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Impact of Irrigation Applications at Soil Moisture Deficits on Plant Development and Yield of Indeterminate and Determinate Soybean Varieties

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Impact of irrigation applications at soil moisture deficits on plant development and yield of indeterminate and determinate soybean varieties

By

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Impact of irrigation applications at soil moisture deficits on plant development and yield of indeterminate and determinate soybean varieties

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As the Mississippi River Alluvial Aquifer declines, it is the duty of soybean producers to become more efficient irrigators. Research was established in 2012 and 2013 in the Mississippi Delta to evaluate plant development and yield of an indeterminate soybean variety with irrigation initiated at the R1 producer standard and compared to initiation timings at the R2, R4, and R5 growth stages once a 2” deficit was reached according to the FAO-56 Penman-Monteith model. Research was also conducted to evaluate seeding rates in irrigated and non-irrigated systems in Starkville and Stoneville, MS in 2013 and 2014. These data indicate that delaying irrigation initiation beyond R1 did not adversely affect yield, and in some instances even provided a small yield increase. Irrigation did show consistent yield benefit regardless of initiation timing over a non-irrigated system. No optimum seeding rate in terms of yield or net return was observed across site years.

DEDICATION

I would like to dedicate this research first and foremost to my family. My parents Dr. Michael and Karen Brown have always supported me beyond what I deserve. Their guidance through difficult decisions and constant reinforcement to complete something that you've started is a large part of why I was able to accomplish goals at all levels of my education. Their leadership stems from the great, Godly grandparents that I have in Billy Ray and Helen Brown and Harold and Carolyn Ross. The examples of love and faith that both sets of grandparents have shown me have helped to develop me into the man I am today. Lastly, I want to dedicate this work to the love of my life Kayla Thompson. The love and care Kayla shows and provides me are the fuel I have needed to complete this research. This and any other work I do is all in hopes to better provide and support she, and all those I love. Without these people, none of this would have been possible.

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INTRODUCTION

History of Soybean Production

Soybean production has long been a highly valued crop in the United States and the state of Mississippi. With its protein content and high-quality of oil, soybeans serve the needs of both humans and animals in many ways (Heatherly and Hodges 1999). The plant Soybean (*Glycine max*) entered North America in the 18th century, but was not put into production for consumption of protein meal and processed for oil until the 1930's. Since that time, the crop has grown to be the most widely grown oilseed in the world (Hoeft et al. 2000). The United States alone has seen a jump in planted soybean hectares from 1.21 million in 1930, to 31.24 million hectares in 2012. The same trend of growth can be seen in Mississippi as well; from 34,400 hectares planted in 1930 to the 900,000 hectares in 2012 (NASS 2014).

With this increase in production, agricultural practices have evolved over this time as well. Growers discovered new ways to improve their growing environment through cultivation techniques, limiting weed competition and pest damage, along with implementation of other cultural practices and technologies. Humble beginnings at an average of 6.5 to 18 bushels per acre (bu/ac) in Mississippi in the 1930's and 40's have now risen to a state average of 52 bu/ac in 2014 (NASS 2014). Such increase in production has in turn raised the significance of the crop to the Mississippi and US economies. The value that soybean production added to the economy in Mississippi in 2014 reached nearly $1.3 billion in sales according to the National Agricultural Statistics Service (2014). This ranks it as the 3rd most valued commodity for the state, behind only poultry and forestry.

Variety Selection

One practice that has developed greatly, especially in the last few decades, is the use of different soybean varieties to further yield potential. In the southern U.S., soybean producers for many years were limited to mainly determinate varieties, as opposed to indeterminate. This term "determinate" is used when describing a cultivar that has the "growth habit characterized by near cessation of main stem growth at the onset of flowering, a pronounced terminal raceme, and substantially fewer main stem nodes than the indeterminate growth habit" (Bernard 1972). Due to their growth habits, determinate varieties are better adapted to the southern regions of the U.S. because of the area's shorter day/longer night periods as a result of their latitude, as well as warmer temperatures (Hoeft et al. 2000). With the main stem having fully developed at the start of reproductive growth in determinate varieties, the plant can then channel most of its energy use to reproduction and eventually mature seed. Using a variety not suited for the climate makes the plant more susceptible to lodging, as the plant would grow too tall and would not be able to support itself (Hoeft et al. 2000). Other issues may factor into yield loss as well, with late season drought deterring reproductive stages or pod fill. So considering other factors such as planting date, or days to maturity can be useful in maintaining yield potential.

Further developments in agricultural practices have made the strict use of determinate varieties in the southern U.S. region more relaxed in recent years. Latitude/climate is only part of the variety and growth habit decision making process between determinates or indeterminates. Varieties that are indeterminate are defined by "growth habit, characterized by continued main stem growth into the reproductive period, producing a longer stem with more internodes than determinate types" (Bernard 1972). So, indeterminate varieties continue to grow their main stem while flowering or reproductive stages are developing. This makes the flowering period for indeterminate varieties longer than that of determinates (Hoeft et al. 2000). This longer period of reproductive growth can allow for some compensation by the plant in later season adverse environmental conditions like drought or heat stress (Bernard 1972, Hicks et al. 1969, Rode 1979); but, this longer period also provides for a wider window of adverse or yield reducing conditions, making little difference between growth habit yields (Ablett et al. 1989, Foley et al. 1986, Ouattara and Weaver 1994, Robinson and Wilcox 1998). All of these studies noted that differences in yield between growth habits were more likely attributed to characteristics such as of planting dates, irrigation capabilities, double cropping and maturity date rather than just strictly the soybean cultivar (Kilgore-Norquest and Sneller 1999).

Understanding these factors and their role within the environment and soil type in which the crop is grown will allow for a greater yield response for either growth habit. This focus on field capability over historic variety selection has been noted to be beneficial in several studies in various locations in the U.S. comparing indeterminate and determinate varieties (Ablett et al., 1989; Foley et al., 1986; McBroom et al., 1981;

Wilson and Cole, 1968). This also has been tested in variety trials performed by Mississippi State University since 1982. At that time, Mississippi growers were planting around 90% maturity groups (MG) VI and VII. Since that time, in most recent surveys Mississippi producers are growing nearly 90% MG IV (mainly indeterminate) and MG V soybeans (MSU Extension Service 2012). Further understanding and change in practices have allowed producers to advance yields using maturity groups that at one time were rarely seen in the state.

Irrigation and ESPS

Many advances have attributed to the growth of soybean acreage and yields in Mississippi such as genetically modifying crop genes for tolerance of herbicides, precision planting and pest management, and increased irrigation capabilities and efficiencies. As discussed previously, water or moisture during plant development can greatly contribute to increasing yields for modern soybean production (Hoeft et al. 2000). The authors of *Modern Soybean Production in the Midsouth* explain that having irrigation capabilities can offer help to the plant when trying to overcome drought conditions seen in the later portion of the growing season. In some years, this is more of an issue for soybeans planted in late May, such as soybeans planted following a winter wheat crop, as opposed to the more modern Early Soybean Production Systems or "ESPS" in April and early May (Heatherly and Spurlock 1999). Non-irrigated fields rely on the ability to plant early for less risk associated with drought conditions, and this planting window is not always available (Heatherly et al. 1999). These later planted soybeans are thus susceptible to the crop water deficits in the Mid-South that usually develop in June and carry into September (Boykin et al. 1995). This goes back to the change in practices of maturity groups V through VIII in later planting dates (Conventional Soybean Production Systems), to the more widely used MG IVs and Vs planted in today's ESPS. The late season drought aforementioned is a "prime cause for the low yields of the MG V through VIII cultivars that are in high-water-demanding reproductive stages during the same period" (Heatherly and Hodges 1999).

Seeding Rates

A commonality between growth habits is that all depend on water for growth and compete with the neighboring plants in the row for the available soil moisture. When maximizing yield potential in a growing environment, seeding rate can also be a cost minimizing and yield maximizing decision. With the rising seed costs and technical fees, soybean seed has become an even greater economic decision to consider. What plant population to use, has been found to have a wide range of high yielding possibilities. Previous studies have shown little to no significant yield loss due to low densities producing more nodes per plant and increasing the number of pods on both the main stem and branches (Ablett et al. 1991, Norsworthy and Frederick 2002, Cox et al. 2010). For example, in a study in 2007 that used 309,000 seeds ha^{-1} as the mean density saw no significant yield change when population densities were increased or decreased by 40% (Rich and Renner 2007). Such studies would suggest that there are cost saving/yield maintaining strategies available through lower seeding rates.

Population densities, like varieties and irrigation, are not fixed across environments. Conditions of the environment such as temperature and precipitation have been seen as important factors influencing soybean vegetative growth and yield (Chen and Wiatrak, 2010, 2011). Soil moisture during the growing season is thus important when balancing seeding rate and soil moisture (Devlin et al. 1995). Irrigation could play a key role in allowing for the use of lower population densities to maintain the soil moisture needed for optimum yield. It was seen in another study that under drought-stressed conditions, soybean yield may not hold due to higher seeding rates competing for soil moisture (Alessi and Power 1982, Elmore 1998). With such a wide range of densities and data supporting maintaining yield potential across different environmental conditions, it raises questions of what densities are economically beneficial for irrigated soybeans in Mississippi?

Moving forward, the opportunity arises to evaluate the ability to maintain or progress the yields of the MG IV and MG V soybeans through irrigation deficit timings and soybean population densities. This in turn will reduce the stress and contribute to the sustainability of the alluvial aquifer by reducing the number of irrigation applications as well as maintaining yield potential for producers. This project will evaluate plant development of indeterminate varieties subjected to irrigation initiation applications determined by monitoring soil moisture levels throughout the reproductive growth stages. In addition, an economic evaluation can determine overall irrigation costs and seed costs associated with different plant population densities. Ultimately this could help restore or maintain levels of the alluvial aquifer without reducing the productivity of soybean growers.

Irrigation and the Mississippi Alluvial Aquifer

As the ESPS began to grow in Mississippi, so did the need for irrigation to allow for the yield potential that this system can bring. According to the Yazoo Mississippi Delta Joint Water Management District (YMD) the number of irrigation wells in the

Mississippi Delta began to increase in the 1970's. Drawing water from nearby streams and rivers was a widely used practice at this time, and in severe drought conditions of 1988 water systems were depleted heavily. More deep-water wells were drilled subsequently, mostly into the Mississippi River alluvial aquifer (YMD 2006).

This natural aquifer is located in the northwestern region of the state spanning over approximately 19 counties covering 7,000+ square miles. This area's climate is shown to follow the late season drought pattern previously noted with about only 17% of the annual rainfall coming in the late summer and early fall (YMD 2006). With these conditions, the Mississippi Delta has now grown to 80% of their water usage being for agriculture with 14,750 groundwater use permits and 2,250 surface water permits being issued in the region; the vast majority of these being from the alluvial aquifer (YMD 2006). The land in the Mississippi River alluvial plain is flat (the Delta), and significant portions have now been graded to facilitate surface water drainage and furrow irrigation (Heatherly and Hodges 1999).

Irrigation Practices in Mississippi

Furrow irrigation is defined by Texas A&M University Extension as delivery of water from an irrigation well via underground supply pipeline to which ground pipe is connected. The water flows by gravity on the surface through the furrows between crop rows (AgriLIFE Extension 2001). So as this method and others, including flooding, levees, and center pivots, began to progress throughout the state, so did the acres of soybeans and other crops that were being irrigated. According to the Cropland Data Layer provided annually by the USDA, Mississippi has now reached the point where 938,697 acres of the total 1,582,447 of soybeans in Mississippi were irrigated in 2010

(CDL 2010). That is almost 60% of the acres in the state. All those acres average 0.9 acre feet of groundwater applied according to the YMD survey from 1999 to 2006 (Powers 2007). With this vast number of acres using the waters of the alluvial flood plain, supplies have decreased at an approximate rate of 300,000 acre-feet per year (Pennington 2006).

As the use of irrigation continues, so could the depletion of the aquifer as a resource. One study predicts that if practices and precipitation continues in the current trends, the aquifer will continue to decrease by over 1.1 million acre feet by 2053 (Merrell 2009). Conservation efforts and changes in practices have already begun to be implemented, however. The Pipe Hole and Universal Crown Elevation Tool (PHAUCET) program provided by YMD is an evaluation and design tool for furrow irrigation systems. Field and technical information is used to determine existing system performance and define alternatives for improving irrigation efficiency (YMD 2006). The same study mentioned previously examined the loss of water under a model that included extreme conservation efforts and the estimated impact it could have on aquifer levels. That model resulted in estimates of a replenishment of over 3 million acre feet to the aquifer by 2047 (Merrell 2009).

Irrigation Management

So as irrigation continues in the Mississippi Delta and further develops in the region and other areas of the state, management becomes a key issue for producers. “If an irrigation system is in place, then it should be used since the ownership or fixed costs associated with the equipment will exist regardless of whether or not the system is used…and the advantages from irrigating soybeans in the mid-southern US are well documented with results indicating that irrigation significantly increases yields by overcoming drought" states Larry Heatherly (Heatherly and Hodges 1999, Reicosky and Heatherly 1990). This clear yield potential increase combined with the investments made by many farmers on already installed irrigation systems makes it unlikely in most cases that pumps will be left off in any given year under current regulations. Management, which is described as "the right amount of water at the right time" becomes the next logical step (Heatherly and Hodges 1999).

Irrigation scheduling is the accurate forecasting of water application time and amount for economic yield enhancement. Some of the management practices include amount and frequency of water applied determined by previous application (minus runoff), effective rainfall, and estimated use by the soybean crop (Heatherly and Hodges 1999). These variables can be monitored closely through in-field rain gauges, soil sampling for feel of moisture, or tensiometers (Hoeft et al. 2000). Tensiometers measure soil water tension with great accuracy in the range of 0 to 75/80 cbar (available water in most soils) and have been found to be most effective when placed 30.5 cm deep in clay soils; 15 cm deep in silt loam or sandy soils (Heatherly and Sciumbato 1986).

These scheduling tools are often paired, like many management decisions, with the growth stages of the soybean. W.E. Fehr, and his colleagues, description of these growth stages have thus become the standard in classifying the point in a soybean's life cycle in 1971. Vegetative stages and reproductive stages are separated into the "V" and "R" categories, with vegetative stages being classified with a number corresponding to the number of trifoliates, or nodes, coming from the main stem. For example, if the plant has 3 nodes, then it is in the V3 stage; 4 nodes or trifoliates, it is at V4, and so on. The reproductive stages being at R1, when a flower has emerged and is visible anywhere on the plant. Growth stage R2 is when a flower blooms within the 2 uppermost nodes of the plant. These are the two flowering stages (R1 and R2), which are followed by pod set stages (R3 and R4). R3 is denoted by a 3/16 inch pod in the four uppermost nodes, where a bloom or flower once resided. Pods will then elongate, and once a pod in the upper four nodes has reached ¾ of an inch in length, that plant has then reached the R4 stage. Continuing its development, soybeans will then enter into the pod fill stages. Seed development begins at R5, where a seed is visible within the pod, progressing to a full pod at the R6 growth stage. Beyond R6, soybeans begin physiological maturity at R7 when a brown, or mature, pod is seen anywhere on the plant. The stages conclude at R8 when 50% of the plant or more has reached mature pod stage (Fehr et al. 1971). Once the plant has reached full maturity and optimum seed moisture has been obtained, harvest can begin.

These universal stages provide a language between research and commercial production for decisions on pest management, as well as irrigation management. Irrigation is rarely scheduled before reproductive growth stages begin, regardless of cultivar, with some suggesting to wait until R3 before pod fill begins (Hoeft et al. 2000). When to irrigate, however, should be more focused on the irrigation management definition itself where accurate forecasting is the focus.

A cumulative study by David Reicosky and Larry Heatherly in 1990 combined the works of many determinate soybean irrigation studies in Arkansas, Louisiana, and Mississippi. These studies looked at irrigation initiation and the results are as follows:

- Irrigation before R1 (beginning bloom) produced no appreciable yield advantages.
- 6 years of data from Stoneville, MS verified that water use by determinate soybeans prior to R1 was significantly less than water use after R1.
- Irrigation delayed until R4 (full pod stage) or the beginning of seed development (R5) in normal years of rainfall limitations resulted in seed yields lower than those where irrigation started at R1

So based upon this accumulation of data from numerous studies, Reicosky and Heatherly determined in 1999 that irrigation during the entire reproductive phase is the most desirable when attempting to maximize yield and thus net return (Griffin et al. 1985, Reicosky and Heatherly 1990, Heatherly and Spurlock 1993). Obtaining maximum yield potential during these reproductive growth stages is so critical because these stages are where available water is normally at its lowest levels, evapotranspiration is at a season high, all while pod development, seed growth, and seed weight are being determined.

Maximizing yield also comes with costs. Irrigation, no matter the type, comes with overhead costs such as initial fixed costs of well drilling and instillation, pump engines and fuel, as well as pipe and labor to apply. Texas A&M University estimates that furrow irrigation can be calculated in pumping cost in dollars per acre, by using the total operating costs per acre-inch and multiplying by the number of acre-inches of water pumped in the crop scenario. Over 6 scenarios, in moderately irrigated soybeans, the costs equaled $6.32 per acre-inch (AgriLIFE Extension 2001). Since that time, with increases for most inputs, Mississippi State University Extension Service soybean planning budget estimates irrigation costs at $24.23/ha for 2012 and $23.12/ha for 2013.

Just like prices and yields, this number does not remain fixed between years. So measuring this cost versus the estimated returns for the year's crop becomes the focus for the producer who plans to implement irrigation as a profit maximizing tool.

Moving into an era of necessary water conservation, it is now time to research the possibilities of yield maintaining or yield boosting strategies while reducing water use. As the Mississippi River Alluvial Aquifer declines, it has become the duty of soybean producers in Mississippi, and across the Mid-South, to become more efficient irrigators. This research aims to investigate these possibilities by analyzing the plant development and yield effects on an indeterminate soybean variety with irrigation initiated at the R1 producer standard and compare it to initiation timings at the R2, R4, and R5 growth stages. Through this study and a study investigating optimum seeding rates in both irrigated and non-irrigated environments, it is the hope that producers will have the capability to become more efficient in their effort to meet the demands of an ever-growing world population.

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CHAPTER II

IMPACT OF IRRIGATION INITIATION DETERMINED BY GROWTH STAGE ON PLANT DEVELOPMENT AND YIELD OF AN INDETERMINATE VARIETY IN AN EARLY SOYBEAN PRODUCTION SYSTEM (ESPS)

Irrigation has proven to be a yield maximizing and risk reducing practice for soybean producers across the globe, and in that aspect can be paralleled with many other farming advancements. Management of that practice differs however, due to the main source of this farming implement being a publically coveted resource: water. To maintain this tool as a farming practice, advances in irrigation efficiencies and water management must be achieved. Without such strides, it is predicted that the Mississippi Alluvial River Valley Aquifer (MARVA) could no longer be a resource (under current methodologies) or so economically unfeasible to obtain, that irrigation would be very limited and highly regulated resource (Merrell 2009).

Currently, Mississippi is under a voluntary metering program of monitoring water use in irrigating crops from ground water sources. "Both the requirement to have 5% Delta-wide… and the requirement for all participants to report pumpage…must be met or the Voluntary program ends and a mandatory metering program will be implemented by MDEQ" states the current regulations in place for Mississippi producers, with a 10% metering program forthcoming (Williams and Parish 2015). As the leader in both acreage and groundwater use (40% in 2010), soybean producers bare much of the load moving forward in becoming more efficient irrigators (YMD 2010).

Advances have been made within research and farmer's implementation of new irrigation practices in this region. Researchers in the MARVA region (AR, MS, LA) have shown that usage of computerized hole-selection software reduces water and fuel usage by 20 percent versus conventional irrigation methods in regular-shaped fields, and up to 50% in irregular-shaped fields (Massey 2011, Krutz 2013). Surge valves are also continuing to show greater water use efficiencies, along with other management strategies of tail-water recovery, monitoring output with flow meters, and scheduling tools like soil moisture sensors.

Scheduling irrigation for many producers in the last few decades has been based off of many research and extension recommendations that a soybean crop could tolerate drought stress with no adverse yield effects up until the reproductive growth stage (Griffin et al. 1985, Reicosky and Heatherly 1990, Heatherly and Spurlock 1993). Further research using soil moisture deficit models suggested a soil moisture threshold of a 2 inch deficit (Torrion et al. 2014, Kirnack et al. 2008). These findings have led Mississippi producers and others in the Mid-South to begin irrigating soybeans at the start of reproductive growth (R1 growth stage), and maintain soil moisture by pumping on a 7-10 day interval regardless of moisture, deficit, or any kind of scientific reading. A USDA survey in 2008 supports these findings, showing that over 80% of producers choose to water based on some other decision method other than a scheduling tool (visual, feel, personal calendar, neighbor) and can be seen in Table 2.6 (Kebede et al. 2014).

The most widely used scientific scheduling tool practiced and accepted is the Penman-Monteith method, which estimates the crop evapotranspiration (ET) for a crop canopy using a reference ET and a crop coefficient (Allen et al. 1998). This method (Penman Monteith FAO^{56}) factors in many soil and atmosphere coefficients to provide a relative soil moisture deficit on which a threshold can be placed for irrigation depending on the given crop (Ortega-Farias et al. 2004). As previously mentioned, the common threshold for Mississippi producers has been when the FAO^{56} model reaches a 2 inch soil moisture deficit. There are studies in recent years however that indicate soil moisture deficits can be pushed beyond 2” during reproductive stages without adversely affecting yields (Krutz et al. 2014). With few (~10%) Mississippi producers and even fewer producers nationally (~4%) using daily ET values, it may be critical to provide data on how drought stress relates to yield loss according to growth stage as a reference moving forward.

Previous research provides data indicating that current irrigation practices being used to combat the stresses of drought are not consistent with soybean sensitivity to drought stress. If management was consistent with drought sensitivity, irrigation would be based upon a function of growth stage and the amount of water used by the plant. Generally, soybean sensitivity to drought stress increases in the order of Vn < R2 < R3-6 growth stages (Ech et al. 1987, Kirnak et al. 2008, Pejic et al. 2014). So with the threat of water scarcity and regulation of water usage, it is, and will continue to be pertinent for soybean producers in the MARVA to manage their water more efficiently going forward. Therefore, research was established to evaluate the impact of initiating irrigation determined by growth stage on yield and plant development when compared to the FAO^{56} model and a non-irrigated system.

Materials and Methods

Experiments were conducted in 2012 and 2013 in the Mississippi Delta to analyze the plant development and yield effects on an indeterminate soybean variety under the Early Soybean Production System (ESPS). The 2012 location was conducted on the Delta Research and Extension Center (DREC) near Stoneville, MS on a Dundee silt loam soil, while the 2013 trial was planted near Tribbet, MS on a Forestdale silty clay loam soil.

Agronomic Management

Plots were 8.13 m wide by 76.2 m long in 2012, while 2013 plots were scaled down to 6.1 m wide by 30.5 m long. Non-irrigated plots were increased to 16.3 m in width to ensure there was no movement of water from adjacent irrigated plots into the non-irrigated plots. The center four rows were harvested, allowing outside rows to act as a buffer between treatments to eliminate effects from water movement from one treatment to the other. Both locations were on conventional tilled 1.0 m beds and planted using an Armor DK 4744 soybean variety with an indeterminate growth habit. In 2012, a seeding rate of approximately 275,650 seeds ha^{-1} was used, while in 2013, seeding rate was 311,220 seeds ha^{-1}. Planting dates for each experiment were April 10, 2012 and April 29, 2013, both of which fall into the ESPS planting window. All pest management decisions followed the Mississippi State University Extension Service’s best management practices for an indeterminate soybean in the Mississippi Delta.

Soil Monitoring and Irrigation

Soil moisture for both locations was monitored using the FAO-56 Penman-Monteith method which determined soil moisture deficits that triggered each irrigation initiation and all other application timings. The amount of water applied during each application was monitored by a McCrometer flow meter and applications were made using 9 mil, 2 ply poly-pipe (plastic tubing). Irrigation was initiated at the R1 growth stage simulating the current producer standard (PS) for Mississippi soybean growers, followed by initiations at the first 2” deficit according to the FAO-56 Penman-Monteith model (FAO), at the R4 growth stage (mid-pod set), and at the R5 growth stage (beginning pod fill). A non-irrigated check (NI) was also included for comparison. Once a treatment was initiated, irrigation was maintained to keep the soil moisture deficit under 2” for the remainder of the growing season. Initiation dates and number of applications, ha-mm applied, and ha-mm applied + rainfall are listed in Table 2.2.

Data Collection

To monitor plant development, a m^2 of row was sampled for total number of plants, total pods, pod weight, and bean weight for each initiation treatment. Those samples were also analyzed to determine the number of beans per pod, or pod type, for each m^2 of row. Number of blank, one bean, two bean, three bean, and four bean pods were counted and totaled in the m^2 to determine differences in pod load. Seed quality was also monitored by analyzing harvested seed for damage, mold, trash content, split kernels and 100 seed weight. Yield was collected using a two row Kincaid (Massey Ferguson) 8XP plot combine, equipped with a 2 meter platform header and data collection system that tested for seed moisture and test weight of each individual plot.

Statistical Analysis

A randomized complete block design with four replications was utilized for this irrigation initiation study. Treatments included: Non-irrigated, well-watered or the producer standard of initiation at first flower or beginning reproductive growth stages, FAO56 Penman-Monteith 2" deficit initiation, and when a Penman-Monteith deficit was reached at R4 and R5 growth stages. All data were analyzed using the Proc Mix procedure in SAS 9.4. Means were separated using Fisher's protected LSD at $\alpha=0.05$. Data was divided into two site years and analyzed separately due to variances between both locations and environmental conditions across two years. Analysis of variance p-values are shown by each site year (Table 2.1).

Results and Discussion

Plants in m^2, Total Pod, Pod Weight, and Bean Weight

Plants collected in a m^2 ranged from 23-25 in 2012 and 18-22 in 2013 across each initiation treatment (Table 2.3). From those plants, there was no significant difference in total number of pods for 2012. In 2013, however, plots where irrigation was initiated at R4 resulted in significantly more total pods than plots where irrigation was initiated at R1 (Table 2.3). Evaluation of pod weight showed similar results, with 2012 having no significant difference for any initiation timing, but in 2013, irrigation initiation at R4 and R5 resulted in a greater pod weight than initiating irrigation at first flower (Table 2.3). Plots where irrigation was initiated at R5 resulted in a heavier seed weight compared to plots with initiation at R1 in 2013 as well. All irrigation timings resulted in soybeans with a greater number of pods, pod weight and seed weight than did the non-irrigated treatments in both 2012 and 2013 (Table 2.3).

Pod Type

Pod development was evaluated to determine if earlier initiated irrigation would result in a greater number of three and four bean pods. In 2012, no significant difference was seen between initiation treatments regarding any pod type. In 2013, R5 initiated treatments had a significantly higher number of one bean pods than did any other irrigated treatment. All irrigated treatments showed a greater number of one bean pods than the non-irrigated treatment. Two bean pods were also higher in the R5 initiated treatment compared to the PS and NI treatments. No irrigation resulted in soybeans with the lowest number of two bean pods as well. In 2013, no four bean pods were observed in any plot (Table 2.4).

Soil Moisture Deficit Levels

Soil moisture monitored by the Penman-Monteith FAO^{56} Model was tracked daily for each irrigation initiation treatment. It was observed that when the PS initiation occurred, those treatments were at a 0.94” deficit in 2012 and a 0.34” deficit in 2013, well below the 2” threshold in both site years. The R4 initiated treatment spent 24 days over the 2” threshold in 2012, peaking at a 3.38” deficit; while in 2013 the R4 initiated treatment reached a 4.40” deficit in its 14 days spent over threshold. Plants with irrigation initiated at R5 also spent 24 days over threshold and peaked at the same 3.60” deficit as the R4 treatment due to rain events in 2012. In 2013, the R5 initiated crop reach a 6.84” deficit before being irrigated and spent 23 days over the 2” threshold. Substantially more rainfall in 2012 held the deficit for non-irrigated plots lower for most of the reproductive stages (although over 2” threshold) and peaked at a 5.94” deficit during R7. Non-irrigated plots in 2013 saw a much higher peak deficit at 14.98” during R6 and R7 stages. These deficits can be seen in Figures 2.1 and 2.2.

Yield and Return

Yield results in 2012 indicate that R5 irrigation initiated plots produced a significantly greater yield than initiating irrigation by the producer standard (Table 2.5). Plots initiated at the FAO-56 model and R4 growth stage resulted in comparable yields to the producer standard treatment. In 2013, all irrigated plots resulted in a significantly higher yield than the non-irrigated treatment, and all irrigated plots were comparable statistically (Table 2.5). These data indicate that yield was not limited by delaying irrigation past the R1 growth stage, and in some instances yields were even boosted when irrigation initiation was delayed in this study. Gross and net returns were also analyzed to include soybean price and cost of irrigation applications based on MSU-ES Soybean Planning Budget at $24.23/ha for 2012 and $23.12/ha for 2013. Return results followed the same trend as the yield results with R5 treatment returns being significantly greater in 2012 than the producer standard treatment; while in 2013, all irrigated treatments resulted in comparable gross and net returns (Table 2.5). Again, these comparable or boosted yields were achieved while eliminating 1-4 irrigation events, which saved 4-8 meters of water per hectare (Table 2.2).

Conclusion

By delaying irrigation initiation beyond R1, no hindrance was observed on yield or return for a producer. Also, when irrigation is delayed, no significant difference in pod load, number of plants in a m^2, or type of pods were observed. Beyond yield, such observations on plant development and stand continue to prove the soybean’s ability to adapt and maintain yield under different environments. This lack of adverse affects combined with cost savings in less pumping time could benefit producers moving forward. Not only would producers benefit, but the longevity and viability of the Mississippi Alluvial River Valley Aquifer could also see progress with fewer ha-mm’s being applied across the growing hectares of soybeans in Mississippi and elsewhere. The results from this study also continue to support the economic benefit of irrigation capabilities for soybean producers with irrigated treatments significantly out-performing non-irrigated treatments across all sites and treatments. Although past studies show that water availability is key for reproductive stages of soybean production, efficient management of that water during those stages is key to reaping benefits for the producer while conserving the capability and freedom to irrigate their crop for generations to come.

Table 2.1 Analysis of variance p-values for soybean pod type[a]: blank, one bean, two bean, three bean, four bean; plants per meter of row; total pods[a]; pod weight[a]; bean weight[a]; yield; gross return[b]; net return[c].

Source	Degrees of Freedom	Blank Pod	One Bean Pod	Two Bean Pod	Three Bean Pod	Four Bean Pod	Plants per m^2	Total Pods in m^2	Pod Weight	Bean Weight	Yield	Gross Income[b]	Net Income[c]
2012	1	0.2016	0.3004	0.5741	0.3137	0.6874	0.5642	0.5563	0.1097	0.0369	<.0001	<.0001	<.0001
2013	1	0.9132	0.0002	0.0002	0.0784	------	0.6752	0.0005	<.0001	0.0153	0.0194	0.0194	0.2573

[a] Data recorded from plants collected in a meter of row

[b] Yield per kg ha-1 x market price

[c] Gross income less irrigation costs (all other costs assumed fixed)

Table 2.2 Irrigation initiation dates, number of applications made, hectare centimeters applied, and effective rainfall plus irrigation in hectare millimeters.

Year	Irrigation Initiation Timing	Initiation Date	Number of Irrigation Events	ha-mm Applied	ha-mm Applied + Rainfall
2012	NI	-----	-----	-----	1.2
	PS	May 17, 2012	6	2.5	3.7
	FAO	May 24, 2012	5	2.1	3.3
	R4	June 4, 2012	4	1.6	2.9
	R5	June 22, 2012	4	1.6	2.9
2013	NI	-----	-----	-----	0.4
	PS	May 31, 2013	8	2.2	2.6
	FAO	June 17, 2013	6	1.8	2.2
	R4	June 25, 2013	5	1.6	2.0
	R5	July 8, 2013	4	1.6	2.0

Table 2.3 Total pods and pod/bean weight in a m^2 under different irrigation initiation timings as affected by environment[a].

Year	Irrigation Initiation Timing	Plants[c] per m^2	Total Pod[de]	Pod Weight[de]	Bean Weight[d]
2012	NI	25	1179	643	394 b
	PS	23	1293	840	543 a
	FAO	24	1322	839	542 a
	R4	23	1376	849	558 a
	R5	25	1371	837	513 a
2013	NI	18	545 c	194 c	108 c
	PS	21	759 b	279 b	151 bc
	FAO	19	895 ab	343 ab	176 ab
	R4	20	955 a	358 a	178 ab
	R5	22	903 ab	386 a	217 a

[a] Data was split between years due to year being highly significant for pod count and weight when compared across years.

[b] Means within a column are separated based on Fisher's protected LSD at $p \leq 0.05$..

[c] No significant difference was found between plants m^2 for either 2012 or 2013

[d] Data collected from plants in a m^2

[e] No significant difference was found between initiation treatments in 2012

Table 2.4 Pod development (pod type) in an m^2 of row for each irrigation initiation timing as affected by environment[a].

Year	Irrigation Initiation Timing	Blank Pod[c]	One Bean Pod[d]	Two Bean Pod[d]	Three Bean Pod[c]	Four Bean Pod[ce]
2012	NI	13	62	346	714	44
	PS	12	61	295	865	59
	FAO	34	87	311	832	56
	R4	14	59	328	923	52
	R5	11	60	357	895	48
2013	NI	49	192 c	197 c	108	---
	PS	51	264 b	309 b	135	---
	FAO	53	307 b	365 ab	171	---
	R4	42	305 b	377 ab	179	---
	R5	50	375 a	407 a	123	---

[a] Data was split between years due to year being highly significant for pod count and weight when compared across years.

[b] Means within a column are separated based on Fisher's protected LSD at $p \leq 0.05$..

[c] No significant difference was found between initiation timings for either 2012 or 2013

[d] No significant difference was found between initiation treatments in 2012

[e] No four bean pods were found in 2013

Table 2.5 Yield and economic returns for each irrigation initiation timing as affected by year[a].

Year	Irrigation Initiation Timing	Yield[bc]	Gross Return[bd]	Return Above Irrigation[bef]
2012	NI	4294 c	971 c	971 c
	PS	5531 b	1251 b	1105 b
	FAO	5640 ab	1275 ab	1143 ab
	R4	5588 ab	1264 ab	1145 ab
	R5	5768 a	1304 a	1184 a
2013	NI	3164 b	647 b	634
	PS	4753 a	971 a	811
	FAO	4619 a	944 a	803
	R4	4719 a	964 a	832
	R5	4470 a	913 a	792

[a] Data was split between years due to year being highly significant for yield and returns when compared across years.
[b] Means within a column are separated based on Fisher's protected LSD at $p \leq 0.05$..
[c] Yield expressed as kg ha^{-1}
[d] Yield per kg ha-1 x market price
[e] Gross income (U.S. dollar) less irrigation costs per ha^{-1} (all other costs assumed constant)
[f] Irrigation costs based on MSU-ES Soybean Planning Budget at $24.23/ha for 2012 and $23.12/ha for 2013
[g] Net Return in 2013 showed no significant difference between initiation timings

Table 2.6 Irrigation scheduling methods used on farms in Mississippi, Arkansas and Louisiana (USDA-NASS, 2008).

Method	**Mississippi**	**Arkansas**	**Louisiana**	**National Average**
			Farms (%)	
Condition of Crop (visual)	47.2	48.8	56.7	43.9
Feel of soil	23.9	20.6	16.5	24.8
Daily crop evapotranspiration (ET)	9.6	3.8	2.2	3.4
Personal calender schedule	7.9	10.8	13.7	10.1
Soil moisture sensing device	4.6	3.4	1.9	4.4
When neighbors irrigate	2.2	2.5	1.2	3
Commercial or government scheduling device	1.4	3.4	1.8	2.7
Plant moisture sensing device	0.1	1.3	1.1	0.8
Computer simulation models	0.2	0.5	0.3	0.6
Scheduled by water delivery organization	0.1	0.3	0.7	3.6
Other	3	4.7	3.9	4.6

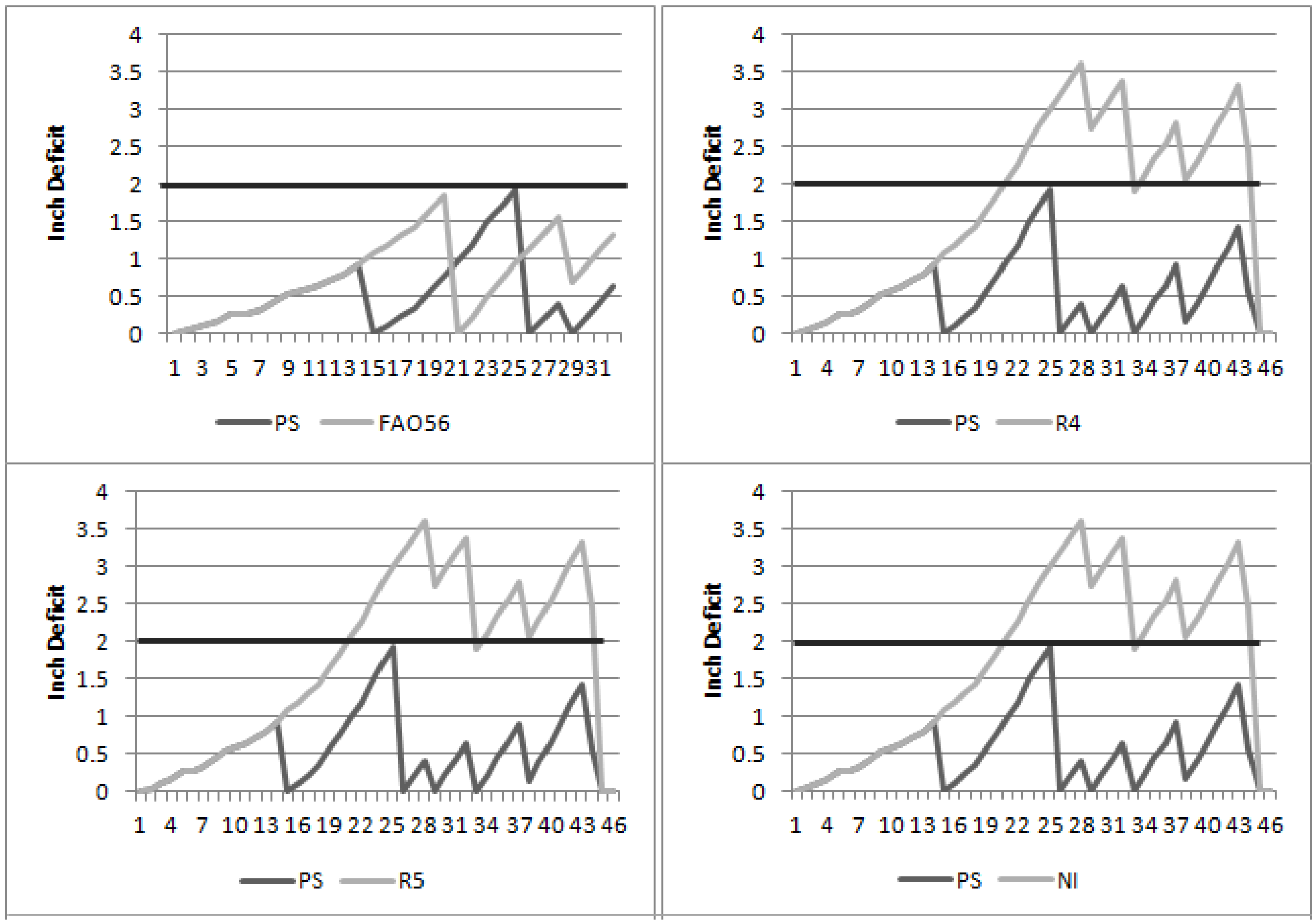

Figure 2.1 Soil Moisture Deficit Levels by Initiation Timing Compared to the Producer Standard 2012

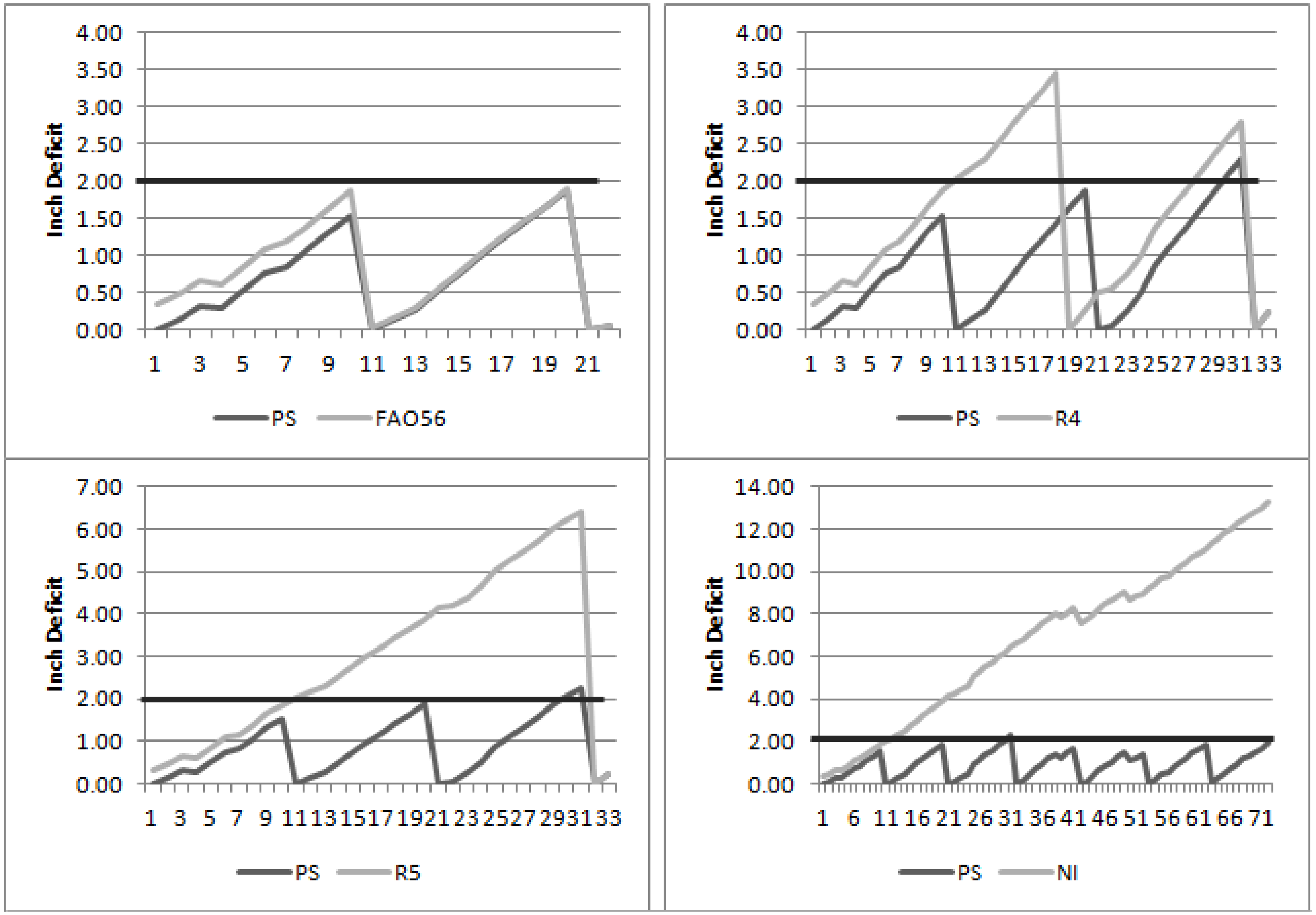

Figure 2.2 Soil Moisture Deficit Levels by Initiation Timing Compared to the Producer Standard 2013

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CHAPTER III

EVALUATION OF PLANT DEVELOPMENT AND YIELD FOR AN IRRIGATED AND NON-IRRIGATED INDETERMINATE AND DETERMINATE SOYBEAN VARIETY UNDER DIFFERING SEEDING RATES

As technology advances in agriculture, practices that have long been researched and developed now face new evolutions and allow for greater efficiency in modern methodology for soybean producers. Technical fees, hauling cost, development of seed treatments and other factors have driven seed costs higher in today's agricultural systems. The USDA estimates that in 2013 farms were spending 6% of their total expenditures on seed or plants for that year's production (up from 5.8% in 2012), making the seed business a 22.1 billion dollar industry (NASS 2014). Advancements in precision agriculture technology have also made planting a more efficient process through variable seeding rates and more accurate seed spacing. When you combine these factors with a need to become for efficient irrigators, questions arise regarding optimum seeding rates for irrigated and non-irrigated systems under both furrow and center pivot irrigation.

Different seeding rates can provide different benefits, however. High plant populations can have some advantages such as quicker canopy closure, greater light interception, and lower weed competition but also have disadvantages like increased competition for nutrients and water, higher probability of lodging, and added seed costs (Heatherly and Hodges 1999, Hoeft et al. 2000, Robinson and Conely 2007). Soybeans have also shown to be adaptable to their competition. Previous studies have shown little or no significant yield loss, attributed to lower densities producing more nodes per plant and increasing the number of pods on both the main stem and branches (Ablett et al. 1991, Norsworthy and Frederick 2002, Cox et al. 2010). Harvesting the lower density crop has shown to be more difficult however, with pods developing closer to the ground and thus, remaining in the field due to the combine header's inability to cut all the way to the soil surface (Robinson and Conely 2007).

This adaptability to environment also makes quantifying yield response to plant populations a difficult task. For example, in a study in 2007 that used 309,000 seeds ha^{-1} as the mean density no significant yield change was observed when population densities were increased or decreased by 40% (Rich and Renner 2007). Similarly, a study in Arkansas in 2003 showed "broad range of soybean MGs can produce similar yield in the Midsouth, but optimal seeding densities and irrigation requirements vary by maturity. Further, this research demonstrates some of the difficulties that can be encountered when expressing soybean yield as an empirical function of soybean population density" (Edwards and Purcell 2005). Such studies would suggest that there are cost saving/yield maintaining strategies available through lower seeding rates. However, such strategies propose added secondary costs through herbicide applications and harvesting difficulties. Balancing this risk could provide benefits of lower competition for water and nutrients and reduced seed costs through reduced populations.

Population densities, like varieties and irrigation, are not fixed across environments. Environmental conditions such as temperature and precipitation have been seen as important factors influencing soybean vegetative growth and yield (Chen and

Wiatrak, 2010, 2011). Edwards and Purcell's study in 2005 shows the variation that combinations of maturity groups (MG), planting date, and irrigation amounts can often provide with year to year irrigation needs not necessarily following historical trends and varying among maturity groups. "Irrigation requirements generally increased as soybean maturity increased, but differences in irrigation requirement among MGs varied by year. For example, in 2001, MG III and later soybean required 50% more irrigation than MG 00 soybean and 25% more irrigation than MG I and II soybean" (Edwards and Purcell 2005). Under non-irrigated conditions variability exists between seeding rate and yield response. Under drought-stressed conditions, soybean yield may not hold due to higher seeding rates competing for soil moisture (Alessi and Power 1982, Elmore 1998).

With such a wide range of densities and data supporting maintaining of yield potential across different environmental conditions, it raises questions of what densities are economically beneficial for irrigated and non-irrigated soybeans in Mississippi. This research aims to provide a comparison of seeding rates for MG IV and V soybeans under irrigated and non-irrigated conditions on two different soil types in both the Mississippi Delta and Hill regions and analyzing this in yield response and net return above seed costs.

Materials and Methods

Experiments were conducted at two locations in 2013 and 2014 to evaluate potential differences in plant development and yield for irrigated and non-irrigated indeterminate and determinate varieties under differing plant populations. Research sites in 2013 and 2014 were the Mississippi State University R.R. Foil Plant Science Research Center in Starkville, Mississippi (33°28'25.3"N 88°47'10.6"W) and the Mississippi State

University Delta Research and Extension Center (DREC) in Stoneville, Mississippi (33.435025ºN, 090.909156ºW).

Agronomic Management

Trials were planted 30 May 2013 in Starkville and 24 June 2013 in Stoneville. The planting dates were delayed due to wet field conditions. The following year, trials were planted 22 May 2014 in Starkville and 17 June 2014 at the DREC location with planting dates being delayed again due to wet field conditions. Seedbeds were prepared using conventional tillage on a 38” row spacing in both locations in both years. The Plant Science Research Center location in Starkville consisted of a Leeper sandy clay loam soil while the DREC location consisted of a Sharkey clay soil. The soybean varieties planted were an Asgrow AG4632 as the indeterminate variety and an Asgrow AG5532 for the determinate variety. Each variety was planted at seeding rates of 222,300, 259,350, 269,400, 333,450, 370,500, and 407,550 seeds to the hectare. These seeding rates were achieved by cone planting each row with the calculated number of seeds per row to achieve each given seeding rate. The number of seeds per 12.19 meters of row is as follows: 262, 305, 349, 393, 436, 479 for each seeding rate, respectively.

Experimental Design

The experiment was set up in a split-split plot design, with the main factor, or block, being irrigation and sub-factor A being maturity group and subfactor B being seeding rate. Maturity group and seeding rate treatments were randomized into plots within irrigated or non-irrigated blocks using ARM 9.2. Plots consisted of four, 97 cm wide rows that were 12.19 m long. Irrigated and non-irrigated blocks were 4 plots, or 16 rows wide and were separated by 4 row border strips at the Starkville location and 8 row borders at the DREC location. These border strips provided a buffer for any leaching of water to not cross-contaminate plots when irrigation was applied. Due to the cracking-clay soils at the DREC location, larger borders were required to contain underground leaching.

Irrigation Management

Soil moisture was monitored using WaterMark Digital Soil Moisture Meter placed in the plant's rooting zone at depths of 15, 30, and 60 centimeters. These soil moisture meters were placed within the row once the soybean roots had been established to minimize any altering of the plants natural water uptake. Soil moisture, in centibars, was then recorded to data loggers on a microSD card that was monitored weekly.

In the 2013 growing season, the Starkville location required only two irrigation events as follows: 26 August at the R4.5 growth stage, and 9 September at the R5.5 growth stage. The DREC location in 2013 received three irrigation events on 21 August at R3, 29 August during R4, and 9 September at R6. Irrigation application timings were similar in 2014 with two applications in Starkville and three at DREC. The Starkville location received applications in 2014 on 4 August at R4.5 and 22 August at the R6 growth stage. Applications at the DREC location were made 6 August at R3, 26 August at R5, and 16 September during the R6 growth stage. These applications were made according to the sensor readings when the weighted average of 100 centibars was reached across the three sensor depths. Environmental conditions during earlier reproductive growth stages provided ample rainfall in both years where irrigation events were not needed.

Data Collection and Analysis

Stand counts were recorded approximately 4 weeks after planting by counting the total number of plants in 91 cm of row, with 5 sub-samples per plot. Plant heights were also recorded once the crop reached the R5 growth stage, measuring to the growing point of 5 random plants per plot. Harvest was conducted on 10 October 2013 in Starkville and on 28 October 2013 at the DREC. The 2014 locations were both harvested on 21 October at the Starkville and DREC sites. Yield was recorded from the plots' center two rows at both locations in both years. All data were subjected to analysis of variance (ANOVA) using the Proc Mixed procedure in SAS 9.4. Means were separated using Fisher's Protected LSD at α=0.05.

Results and Discussion

Irrigated versus Non-Irrigated Yield

Irrigation has been well documented as a yield boosting, risk mitigating tool for producers in Mississippi and many other climates (Hoeft et al. 2000, Heatherly and Hodges 1999, Reicosky and Heatherly 1990). The data from both the Starkville and DREC locations of this study demonstrate the yield advantages irrigation can bring with all four site years irrigated plots resulting in a higher yield, with 3 of the 4 site years having statistically greater yields for irrigated plots than non-irrigated (Table 3.1). Across 4 site years the mean yield for irrigated plots averaged 726 kg ha^{-1} greater yield than the mean yield of non-irrigated plots.

Indeterminate versus Determinate Yield for Irrigated and Non-Irrigated Systems

The irrigated MG IV soybean resulted in significantly greater yield than the non-irrigated MG IV and both the irrigated and non-irrigated determinate variety MG V in 2014 (Table 3.2). The MG IV non-irrigated yields were comparable to the irrigated MG V at the Starkville location in 2014, and even yielded significantly better than the irrigated MG V at the DREC 2014 location. The 2013 data are not shown due to MG having no significant difference in yield. Even though these trials were not planted within the ESPS planting date window, MG IV indeterminate varieties proved to be comparable or greater yielding than that of the determinate MG V variety.

In a study done across the Midsouth in 2012 and 2013 comparing MG's III, IV, V, and VI similar results were observed to this study regarding yield during a mid, to late planting window. In data compiled from Mississippi, Louisiana, Texas, Arkansas, Tennessee and Missouri MG IV and V soybeans planted during the ESPS were comparable in yield; however as you progressed planting date into a later window of late-May through mid-June yield began to decline for the MG V soybeans. Entering the latest planting dates of mid to late June, MG V soybean yields declined up to 30% compared to the MG IV's (Purcell 2014). Such data supports the notion that the decision of what seed to plant should not solely be based on a particular growth habit or historical assumptions, rather selecting a variety that has the genetics to best fit the field conditions, planting date and management strategies of that particular growing season.

Seeding Rate

Seeding rate proved to have a significant effect on yield in 3 of 4 site years in this study. The Starkville 2014 location resulted in 370,500 seeds ha^{-1} having a significantly higher yield than lower seeding rates of 269,400; 256,350; or 222,300 seeds ha^{-1}. For the DREC 2013 location the treatments with the two highest seeding rates of 407,550 and 370,500 seeds ha^{-1} out-yielded the three lowest seeding rate treatments. For the DREC location in 2014 however, seeding rate did not influence soybean yield as heavily, with only the 222,300 seeds ha^{-1} (lowest seeding rate) yielding significantly less than all the other seeding rates (Table 3.3).

Higher seeding rates also come with added costs. Each site year resulted in a different optimal seeding rate regarding return, less seed cost. Starkville 2013 site's highest net return came from a seeding rate of 269,400 seeds ha^{-1}, while the DREC 2013 optimum seeding rate was 407,550 (Table 3.4). It should be considered however, that the actual plant populations at DREC in 2013 were drastically lower due to early season rain, observed from the very low stand counts (Table 3.5). Returns in 2014 also varied between the two locations with Starkville's highest return resulting from the 370,500 seed ha^{-1} rate, and DREC's being the second lowest seeding rate of 259,350 seeds ha^{-1} (Table 3.4). Both yield and return means were averaged across irrigated and non irrigated systems due to no interaction being seen between irrigation and seeding rate. Over all four site years, the most consistent seeding rate in terms of yield and return was the 333,450 seeds ha^{-1}.

Stand Count, Plant Population and Plant Height

Stand count data indicate that plant populations were congruent with seeding rate, meaning the seeds germinated relatively consistently between each seeding rate. No population was lower for a given plot than a plot of a higher seeding rate. Due to sampling methods, plant population estimates may have resulted in a higher population than initial seeding rate would allow, even with 100% germination. As a whole, stand counts and population numbers showed the general trend of plant populations the seeding rates were designed to achieve. Plant populations at the DREC location in 2013 were extremely low and much lower than other site years due to delayed planting and excessive rains during June 2013. Plant height data for 3 of 4 site years showed the common trend of higher populations growing a taller plant due to competition for light and leaf exposure (Table 3.6). This was comparable to a soybean irrigation study in 1973, where plant height increased as population increased. Plant height variability is often attributed to varietal difference as well (Doss and Thurlow 1973). No differences in lodging were observed for differing seeding rates in any site year. There were also no differences observed in ability to facilitate harvest or maturity due to seeding rate. Any difference in maturity was strictly between MG or growth habit of the two differing varieties.

Conclusion

Much like other seeding rate or plant population studies, an optimum seeding rate across environments is hard to quantify (Chen and Wiatrak 2011, Cox et al. 2010, Edwards and Purcell 2005). Optimum yield may differ not only between maturity groups, varieties, or planting dates, but also regardless of those factors amongst different field locations. In a similar study done on optimum seeding rates in the southern US it is stated as “not only do population responses differ among MG…but they also differ within a MG at a location for different sowing dates.” (Ball et al. 2000).

Populations at the 2013 DREC location were so low that seeding rate showed little result as a yield limiting component. In 2013 and 2014 at the Starkville location, as well as the DREC location in 2014, the highest net return varied in regards to seeding rate, even with more consistent plant populations under each environment when compared to the DREC location in 2013. Such variation would support findings that soybeans are a very adaptable plant through adding nodes and leaf surface in lower populations or growing taller yet using nutrients and water more efficiently in higher population scenarios. As seed costs continue to rise, additional research will need to be conducted to quantify optimum seeding rates for both determinate and indeterminate varieties. Much like when selecting whether to plant an indeterminate or determinate growth habit, or selecting a certain variety, field history and irrigation capabilities may have a greater influence on decision making than a broad determination of general optimum seeding rate. Overall, plant population should be monitored to ensure that lack of germination or failed stand does not hinder yield.

Table 3.1 Mean yield[c] for irrigated versus non-irrigated strategies within each site year[a]

	Starkville		DREC	
	2013 [b]	2014	2013[b]	2014[b]
Irrigated[d]	3705 a	4035	2293 a	3436 a
Non-Irrigated	2317 b	3441	1590 b	3214 b

[a] Data was split between site year due to site being highly significant for yield.

[b] Means within a column are separated based on Fisher's protected LSD at $p \leq 0.05$.

[c] Yield expressed as kg ha^{-1}

[d] Irrigation amounts varied by site dependent on weather/rainfall. Irrigation was only applied as necessary.

Table 3.2 Mean yield[c] by maturity group for irrigated versus non-irrigated within each site for 2014[ab]

		Starkville 2014[cd]	DREC[cd]
--- MG IV---	Irrigated[e]	4444 a	3696 a
	Non-Irrigated	3662 b	3444 b
--- MG V---	Irrigated[e]	3626 bc	3177 c
	Non-Irrigated	3221 c	2984 d

[a] Data was split between site year due to site being highly significant for yield.

[b] 2013 data showed no significance between MG for either site year

[c] Means within a column are separated based on Fisher's protected LSD at $p \leq 0.05$.

[d] Yield expressed as kg ha^{-1}

[e] Irrigation amounts varied by site dependent on weather/rainfall. Irrigation was only applied as necessary.

Table 3.3 Mean yield[c] for seeding rate within each site year[a]

	Starkville		DREC	
Seeding Rate [d]	2013[e]	2014[b]	2013[b]	2014[b]
407,550	2787	3857 ab	2130 a	3369 a
370,500	3038	4019 a	2086 a	3370 a
333,450	3011	3810 ab	1995 ab	3374 a
269,400	3141	3681 bc	1883 bc	3299 ab
259,350	3081	3622 bc	1809 c	3335 a
222,300	3007	3440 c	1746 c	3203 b

[a] Data was split between site years due to site being highly significant for yield.

[b] Means within a column are separated based on Fisher’s protected LSD at $p \leq 0.05$..

[c] Yield expressed as kg ha^{-1}

[d] Seeding rate expressed as seeds ha^{-1}

[e] No significant difference between populations for particular site year

Table 3.4 Estimated net return after seed cost for each site year by seeding rate[ab]

		Starkville				DREC			
		2013		2014		2013		2014	
Seeding Rate [c]	$/ha seed cost[d]	Gross Return[e]	Net Return[f]	Gross Return[e]	Net Return[f]	Gross Return[e]	Net Return[f]	Gross Return[e]	Net Return[f]
407,550	203.56	1,770	1,566	2,211	2,007	1,352	1,149	1,931	1,728
370,500	185.06	1,929	1,744	2,304	2,119	1,324	1,139	1,932	1,747
333,450	166.55	1,912	1,745	2,184	2,017	1,267	1,100	1,934	1,767
269,400	134.55	1,994	1,860	2,110	1,975	1,196	1,061	1,891	1,756
259,350	129.54	1,956	1,827	2,076	1,947	1,149	1,019	1,912	1,782
222,300	111.03	1,909	1,798	1,972	1,861	1,109	998	1,836	1,725

[a] Data was split between site years due to site being highly significant for yield.

[b] All other costs beyond seed cost held constant

[c] Number of seeds in ha^{-1}

[d] Cost of seed based on MSU-ES 2014 Soybean Planning budget at $67.40/50lb of seed

[e] Return based on average commodity price for the growing year. 2013=$14.40/bu 2014=$13.00/bu

[f] Net return = Gross return – Seed Cost in a ha^{-1}

Table 3.5 Stand count[a] and plant population calculations[b] for each site year[c]

	Starkville				DREC			
	2013		2014		2013		2014	
Seeding Rate [d]	STDCT	Population	STDCT	Population	STDCT	Population	STDCT	Population
407,550	27	304,647	27	307,479	14	157,210	30	341,329
370,500	27	301,106	25	281,561	13	149,562	29	333,681
333,450	26	290,625	23	260,741	13	149,278	27	302,664
269,400	24	271,080	20	232,132	12	138,798	24	274,621
259,350	23	260,600	19	216,553	11	126,334	23	255,359
222,300	22	245,162	16	182,561	10	116,562	20	229,441

[a] Stand counts of number of plants in 0.913 m^2 of row

[b] Population calculated from stand count and expressed as plants in a ha^{-1}

[c] Data was split between site years due to site being highly significant.

[d] Seeding rate expressed as seeds ha^{-1}

Table 3.6 Plant heights by seeding rate for each site year[ab]

	Starkville		DREC	
Seeding Rate [b]	2013	2014	2013	2014
407,550	92	84	68	65
370,500	89	84	65	65
333,450	87	86	66	64
269,400	90	81	66	62
259,350	90	80	63	61
222,300	87	81	61	59

[a] Measured in cm from soil line to terminal node

[b] Data was split between site years due to site being highly significant.

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