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Narrow-Row Production System for Soybeans in Mississippi Delta

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Abstract

The majority of irrigated soybean [*Glycine max* (L.) Merr.] in Mississippi are planted on raised beds spaced 38 to 40 inches apart. Recently, there has been an increased interest in planting soybean in narrower rows due to multiple potential benefits including increased light interception, improved weed control, and greater yield potential. Field studies were conducted at Stoneville, MS in 2016 and 2017 and at Hollandale, MS in 2016 to evaluate the effects of row spacing and seeding rates on irrigated soybean canopy closure, seed yield, and net returns. Row spacing treatments consisted of a single row (one plant row on a 40-inch spaced bed), twin row (two paired plant rows spaced 8 inches apart planted on 40-inch bed), and narrow row (four plant rows spaced 20 inches on an 80-inch wide bed). Each row-spacing treatment was also planted at seeding rates of 100,000, 140,000 and 180,000 seeds acre^{-1}. Canopy closure was greatest with the narrow-row spacing followed by the twin- and single-row spacing. Seed yield was 12% greater for the narrow-row spacing compared to single-row spacing. Net returns for row spacing followed the same trend as soybean seed yield at both locations. At Stoneville, a \$62 acre^{-1} economic advantage was realized for the narrow-row spacing compared with single- and twin-row spacing. Results indicate that it would be economically beneficial for soybean producers in the Mississippi Delta to switch to either a twin-row or narrow-row spacing production system for furrow irrigated soybean.

Soybean acreage in Mississippi has increased by 96% from 1930 to 2017 (USDA, 2016) and it is currently the most widely planted row crop in Mississippi, covering about 2,041,046 acres in 2016 (USDA, 2016). In the Mississippi Delta, soybean was initially planted on a similar row pattern as cotton, the predominant crop, with a single drill planted on raised beds spaced 40 inches apart. In recent years, twin-row production has gained popularity in Mississippi and much of the midsouthern United States. The twin-row planting system consists of two drills spaced 8 inches apart planted on each raised bed and centers of raised beds are between 38 and 40 inches apart (Bruns, 2011b). Soybean producers in the Mississippi Delta have switched to a twin-row planting system due to seed yield increases compared with single-row planting (Bruns, 2011a). Higher yields realized in the twin-row planting system is likely due to faster canopy closure and a greater light interception (Robles et al., 2012).

Crop Management

Core Ideas

- Soybean yielded more in narrow row spacing compared to single row spacing.
- Soybean yielded more in twin-row spacing than single row spacing at one location.
- Narrow row spacing resulted in a greater economic returns than single row spacing.

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Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.304	foot, ft	meter, m
67.19	60-lb bushel per acre, bu/acre	kilogram per hectare, kg/ha
25.4	inch	millimeter, mm (10^{-2} m)

As the shift from single- to twin-row continues in Mississippi, some producers have considered moving to an even narrower row spacing that will result in greater seed yield and improve soybean competitive ability with weeds (particularly with Palmer amaranth). A move to narrower rows is supported by multiple studies, predominantly in the Midwestern United States, that have shown consistently greater yields for soybean produced in narrow rows (8, 10, 15, and 30-inch spacing) (Taylor et al., 1982; Devlin et al., 1995; Mickelson and Renner, 1997; Elmore, 1998; Nelson and Renner, 1998; Swanton et al., 1998; Bowers et al., 2000; De Bruin and Pedersen, 2008; Thompson et al., 2015). Greater soybean yields were attributed to the development of full canopies earlier than those planted at wider spacing (Shibles and Weber, 1966; Taylor et al., 1982; Heatherly et al., 1999) and the rapid canopy closure increases the total amount of solar radiation intercepted by the crop (Ethredge et al., 1989). The more rapid canopy closure of narrow rows also increases weed suppression (Buhler and Hartzler, 2004), reduces soil temperature, and soil evaporation (Hoeft et al., 2000).

As a narrower row spacing is adopted, soybean producers in Mississippi must also consider the seeding rate that will be utilized. The optimal seeding rates for soybean in Mississippi varies from 150,000 to 187,580 seeds acre^{-1} depending on soil texture, soybean maturity group, and desired final plant population (Koger, 2009). Some previous studies have reported an interaction between row spacing and seeding rate. For example, in Wisconsin, Oplinger and Philbrook (1992) showed that increasing seeding rates in narrow rows lead to increased yields compared with wide rows. Despite the trend toward narrower row spacing in Mississippi and much of the midsouthern United States, limited information is available to producers about the potential effects of the narrow row on canopy closure, seed yield, and production economics. Therefore, the purpose of this study was to evaluate multiple soybean row spacings and seeding rates for the raised-bed, irrigated soybean production systems characteristic of the Mississippi Delta region.

Materials and Methods

Field studies were established at two on-farm locations during the 2016 growing season in Stoneville, MS (33°24′ N lat., 90°53′ W long.) and Hollandale, MS (33°12′ N lat., 90°53′ W long.) and only at Stoneville during the 2017 growing season. The cooperating farmer in Hollandale sold his wide-row planting equipment after the 2016 growing season, and therefore, the study was not repeated in 2017. The predominant soil texture for both locations was Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts), which is also the predominant soil texture found in the Mississippi Delta. In both years, Asgrow AG4632 (MG IV) (Monsanto Co., St. Louis, MO) soybean variety was planted. In the fall of each year, sites were prepared with a disc-harrow and then raised beds were formed using a disk hipper to facilitate furrow irrigation. In 2016, soybean was planted on 9 April and 10 May at Stoneville and Hollandale, respectively, and on 8 April at Stoneville in 2017. The preceding crop in all site-years was soybean. Fields were maintained weed-free through the use of pre- and postemergence herbicides. Irrigation scheduling for the experimental sites were based on soil moisture monitoring using three Watermark 200SS soil moisture sensors (Irrometer Company, Riverside, CA) installed at 6-, 12-, and 24-inch depths. Irrigation was applied when the weighted average of the soil water potential over all the 24-inch depth was −70 cbar. Cooperating farmers regularly scouted for insect pests and diseases and applied control measures based on Mississippi State University Extension recommendations.

Experimental design was a randomized complete block with a split–plot treatment arrangement replicated three times at both locations. The main plot factor was row spacing, which consisted of single row (one plant row on 40 inches spaced bed), twin row (two paired plant rows spaced 8 inches apart on a 40 inch beds), and narrow row (four plant rows spaced 20 inches on 80-inch wide beds). The sub-plot factor was three seeding rates of 100,000, 140,000 and 180,000 seeds/acre. Currently, Mississippi State recommends a seeding rate of 140, 000 seeds/acre for a maturity group IV soybean planted in April to May on clay soil texture. The range of seeding rates was included to determine if an interaction between row spacing and seeding rate existed. The plot size was 512 × 26 ft at Stoneville site and 1485 × 40 ft at the Hollandale site.

Canopy closure was monitored weekly (weather and field conditions permitting) in each plot for all locations from early vegetative growth until canopy closure reached 95%. The Canopeo application (Patrignani and Ochsner, 2015), which processes above-canopy digital images to determine the percent of green pixelation (leaf-ground ratio) was utilized to determine canopy closure percentages. The camera was positioned directly above the canopy and objective lens pointed down at a 90° angle. The camera was held at a constant height, angle, and position above the canopy to

Table 1. Monthly precipitation measured at a weather station located in Stoneville, MS during 2016 and 2017 growing season and 10-yr average precipitation.

Month	Monthly total precipitation		
	2016	2017	10-yr average (2006–2015)
	in		
March	18.5	3.2	5.5
April	4.3	6.7	5.5
May	3.2	4.7	5.1
June	5.1	7.5	3.2
July	6.7	4.3	3.9
August	5.5	10.6	2.8
September	0.4	1.6	3.9
October	0.4	0.4	5.1
Total	44.1	39.0	35.1

ensure accurate and consistent measurements using a custom device built out of 1-inch diameter PVC pipe. The camera was at a height that would photograph the two center rows of each plot (80 inches).

Cooperating farmers harvested the entire area of each subplot using commercial combines. These included a Case 2388 (Case IH, Racine, WI) at Stoneville and a John Deere 960 (Deere & Co., Moline, IL) at Hollandale. After each plot was harvested, it was weighed in a Par-Kan GW 200A weigh wagon (Par-Kan, Silver Lake, IN) in Stoneville and Killbros 35 Series Grain Cart (KB Killbros, Kalida, OH) in Hollandale. Both of the weigh wagons scales were calibrated before harvest. The resulting soybean seed yield was adjusted to 13% moisture content.

Since switching to a new soybean row spacing would require capital outlay to purchase a new soybean planter, we wanted to determine if such a switch was economically justified based on the data gathered in this study. A partial budget approach was used to estimate the change in net annual profit from seed yield differences between the single-row, twin-row, and narrow-row systems. Mississippi State soybean planning budgets were used to compare annual use, performance, repair, maintenance, and capital recovery cost based on initial purchase price of single-, twin-, and narrow-row planters (Falconer et al., 2016). It was assumed that new planting equipment purchased would be 40-ft wide, which is the width commonly used for furrow irrigated production systems in the Mississippi Delta. For each site-year, the average seed yield for each row spacing was multiplied by the soybean seed price of \$9.80 bu^{-1} (average of two years, 2016 and 2017) to determine the total revenue per acre (USDA, 2016; USDA, 2017). The annual cost/acre of the new planter was subtracted from the total revenue to obtain a net return. For the purposes of these analyses, we considered the single-row system to be the standard condition for producers in the state. Therefore, the relative advantage of switching to a twin- or narrow-row spacing over a single-row spacing was calculated by subtracting net returns of the single-row spacing from the net returns of the twin- or narrow-row planting treatments.

Statistical analysis was performed with SAS statistical software (SAS Institute, Cary, NC) using the GLIMMIX procedure. The Univariate procedure of the SAS statistical software was used for testing normality of the data. Row spacing, seeding rate, and row spacing × seeding rate interaction were considered fixed effects, while replication was considered a random effect. Year was also considered a random effect for the analysis of the Stoneville site. Canopy closure data were analyzed using a repeated measure model statement in the GLIMMIX procedure. The canopy closure for both locations and an advantage over single-row production data for Stoneville location was log transformed for analysis. However, the data was back transformed for the presentation of results. Significance was assessed at $P \leq 0.05$ and means were separated using the Tukey-Kramer grouping.

Results

Environmental Conditions during the Growing Seasons

Environmental conditions differed between the 2016 and 2017 growing seasons (Table 1). The 2016 growing season had more total precipitation from March to October than 2017 with precipitation totals of 44.1 and 39 inches for 2016 and 2017, respectively. Rainfall distribution was markedly different between years. Despite the above average spring rainfall in 2016 and the below average spring rainfall in 2017, soybean was planted within the recommended planting window from April to May in both years.

Canopy Closure

Canopy closure at Stoneville, MS was influenced by row spacing and seeding rate main effects (Table 2). There was no significant interaction present between the row spacing and seeding rate. The narrow-row spacing had 37 and 5% greater canopy closure than single- and twin-row spacing, respectively (Table 3). At Stoneville, when data was averaged over row spacing, the 180,000 seeds acre^{-1} (55.86%) rate had 9 and 4% greater canopy closure compared to 100,000 and 140,000 seeds acre^{-1}, respectively.

At Hollandale in 2016, the interaction of row spacing and seeding rate affected canopy closure (Table 2). Increasing the seeding rate for single-row spacing did not increase the canopy closure at Hollandale. However, canopy closure was increased with an increase in seeding rate for twin-row spacing. Within the narrow-row spacing, 140,000 seeds acre^{-1} had 10% higher canopy closure than the 100,000 seeds acre^{-1} (Table 4). However, canopy closure at 180,000 seeds acre^{-1} was not significantly different from the other two seeding rates in the narrow-row spacing treatment. When canopy closure was compared separately for each seeding rate, the single-row spacing had decreased canopy closure than twin- and narrow-row spacing at Hollandale.

Table 2. *P*-values showing the model significance from GLIMMIX procedure for main effects of seeding rate, row spacing and their interaction for soybean seed yield, canopy closure, net returns, and advantage over single-row spacing in Stoneville and Hollandale, MS.

Source of variation	Seed yield		Canopy closure		Net returns†		Advantage over single-row spacing‡	
	Stoneville	Hollandale	Stoneville	Hollandale	Stoneville	Hollandale	Stoneville	Hollandale
	P-values							
Row Spacing (RS)	**0.0005**	**0.0022**	**< .0001**	**< .0001**	**0.0007**	**0.0039**	**0.0315**	0.7877
Seeding Rate (SR)	0.0735	0.7874	**< .0001**	**< .0001**	0.0735	0.7874	0.8632	0.0591
RS x SR	0.9976	0.2254	0.9922	**< .0001**	0.9976	0.2254	0.7851	0.7161

† Net returns = Gross revenue – Planter cost.

‡ Advantage over single-row spacing = Net returns (narrow- or twin-row spacing) – Net returns (single-row spacing).

Soybean Seed Yield

Soybean seed yield was only affected by the main effect of row spacing at both Stoneville and Hollandale (Table 2). When examined across seeding rates at Stoneville, the narrow-row spacing increased soybean seed yield by 12 and 8% compared with single- and twin-row spacing, respectively (Table 3). However, no differences in yield were observed between the single- and twin-row spacing for planting soybean in Stoneville.

When averaged over seeding rates at the Hollandale location, soybean seed yield was 11 and 12% greater than the single-row spacing for twin- and narrow-row spacing, respectively, (Table 3). In contrast to Stoneville, soybean seed yield did not differ between twin- and narrow-row spacing.

Economic Analyses

For both locations, net returns were only affected by row spacing (Table 2). At Stoneville, the economic advantage of switching from single-row spacing to twin- or narrowrow spacing was affected by the row spacing. At Stoneville, the net returns were 11% ($78) and 9% ($62) greater with narrow-row spacing as compared with single- and twin-row spacing, respectively (Table 5). Furthermore, the economic advantage of switching to narrow-row spacing resulted in $62/acre more returns than switching to the twin-row planting.

At Hollandale, the net returns of single-row spacing were 9 ($76) and 10% ($82) less than the twin- and narrow-row spacing, respectively (Table 5). Net returns were similar between twin- and narrow-row spacing.

Table 3. Soybean seed yield and canopy closure as affected by row spacing in Stoneville and Hollandale, MS. Data are averaged over seeding rates due to the absence of interaction between row spacing and seeding rates. Data are also averaged over years for the Stoneville site. The canopy closure data is average over time.

Row spacing‡	Soybean seed yield		Canopy closure	
	Stoneville	Hollandale	Stoneville	Hollandale
	bu acre^{-1}		%	
Single	72.1b†	62.9b	48.62c	48.12c
Twin	74.3b	69.8a	51.54b	62.62b
Narrow	80.5a	70.5a	60.41a	65.82a

† Means within a column or row followed by the same letter are not significantly different at $P \leq 0.05$.

‡ Single row (one plant row on 40 inches spaced bed); twin-row (two paired plant rows spaced 8 inches apart planted on a 40-inch bed); narrow row (four plant rows spaced 20 inch apart on a 80 inches wide bed).

Discussion

In this study, row spacing significantly affected soybean seed yield. The results of this study support the findings of numerous other studies across the United States (Taylor, 1980; Graterol et al., 1996; Bowers et al., 2000). Andrade et al. (2002) reported that improved light interception during the critical growth stages was responsible for yield increases in narrow rows. Similar to our study, Graterol et al. (1996) observed that in a year with adequate precipitation, narrow- and twin-row soybean spacing offered seed yield advantages over single-row soybean planting arrangements. Also, Taylor (1980) reported a 17% seed yield advantage for narrow rows (10-inch rows) compared with single rows (40-inch rows) in a year with plentiful rainfall, but found no difference in soybean seed yield in years with lower seasonal water supply.

Based on 21 field experiments, Bowers et al. (2000) reported that for narrow-row spacing, seed yield either increased or was not different from single-row spacing. They determined that this depended on environmental conditions (rainfall and

Table 4. Canopy closure as affected by the interaction of row spacing and seeding rate at Hollandale, MS in 2016. The canopy closure data is average over time.

Row spacing‡	Seeding rate (seeds acre^{-1})		
	100,000	140,000	180,000
	Canopy closure (%)		
Single	47.62d†	47.32d	49.38d
Twin	58.21c	62.36bc	67.29a
Narrow	63.11bc	69.48a	64.87ab

† Means within a column or row followed by the same letter are not significantly different at $P \leq 0.05$.

‡ Single row (one plant row on 40 inches spaced bed); twin-row (two paired plant rows spaced 8 inches apart planted on a 40-inch bed); narrow row (four plant rows spaced 20 inch apart on a 80 inches wide bed)

Table 5. Net returns and economic advantage of twin- or narrow-row spacing over single-row spacing in Stoneville and Hollandale, MS. Data are averaged over seeding rates due to the absence of interaction between row spacing and seeding rates.

Location	Row spacing	Soybean yield	Planter cost	Soybean price	Gross revenue†	Net returns‡	Advantage over single-row spacing§
		bu $acre^{-1}$	———	———	cost $acre^{-1}$	———	———
Stoneville	Single	72.1	7.9	9.8	708	700b ¶	–
	Twin	74.3	13.4	9.8	729	716b	16b ¶
	Narrow	80.5	12.4	9.8	790	778a	78a
Hollandale	Single	62.9	7.9	9.8	618	610b	–
	Twin	69.8	13.4	9.8	686	686a	76a
	Narrow	70.5	12.4	9.8	692	692a	82a

† Gross revenue = Soybean yield × Soybean price.

‡ Net returns = Gross revenue – Planter cost.

§ Advantage over single-row spacing = Net returns (narrow- or twin-row spacing) – Net returns (single-row spacing).

¶ Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. Means are compared between row spacings separately for each location.

soil moisture) where soybean seed yield was more responsive to row spacing when the total rainfall during July and August ranged from 4 to 11 inches. The authors concluded that the effect of row spacing on soybean seed yield was mediated by rainfall and soil moisture (Bowers et al., 2000). Similarly, multiple previous studies have suggested that drought stress during critical soybean growth stages, such as seed formation and development could decrease seed yield with narrow-row spacing (Taylor, 1980; Alessi and Power, 1982; Zaffaroni and Schneiter, 1989; Devlin et al., 1995; Elmore, 1998). However, in the furrow irrigated soybean production systems characteristics of the Mississippi Delta, irrigation water is readily available and can usually be applied in a timely manner, reducing the risk of decreased yield due to drought stress for narrow-row soybean.

In this study, the twin-row spacing out yielded the single-row spacing only at Hollandale. This could have been a result of planting date differences between the two locations; Stoneville was planted almost a month before Hollandale. It is possible that the increased light interception provided by the narrow row early in the growing season, when soybean growth is normally slow, could have resulted in increased seed yield. It has been reported that later than optimum planting dates can result in greater seed yield for narrow rows compared to when planted at the optimum planting date (Parker et al., 1981; Beatty et al., 1982; Boquet et al., 1982; Parvez et al., 1989; Board et al., 1990).

In this study, soybean canopies reached maximum light interception sooner in narrow- and twin-row spacing compared to single-row spacing. Narrow-row spacing allows increased canopy leaf area development and a greater light interception (Shibles and Weber, 1966). Changes in row spacing affects canopy formation rate, which determines total dry matter accumulation and seed yield (Andrade et al., 2002). Similarly, the results of this study also suggest seed yield advantages for narrow rows is closely related to the increased rate of canopy closure prior to the critical pod development growth stage. Also, increased plant population from the higher seeding rates resulted in more rapid canopy closure for the twin row spacing.

Net returns followed the same trend as soybean seed yield at both locations, indicating that it would be economically beneficial for irrigated soybean producers in the Mississippi Delta to switch to a narrow-row soybean production system. We realize that a partial budgeting approach to economic analysis is rather simple and there are a number of other factors must be considered when switching to a narrow-row system. When planting on narrow rows, the bed used to accommodate the row spacing is twice the width of beds for single- and twin-row planting. Bedding equipment must either be altered, or new equipment purchased that can form the wider bed. Also, for producers who grow soybean in rotation with either corn or cotton, there is limited research regarding narrow-row corn production, especially in the midsouthern United States. Likewise, there is limited peer-reviewed research on narrow-row cotton production. This means that producers in the Mississippi Delta would likely need to have two separate planters; a narrow-row planter for soybeans and a more traditional wide row planter for corn and/or cotton. This would increase equipment costs and affect the profitability of switching to a narrow-row spacing in a soybean–corn/cotton cropping systems.

Another consideration with this narrow-row system is that the wide bed configuration necessary for furrow irrigating narrow-row soybean production requires capillary action to move water from the irrigation furrow to the middle of the bed. This means that this narrow-row system would likely not be viable on the sandier soils that are also common in the Mississippi Delta.

Despite these limitations potential limitations, the results of this study suggest that using a narrow-row soybean production system for furrow irrigated soybean in the Mississippi Delta can increase soybean seed yields and economic returns

Soybean producers that have the appropriate soil types should consider moving to a narrow-row production system.

References

Alessi, J., and J. Power. 1982. Effects of plant and row spacing on dryland soybean yield and water-use efficiency. Agron. J. 74:851–854. doi:10.2134/agronj1982.00021962007400050019x

Andrade, F.H., P. Calvino, A. Cirilo, and P. Barbieri. 2002. Yield responses to narrow rows depend on increased radiation interception. Agron. J. 94:975–980. doi:10.2134/agronj2002.0975

Beatty, K., I. Eldridge, and A. Simpson. 1982. Soybean response to different planting patterns and dates. Agron. J. 74:859–862. doi:10.2134/agronj1982.00021962007400050021x

Board, J., B. Harville, and A. Saxton. 1990. Narrow-row seed-yield enhancement in determinate soybean. Agron. J. 82:64–68. doi:10.2134/agronj1990.00021962008200010014x

Boquet, D., K. Koonce, and D. Walker. 1982. Selected determinate soybean cultivar yield responses to row spacings and planting dates. Agron. J. 74:136–138. doi:10.2134/agronj1982.00021962007400010035x

Bowers, G.R., J.L. Rabb, L.O. Ashlock, and J.B. Santini. 2000. Row spacing in the early soybean production system. Agron. J. 92:524–531. doi:10.2134/agronj2000.923524x

Bruns, H.A. 2011a. Planting date, rate, and twin-row vs. single-row soybean in the Mid-South. Agron. J. 103:1308–1313. doi:10.2134/agronj2011.0076

Bruns, H.A. 2011b. Comparisons of single-row and twin-row soybean production in the Mid-South. Agron. J. 103:702–708. doi:10.2134/agronj2010.0475

Buhler, D.D., and R.G. Hartzler. 2004. Weed biology and management. In: H.R. Boerma and J.E. Specht, editors, Soybeans: Improvement, production, and uses. ASA, CSSA, and SSSA, Madison, WI. p. 883–918.

De Bruin, J.L., and P. Pedersen. 2008. Effect of row spacing and seeding rate on soybean yield. Agron. J. 100:704–710. doi:10.2134/agronj2007.0106

Devlin, D., D. Fjell, J. Shroyer, W. Gordon, B. Marsh, L.D. Maddux, V.L. Martin, and S.R. Duncan. 1995. Row spacing and seeding rates for soybean in low and high yielding environments. J. Prod. Agric. 8:215–222. doi:10.2134/jpa1995.0215

Elmore, R.W. 1998. Soybean cultivar responses to row spacing and seeding rates in rainfed and irrigated environments. J. Prod. Agric. 11:326–331. doi:10.2134/jpa1998.0326

Ethredge, W., D. Ashley, and J. Woodruff. 1989. Row spacing and plant population effects on yield components of soybean. Agron. J. 81:947–951. doi:10.2134/agronj1989.00021962008100060020x

Falconer, L., T.W. Allen, J.A. Bond, B.R. Golden, J. Gore, H.C. Pringle, and J.T. Irby. editors. 2016. Delta 2017 planning budgets. Budget Report 2016-05. Dep. Of Agric. Economics, Mississippi State Univ., Starkville, MS. p. 271.

Graterol, Y., R. Elmore, and D. Eisenhauer. 1996. Narrow-row planting systems for furrow-irrigated soybean. J. Prod. Agric. 9:546–552. doi:10.2134/jpa1996.0546

Heatherly, L.G., A. Blaine, H. Hodges, R.A. Wesley, and N. Buehring. 1999. Variety selection, planting date, row spacing, and seeding rate. In: L.G. Heatherly and H. Hodges, editors, Soybean production in the Midsouth. CRC Press, Washington, D.C. p. 41–47.

Hoeft, R.G., S.R. Aldrich, E.D. Nafziger, and R.R. Johnson. 2000. Modern corn and soybean production. MCSP Publications, Champaign, IL.

Koger, C.H. 2009. Optimal plant populations/seeding rates for soybean. Mississippi State Univ. Ext. Serv., Mississippi State, MS. https://www.mssoy.org/uploads/files/seeding-rate-plant-pop-msu-es.pdf (Accessed 7 Sept. 2018).

Mickelson, J.A., and K.A. Renner. 1997. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. J. Prod. Agric. 10:431–437. doi:10.2134/jpa1997.0431

Nelson, K.A., and K.A. Renner. 1998. Weed control in wide-and narrow-row soybean (*Glycine max*) with imazamox, imazethapyr, and CGA-277476 plus quizalofop. Weed Technol. 12:137–144. doi:10.1017/S0890037X00042706

Oplinger, E., and B. Philbrook. 1992. Soybean planting date, row width, and seeding rate response in three tillage systems. J. Prod. Agric. 5:94–99. doi:10.2134/jpa1992.0094

Parker, M., W. Marchant, and B. Mullinix. 1981. Date of planting and row spacing effects on four soybean cultivars. Agron. J. 73:759–762. doi:10.2134/agronj1981.00021962007300050003x

Parvez, A., F. Gardner, and K. Boote. 1989. Determinate-and indeterminate-type soybean cultivar responses to pattern, density, and planting date. Crop Sci. 29:150–157. doi:10.2135/cropsci1989.0011183X002900010034x

Patrignani, A., and T.E. Ochsner. 2015. Canopeo: A powerful new tool for measuring fractional green canopy cover. Agron. J. 107:2312–2320. doi:10.2134/agronj15.0150

Robles, M., I.A. Ciampitti, and T.J. Vyn. 2012. Responses of maize hybrids to the twin-row spatial arrangement at multiple plant densities. Agron. J. 104:1747–1756. doi:10.2134/agronj2012.0231

Shibles, R., and C. Weber. 1966. Interception of solar radiation and dry matter production by various soybean planting patterns. Crop Sci. 6:55–59. doi:10.2135/cropsci1966.0011183X000600010017x

Swanton, C.J., T.J. Vyn, K. Chandler, and A. Shrestha. 1998. Weed management strategies for no-till soybean (*Glycine max*) grown on clay soils. Weed Technol. 12:660–669. doi:10.1017/S0890037X00044523

Taylor, H. 1980. Soybean growth and yield as affected by row spacing and by seasonal water supply 1. Agron. J. 72:543–547. doi:10.2134/agronj1980.00021962007200030032x

Taylor, H., W. Mason, A. Bennie, and H. Rowse. 1982. Responses of soybeans to two row spacings and two soil water levels. I. An analysis of biomass accumulation, canopy development, solar radiation interception and components of seed yield. Field Crops Res. 5:1–14. doi:10.1016/0378-4290(82)90002-8

Thompson, N.M., J.A. Larson, D.M. Lambert, R.K. Roberts, A. Mengistu, N. Bellaloui, and E.R. Walker. 2015. Mid-south soybean yield and net return as affected by plant population and row spacing. Agron. J. 107:979–989. doi:10.2134/agronj14.0453

USDA. 2016. Mississippi daily grain report. Agricultural Marketing Service, Jackson, MS. www.ams.usda.gov/mnreports/JK_GR110.txt.

USDA. 2017. Mississippi daily grain report. Agricultural Marketing Service, Jackson, MS. www.ams.usda.gov/mnreports/JK_GR110.txt.

Zaffaroni, E., and A. Schneiter. 1989. Water-use efficiency and light interception of semidwarf and standard-height sunflower hybrids grown in different row arrangements. Agron. J. 81:831–836. doi:10.2134/agronj1989.00021962008100050026x