Seeding rate effects on soybean height, yield, and economic return

The increased seed cost for glyphosate-resistant soybean, when compared with conventional soybean cultivars, makes seeding rate an important decision in soybean production systems. High soybean yields are possible with a wide range of plant densities because plants can adjust to low population density by producing more branches per plant and by increasing the number of pods on both the main stem and branches.

Environmental conditions such as temperature and precipitation are important factors influencing soybean vegetation growth and yield. Due to the erratic precipitation during the growing season in the southeastern coastal region of the United States, soybean is frequently exposed to drought stress, which may result in yield reduction. Under drought-stressed conditions, grain yield may not increase with high seeding rates because of competition for limited soil moisture. Though mature plant height is usually not considered an important factor in determining grain yield, it is affected by environmental conditions. It has been observed that both plant height and grain yield increased with seeding rate only under high-yield environmental conditions. Therefore, a positive response of plant height to seeding rate may indicate a less stressed environmental condition.

There are five soybean maturity groups (MG) planted in this region. Soybean MG IV is part of the early soybean production system (April planted), MG V and VI are for the full-season production system (May planted), and MG VII and VIII are for the double-cropping production system (DCPS) (June planted). Lowering seeding rates for the short-season soybean MG IV and late-planted soybean MG VII and VIII may reduce the amount of vegetative growth and reduce yield because of the short growth period. Conversely, soybean cultivars in MG V and VI that are planted in the full-season soybean production system may be able to maintain yield at lower seeding rates because the long growing period allows branch development to achieve desired leaf area index and normalized difference vegetation index.

Materials and methods

A three-year experiment was conducted under nonirrigated conditions at the Clemson University Edisto Research and Education Center near Blackville, SC in the Southeastern Coastal Plain from 2007 to 2009. The field was in the rotation of corn and soybean production with a winter wheat cover crop before the experiment. During the experimental period, only soybean and the winter wheat cover crop were kept in the system.

Five soybean maturity groups (IV through VIII) were used in the study. For each MG, a separate experiment was conducted using a randomized complete block design with four blocks. Seeding rates were 55,060; 82,600; 110,121; 137,650; and 165,180 seeds/ac in 2007. An additional rate of 27,530 seeds/ac was included in 2008 and 2009 because soybean grain yield at the lowest seeding rate in 2007 did not differ from the yield at the recommended seeding rate for all maturity groups. Only one cultivar for each maturity group was studied in each year.

Abbreviations: DCPS, double-cropping production system; MG, maturity group.
A partial-budget analysis was used to evaluate economic return for the seeding rates. Gross revenue was the product of commodity price and grain yield. Partial economic return was the gross revenue minus the sum of seed cost and hauling and handling charges. Seed and grain sale prices and hauling and handling charges were obtained from the South Carolina Soybean Enterprise Budgets. Average seed cost and grain sale prices during 2007–2009, which were about $0.82/lb and $0.17/lb, respectively, were used for the partial-budget analysis. Hauling and handling charges were nearly $0.01/lb. Mean seed number per pound was generated from three random seed samples for each cultivar used in this study and was averaged across years for each soybean maturity group. Therefore, seed size was set at 2,955; 3,182; 3,410; 2,727; and 3,000 seeds/lb for cultivars in MG IV, V, VI, VII, and VIII, respectively. Other costs such as equipment and drying were assumed to be the same for the different seeding rates and thus had no effect on economic return.

Results and discussion

Plant height

For MG IV, plant height increased linearly with increasing seeding rate in 2007 and 2009, but not in 2008. Plant height of cultivars in MG V and VI responded linearly to seeding rate in all three years. The response of plant height to seeding rate for cultivars in MG VII and VIII was positive and linear in 2007 and 2008, but not in 2009. An increase in plant height with seeding rate due to intraplant competition was reported. For cultivars in MG IV in 2008 and MG VII and VIII in 2009, the nonresponse of plant height to seeding rate was probably due to drought stress during vegetative growth. Total precipitation during the period from planting to the R5 stage for MG IV was low in 2008 and only 55 and 42% of that in 2007 and 2009, respectively. Total precipitation during the vegetative stage (from planting to R1 stage) in 2009 was moderate among the three years for determinate soybean cultivars in MG VII and VIII; however, its distribution was uneven as the precipitation in the first month after planting was only 27 and 26% of the total for MG VII and VIII, respectively. The dry soil conditions after planting may have slowed plant growth.

Grain yield and precipitation conditions

For the soybean cultivars in MG IV, grain yield did not respond to seeding rate in 2007 and 2008 but increased linearly with increasing seeding rate in 2009. Precipitation distribution during the growing season in each year may explain most of the yield responses to increasing seeding rates found for soybean in MG IV. Total precipitation during the soybean growing season was more in 2009 than the other two years. Plants at a higher density should have experienced greater competition because of less available soil water in 2007 and 2008 compared with plants at a lower density. In addition, total precipitation during the seed-filling stage in 2007 and from planting to the R5 stage in 2008 was only 63 and 32% of the 30-year average, respectively. Though the precipitation during the period of R1 to R5 for the MG V soybean cultivar in 2009 was only 39% of the 30-year average, plants might have suffered less drought stress as 40% of the precipitation during vegetative stages (0 to R1) occurred one week before flowering. Thus, a positive yield response to seeding rate was only observed in 2009 when less drought stress may have occurred. This agrees with reports that drought stress during the growing season, especially during the pod-filling stage, can have a large effect on yield, and that grain yield may not respond to increasing seeding rate under dryland conditions.
Grain yield of soybean cultivars in MG V varied with seeding rate by a linear function in 2008 and quadratic function in 2009, while grain yield for soybean cultivars in MG VI did not respond to increasing seeding rates in all three years. Precipitation during the period of R1 to R7 was about 65 and 60% of the 30-year average for soybean cultivars in both MG V and VI in 2007 and 2009, respectively. The distribution of precipitation was uneven in 2009 during the vegetative period for MGs V and VI: about 80% of the precipitation occurred in the first 18-day period with only 20% occurring in the last 35-day period. The percentage of the total precipitation over the 30-year average during the seed-filling stages was 34, 100, and 20% for MG V and 32, 41, and 23% for MG VI in 2007, 2008, and 2009, respectively. This likely resulted in water stress for MG V in 2007 and 2009 and for MG VI in all three years. However, grain yield of MG V in 2009 still responded to increasing seeding rate. The different responses of MG V and VI to increasing seeding rate in 2009 may have been due to the differences in maturity and cultivar. The average grain yields of soybean cultivars in MG V and VI were in the order of 2008 > 2007 > 2009 (P ≤ 0.001). Grain yield in 2007 and 2009 was only 76 and 52% for MG V and 52 and 46% for MG VI, respectively, compared with the grain yield in 2008. Though the precipitation during the whole growing season in 2007 and 2009 was about 80 and 101% of that in 2008 for both maturity groups, total precipitation during the reproductive stages (R1–R7) in 2007 and 2009 was only 60 and 55%. This reflects the importance of timely distribution of precipitation on grain yield. The effect of seeding rate on grain yield for MG VII was significant in 2009, but insignificant in 2007.

For soybean cultivars in MG VII, total precipitation during the early and late reproductive stages (R1–R5 and R5–R7, respectively) in 2007 was 59 and 27%, respectively, of the 30-year average. The total precipitation for MG VIII cultivars during the early reproductive stages in 2009 and the late reproductive stages in 2007 were only 25 and 17%, respectively, of the 30-year average. These conditions might also have strengthened the competition for limited soil water as seeding rate increased. The total and timely distribution of precipitation in 2008 provided favorable growing conditions for MG VII and VIII soybean cultivars. Grain yield in 2008 increased with increasing seeding rate; however, yield reached a plateau at a seeding rate of 92,388 seeds/ac for MG VII and showed a slight decline at higher seed rates for MG VIII. This reduction in grain yield with such high seeding rates might have been due to limitations other than soil moisture; it has been suggested that interplant shading and competition for light were more severe.

### Economic return and optimum seeding rates

For MG IV cultivars in the early soybean production system, there was a negative linear relationship between seeding rate and partial economic return in 2008 and no significant relationship in 2007 and 2009. Across years and seeding rates, the average economic return in the three years for MG IV was only 56, 59, 57, and 60% of that for MG V, VI, VII, and VIII, respectively. It was suggested that the lower grain yield of MG IV was due to its shorter duration of vegetative stage compared with soybean cultivars in MG V to VIII under the same environmental conditions.

For soybean maturity groups in the full-season soybean production system, economic return responded to seeding rate by a quadratic function for MG V and a negative linear function for MG VI in 2009. In this study, economic return for MG V increased with increasing seeding rate when seeding rate was not greater than 93,360 seeds/ac in two out of three years (Table 1).

For soybean cultivars in MG V, the predicted seeding rate for maximum yield in 2009 was 153,840/acre, which was 40% greater than the predicted economically optimum seeding rate (Table 1). In this study, seeding rates of 84,453 to 102,267 seeds/ac produced an economic return within $1.01/ac of the maximum value for the MG V

<table>
<thead>
<tr>
<th>MG</th>
<th>Year</th>
<th>Estimated maximum economic return</th>
<th>Seeding rates at maximum economic return</th>
<th>Seeding rates at maximum yield</th>
<th>Seeding rates within $1.01/ac maximum economic return</th>
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<tbody>
<tr>
<td>V</td>
<td>2009</td>
<td>288</td>
<td>93,360</td>
<td>131,943</td>
<td>84,453–102,267</td>
</tr>
<tr>
<td>VII</td>
<td>2008</td>
<td>513</td>
<td>72,510</td>
<td>92,388</td>
<td>69,757–165,182</td>
</tr>
<tr>
<td>VIII</td>
<td>2008</td>
<td>542</td>
<td>325,900</td>
<td>163,158</td>
<td>124,858–138,947</td>
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</table>
For MG VI cultivars, there was no clear indication of an optimum seeding rate in 2007 and 2008 as economic return did not differ with seeding rate. The economically optimum seeding rates for MG VI were about 50% of the recommended seeding rate, which is 110,121 seeds/ac for the region.

For MG VII and VIII cultivars in the DCPS, there were no valid response functions to describe the relationship between partial economic return and seeding rate in 2007 and 2009. In 2008, however, there was a quadratic-plateau and a quadratic response of economic return to seeding rate for MG VII and VIII, respectively. The predicted economically optimum seeding rate for MG VII in 2008 was 72,510 seeds/ac with a maximum economic return of $513/ac; and the rate of 69,757 seeds/ac or greater produced an economic return within $1.01/ac of the maximum (Table 1). This optimum seeding rate for maximum economic return was 20% greater than that for the maximum yield. For MG VII in 2007 and 2009, however, there was no difference of economic return among various seeding rates. Considering all these variations together, seeding rates of 69,757 to 165,182 seeds/ac for MG VII cultivars would achieve the optimum economic return.

For the soybean cultivar in MG VIII in 2008, the economically optimum seeding rate was 131,943 seeds/ac, which was 20% less than the seeding rate to maximize yield (Table 1). However, seeding rates of 124,858 to 138,582 seeds/ac produced economic returns within $1.01/ac of the maximum. In 2007 and 2009, there was no difference of economic return for MG VII among seeding rates. The mean economic return in 2007 and 2009 was less than that in 2008, which was probably related to the lower amount of precipitation in 2007 and 2009 (38 and 31% less than the 30-year average precipitation, respectively). High seeding rates for cultivars in MG VIII have been shown to improve the potential for attainment of a leaf area index of 3.5 to 4.0 within the shorter growing season for the DCPS, which ensures maximized light interception and crop biomass. High seeding rates may also provide compensation for seeds that do not attain good seed-to-soil contact due to the high level of small-grain residue that can be present in DCPS.

Conclusions

This study demonstrates the effects of seeding rate on mature plant height, yield, and economic return for soybean cultivars in MG IV, V, VI, VII, and VIII. Plant height increased linearly with increasing seeding rate for soybean cultivars in MG IV in 2007 and 2009, MG V and VI in all three years, and MG VII and VIII in 2007 and 2008. Grain yield increased linearly with increasing seeding rate for soybean cultivars in MG IV in 2009 and MG V in 2008. Grain yields for MG V, VII, and VIII were not affected by seeding rates when precipitation was about 30% lower than the 30-year average, likely because of greater competition for limited soil water at a higher population density. Economic return decreased linearly with increasing seeding rate for MG IV in 2008 and MG VI in 2009 and responded to seeding rate by quadratic functions for MG V in 2009 and VIII in 2008 and by a quadratic-plateau function for MG VII in 2008.

The results from this study indicate that optimum seeding rate could be reduced by 25 and 50% for MG V and VI, respectively; however, for MG VII and VIII cultivars, the optimum seeding rates could be increased by 3 to 12% and 12 to 21%, respectively, compared with the currently recommended seeding rate. For soybean cultivars in MG VII and VIII, which are for the DCPS, high seeding rates should facilitate rapid canopy cover and increase yield potential during a short growing season. Within a given MG, it is likely that cultivars may respond differently to seeding rate.