MISSISSIPPI SOYBEAN PROMOTION BOARD
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FINAL REPORT

Project Title: Row-Crop Irrigation Science Extension and Research (RISER) Program—Row Spacing and Plant Population

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Objective: Determine the effect of row spacing and plant population on soybean grain yield, WUE, and economic net return.

EXECUTIVE SUMMARY

Sustainable production of furrow-irrigated soybean in the Midsouth is predicated on optimizing water use efficiency (WUE) of withdrawals for irrigation from the Mississippi River Valley Alluvial Aquifer (MRVAA), while concomitantly maintaining or improving on-farm profitability. This research was conducted to determine if soybean row spacing and plant population interact to effect soybean grain yield, net return, and water use efficiency (WUE).

An experiment using a split-plot arrangement of treatments in a randomized complete block design with four replications of each treatment was conducted on a Sharkey clay in 2016 and 2017 at the Delta Research and Extension Center located in Stoneville, Mississippi. Soybean HBK LL 4653 was planted on 26 May 2016 and 11 May 2017. The whole plot was row spacing (NARROW, 50.8 cm wide; CONV, 101.6 cm wide) and sub-plot was plant population (276,640, 345,800, and 414,960 plants ha^{-1}).

Irrigation was applied when the weighted average of the soil water potential in the 0- to- 61-cm rooting depth reached -100 kPa as measured by Watermark Model 200SS soil water potential sensors that were installed at 15-, 30-, and 61-cm depths within one replication. Irrigation was terminated at the R6.5 growth stage as recommended by the Mississippi State University Extension Service.

Plots were furrow-irrigated where water was pumped through 30.5-cm-diameter lay-flat polyethylene tubing laid perpendicular to the soybean rows. Computerized hole selection was calculated with the Pipe Hole And Universal Crown Evaluation Tool (PHAUCET) version 8.2.20 (USDA-NRCS, Washington, DC).

For soybean grain yield and economic net return, the row spacing main effect only was significant ($P = 0.0494$) (Table 1). Soybean grain yield and net return for NARROW increased 2.7% and 2.9%, respectively, compared to CONV. WUE was similar in the two row spacings. This indicates that conversion to NARROW soybean production systems will improve soybean grain yield and on-farm profitability on MidSouth clay-textured soils while maintaining equivalent WUE.

These results indicate that a yield gain of 2.0 bu/acre resulting from NARROW production will recoup the purchase price of a narrow row planter after planting 548 acres at $10/bushel soyban price (Table 2).

Table 1. Mean soybean grain yield (bu/acre), water use efficiency (WUE, bu/acre/inch), and net returns ($/acre) to irrigation for a study conducted in Stoneville, MS from 2016-2017 as affected by row spacing (CONV AND NARROW) and plant population (plants/acre).

Row Spacing	Plant Population	Yield	WUE	Net Return
CONV	112,000	66.6	3.09	590.89
	140,000	65.7	3.28	582.80
	168,000	66.1	3.28	586.84
	Average	**66.1 b**	**3.22 a**	**586.84 b**
NARROW	112,000	67.2	3.13	596.56
	140,000	68.1	3.17	605.48
	168,000	68.5	3.17	609.12
	Average	**67.9 a**	**3.16 a**	**603.72 a**

*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 2. Planted acres needed to recoup purchase price of 24-row planter based on bu/acre yield increase and bushel price.

Bu/acre Increase	Bushel Price 8.50	9.00	9.50	10.00	10.50	11.00
	Acres					
2.0	644	608	576	548	522	498
4.0	322	304	288	274	261	249
8.0	161	152	144	137	130	124
16.0	81	76	72	68	65	62

ROW SPACING AND PLANT POPULATION

ABSTRACT

Sustainable production of furrow-irrigated soybean in the Midsouth is predicated on optimizing water use efficiency (WUE) of withdrawals from the Mississippi River Valley Alluvial Aquifer (MRVAA), while concomitantly maintaining or improving on-farm profitability. This research was conducted to determine if soybean row spacing and plant population interact to effect soybean grain yield, net return, and water use efficiency (WUE).

An experiment using a split-plot arrangement of treatments in a randomized complete block design with four replications of each treatment was conducted on a Sharkey clay in 2016 and 2017. The whole plot was row spacing (NARROW, 50.8-cm; and CONV, 101.6-cm) and sub-plot was plant population (276,640, 345,800, and 414,960 plants ha^{-1}).

For soybean grain yield and economic net return only, the row spacing main effect was significant (P = 0.0494). Soybean grain yield and net return for NARROW increased 2.7% and 2.9%, respectively, compared to CONV. This indicates conversion to NARROW soybean production systems will improve soybean grain yield and on-farm profitability on MidSouth clay-textured soils while maintaining equivalent WUE.

INTRODUCTION

The Mississippi River Valley Alluvial Aquifer (MRVAA) underlies approximately 83,000 km^2 of the Midsouthern US, and is the main source of water used for irrigation of Mississippi Delta row crops. Over the past three decades, the number of agricultural wells has increased 6.8 fold (Sam Mabry, Personal Communication, 2017), and sustained heavy pumping from multiple wells for extensive periods has led to substantial, widespread water-level declines (Guzman et al. 2014).
To improve irrigation management in the region, exploring the impacts of cultural practices such as row spacing and plant population WUE needs to be evaluated.

In the Midsouth, soybean production generally uses wide rows on raised beds to accommodate furrow irrigation, and utilizes the same equipment as for cotton and corn planting and tending. Common row widths used for soybean in the lower Mississippi River Valley range from 88 to 102 cm wide. Bedding refers to ridging soil or raising the seedbed above the area of peak water accumulation or above the mean water elevation of the field. Bedding systems vary by the height of the bed, the width of the bed, and the number of rows each bed supports. Wide beds capable of supporting more than one row can be constructed and could be incorporated with narrow-row configurations currently utilized in the Mississippi Delta and the early season production system (ESPS) for soybean. Furthermore, the ESPS is suited for the use of narrow-row culture to accommodate the narrow growth habit of indeterminate MG IV cultivars (Heatherly and Bowers 1998).

The ESPS results in less extensive vegetative growth, a reduced need for mechanical weed control, and an increased need for maximum light interception. Manipulation of inter- and intra-row spacing facilitates fast canopy closure and distributes plants more evenly. Even distribution maximizes light interception and growth and development by eliminating competition between plants.

Soybean yields in the Midwestern United States usually are greater from plants in narrow rows than in the historical 102-cm-wide rows (Pendleton and Hartwig, 1973; Cooper, 1977). This yield increase, at equivalent plant populations, is attributed to the development of a canopy that provides complete ground cover and greater light interception compared to wide-row spacing by the time rapid podfill occurs (Shibles and Weber, 1966; Johnson et al. 1982; Board et al. 1992).

Rapid canopy development may be a disadvantage during dry years, however, because the increased early season exposure of leaves to full sunlight usually increases the use of stored soil water, if other factors are equal. If more stored soil water is used early in the growing season, less water is available during the critical podfilling stages and supplemental water would need to be applied. Taylor (1980) found the yield advantage of narrow rows more evident where moisture was sufficient. Accordingly, narrow-row configurations work well in areas where early season soil moisture is not a limiting factor.

The spatial distribution of plants in a crop community is an important determinant of yield (Egli 1998; Bullock et al. 1998). Manipulation of planting pattern and density of soybean has resulted in variable growth and seed yield responses (Duncan 1986; Robinson and Wilcox 1998). Plant density strongly affects leaf area, and therefore light interception and canopy photosynthesis in soybean (Wells 1991; Board 2000; Singer 2001). However, in most reported experimental results, yield responses to plant population have seldom been large and are frequently irregular (Lehman and Lambert 1960; Mason et al. 1980; Reiss and Sherwood 1965; Weber et al. 1966). Timmons et al. (1967) found greatest soybean yields were obtained with low plant population when planted in narrow rows, but higher planting rates were required for maximum yield in wider rows. Cooper (1977) found similar trends at some Illinois locations, but not at others. Taylor (1980), Stone et al. (1976), and others have attempted to relate row spacing and population effects to soil water depletion and evapotranspiration rates for soybeans. In a year of above-normal precipitation in Iowa, Taylor (1980) obtained 17% greater soybean yield from 25-cm-wide rows than from 100-cm-wide rows, but he found no row spacing effects in drier years.

The question of water use rate, as affected by planting geometry, becomes of major significance to soybean production in the Midsouth. In such situations, water availability may assume greater importance than availability of solar radiation in limiting the growth of most crops. The objective of this research is to determine the impact row spacing and plant populations have on soybean grain yield, WUE, and net return.

MATERIALS AND METHODS

Site Description and Experimental Design

To determine the effect that row spacing and plant population have on soybean grain yield, WUE, and economic net return, an experiment was conducted at the Delta Research and Extension Center located in Stoneville, Mississippi. Soybean HBK LL 4653 was planted on 26 May 2016 and 11 May 2017. Plots were 12.1-m wide and 140.6-m long, and the soil texture of the field was Sharkey Clay (very-fine, smectitic, thermic Chromic Epiaquerts). Treatments were in a split-plot arrangement within a randomized complete block design with four replications. The main plot factor was row spacing that consisted of 1-m-wide rows (CONV) and 50-cm-wide rows (NARROW) on 2-m-wide raised seed beds. The NARROW beds contained four rows of planted soybean spaced 50 cm apart. The sub-plot factor was plant populations of 276,640, 345,800, and 414,960 plants ha^{-1}.

Irrigation Scheduling

Irrigation was applied when the weighted average of the soil water potential in the 0- to- 61-cm rooting depth reached -100 kPa as measured by Watermark Model 200SS soil water potential sensors (Irrometer Company Inc., Riverside, CA) that were installed at 15-, 30-, and 61-cm depths within one replication. Irrigation was terminated at the R6.5 growth stage as recommended by the Mississippi State University Extension Service.

Irrigation Delivery

Plots were furrow-irrigated where water was pumped through 30.5-cm-diameter lay-flat poly-ethylene tubing (Delta Plastics, Little Rock, AR) laid perpendicular to the soybean rows. Computerized hole selection was calculated with the Pipe Hole And Universal Crown Evaluation Tool (PHAUCET) version 8.2.20 (USDA-NRCS, Washington, DC). Input parameters for computerized hole selection were implemented as described by Bryant et al. (2017). Flow rate at the field inlet was determined with a M^cCrometer flow tube with attached M^cPropeller bolt-on saddle flowmeter (M^cCrometer Inc., Hemet, California). During each irrigation event, 24.7 cm ha^{-1} of water was applied, and flow down each furrow was managed to stay within 11.3-22.7 L min^{-1}.

Agronomic practices outside of irrigation scheduling were conducted according to Mississippi State University Extension Service recommendations for regional producers (Catchot 2017; Bond et al. 2017). Growth stage of each treatment was taken once a week. The center two rows of each plot were mechanically harvested at physiological maturity when seed moisture was between 15-25% and yields were determined with a calibrated yield monitor (Ag Leader Technology, Ames, Iowa).

Water use efficiency was calculated as described by Viets (1962):

$$WUE = \frac{Y}{WA}$$

where WUE is water use efficiency (kg/ha mm^{-1}), Y is soybean grain yield (kg/ha), and WA is water used to produce the crop (ha mm^{-1}).

Economic Analysis

The model used to estimate irrigation costs in this research incorporates irrigation enterprise budgets developed utilizing the Mississippi State University Budget Generator. The model develops estimates of total receipts, total direct expenses, total fixed expenses, total specified expenses, and net returns above total specified expenses on a per hectare basis. The cost estimates are adjusted on an annual basis for the 2016 and 2017 crop years for changes in variable input costs other than diesel prices. Soybean prices were held constant at $10.00 per bushel. Assumptions related to equipment utilized in each enterprise budget are reported in Table 3. The values for purchase price and fuel consumption are based on personal communications with Mississippi Delta region irrigation equipment input and service providers.

Statistical Analysis

Using the GLIMMIX procedure of SAS (Statistical Analytical System Release 9.4; SAS Institute Inc., Cary, North Carolina), an initial analysis was conducted with year, row spacing, and plant population serving as fixed effects and replication within year, replication by row spacing within year serving as random terms. For soybean grain yield, average plant height, number of main stem nodes, and average pods per 1-m^2 F-values were small compared to the row spacing and plant population interaction values, so a second analysis was conducted with year serving as a component of error. In the second analysis, row spacing and plant population served as fixed effects and year, replication within year, year by row spacing, replication by row spacing within year, and year by plant population within row spacing served as random terms. Degrees of freedom were estimated using the Kenward-Roger method. Means were separated using the LSMEANS statement. Differences were considered significant for α=0.05.

RESULTS AND DISCUSSION

Seasonal Rainfall

Seasonal rainfall varied by year during the study compared to the 10 year average rainfall (YAR) amounts (Table 4). In 2016, rainfall amounts during April and May were approximately 23% and 37% less, respectively, than the 10 YAR amount. However, during June, July and August, rainfall amounts were 70%, 60%, and 97% higher, respectively, than the 10 YAR. In 2017, rainfall amounts during April and May were 18% more and 5% less, respectively, than 10 YAR. Months of June, July and August had 156%, 6%, and 286% more rainfall, respectively, than 10 YAR amounts. Relatively normal to below-normal rainfall allowed for timely planting, and rainfall during the months of critical reproductive growth lead to only one irrigation event needed during 2016 for all plant populations of NARROW and the CONV 276,640 seed ha^{-1}.

Soybean Grain Yield

For soybean grain yield, only the row spacing main effect was significant (P = 0.0433). NARROW soybean yielded 2.7% more than CONV. Our results agree with others that by reducing row spacing in irrigated environments from 102-cm to 25-cm, soybean grain yield increases from 135 to 605 kg ha^{-1} (Wiggins, 1939; Bowers et al., 2000; Bullock et al., 1998; Ethredge et al., 1989; Heatherly, 1988; Holshouser and Whittaker, 2002; Oriade et al., 1997; Reddy, 2002; Walker et al., 2010). The greater yields of NARROW are due to the benefits of faster canopy closure and increased light interception by the time rapid podfill occurs (Boquet, 1990; Bowers et al., 2000; Holshouser and Whittaker, 2002; Ethredge et al., 1989; Bullock et al., 1998).

While results for irrigated soybean are consistent, yield benefits from narrow row spacing in rainfed environments vary depending on climatic conditions (Epler and Staggenborg, 2008; Heatherly, 1988; Heitholt et al., 2005). Yield gain from narrow row spacing in rainfed environments may not be observed in years with extreme water-deficit stress (Alessi and Power 1982; Taylor 1980). Conversely, in years with adequate soil moisture, yield gains from narrow row spacing in rainfed environments are similar to those of irrigated soybean.

Water Use Efficiency

For WUE, there was no interaction or main effect ($P \geq 0.7013$). These results indicate that NARROW utilizes equivalent water relative to CONV. Conversely, others have noted that NARROW row systems utilize more stored water than CONV due to NARROW having more evenly distributed plant roots in the soil profile (Sharrat and McWilliams, 2005; Dalley et al., 2006; Krutz et al. 2007). However, our results indicate that in years with adequate soil moisture, WUE is equivalent for NARROW and CONV.

Harvest Samples

For plant height, number of main stem nodes, and average number of pods per 1-m^2, only row spacing affected pods per per m^2 ($P = 0.0373$). Our data indicate that decreasing row spacing from 101.6 cm to 50.8 cm increased pods per m^2 by 13.6%. These results coincide with the literature in which parameters attributable to yield were higher when row spacing decreased from 76 cm to 19 cm (Kolaric et al. 2014; Cox et al. 2010; Cox and Cherney 2011).

Economic Net Return

For net return, only the row spacing main effect was significant ($P = 0.0433$). Net return for NARROW was 2.9% greater than that for CONV. Yet, 63% of local producers have not adopted NARROW row soybean production due to increased cost of establishing the system. However, Oriade et al. (1997) were the first to confirm the economic benefits of narrow row soybean production systems in the Mississippi Delta. Subsequent research found that yield benefits offset the higher costs of equipment, seed, and weed management associated with narrow row spacing, supporting the findings of Oriade et al. (1997) (Heatherly et al. 2001; Reddy 2002). Our results indicate that with a yield gain of 135 kg ha^{-1} due to NARROW production, the purchase of a narrow row planter can be recouped after planting 1,352 ha at 10$ bushel price.

CONCLUSION

This research was conducted to determine if soybean row spacing and plant population interact to effect soybean grain yield, net return, and WUE. Only the row spacing main effect impacted soybean grain yield and net return, since NARROW increased them by 2.7% and 2.9%, respectively, compared to CONV. Our results indicate that conversion to NARROW soybean production systems will improve soybean grain yield and on-farm profitability on Midsouth clay-textured soils, while maintaining equivalent WUE.

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Table 1. Rainfall (cm) amounts for March through October in 2016, 2017, and 10-year average at Stoneville, MS.

Month	2016	2017	10-Year Average
March	46.91	7.57	14.22
April	10.95	16.84	14.22
May	8.28	12.40	13.11
June	12.85	19.28	7.54
July	16.59	10.95	10.34
August	13.92	27.28	7.06
September	0.86	4.29	9.53
October	0.51	0.56	13.49
Total	**110.87**	**96.62**	**89.51**

Table 2. Mean±SEM plant height (cm), number of main-stem nodes, pods per m^2, soybean grain yield (kg/ha), and water use efficiency (WUE, kg ha^{-1} mm^{-1}) for a study conducted in Stoneville, MS from 2016-2017 as affected by row spacing (CONV AND NARROW) and plant population (plants/ha).

Row Spacing	Plant Population	Yield	WUE	Height	Nodes	Pods	Net Return
	276,640	4,474(59)	8.2(0.3)	96.4(0.4)	17.3(0.2)	1,266(42)	1,459(22)
CONV	345,800	4,415(51)	8.7(0.6)	96.1(0.6)	17.1(0.3)	1,097(121)	1,439(19)
	414,960	4,442(44)	8.7(0.6)	95.8(0.5)	16.6(0.2)	1,301(23)	1,449(16)
	Average	**4,443(52) b**				**1,222(51) b**	**1,449(19) b**
	276,640	4,516(88)	8.3(0.4)	95.1(0.7)	17.9(0.3)	1,399(121)	1,473(33)
NARROW	345,800	4,578(36)	8.4(0.2)	95.0(0.5)	17.3(0.3)	1,338(89)	1,495(13)
	414,960	4,601(106)	8.4(0.4)	96.3(0.6)	16.7(0.3)	1,415(84)	1,504(39)
	Average	**4,565(71) a**				**1,384(62) a**	**1,491(28) a**

*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 3. Hectares needed to recoup purchase price of 24-row planter based on kg ha^{-1} yield increase and bushel price.

Kg ha^{-1} Increase	**Bushel Price** 8.50	9.00	9.50	10.00	10.50	11.00
	-----Hectares-----					
135	1,591	1,502	1,423	1,352	1,288	1,229
270	796	751	712	676	644	615
540	398	376	356	338	322	307
1,075	199	188	178	169	161	154