5-4-2018

Impact of Planting Strategies on Soybean (Glycine Max L.) Growth, Development and Yield

Shane Michael Carver

Impact of planting strategies on soybean (*Glycine max* L.) growth, development and yield

By

Shane Michael Carver

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

Impact of planting strategies on soybean (*Glycine max* L.) growth, development and yield

By

Shane Michael Carver

Approved:

____

J. Trenton Irby
(Major Professor)

____

Angus L. Catchot Jr.
(Minor Professor)

____

Daniel B. Reynolds
(Committee Member)

____

Darrin M. Dodds
(Committee Member)

____

Michael S. Cox
(Graduate Coordinator)

____

J. Mike Phillips
(Department Head)

____

George M. Hopper
Dean
College of Agriculture and Life Sciences

Name: Shane Michael Carver

Date of Degree: May 4, 2018

Institution: Mississippi State University

Major Field: Agronomy

Major Professor: J. Trenton Irby

Title of Study: Impact of planting strategies on soybean (*Glycine max* L.) growth, development and yield

Pages in Study: 46

Candidate for Degree of Master of Science

Soybean seed is one of the most costly inputs for soybean producers. Research was conducted in 2016 and 2017 in Mississippi to evaluate the impact of row spacing, planting date and seeding rate on soybean yield. Additional research was conducted to determine the optimal replant seeding rate, following a sub-optimal stand of soybean, to maximize soybean yield. These data suggest an early planting date, mid-April, at a seeding rate of 296,400 seeds ha^{-1}, no matter the row spacing, resulted in the greatest soybean yield. No yield differences were observed for a replant seeding rate of 160,500 seeds ha^{-1} added to a 50% reduced stand when compared to the optimum stand treatment. Soybean yield was greater for the optimum stand treatment when compared to complete removal followed by full replant treatment, or 321,000 seeds ha^{-1}.

DEDICATION

I would like to dedicate this research first and foremost to my Lord and Savior Jesus Christ. Without him, none of this would be possible. Next, I would like to dedicate this research to my parents, Mike and DeAnn Carver and siblings Heath and Kali Carver. I would not be where I am today without the immense support, guidance and love provided by my family through all decisions to this point. I would also like to dedicate this research to my grandparents, Patricia Hall and Janice Carver, and in particular my grandfathers, Dee Hall and Jerry Carver. I am very thankful for the lessons learned and the time spent with these two men. I would like to dedicate this research to all of my friends and colleagues who have supported and worked alongside me through this process. Lastly, I would like to dedicate this work to Morgan Brewer. She has supported and encouraged every decision I have made up to this point in my education and without her this would not be possible.

ACKNOWLEDGEMENTS

I would like to express my most sincere gratitude to the people who have given so much time and effort to aid in this research. First, and foremost, my most sincere appreciation is expressed to Dr. Trent Irby, my major professor, for his guidance and friendship throughout this process. His time, teaching and support have both educated and blessed me in way that will help me for the rest of my career.

I would also like to thank the other members of my committee, namely, Dr. Angus L. Catchot, Dr. Daniel B. Reynolds and Dr. Darrin M. Dodds, for the willingness to provide aid and direction for the duration of this degree. I very much appreciate all time they took to work with me and help me achieve my goals toward finishing this degree.

I would also like to thank Mrs. Alanna Scholtes for her endless effort and coordination toward this research. I would also like to thank the graduate students, Mr. Greg Flint and student workers that worked tirelessly with me on this project. Without the assistance of these people, this research could not have been completed. I have been fortunate to be surrounded by such a great friends that I have learned so much from each of them. I would like to thank Chase Floyd, Michael Plumblee, Lucas Franca, Chase Samples, Bradley 'Nunchuck' Wilson, Savana Davis, Chad Abbot and Zach Reynolds. These people have been a great help along the way and I appreciate the hard work they were willing to give in order to help me complete this research.

Finally, I would like to thank Dr. Jan DuBien for her countless hours of statistical support and guidance in teaching me through the analysis of these research data. She has taught me a great deal about statistical analysis. I greatly appreciate all that she and many others were willing to offer to help me finish this project.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

LITERATURE REVIEW AND INTRODUCTION

Soybean (*Glycine max* L.) is a major export commodity for the United States and, in recent years has become a key crop in the mid-southern United States (U.S.), a region containing portions of Arkansas, Louisiana and Mississippi, among other states (USDA-ERS, 2017). Soybean ranks as the leading row crop in Mississippi, holding more value of production, in dollars, than that of all grains, hay, sweetpotatoes and peanuts combined (USDA-NASS, 2017b). Soybean provides a high-quality oil and protein that is considered very valuable and beneficial for livestock and other animal feeds, as well as human food (Heatherly and Hodges, 1999). Soybean is thought to have been domesticated in the Yangtze River Valleys of central to southern China an estimated 3,000 to 5,000 years ago (Purcell et. al., 2014).

Present day soybean production has improved drastically since times before World War II, where soybean was primarily used for livestock forage and a tool to improve soils in areas of poor soil quality. Soybean closely compares to alfalfa, being of high quality suitable for abundant hay or grazing pasture for livestock (Mississippi Forages: Soybean). The increase in demand for vegetable oils during this time in history resulted in changes to the intended use of the crop. One of the largest uses of soybean oil in the 20th century was for margarine. Soybean oil use in margarine increased total production from 1360 kg in 1932 to 957.5 thousand kilograms (kg) in 1944, this was also the same trend for shortening and drying industries (Munn, 1950).

Soybean acreage in Mississippi has increased by 10% from 2014, with an estimated 910,350 hectares (ha) planted out of 329,220 ha of total dedicated crop land. In the years 2012-2017, the average United States soybean yield increased by 638.9 kilograms per hectare (kg ha^{-1}), while Mississippi's soybean yields followed a similar trend increasing 470.76 kg ha^{-1}. This increase in soybean production of 2,638,818,971 kg, resulted in Mississippi being the 12th largest soybean producing state in the United States (USDA-NASS, 2017a).

Soybean is an erect, branching, annual dicot varying in height, with groups of three hairy leaflets, commonly referred to as a trifoliate. During reproduction, soybean will develop self-fertilizing flowers that are either purple or white in color, with certain varieties sometimes developing mixed colorations of flowers (Nirala, 2014). Soybean seeds are generally oval in shape and in commercial soybean seed the coloration of the seed itself is normally yellow but may vary from light yellow to black. The seed consists of a large embryo enclosed by the seed coat. The embryo is comprised of two cotyledons, a hypocotyl and a radicle, or root. Soybean is generally planted 2.54 centimeters (cm) deep in the soil and commonly includes a seed treatment containing a fungicide, insecticide, or a combination of both. There is a wide range of planting dates for soybean in the mid-southern U.S., with early planting considered soon after the danger of frost is eliminated, until mid- to late-June (Purcell et al., 2014 and Nirala, 2014).

Regardless of planting date, there are three requirements a soybean seed must have in order to germinate; soil moisture, adequate soil temperature, and oxygen. Soybean seed begin to germinate at soil temperatures between 2.2 and 6.1 degrees Celsius (°C), with the commonly accepted low soil temperature for germination being 10°C, and an optimum soil temperature for germination being 21.1°C (Casteel, 2010, Hicks and Naeve, 2013, and Purcell et al. 2014). As soil temperature increases, the rate of emergence will also increase. The radicle will emerge first and then be followed by the hypocotyl once the seed reaches an adequate moisture level. The coloration of the hypocotyl, once visible, will determine the flower color later in the growing season, greenish for white flowers and purplish for purple flowers. When the hypocotyl emerges it brings with it the two cotyledons that make up the first vegetative stage in the plant development. If soil moisture is low and the top soil has crusted over at this stage, the hypocotyl may become swollen and cotyledons may be damaged as the seedling attempts to emerge. Loss of cotyledons can result in an 8-9% decrease in yield (Purcell, 2014).

Soybean is divided into categories called maturity groups (MG) according to their relative maturity (Lee et al., 2014). There are 3 predominate soybean MG grown in the mid-southern U.S., with late MG III soybean being grown in those areas having a latitude of 36.0 to 37.0ºN, MG IV being grown throughout most of the region and early to mid MG V soybean being grown in areas throughout the southern portion of the mid-southern U.S. to the gulf coast. Soybean is a short day plant, meaning the onset of flowering is determined by the day length, or photoperiod falling below a certain critical value (Purcell et al., 2014). Previous research conducted at the University of Arkansas evaluated day length and flowering date for MG III and V soybean at three locations. These data indicated that the day length requirement for flowering at a maximum rate is less than 13.4 hours for a MG III variety and less than 12.8 hours for a MG V variety, meaning as planting becomes more delayed, the number of days to flowering is decreased (Purcell et al., 2014).

Determinate or indeterminate is a description of the growth habit of soybean. Determinate cultivars terminate apical growth suddenly and initiate flowering without any additional vegetative growth. Indeterminate cultivars continue vegetative growth throughout flowering, resulting in a longer period of flowering with more rapid canopy development after flowering reaching full canopy closure by stem termination (Heatherly and Hodges, 2004). Determinate varieties were the choice of mid-southern U.S. producers for decades. However, a push for an earlier planting and harvest date, along with potential to avoid late season drought and pest pressure, has resulted in a transition from determinate varieties to earlier maturing, indeterminate varieties across most of the mid-southern U.S region. Previously, determinate and indeterminate varieties have been separated by MG, meaning MG V and higher have traditionally represented determinate soybean and MG IV and below have been indeterminate soybean. The past few years have shown that the dividing line of MG IV and V is fading with some varieties of MG V being indeterminate and MG IV being determinate (Lee et al., 2014).

Soybean growth stages are divided into vegetative and reproductive growth depending on the stage of the plant. Stages from emergence to first flower along the main stem are considered to be vegetative, and are to be designated with a V(n), and from first flower along the main stem to mature pod color and mature seed are considered reproductive stages, and are to be designated with a R(n). When the hypocotyl emerges through the soil with the cotyledons and the cotyledons are fully open the plant is considered to be at the VC growth stage. The first true leaves to develop and fully open, at the first node on the main stem, are called unifoliates and at this point the growth stage is characterized as V1. The first trifoliate, or group of three leaflets, on the main stem of the plant is considered V2 for being on the second node of the stem. Each additional node and trifoliate will be continuously counted upward on the stem as V3, V4…V(n), meaning that each node along the main stem indicates another vegetative growth stage. Reproductive growth begins when there is a single flower at any node along the stem, with this stage of development being referred to as R1. With indeterminate varieties an observation of a flower at a node below the uppermost node with a completely unrolled leaf indicates that the soybean plant has reached the second reproductive stage, or R2. As pollination continues, R3 begins with pod growth, which is defined by having a single .45 cm long pod in the upper four nodes of the plant. Once those pods reach 1.9 cm long the plant has then progressed to the R4 growth stage. As visible seeds, about the size of a BB (4.45 millimeter (mm)), begin to develop in a pod, located in the upper four nodes, the soybean plant progresses to the R5 growth stage. After the seeds develop to the point where they have completely filled the pod cavity, meaning that the seed in the center of the pod has flattened ends from being pressed between the seed on either side, in the upper four nodes, the plant is considered to be R6. When there is one pod of mature color, yellow/brown, anywhere on the plant, the growth stage is then considered to be R7.

The final stage, R8, is not reached until 95% of the pods on the plant are of mature color and those pods contain mature seeds (Pedersen et al., 2008 and Fehr et al., 1971).

In 1980, MG VI and VII varieties were planted on 90% of the soybean acres in Mississippi. However, in 2014, more than 90% of the soybean acres in Mississippi were planted with earlier maturing MG IV and V varieties (Mississippi State University Extension Service, 2012). This change in production practice in Mississippi and across a large portion of the mid-southern U.S. reflects the adoption of the Early Soybean Production System, or ESPS. The conventional production system, planting MG V, VI, VII, and VIII varieties in May and June, had a tendency to result in what we now recognize to be reduced yields, for non-irrigated soybean, due to these later maturity group soybean being in reproductive stages during the historically drier portion of the growing season. Previous research conducted in Stoneville, MS, from 1979-1990, depicted the effects of conventional production systems, where MG V-VIII were planted from May 12 to May 27. These MG's began setting pods from August 5 to August 16, which means seed fill would occur 12 to 14 days after the onset of setting pods. Podset and seed fill during this period of potential drought stress in soybean has the greatest effect on yield confirming a low yield plateau for this production system in the Mid-Southern U.S. (United Soybean Board, 1998).

Moving forward, with seed inputs being approximately 30% of the overall production costs, having the ability to reduce seed costs by planting an optimum seeding rate, in combination with an optimal row spacing and planting date would be beneficial to producers (U.S. Soy Statistics, 2014). Throughout the planting season there are many variables that cannot be controlled that can result in suboptimal plant stands and reduced yields, with environmental conditions being near the top of this list (Wiebold, 2012, Whingham et al., 2000). Producers in the mid-southern U.S. have the ability to utilize various planting strategies that can maximize soybean yield, therefore, the objectives of this research are to: 1) evaluate the effect of row spacing, planting date and seeding rate on soybean growth, development and yield and 2) determine the optimal seeding rate and planting approach for replant situations in soybean.

References

Anonymous. Mississippi Forages: Soybean. Mississippi State Extension Service. http://msucares.com/crops/forages/legumes/warm/soybean.html.

Casteel, S. 2010. Soybean physiology: How well do you know soybeans? Purdue University: Soybean Extension.

Fehr, W.R., Caviness, C.E., Burmood, D.T., Pennington, J.S. 1971. Stage development descriptions for soybeans. *Crop Sci.* 11:929-930.

Heatherly, L.G., and Hodges, H.F. 1999. Soybean production in the midsouth. CRC Press. Boca Raton, FL. Pp. iii, 46-49.

Heatherly, L.G., and Hodges, H.F. 2004. Effect of soybean stem growth habit on height and node number after beginning bloom in the midsouthern USA. *Crop Sci.* 44:1855-1858.

Hicks, H.R., Naeve, S. 2013. The soybean grower's field guide for evaluating crop damage and replant options. University of Minnesota Extension. http://www.extension.umn.edu /agriculture/soybean/planting/the-soybean-growers-field-guide-for-evaluating-crop-damage-and-replant-options/#making.

Lee, C. Knott, C., Ritchey, E. 2014. Soybean variety selection. University of Kentucky Coop. Extension Service. AGR-129:1-5.

Mississippi State University Extension Service. 2012. Soybean production in Mississippi. Mississippi Agricultural and Forestry Experiment Station. http://msucares.com/crops/soybeans/recommend.html.

Munn, Alvin A... "Production and utilization of the soybean in the United States". *Econ. Geo.* 26.3 (1950): 223–234. Web

Nirala, Satyavrat. 2014. Soybean plant. 2014 Encyclopedia Britannica.

Pedersen, Pelle, S. Kumudini, J. Board, S. Conley. 2008. Soybean growth and development. Using Foliar Fungicides to Manage Soybeans. Pp. 41-45.

Purcell, L. C., Salermon, M., and Ashlock, L. 2014. Soybean growth and development. University of Arkansas Extension. *Arkansas Prod. Handbook* 2:1-8.

United Soybean Board. 1998. Early Soybean Production System Handbook. Soybean Checkoff. http://unitedsoybean.org/wpcontent/uploads/ESPS_Handbook_19984.pdf.

[USDA] U.S. Department of Agriculture. 2014. National Agriculture Statistics Service. 2014 State Agriculture Overview. Mississippi. Mississippi Dept. of Agriculture and Commerce. http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MISSISSIPPI.

[USDA-ERS]. U.S. Department of Agriculture – Economic Research Service. 2017. Trade. https://www.ers.usda.gov/topics/crops/soybeans-oil-crops/trade.aspx.

[USDA] U.S. Department of Agriculture. 2017a. National Agriculture Statistics Service. 2017 State Agriculture Overview. Mississippi. Mississippi Dept. of Agriculture and Commerce. http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MISSISSIPPI.

[USDA] U.S. Department of Agriculture. 2017b.National Agriculture Statistics Service. Crop Production 2017 Summary. http://www.usda.gov/nass/PUBS/TODAYRPT/cropan15.pdf.

U.S. Soy Statistics. 2014. U.S. Soybean production costs & returns 2014. http://soystats.com/production-costs-returns/.

Whingham, K., D. Farnham, J. Lundvall, and D. Tranel. 2000. Soybean replant decisions. Iowa State University Extension. http://agris.fao.org/agris-search/search.do?recordID= US201300093488

Wiebold, W., Massey, R. 2012. Corn and soybean replant decisions. University of Missouri Extension. http://extension.missouri.edu/explorepdf/agguides/crops/g04091.pdf.

CHAPTER II

EVALUATING THE EFFECT OF ROW SPACING, PLANTING DATE AND SEEDING RATE ON SOYBEAN (*Glycine max* L.) GROWTH, DEVELOPMENT AND YIELD.

Abstract

Soybean (*Glycine max* L.) seed is one of the more costly inputs for soybean producers. Soybean producers must select an optimal seeding rate, row spacing and planting date to maximize yield potential. Current seeding rate recommendations in the mid-southern U.S. range from 296,400 to 345,800 seeds per hectare (seeds ha^{-1}) to achieve a final overall plant population of 197,600 to 247,000 plants per hectare (plants ha^{-1}). In addition, soybean produced on narrow row spacings, those less than 76.2 centimeters (cm), may result in an increased yield when compared to soybean produced on rows being 76.2 cm or greater in width. The common soybean planting window in Mississippi begins in mid-April and ends late-June with the potential to plant earlier in the month of April if weather and field conditions permit. Optimizing soybean row spacing pattern and seeding rate within a given planting date may assist in stabilizing yield in systems lacking the ability to use irrigation as a means to alleviate stress throughout the growing season Therefore, the objective of this research was to evaluate the effects of row spacing, planting date and seeding rate on soybean growth, development and yield in a rain-fed environment.

Experiments were conducted at the R.R. Foil Plant Science Research Center near Starkville, MS and Black Belt Branch Experiment Station near Brooksville, MS in 2016 and 2017 as well as the Delta Research and Extension Center in Stoneville, MS in 2016. Treatments were arranged using a split-split plot design with the main plot factor being row spacing, the sub-plot factor being planting date and the sub-sub-plot factor being seeding rate. The row spacing component was comprised of ultra-narrow, narrow and wide row spacings, or 38-, 76-, and 97-cm, respectively. A maturity group IV, indeterminate soybean variety was planted in mid-April, mid-May and mid-June to five seeding rates including 197,600; 247,000; 296,400; 345,800; or 396,200 seeds ha^{-1} occurring within each planting date and row spacing configuration. With respect to soybean yield, the independent factor of seeding rate as well as the combination of row spacing and planting date was significant when pooled across year and location. Soybean yield was greater when seeded at a rate of 345,800 seeds ha^{-1}, or greater, when compared to seeding rates of 247,000 seeds ha^{-1}, or less, but no significant difference was observed between seeding rates of 396,200; 345,800; and 296,400 seeds ha^{-1}. No difference in yield was observed following seeding rates of 247,400 and 296,400 seeds ha^{-1}. All row spacings planted in mid-April and mid-May resulted in greater yields when compared to soybean planted in across all row spacings in mid-June. These data suggest planting soybean to seeding rates of 296,400 seeds ha^{-1}to maximize yield in rain-fed environments across the mid-southern U.S.

Introduction

Soybean (*Glycine max* L.) acres in the mid-southern U.S., a region including western Tennessee, southeast Missouri, Arkansas, Louisiana and Mississippi, were predominately planted to MG VI and VII varieties during the 1980's. During this time, producers in this region were utilizing conventional production systems which included planting maturity group (MG) V, VI, VII, and VIII soybean varieties in May and June. In rain-fed growing conditions, conventional production systems tend to result in low yields, primarily due to these later maturing soybean varieties reaching reproductive growth stages during a drier portion of the growing season (United Soybean Board, 1998). Previous research conducted in Stoneville, MS from 1979 to 1990 depicts environmental effects on conventional production systems where MG V to MG VIII varieties were planted from May 12 to May 27. Varieties within these maturity groups began setting pods from August 5 to August 16 which means seed fill would occur 12 to14 days after the onset of setting pods. Podset and seed fill during this period of potential drought stress in soybean has the greatest effect on yield confirming a low yield plateau for this production system in the mid-southern U.S. (United Soybean Board, 1998). Therefore, a need for change existed with respect to production methods in a region where soybean reproductive stages occur during times of environmental stress or possible drought.

The Early Soybean Production System, or ESPS, which consisted of planting an earlier maturing soybean variety earlier in the growing season, was adopted. This results in reproductive stages typically occurring while there was an adequate supply of soil moisture. Adoption of earlier planting dates allows soybean reproductive stages to occur between early June and late July and increases the probability of avoiding drought stresses that may occur later in the growing season (United Soybean Board, 1998, Heatherly and Hodges, 1999). The ESPS has resulted in greater yields than the previously utilized conventional soybean production systems (Heatherly and Hodges, 1999). A study conducted by Bowers (1995) suggested that by planting early-maturing varieties in April, soybean yield was greater compared to later-maturing varieties planted in May in northeast Texas. Bowers also observed that early-maturing varieties planted in May yielded greater than or equal to that of later-maturing varieties planted in May (Heatherly, 2014; Heatherly and Hodges, 1998; Bowers, 1995). Although yield potential is greater with the ESPS, there is increased risk from potential of delayed emergence and increased probability of cold-induced injuries to plants, pod shattering, and decreased seed quality. Once emerged, the growing point of soybean is above ground, making it more vulnerable to adverse environmental conditions. Cold injury typically occurs from frost events where the exposed portion of the soybean plant is damaged. Survival of a soybean plant can be assessed by examining the damaged portions. If the plant only received damage from frost above the cotyledonary node, regrowth from the auxiliary buds may occur at that node. However, if the plant received frost damage below the cotyledonary node, it will not survive (Nielsen and Christmas, 2002). Shattering occurs when seed is released from the pod by rapid drying of the pods and seeds before harvest. This is overcome by timely harvest when seed is at an adequate moisture, typically from August 15 to September 30 (United Soybean Board, 1998; Heatherly and Hodges, 1999; Heatherly, 2014).

Soybean seed and the associated technology fees are a major soybean production cost. Reduced seeding rates may give producers the ability to reduce overall production costs. In 2014, operating costs for soybean production in the United States totaled $452.16 per planted hectare with nearly 30% of that coming from seed cost (U.S. Soy Statistics, 2014). This increased need to reduce seed costs prompted a recent experiment conducted through the Louisiana State University AgCenter from 2009-2011, evaluating economic losses from reduced seedling emergence and plant depth as well as determining the minimal optimum plant population for soybean production. Board et al. (2013) found that, for Louisiana, the minimal optimum plant population was approximately 222,300 plants per hectare (plants ha^{-1}). Soybean was seeded at a rate of 271,000 seeds per hectare (seeds ha^{-1}) at 92% germination to achieve a plant population of 223,300 plants ha^{-1} (Board et al., 2013). Other research by Rich and Renner, 2007, resulted in no significant yield differences when increasing or decreasing the initial seeding rate of 308,750 seeds ha^{-1} by 40%. Additional research found that under high-yielding conditions, yield was maximized under a 76.2 centimeter (cm) row at a seeding rate of 284,050 seeds ha^{-1}, whereas locations with less than optimal soil moisture showed no significant increase with respect to yield as seeding rate increased (Devlin et al., 1995). These data suggest there are cost saving strategies related to seed that producers can utilize while also maintaining yield.

High plant populations in soybean have advantages and disadvantages. Higher plant populations may result in more rapid canopy closure, increased light interception, and reduced weed competition. However, yield increases are not always observed following increased seeding rates. Disadvantages of high plant populations are increased plant competition and ultimately greater production costs to the producer (Bruin and Pedersen, 2008). There are multiple factors taken into consideration when determining an optimum seeding rate such as row spacing, germination percentage, and whether or not the area in question will be irrigated (Robinson, 2007). Germination percentage refers to the percentage of seeds that produced a plant in a warm germination test. Although germination percentage can vary from seed-lot to seed-lot, high germination rate does not guarantee that percentage of the final stand due to possible cracks in the seed coat or seed-borne diseases, during or post planting, respectively (Olechowski, 1983). The row spacing utilized is typically dependent on location and production practices. In rain-fed scenarios in the mid-southern U.S. soybean are commonly planted on 76 to 97 cm raised beds, as well as drilled and wide rows on flat ground.

With seed costs and technology fees increasing, producers are faced with difficult decisions regarding optimal soybean seeding rates to utilize in various row spacing scenarios in a given planting date range. Current seeding rate recommendations in the mid-southern U.S. range from 296,400 to 345,800 seeds ha^{-1} with the common planting window for Mississippi soybean growers beginning in April and ending late-June (Johnson, 2011). Therefore, it is important to determine the optimum row spacing and seeding rate combination for maximizing soybean yield and profitability within a given planting date. Therefore, the objective of this research was to evaluate the effects of row spacing, planting date and seeding rate on growth, development and yield of soybean grown under rain-fed conditions.

Materials and Methods

Field trials were conducted at three locations in 2016 and two locations in 2017, 5 total locations, at Mississippi State University (MSU) research facilities. Experimental locations included the R.R. Foil Plant Science Research Center (2016 and 2017) near Starkville, MS (33.474844ºN, -88.786186ºW), on a Marietta Fine Sandy Loam soil (Fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts) (USDA-NCSS, 2000b), MSU Delta Research and Extension Center in Stoneville, MS (33.402072ºN, -90.925853ºW), in 2016, on a Sharkey Clay soil (Very-fine, smectitic, thermic Chromic Epiaquerts)

(USDA-NCSS, 2013) and the MSU Black Belt Branch Experiment Station (2016 and 2017) in Brooksville, MS (33.257887ºN, -88.554029ºW), on a Brooksville Silty Clay soil (Fine, smectitic, thermic Aquic Hapluderts) (USDA-NCSS, 2000a).

Agronomic Management

Each location was planted with an indeterminate, Roundup Ready 2 Xtend, maturity group IV soybean variety, Asgrow[1] AG47X6 (2016) and Asgrow AG46X6 (2017). Seed was planted to three row spacings consisting of wide, narrow and ultra-narrow rows, or 97, 76 and 38 cm row spacings, respectively. Wide and narrow row spacings were planted with an ALMACO[2] planter, equipped with a hydraulic telescoping toolbar and John Deere[3] MaxEmerge XP row units, whereas, the ultra-narrow row spacings were planted with a Great Plains 3P606NT Drill[4]. Seed at each row spacing was planted mid-April, mid-May or mid-June, representing early-, mid- and late-season planting dates, using five different seeding rates for each planting date and row spacing combination. Seeding rates included: 197,600; 247,000; 296,000; 345,000; and 395,000 seeds ha^{-1}. Actual planting dates are listed in Table 2.1. Combinations of row spacing, planting date and seeding rate were planted in plots measuring 12.2 meters (m) in length with a 6.1 m alley between replications, to achieve a total of 45 treatments and 4 replications of each treatment. Furthermore, planting date and seeding rate were randomized within each row spacing, where all factors were fixed. Row spacing was assigned within a field to allocate for ease of plot maintenance and harvest.

[1] Monsanto Company, 800 N. Lindberg Blvd., St. Louis, MO. 63167. USA.
[2] ALMACO, 99 M. Ave. Nevada, IA, 50201. USA.
[3] Deere & Company World Headquarters, 1 John Deere Pl, Moline, IL. 61625. USA.
[4] Great Plains Manufacturing, Inc., 1525 E. North St., Salina, KS. 67401. USA.

Land preparation at all locations consisted of a tillage event to prepare for field conditions suitable for planting conditions. Each location was left fallow in the fall and planted to a stale seedbed in the spring. Soil samples were obtained each fall with all fertility management practices being based on MSU Extension recommendations. Fertilizer applications were made in the fall of the previous crop year. In addition, all other crop management needs implemented throughout the growing season were based on MSU Extension recommendations for soybean. Seeds were treated with Acceleron[1] Standard in both years.

Data Collection

Data collection comprised of plant heights and node counts measured at the R5.5 growth stage, along with weekly documentation of growth stage recorded throughout the growing season. Overall seed yield was also measured at harvest using a Kincaid[5] 8-XP High Performance Multi-Crop Plot Combine. Soybean yield was adjusted to 13 percent standard moisture and harvest dates are listed in Table 2.1. Partial budget analysis of soybean seeding rates were calculated and are listed in Table 2.6.

Statistical Analysis

Treatments were arranged in a split-split-plot with the main plot factor (fixed) being row spacing (3), sub-plot factor (fixed) being planting date (3), and the sub-sub-plot factor (fixed) being seeding rate (5), totaling 45 treatments. These data were pooled and analyzed from all locations and site years, where location and replication were each treated as random. Statistical analysis was completed in PROC GLIMMIX using

[5] Kincaid Equipment Manufacturing, Co., 210 W. 1st St., Haven, KS. P.O. Box 400. 67543. USA.

Statistical Analysis Software (SAS) version 9.4[6] (SAS Institute Inc., Cary, NC). Means were separated using Multiple Pairwise t-Test at an $\alpha=0.05$.

Results and Discussion

Plant Height, Node Count and Soybean Yield

Node count ($p \geq 0.1618$) parameters were not significantly affected by any treatments when pooled across all site-years (Table 2.2). The number of nodes per plant when documented at the R5.5 growth stage, ranged from 22.99 nodes for soybean planted to an ultra-narrow row spacing planted in mid-May at the 396,200 seeds ha^{-1} seeding rate to 17.10 nodes for soybean planted to a wide row spacing in mid-June at the 396,000 seeds ha^{-1} seeding rate. Planting date ($p < 0.0001$) was significant, with respect to plant height when averaged across row spacing and seeding rate, as well as location and year (Table 2.2). Soybean planted in mid-May resulted in the greatest plant height when compared to the mid-June and mid-April planting date timings. Additionally, soybean planted in mid-June resulted in greater plant height when compared to those planted in mid-April (Table 2.3).

Seeding rate ($p < 0.001$) was significant with respect to soybean yield across location and year (Table 2.2). No differences in yield were observed following seeding rates of 296,400; 345,800; and 396,200 seeds ha^{-1} (Table 2.4). Additionally, no differences in yield were observed following seeding rates of 296,400 and 247,000 seeds ha^{-1}; however, seeding soybean at a rate of 345,800 seeds ha^{-1} resulted in greater yield compared to soybean yield following the 247,000 seeds ha^{-1}. Seeding rates of 197,600

[6] SAS Instutute Inc., Corporate Headquarters, 100 SAS Campus Dr. Cary, NC, 27513-2414. USA.

seeds ha^{-1} resulted in the lowest yield when compared to all other seeding rates. These data further solidify the current MSU Extension recommendations, suggesting a seeding rate range of 296,400 to 345,800 seeds ha^{-1} should be utilized to maximize soybean yield no matter the row spacing or planting date.

Row spacing by planting date ($p = 0.0282$) interact, when averaged over seeding rate and site-year (Table 2.5). Yield was greater for soybean planted to an ultra-narrow, or 38 cm, row spacing in mid-April or mid-May, when compared to soybean planted in mid-June. There was no difference in yield when soybean was planted to narrow rows in mid-April and mid-May, but soybean planted to these mid-April and mid-May planting dates yielded greater than the mid-June planting date. The same was true for wide row soybean, with yields of 2648.2 and 2630.6 kg ha^{-1} for mid-May and mid-April, respectively. These results are similar to the findings of Heatherly and Hodges (1999) and also Bowers (1995), in that greater yields can be observed from MG IV soybean planted earlier in the planting season. These data may be further confirmed by the results of Mississippi's soybean production during 2017, where 69% of the state's acreage was planted by the end of April, compared to only 38% of the acreage being planted by this calendar date on the 5 year average. During 2017, Mississippi set a new state yield record of 3561.6 kg ha^{-1}, which can partially be attributed to the progress of planting during the optimum planting window (USDA-NASS, 2017b). Therefore, these data further support the yield benefit that the ESPS has demonstrated to be successful in Mississippi and across the mid-southern U.S (Heatherly, 2014).

Economics

Economics for seeding rate evaluations were based on a seed cost of \$75.00 per 140,000 seeds and a grain value of \$9.75 per 27.22 kg^{-1} (USDA-NASS, 2017). Seed cost prorated for each seeding rate is as follows: \$211.70; \$185.25; \$158.77; \$132.32; \$105.86; for seeding rates of 396,200; 345,800; 296,400; 247,000 and 197,600 seeds ha^{-1}, respectively. Gross returns were calculated by multiplying grain value and overall soybean yield for each treatment, followed by net returns above seed costs being calculated from the difference in gross return and seed cost (Table 2.6). Partial budget analysis was carried out to compare profitability of various seeding rate strategies. Seeding rates of 247,000 and 296,400 seeds ha^{-1} were found to be the most profitable with a difference in net return being \$22.66 and \$30.16, respectively. These data may be further supported by the findings of Thompson et al. (2015), which stated that net returns were maximized by utilizing the lowest seeding rate that also maximized yield.

Conclusion

The mid-southern U.S. is notorious for receiving untimely rainfall and sporadic weather patterns during the early portion of the planting season which ultimately results in potential delays in soybean planting. These data suggest that if planting is delayed beyond April, there is still opportunity to optimize yield in later planting dates across all row spacings configurations commonly used in Mississippi by seeding soybean at rates of 296,400 seeds ha^{-1}. However, to maximize yield, soybean should be planted in April at 296,400 seeds ha^{-1} regardless of row spacing. As varieties of various growth characteristics improve, further research is needed to determine the effect that seeding rates, both less than and greater than those evaluated in this study may have on soybean yield. However, under current best management practices in non-irrigated, or rain-fed, soybean production, seeding rates of 296,400 to 345,800 seeds ha^{-1} should be implemented, in mid-April, or earlier, across all row spacings, to maximize yield. The economic breakdown further explains the importance of utilizing the proper seeding rate range of 296,400 to 345,800 seeds ha^{-1}. These data suggest that soybean profitability can be maximized, in a non-irrigated environment within this seeding rate range.

Table 2.1 Planting and harvest dates for locations of Starkville and Brooksville, MS in 2016 and 2017 and Stoneville, MS in 2016.

	-------Starkville-------		-------Brooksville-------		Stoneville
	2016	2017	2016	2017	2016
Early[b]-Planting	26-Apr	21-Apr	--[a]	24-Apr	--[a]
Mid[c]-Planting	19-May	--[a]	12-May	10-May	5-May
Late[d]-Planting	9-Jun	10-Jun	8-Jun	10-Jun	12-Jun
Early-Planting Harvest	21-Sep	27-Sep	29-Sep	21-Sep	--[a]
Mid-Planting Harvest	30-Sep	--[a]	29-Sep	4-Oct	5-Oct
Late-Planting Harvest	30-Sep	13-Oct	29-Sep	4-Oct	5-Oct

[a] Not planted within the planting date parameters due to weather conditions
[b] Mid-April
[c] Mid-May
[d] Mid-June

Table 2.2 Analysis of variance probability values for growth parameters and yield for treatment combinations of row spacing, planting date and seeding rate during 2016 and 2017.

Source	Height at harvest	Nodes at harvest	Yield
	-----------------------------p-value[a]-------------------------------		
RS[b]	0.0575	0.8010	0.5618
PD[c]	<0.0001	0.1337	<0.0001
RS*PD	0.0581	0.3251	0.0282
SR[d]	0.3216	0.2314	<0.0001
RS*SR	0.6667	0.5619	0.9224
PD*SR	0.9605	0.3430	0.7410
RS*PD*SR	0.9789	0.5139	1.0000

[a] Data was pooled across site-years of 2016 and 2017
[b] Row Spacing
[c] Planting Date
[d] Seeding Rate

Table 2.3 Soybean plant height for seeding rate averaged across row spacing and planting date for all site-years.

Planting Date	Plant Height[ab]
	-------cm-------
Mid-April	73.6 c
Mid-May	83.6 a
Mid-June	78.2 b

[a] Measured in centimeters from soil level to terminal node obtained at R5.5 growth stage.
[b] LS-means within the same column followed by the same letter are not significantly different according to multiple pairwise t-tests at P = 0.05.

Table 2.4 Soybean yield for seeding rate averaged across row spacing and planting date for all site-years.

Seeding Rate -------seeds ha^{-1}-------	Yield[ab] -------kg ha^{-1}-------
197,600	2139.7 c
247,000	2276.6 b
296,400	2371.5 ab
345,800	2439.7 a
396,200	2476.5 a

[a] LS-means within the same column followed by the same letter are not significantly different according to multiple pairwise t-tests at P = 0.05.

Table 2.5 Soybean yield for row spacing by planting date averaged across seeding rate for all site-years.

Row Spacing*Planting Date	Yield[a] -------kg ha^{-1}-------
Ultra-Narrow[b]*Mid-April	2851.2 a
Ultra-Narrow*Mid-May	2527.4 a
Ultra-Narrow*Mid-June	1829.6 c
Narrow[c]*Mid-April	2377.6 ab
Narrow*Mid-May	2420.6 ab
Narrow*Mid-June	1768.2 c
Wide[d]*Mid-April	2630.6 a
Wide*Mid-May	2648.2 a
Wide*Mid-June	2013.9 bc

[a] LS-means within the same column followed by the same letter are not significantly different according to multiple pairwise t-tests at P = 0.05.
[b] 38.1 cm row spacing
[c] 76.2 cm row spacing
[d] 96.5 cm row spacing

Table 2.6 Soybean yield for seeding rate averaged across row spacing and planting date for all site-years.

Seeding Rate	Seed Cost[a]	Gross Return[b]	Net Return[c]	Difference in Net Return
-----seeds ha^{-1}----	US\$ ha^{-1}	US\$ ha^{-1}	US\$ ha^{-1}	US\$ ha^{-1}
197,600	105.86	736.60	660.30	0
247,000	132.32	781.69	682.96	22.66
296,400	158.77	815.03	690.46	30.16
345,800	185.25	833.00	688.39	28.09
396,200	211.70	849.04	675.10	14.80

[a] Seed cost based off of $75.00 per 140,000 seeds

[b] Soybean value of $24.08 ha^{-1}, from Mississippi October 2017.

[c] Net return above seed costs = gross return – calculated seed cost.

References

Anonymous. Soybean Production in Mississippi. Mississippi State Extension Service. http://extension.msstate.edu/agriculture/crops/soybeans (accessed 13 March 2018).

Board, J., Kahlon, C., Harrel, D., Udeigwe, T., Stapp, J., Talbot, T. 2013 Can soybean seeding rates be reduced without affecting yields in Louisiana? Louisiana State University Extension Service. http://www.lsuagcenter.com/~/media/system/5/2/1/9/5219129b30146b79fee2bb41a74fa921/b892soybeanseedingratesjan2013.pdfBowers, G.R. 1955. An early season production system for drought avoidance. *J. Prod. Agric*: 8:112-119. (accessed 13 March 2018).

Bruin, J.L., and Pedersen, P. 2008. Effect of row spacing and seeding rate on soybean yield. *Agron. J.* 100:704-710.

Devlin, D.L., Fjell, D.L., Shrover, D.J., Gordon W.B., Marsh, B.H., Maddux, L.D., Martin, V.L., and Duncan, S.R. 1995. Row spacing and seeding rates for soybean in low and high yielding environments. *J. Prod. Agric.* 8:215-222.

Heatherly, L.G., and Hodges, H.F. 1999. Soybean production in the mid-south. CRC Press. Boca Raton, FL. Pp. iii, 46-49.

Heatherly, L.G. 2014. Row Spacing Decisions. Mississippi Soybean Promotion Board. https://www.mssoy.org/uploads/2012/04/ROW-SPACING-DECISIONS-MAR-20121.pdf (accessed 13 March 2018).

Nielsen, R.L., E. Christmas. 2002. Purdue University, Dept. of Agronomy. Early Season Frost & Low Temperature Damage to Corn and Soybean. https://www.agry.purdue.edu/ext/corn/news/articles.02/Frost_Freeze-0520.html (accessed 13 March 2018).

Johnson, C. 2011. Whats the right rate? Corn and Soybean Digest, vol. 17(no. 10), p. 12

Olechowski, H.T. 1983. Agronomy Guide for Field Crops. Ontario Ministry of Agriculture. http://www.omafra.gov.on.ca/english/crops/pub811/pub811.pdf (accessed 13 March 2018).

Rich, A.M., and K.A. Renner. 2007. Row spacing and seeding rate effects on eastern black nightshade (*Solanum ptycanthum*) and soybean. *Weed Technol.* 21:124-130.

Robinson, Andrew P., Conley, S. 2007. Plant populations and seeding rates for soybeans. Purdue Extension. https://www.extension.purdue.edu/extmedia/ay/ay-217-w.pdf (accessed 13 March 2018).

Thompson, N.M., J. Larson, D. Lambert, R. Roberts, A. Mengistu, N. Bellaloui, E. Walker. 2015. Mid-South Soybean Yield and Net Return as Affected by Plant Population and Row Spacing. Agron. J. 107: 979-989.

United Soybean Board. 1998. Early Soybean Production System Handbook. Soybean Checkoff. https://unitedsoybean.org/wp-content/uploads/ESPS_Handbook_19984.pdf (accessed 13 March 2018).

[USDA] U.S. Department of Agriculture. 2017. National Agriculture Statistics Service. Price Received: October 2017. https://quickstats.nass.usda.gov/results/32D6926C-ABEC-3A8B-9A31-5FAFB29FA480. (accessed 13 March 2018).

[USDA] U.S. Department of Agriculture. 2017b. National Agriculture Statistics Service. Crop Production 2017 Summary. http://usda.mannlib.cornell.edu/usda/nass/CropProdSu//2010s/2017/CropProdSu-01-12-2017.txt (accessed 13 March 2018).

U.S. Soy Statistics. 2014. U.S. Soybean production costs & returns 2014. http://soystats.com/production-costs-returns/. (accessed 13 March 2018).

CHAPTER III

DETERMINING THE OPTIMAL SEEDING RATE AND PLANTING APPROACH FOR REPLANT SITUATIONS IN MISSISSIPPI SOYBEAN (*Glycine max*)

Abstract

Throughout the planting portion of the growing season, there are many uncontrolled variables that have the potential to contribute to suboptimal soybean (*Glycine max* L.) populations that may ultimately result in reduced yield. The soybean planting window in Mississippi typically begins in early-April when environmental conditions tend to be less favorable for achieving maximum stand potential. Determining replant methods when faced with suboptimal soybean stands may prove beneficial to soybean producers. This experiment was conducted to determine the optimal replant strategy for various levels of reduced soybean populations.

This experiment was conducted during 2016 and 2017 in Starkville and Stoneville, MS, as well as Brooksville, MS in 2017. Indeterminate, maturity group IV Roundup Ready (RR) and LibertyLink (LL) varieties were blended to achieve seeding rates that could be reduced by specific percentages using chemical removal methods. This experiment consisted of 25 treatments where initial seeding rates targeted 321,100 seeds per hectare and blended percentages of the seeding rate were as follows: 100% RR & 0% LL, 75% RR & 25% LL, 50% RR & 50% LL, 25% RR & 75% LL, and 0% RR& 100% LL. Glyphosate, 333.33 g a.e. ha^{-1}, was applied across the entire experiment at the V1 growth stage in order

to eliminate the LL variety, leaving the initial RR population. Replanting occurred 7 to 17 days after the application of glyphosate at reseeding percentages of 100%, 75%, 50%, 25%, and 0% using the RR variety. Data collection consisted of final node count, final plant height and overall soybean yield.

The combination of soybean stand removal by replant resulted in significant differences within parameters of number of nodes, plant heights and soybean yield. Soybean yield for the treatment of 0/0% removal/replant was greater than that of the 100/100% removal/replant. No soybean yield difference was observed for treatments of 50/50% removal/replant and 0/0% removal/replant. When 75% of the initial population was removed, yield was maximized by replanting at least 75% in the existing stand. No differences in plant height were observed for the treatments of 0/0% removal/replant and 100/100% removal/replant. Final node count indicated a significant difference in number of nodes between the 0/0% removal/replant and 100/100% removal/replant.

Introduction

Mississippi soybean (*Glycine max* L.) growers typically experience an extended planting window beginning in April, or earlier if weather permits, and ending in late June. With such a broad planting window, there are many uncontrolled variables that can potentially reduce soybean populations at or soon after emergence. If the soybean stand from the initial planting is less than optimal, replanting may be an effective option to consider (Olechowski, 1983). The question of how to proceed with a replant situation can be one of the most challenging decisions growers may face due to increasing costs of operation and seed inputs. Numerous factors need to be considered when making a soybean replant decision but the conclusion should be primarily based on plant population by stand counts along with interacting factors such as weather, current plant density, calendar date, condition of the original stand, and the economics that come along with replanting (Wiebold, 2012, Whingham et al., 2000). Many factors can contribute to a suboptimal soybean stand including poor seed bed, poor seed quality or poor germination percentages, as well as soil crusting and environmental induced plant injury that may occur at or soon after emergence. Identifying these issues are important to avoid similar results following a replant.

When measuring reductions in soybean plant populations, accurate plant stand estimates and timing of these estimates are essential. After a detrimental event or poor plant emergence has occurred, postpone the plant stand estimations 3 to 5 days to allow soybean to start regrowth following the injury or poor growing conditions (Whingham et al., 2000). When obtaining a plant stand value, it is critical to only count the healthy plants and avoid those severed below the cotyledons with no potential for regrowth.

Environmental conditions are important to observe after the plant injury has occurred. For example, environmental conditions consisting of warm temperatures and adequate sunlight provide benefit to wounded plants and can potentially result in a greater chance of survival compared to cool, cloudy conditions that can restrict plant growth ultimately resulting in further stand reductions. Two common methods of obtaining plant density include counting plants in specified row lengths or in circle measurements (Whingham et al., 2000). Row length density measurements can be obtained by a representation of a hectare (ha). For example, on a 96.5 centimeter (cm) row spacing, a total of 10 plants within 0.31 meters (m) row feet results in a population of 338,390 plants per hectare (plants ha^{-}1). An example of a circle method density measurement would be 12 plants counted inside a 78.7 cm inside diameter of a circle results in 247,000 plants ha^{-1}, or 24 plants counted within a 86.4 cm circle resulting in 410,020 plants ha^{-1} (Whingham et al., 2000).

According to Iowa State University Extension, stand reduction occurs as either uniform thin stands or non-uniform reduced stands. Typically, non-uniform stands will occur from poorly drained, drowned out areas or areas with insufficient moisture and can be identified as having gaps or skips within the row. The size and location of the poor stand should be an additional consideration before replanting. If the reason for stand reduction is from gaps or skips, or diameter of 0.6 meters or less, surrounding soybean plants may have the potential to compensate without a yield reduction. However, if these gaps are greater than 0.6 meters in diameter, yield reductions may occur (Whingham et al., 2000). After these factors have been considered, the next decision is whether or not to fill in suboptimal stands or to completely remove the existing stand by tillage or chemical control and replant the location in its entirety, or leave the existing stand (Gaspar and Conley, 2015). Field studies were conducted at the University of Wisconsin: Arlington Agricultural Research Station in 2012 and 2013 observing planting date, seeding rate and seed treatments with different methods of replant. In these studies, Gaspar and Conley (2015) indicated a suboptimal stand of being less than 247,000 seeds per hectare (seeds ha^{-1}) and that replanting stands lower than this by filling in sparse stands regardless of seed treatment or planting date can increase yield. However, a study at Purdue University found no yield advantage to replanting stands greater than 163,020 plants ha^{-1} (Conley and Robinson, 2007). Determining which method to use in a replant situation, in combination with an optimal seeding rate for that replanting method, could prove useful for soybean growers faced with these decisions. Therefore, the objective of this research was to determine the optimal seeding rate and planting approach for replant situations in soybean.

Materials and Methods

Irrigated and rain-fed field trials were conducted at three Mississippi State University (MSU) research facilities during the 2016 and 2017 growing seasons. These locations included the R.R. Foil Plant Science Research Center near Starkville, MS (33.474844ºN, -88.786186ºW), in 2016 and 2017, on a Marietta Fine Sandy Loam soil (Fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts), where the crop was irrigated (USDA-NCSS, 2000b); MSU Delta Research and Extension Center in Stoneville, MS (33.402072ºN, -90.925853ºW), in 2016 and 2017, on a Sharkey Clay soil (Very-fine, smectitic, thermic Chromic Epiaquerts), where the crop was irrigated (USDA-NCSS, 2013); MSU Black Belt Branch Experiment Station in Brooksville, MS

(33.257887ºN, -88.554029ºW), in 2017, on a Brooksville Silty Clay soil (Fine, smectitic, thermic Aquic Hapluderts) where the crop was rain-fed (USDA-NCSS, 2000a).

Agronomic Management

Land preparation at all locations consisted of tillage followed by bedding in the fall to allow for furrow irrigation, where applicable. Soil samples were obtained each fall and all fertilizer requirements and applications were based on MSU Extension recommendations. In addition, recommended seed treatments were used at planting and all crop management practices were incorporated according to recommendations by MSU Extension.

The experiment locations were planted to various percentages of an indeterminate maturity group IV, Roundup Ready 2 Xtend variety, Asgrow[7] AG46X6 in 2016 and an indeterminate maturity group IV, Roundup Ready 2 variety, Pioneer[8] P47T89R in 2017, where both varieties will be denoted further by RR. The RR variety was then blended with an indeterminate, maturity group IV, LibertyLink[9] (LL) variety, Delta Grow[10] DG4967LL, at various percentages. Seed was planted at the MSU Extension recommended seeding rate of 321,100 seeds ha^{-1}, at a depth of 2.5 to 2.8 cm in row spacings of 97.0 cm and plot length of 12.2 meters, using an Almaco[11] plot planter, with John Deere[12] MaxEmerge XP row units at all site years (Johnson, 2011).

[7] Monsanto Company, 800 Lindberg Blvd. St. Louis, MO. 63167. USA
[8] Pioneer Hi-Bred International Inc., 7300 NW 62nd Avenue, Johnston, IA. 50131. USA.
[9] Bayer CropScience, 2 TW Alexander Dr., Research Triangle Park, NC 27709. USA.
[10] Delta Grow Seed Co. Inc., 220 2nd, England AR. 72046. USA.
[11] ALMACO, 99 M. Ave. Nevada, IA, 50201. USA
[12] Deere and Company World Headquarters, 1 John Deere Pl. Moline, IL. 61265. USA.

Replant Methodology

The initial planting occurred in mid-April to mid-May, with the intention to initiate replant treatments shortly after stand establishment. However, the replant treatments occurred in late-May to early-June, depending on environmental conditions at each location. All initial planting dates occurred between April 21 and May 12 and replant dates occurred between May 24 and June 9. Actual planting and harvest dates can be found in Table 3.1. Additionally, no replant occurred at the Starkville, MS location in 2017 due to excess rainfall; however, data from treatments receiving 0% replant, were still obtained. The RR and LL varieties were mixed at percentages of 100% RR & 0% LL, 75% RR & 25% LL, 50% RR & 50% LL, 25% RR & 75% LL, and 0% RR & 100% LL, respectively, to achieve a seeding rate of 321,000 seeds ha^{-1}. The LL variety was used to allow for randomized plant elimination within the row following a broadcast glyphosate, 333.45 grams a.e. ha^{-1}, application. Once the initial soybean population reached V1, when unifoliate leaves were fully unrolled, at the node above the cotyledons, the LL variety was removed from the initial soybean population (Table 3.1). Replanting consisted of planting back alongside the same row that plants were removed. Replanting into the initial reduced stand occurred at 100, 75, 50, 25, and 0% of the initial seeding rate of 321,000 seeds ha^{-1}using the RR variety that was used in the initial planting, 7 to 17 days after the application of glyphosate. The treatment combinations/replant options then ranged from: (Table 3.2)

1. No removal of the initial population, and do not replant
2. Leaving the initial stand, with various reduced percentages and do not replant.

3. Leaving the initial stand, with various reduced percentages and replant with different percentages of the initial population of 321,000 seeds ha^{-1}.
4. Remove the initial stand and replant with different percentages of the initial population of 321,000 seeds ha^{-1}.
5. Remove the initial stand and do not replant.

Data Collection

Emergence dates were noted for both the initial and replant timings. Growth stages were recorded weekly throughout the growing season along with the date of canopy closure. Final plant heights and node counts were recorded at the R5.5 growth stage. Soybean was harvested using a Kincaid[13] 8-XP High Performance Multi-Crop Plot Combine with the overall harvested width being 1.9 m, or the center two rows of each plot. Soybean yield was adjusted to 13% standard moisture content. Harvest dates for all years and locations are listed in Table 3.1.

Statistical Analysis

The experimental design was a factorial arrangement of treatments in a randomized complete block, with four replications of each treatment. There were 5 levels of removal (fixed) from the initial stand and 5 levels of replant (fixed) into the initial stand for a total of 25 treatments. Statistical analysis was completed in PROC GLIMMIX using Statistical Analysis Software[14] (SAS) version 9.4, where environment

[13] Kincaid Equipment Manufacturing, Co. 210 W. 1st St. Haven, KS. P.O. Box 400. 67543. USA.
[14] SAS Institute Inc., Corporate Headquarters, 100 SAS Campus Dr. Gary NC, 27513-2414. USA.

and replication were treated as random. Factors were averaged across all locations and years, with means separated using Multiple Pairwise t-Tests at $\alpha=0.05$.

Results and Discussion

Soybean Yield

All treatment combinations were evaluated (Table 3.3), however not all combinations are practical for soybean production and data analysis revealed these treatments to be insignificant (Table 3.3); thus emphasis will be on the following treatments within the factors that showed significance (Table 3.4). Treatments were selected to display the effects of replanting at the percentages that was removed compared to no replant occurring for each level of removal. Factors of removal ($p < 0.0001$) and replant ($p < 0.0001$) were independently significant with respect to soybean yield. However, the interaction of removal by replant ($p < 0.0001$) was also significant, when averaged across site-year (Table 3.2). Therefore, the interaction of the two factors will be the focus for further discussion (Table 3.3 and Table 3.4). The treatment of 0% removal and 0% replant resulted in greater soybean yield than that of 100% removal and 100% replant treatment, which is likely a result of the 100% removal and 100% replant treatment performing as a delayed planting date. The difference in yield from the two previously mentioned treatments was 1254.3 kilograms per hectare (kg ha^{-1}). Similar results were found by Gaspar, Conley and Mitchell (2014), which stated that a tillage operation or elimination of the existing stand limited yield due to the delay in planting when compared to replanting into an existing stand.

When the initial soybean population is reduced by 25%, no yield benefit was observed from replanting into the existing stand, no matter the replant population.

Furthermore, no difference in yield was observed when the soybean population was reduced by 25% and maintained, compared to the treatment of 0% removal and 0% replant. These data produced similar results to that of Gaspar, Conley and Gaska (2014), which suggests not replanting into stands reduced to 247,000 plants ha^{-1} or greater (Table 3.4).

When stands are further reduced to 50% of the initial soybean population, these data would suggest to replant or fill in the existing suboptimal soybean stand. A replant seeding rate of 80,250 seeds ha^{-1} or less resulted in a yield reduction when compared to the 0% removal and 0% replant treatment. Additionally, yield reductions were also observed for replant seeding rates of 240,750 seeds ha^{-1} or greater, when compared to the 0% removal and 0% replant treatment. When soybean populations are reduced by 50%, these data suggest replanting into the existing stand at a seeding rate of 160,500 seeds ha^{-1}, to achieve similar yield as compared to an optimum initial plant stand (Table 3.4).

If stand losses of 75% are observed, these data suggest that soybean yield will be reduced, no matter the seeding rate that is replanted, when compared to that of the 0% removal and 0% replant treatment. However, in order to optimize yield following a 75% reduction in stand, these data suggest replanting into the initial population at a seeding rate of 240,750 seeds ha^{-1}. If the option of replanting into a severely reduced initial soybean stand is unavailable and complete removal of the initial stand is necessary, a seeding rate of, at least, 160,500 seeds ha^{-1}, or 50% of the initial seeding rate, is recommended to optimized the already reduced yield potential (Table 3.4).

Node Count and Plant Height

Plant height ($p < 0.0001$) and node count ($p < 0.0001$), were each significant for the interaction of removal by replant (Table 3.2). Similar trends were observed between node count and plant height for the 0% removal, 0% replant and 100% removal, 100% replant treatments. The previously mentioned treatments resulted in plant heights of 88.8 cm and 91.3 cm, respectively, and node counts of 18.2 and 15.4 nodes per plant, respectively (Table 3.3 and Table 3.4). These data suggest greater internode length for the treatment combination of 100% removal and 100% replant when compared to the treatment combination of 0% removal and 0% replant. These data resemble a soybean study by Doss and Thurlow in 1973 that observed an increase in plant height as soybean population increased, while noting that variation in plant heights can be attributed to different varieties.

Conclusion

The results from this study demonstrate the importance of achieving an adequate plant stand from the initial planting to ultimately maximize soybean yield. However, achieving an adequate plant stand at the initial planting can be challenging due to many factors, both human and environmental. Fortunately, there are options for Mississippi growers when it comes to replanting suboptimal stands to optimize yield. Previous research conducted by Hicks and Naeve (2013) suggests replanting at a reduction of 25% in soybean population. However, our data suggest by removing 25% of the initial soybean stand, Mississippi growers could potentially leave that slightly reduced stand and not see a significant yield decrease. When replanting into a stand previously reduced by up to 25%, there was no increase in yield. This allows growers to save both time and money by not replanting when reductions are this minimal, for no yield benefit from the replant event When 50% of the initial population is removed, a replant of 50%, or 160,500 seeds ha^{-1} resulted in no soybean yield difference compared to the initial planting, receiving no removal or replant. Replanting at 75% of the initial population should occur when stands are reduced by 75%. Other than yield, observations of factors such as plant height and node count will vary based upon the selected variety, and the ability for that variety to respond to a replant scenario, or delayed planting date. Node counts for the treatment combination of removal by replant resulted in fewer nodes as the percentage of replant increased. While plant height was maximized for the 100/100% removal/replant treatment, it also resulted in fewer number of nodes per plant. These data suggest that there are options to maximize soybean yield when reduced soybean stands are present. Reductions of soybean stands by less than 50%, should be withheld and maintained without the need to replant. Retention of a reduced stand should also occur, if at all possible, whenever 50% or greater reductions are observed while replanting into this reduced stand at a rate of 50% of the initial population to maximize yield potential. If complete destruction of the existing stand must occur, it should be noted that a yield reduction will be present, no matter the replant seeding rate.

Table 3.1 Planting and harvest dates for Starkville, Stoneville and Brooksville in 2016 and 2017.

	-------Starkville-------		-------Stoneville-------		Brooksville
	2016	2017	2016	2017	2017
Initial Planting Date	29-Apr	21-Apr	7-May	11-May	12-May
Removal Date[bc]	17-May	11-Jun	15-May	31-May	10-Jun
Replant Planting Date	24-May (25)[a]	--[d]	1-Jun (25)	9-Jun (29)	8-Jun (27)
Harvest Date	30-Sep	27-Sep	5-Oct	11-Oct	4-Oct

[a] Number in parentheses is the number of days that occurred between the initial planting date and the replant date

[b] Glyphosate applied at 333.45 grams a.e. ha^{-1}

[c] Application volume was 140.3 L ha^{-1}

[d] Replant did not occur due to weather, treatments of 0% replant were still obtained

Table 3.2 Analysis of variance probability values for treatment combinations removal and replant growth parameters and yield for 2016 and 2017.

Source	Height at harvest	Nodes at harvest	Yield
	-----------------------------p-value[a]	-----------------------------	-----------------------------
Removal	<0.0001	<0.0001	<0.0001
Replant	<0.0001	<0.0001	<0.0001
Removal*Replant	<0.0001	<0.0001	<0.0001

[a] Data pooled across all site-years of 2016 and 2017

Table 3.3 Final plant height, final node count and soybean yield for all site-years for the combination of removal by replant.

Treatment[a]				
Removal	Replant	Plant Height[b]	Node Count[c]	Yield[d]
-----------%---------		------cm------	nodes plant^{-1}	----kg ha^{-1}----
0	0	18.2 a	18.2 a	3466 a
0	25	16.0 cd	16.0 cd	3271 ab
0	50	15.7 cd	15.7 cd	3161 abc
0	75	16.2 cd	16.2 cd	3181 abc
0	100	16.9 abc	16.9 abc	3249 ab
25	0	18.1 ab	18.1 ab	3255 ab
25	25	17.0 abc	17.0 abc	3183 abc
25	50	15.3 cd	15.3 cd	3073 bc
25	75	15.8 cd	15.8 cd	3190 abc
25	100	15.8 cd	15.8 cd	3216 abc
50	0	18.3 a	18.3 a	3114 bc
50	25	18.1 ab	18.1 ab	3009 bc
50	50	16.8 abc	16.8 abc	3177 abc
50	75	15.0 cd	15.0 cd	3010 bc
50	100	16.4 bcd	16.4 bcd	2904 cd
75	0	18.4 a	18.4 a	2249 fgh
75	25	17.0 abc	17.0 abc	2355 efg
75	50	18.2 a	18.2 a	2536 ef
75	75	16.4 cd	16.4 cd	2679 de
75	100	17.0 abc	17.0 abc	2666 de
100	0	0 e	0 e	0 j
100	25	16.1 cd	16.1 cd	1590 i
100	50	16.4 cd	16.4 cd	2008 h
100	75	16.3 cd	16.3 cd	2149 gh
100	100	15.4 cd	15.4 cd	2213 fgh

[a] LS-means within the same column followed by the same letter are not significantly different according to multiple pairwise t-tests at an $\alpha = 0.05$.
[b] Measured in centimeters from soil line to terminal node.
[c] Counted from first node to terminal node obtained at R5.5 growth stage.
[d] Moisture corrected to standard of 13%.

Table 3.4 Final plant height, final node count and soybean yield for all site-years for the combination of removal by replant.

Treatment[a]				
Removal	Replant	Plant height[b]	Node Count[c]	Yield[d]
----------------%----------------		-----cm-----	nodes plant^{-1}	---kg ha $^{-1}$---
0	0	88.8 ab	18.2 ab	3466 a
25	0	86.3 ab	18.1 abc	3255 ab
25	25	86.7 ab	17.0 bcd	3183 ab
50	0	87.3 ab	18.3 a	3114 b
50	50	83.9 bc	16.8 cd	3177 ab
75	0	75.9 d	18.4 a	2249 d
75	75	79.9 cd	16.4 de	2679 c
100	0	0.0 e	0.0 f	0 e
100	100	91.3 a	15.4 e	2213 d

[a] LS-means within the same column followed by the same letter are not significantly different according to multiple pairwise t-tests at an $\alpha = 0.05$.
[b] Measured in centimeters from soil level to terminal node obtained at R5.5 growth stage.
[c] Counted from first node to terminal node obtained at R5.5 growth stage.
[d] Moisture corrected to standard of 13%.

Figure 3.1 All treatments of soybean yield for all site-years for the combination of removal by replant.

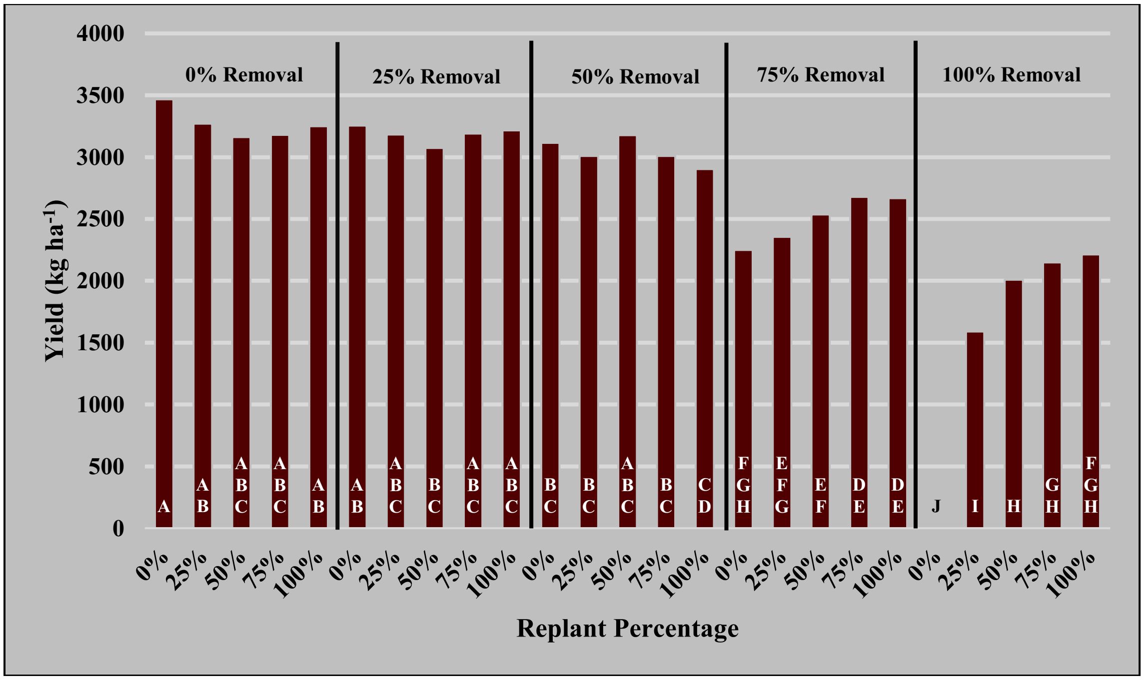
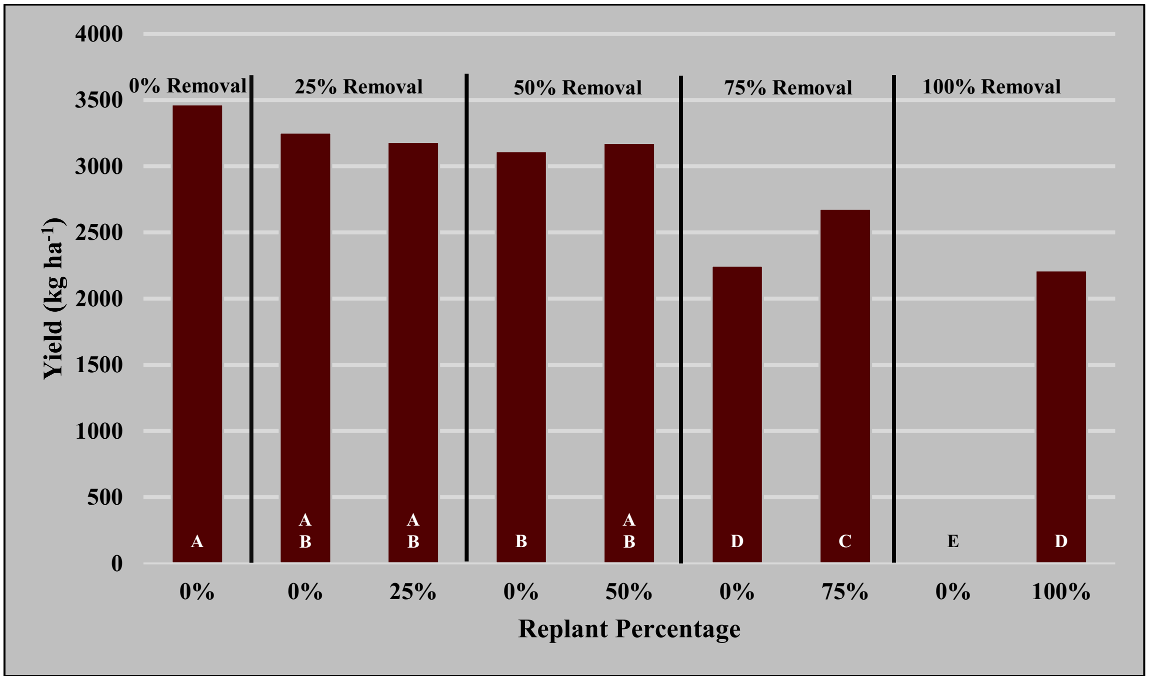


Figure 3.2 Treatments reduced for soybean yield for all site-years for the combination of removal by replant.



References

Conley, S.P. and Robinson, A.P. 2007. Thin soybean stands: Should I replant, fill in, or leave them alone. Coop. Ext. Service. SPS- 104-W. Purdue Univ., West Lafayette, IN.

Doss, B.D. and D.L. Thurlow. 1973. Irrigation, Row Width and Plant population in Relation to Growth Characteristics in Two Soybean Varieties. Agron. J. 66:620-623.

Gaspar, A.P., Conley, S. 2015. Responses of canopy reflectance, light interception and soybean seed yield to replanting suboptimal stands. *Crop Sci.* 55:377-385.

Gaspar, A.P., Conley, S., and Gaska, J.M. 2014. Think twice before replanting soybeans. University of Wisconsin Extension.

Gaspar, A.P., Conley, S., and Mitchell, P. 2014. Economic Risk and Profitability of soybean seed treatments at reduced seeding rates. *Crop Sci. (In Review).*

Hicks, H.R., Naeve, S. 2013. The soybean growers field guide for evaluating crop damage and replant options. University of Minnesota Extension. http://www.extension.umn.edu /agriculture/soybean/planting/the-soybean-growers-field-guide-for-evaluating-crop-damage-and-replant-options/#making.

Johnson, C. 2011. Whats the right rate? Corn and Soybean Digest, vol. 17(no. 10), p. 12

Olechowski, H.T. 1983. Soybean Production. Ontario Ministry of Agriculture. http://eap.mcgill.ca/CPSO_2.htm.

Whingham, K., D. Farnham, J. Lundvall, and D. Tranel. 2000. Soybean replant decisions. Iowa State University Extension. http://agris.fao.org/agris-search/search.do?recordID= US201300093488

Wiebold, W., Massey, R. 2012. Corn and soybean replant decisions. University of Missouri Extension. http://extension.missouri.edu/explorepdf/agguides/crops/g04091.pdf.