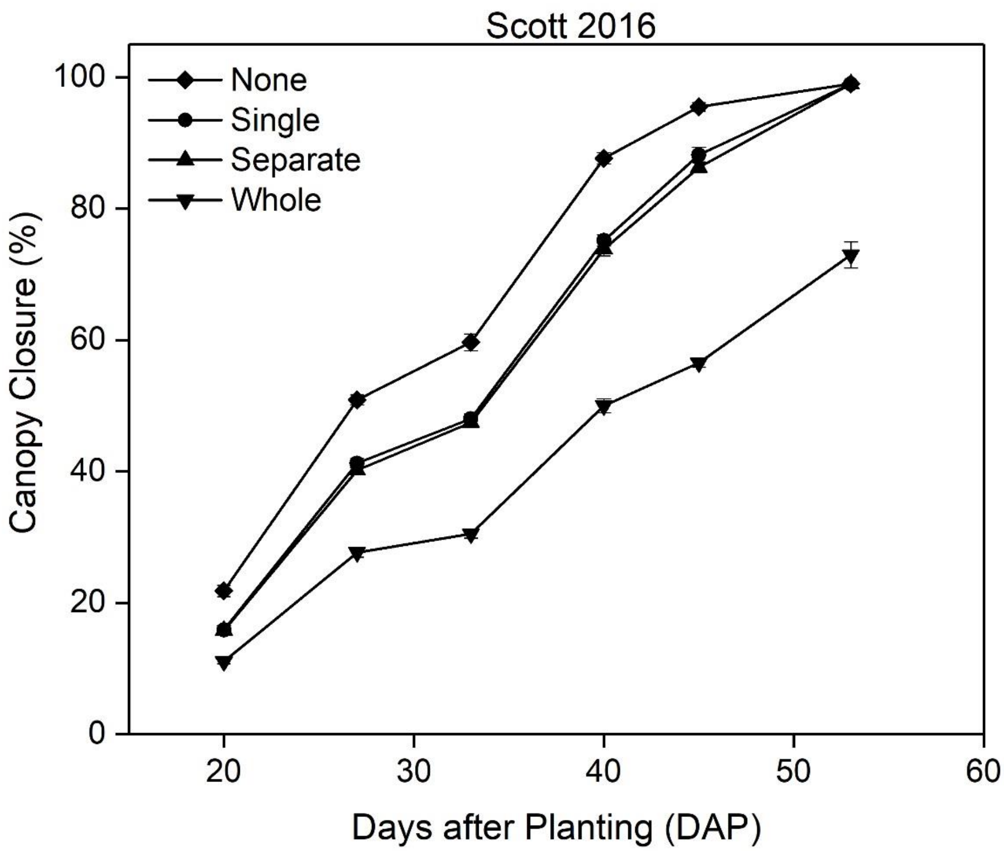

Figure 2.5 Canopy closure at multiple days after planting (DAP) for None, Single, Separate and Whole planter errors at the Scott study location in 2016.

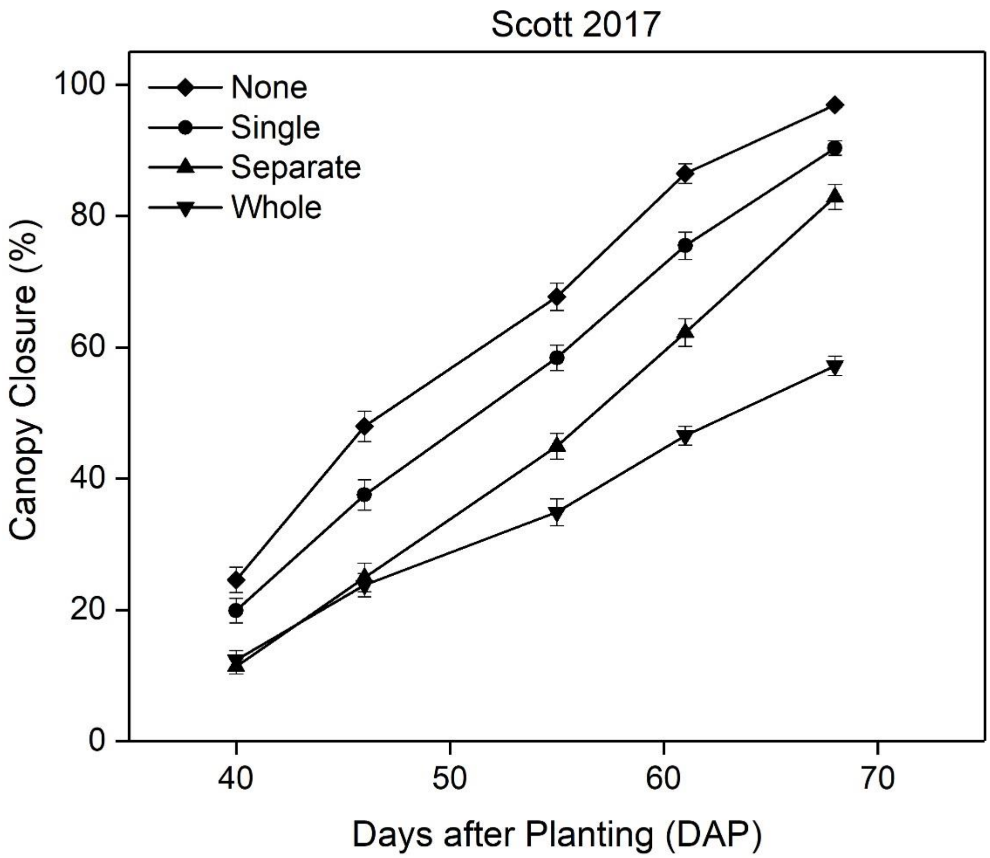

Figure 2.6 Canopy closure at multiple days after planting (DAP) for None, Single, Separate and Whole planter errors at the Scott study location in 2017.

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