# Soybean Planting Date and Maturity Group Selection as a Method to Optimize Net Returns above Total Specified Costs and Irrigation Water Use Efficiency

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**Core Ideas**
- Should soybean maturity group change as planting date progresses to improve irrigation water use efficiency?
- Mid-Southern soybean producers should plant Maturity Group 4 regardless of planting date.
- Planting date and maturity group will interact to effect yield and irrigation water use efficiency.

## Abstract

Sustainable withdrawal from the Mississippi River Valley Alluvial Aquifer is predicated on optimizing irrigation water use efficiency (IWUE) while, concomitantly, maintaining or improving on-farm profitability. This research sought to determine interactions of soybean (*Glycine max* L.) planting date (early, middle, and late) and maturity group (MG) (III, IV, V) on yield, net returns above irrigation costs, and IWUE. Research was conducted near Stoneville, MS on a Dundee silty clay loam from 2015–2017. Planting date and MG interacted to have an effect on yield and IWUE ($P \leq 0.0001$) but not net returns above total specified costs ($P \leq 0.0861$). Relative to planting MG IV early, planting later or switching to another MG either had no effect or reduced yield up to 33.9%. Depending on planting date, the IWUE of MG III was 4.8 to 77.1% greater than that of MG IV and V. Net returns above total specified costs were optimized by planting a MG IV in either the early or mid-planting windows. Our data indicate that the maximum IWUE that can be attained without having an adverse effect on yield and net returns above total specified costs is achieved by planting MG IV early or mid-season. With the use of planting date and MG selection, producers in the Mid-Southern United States can maintain or improve on-farm profitability while concurrently reducing groundwater withdrawals.

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The Mississippi River Valley Alluvial Aquifer (MRVAA) is the primary irrigation source for the Mid-Southern United States (Missouri, Tennessee, Arkansas, Louisiana, and Mississippi) where, over the past three decades, the number of agricultural wells has increased 6.8-fold (Sam Mabry, personal communication, 2017). Groundwater levels in the region are declining due to agricultural withdrawals exceeding recharge rates of the MRVAA (Guzman et al., 2014). Optimizing irrigation water use efficiency (IWUE) for the primary row crops in the region is a means toward achieving sustainable groundwater consumption.

Table A. Useful conversions.

| To convert Column 1 to Column 2, multiply by | Column 1 Suggested Unit | Column 2 SI Unit |
|---|---|---|
| 0.405 | acre | hectare, ha |
| 3.8 | gallons per minute, gal/min | liters per minute, L/min |
| 10.2616 | acre-inch | meter$^3$, m$^3$ |
| 67.19 | bushels/acre, bu/acre | kilograms/hectare, kg/ha |
| 6.535 | bushels/acre-inch, bu/acre-inch | kilograms/hectare-millimeter, kg/ha-mm |

Nationally, Mississippi ranks eighth in terms of irrigated cropland area (USDA-NASS, 2013), and soybean accounts for 47.3% of total irrigation water applied to row crops in the state (Massey et al., 2017). From 2002–2013, average season-long irrigation water applied to soybean in Mississippi was 11 acre-inches, and irrigation rates increased circa 0.8 acre-inches/year (Massey et al., 2017). With approximately 1.57 million soybean acres in the Mississippi Delta, of which 61% are furrow-irrigated (USDA-NASS, 2014; Yazoo Mississippi Delta Joint Water Management District, 2013), there is a critical need for improving IWUE.

Planting early and changing maturity group (MG) as the planting window progresses may be a means to improve IWUE while maintaining or improving net returns above total specified costs. The early soybean production system (ESPS) improved yield and net returns by shifting Mid-Southern United States producers from planting determinate MG V-VII cultivars in May and June to planting indeterminate MG IV cultivars in April and May (Heatherly, 2005). More recently, stability analysis indicated that MG IV and V cultivars had the greatest probability (80%) of achieving yields that exceed 45 bu/acre at early planting dates (ranging from 20 March to 31 May) compared with MG III (70%) and MG VI cultivars (50%) (Salmeron et al., 2014). Moreover, for late planting dates (from 4 May to 17 July), MG III and IV cultivars had the greatest probability (62%) of achieving yields > 45 bu/acre compared with other MGs in the study (57 and 38% for MG V and VI cultivars). These results are critical to the Mid-Southern United States region as producers primarily plant MG IV soybean varieties during the early and mid-planting window and MG IV and V during the late window (T. Irby, personal communication, 2016).

Maturity group may also have an effect on irrigation requirements needed throughout the growing season. Edwards et al. (2003) reported that non-irrigated, MG I-IV soybean had similar yields as those under irrigation in the southeastern United States; yet, Wegerer (2012) identified irrigated MG IV to have superior yield, weed control, and irrigation attributes compared with irrigated MGs II and III. However, MG II and III have greater IWUE than later-maturing varieties due to shorter seed-fill durations (Wegerer et al., 2015; Edwards et al., 2003).

Producers in the Mid-Southern United States utilize the ESPS, and the most commonly planted varieties are indeterminate MG IV and V cultivars (Heatherly, 2005). For local producers to adopt a practice, specifically best irrigation water management strategies, on-farm profitability must be maintained or improved (Kay et al., 2015). Thus, evaluating new practices must be done by selecting the strategies that maximize on-farm profitability and then selecting for the highest IWUE among those strategies. The objective of this study was to determine if planting date and MG interact to have an effect on net returns above total specified costs and IWUE when using soil moisture sensors to determine irrigation scheduling.

## Site Description and Experimental Design

Research was conducted from 2015 through 2017 at the Delta Research and Extension Center, Stoneville, MS on a Dundee silty clay loam (fine-silty, mixed, active, thermic Typic Endoaqualfs). Experimental units, 13.3 ft wide by 35 ft long, were seeded with a John Deere Maxemerge four-row planter (John Deere, Moline, IL) at a depth of 1.2 inches and a rate of 140,000 seeds/acre. The experiment was a split-plot design in a randomized complete block with four replications. The whole plot was planting date, which consisted of 25–26 April (Early), 11–15 May (Mid), and 1–6 June (Late), and the sub-plot was maturity group (MG III, IV, and V) (Table 1). Due to discontinuation of specific varieties and seed availability, some cultivars changed from year to year, but replacement cultivars were of similar maturity (Table 2). All soybean cultivars had an indeterminate growth habit.

## Sensor-Based Scheduling

Irrigation was applied when the weighted average of the soil water potential in the 0- to- 24-inch rooting depth reached 75 centibar (cbar) as measured by Watermark Model 200SS soil

Table 1. Soybean planting and harvest dates by year for a planting date by maturity group study conducted in Stoneville, MS from 2015 to 2017.

| PD[†] | MG[‡] | 2015 Planting | 2015 Harvest | 2016 Planting | 2016 Harvest | 2017 Planting | 2017 Harvest |
|---|---|---|---|---|---|---|---|
| Early | III | 27 April | 22 Aug. | 27 April | 25 Aug. | 25 April | 23 Aug. |
| | IV | 27 April | 9 Sept. | 27 April | 10 Sept. | 25 April | 8 Sept. |
| | V | 27 April | 15 Sept. | 27 April | 16 Sept. | 25 April | 14 Sept. |
| Mid | III | 13 May | 2 Sept. | 16 May | 30 Aug. | 18 May | 30 Aug. |
| | IV | 13 May | 17 Sept. | 16 May | 19 Sept. | 18 May | 20 Sept. |
| | V | 13 May | 28 Sept. | 16 May | 29 Sept. | 18 May | 28 Sept. |
| Late | III | 1 June | 16 Sept. | 7 June | 19 Sept. | 5 June | 14 Sept. |
| | IV | 1 June | 26 Sept. | 7 June | 29 Sept. | 5 June | 27 Sept. |
| | V | 1 June | 1 Oct. | 7 June | 3 Oct. | 5 June | 1 Oct. |

† Planting date.

‡ Maturity group.

**Table 2. Soybean cultivars used in a planting date by maturity group study conducted in Stoneville, MS from 2015 to 2017.**

| MG† | 2015 | | 2016 | | 2017 | |
|-----|---------|---------|---------|---------|---------|---------|
|     | Company | Cultivar | Company | Cultivar | Company | Cultivar |
| III | Asgrow | AG3832 | Asgrow | AG3832 | Asgrow | AG39X7 |
|     | Mycogen | 5N40 | Mycogen | 5N40 | Mycogen | 5N40 |
|     | Pioneer | P93Y92 | Pioneer | P38T61 | Pioneer | P38T61 |
| IV | Asgrow | AG4632 | Asgrow | AG4632 | Asgrow | AG4632 |
|     | Mycogen | 5N451 | Mycogen | 5N451 | Mycogen | 5N451 |
|     | Pioneer | P47T36 | Pioneer | P47T36 | Pioneer | P47T36 |
| V | Asgrow | AG5335 | Asgrow | AG5335 | Asgrow | AG5335 |
|     | Mycogen | 5N52 | Mycogen | 5N52 | Mycogen | 5N52 |
|     | Pioneer | P53T73 | Pioneer | P53T18 | Pioneer | P53T18 |

† Maturity group.

water potential sensors (Irrometer Company Inc., Riverside, CA), installed at 6-, 12-, and 24-inch depths within one replication (Bryant et al., 2017). Irrigation was terminated at the R6.5 growth stage.

## Irrigation Delivery

Experimental units were furrow-irrigated, in which water was applied through 12-inch-diameter lay-flat polyethylene 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 McCrometer flow tube with an attached McPropeller bolt-on saddle flowmeter (McCrometer Inc., Hemet, CA). During each irrigation event, 4 acre-inches of water was applied at 3 gal/min/furrow. Agronomic practices outside of irrigation scheduling were conducted according to Mississippi State University Extension Service recommendations for regional producers (Catchot et al., 2014; Mississippi State University, 2015). Growth stage for each treatment was determined weekly. The center two rows of each plot were mechanically harvested at physiological maturity when seed moisture was between 15 to 25%, and yields were determined with a calibrated yield monitor (Ag Leader Technology, Ames, IA). Irrigation water use efficiency was calculated as described by Vories et al. (2005):

$$IWUE = \frac{Y}{IWA}$$

where IWUE is irrigation water use efficiency (bu/acre-inch), Y is soybean grain yield (bu/acre), and IWA is irrigation water applied (acre-inch).

## Economic Analysis

The economic analysis included in this study is based on enterprise budgeting of net returns above total specified expenses for each treatment (Table 3). Total specified expenses include direct costs and estimates of fixed costs for capital items. Direct costs are based on field records for each treatment and include costs for soybean seed, herbicides, and irrigation costs. Direct costs also include operator labor, fuel, maintenance, and supplies used in planting, herbicide application, cultivation, irrigation setup, and combining. Fixed costs include capital recovery charges for power units used in field operations and irrigation equipment. These costs are calculated using the Mississippi State Budget Generator (MSBG) (Laughlin and Spurlock, 2008). Total specified expenses are calculated for each treatment within each year of the study based on input prices for 2017 (Mississippi State University, 2016). Charges for land rent, general farm overhead, and returns to management are not included in this analysis. Net returns for each treatment were calculated based on the average reported price for the week including the harvest date (USDA, 2017), which was $9.60 per bushel.

## Statistical Analysis

Using the GLIMMIX procedure of SAS (Statistical Analytical System Release 9.4; SAS Institute Inc., Cary, NC), an initial analysis was conducted with year, planting date, and maturity group serving as fixed effects and replication within year, replication by planting date within year, variety within year and maturity group, and planting date by variety within year and maturity group serving as random terms. For soybean grain yield, IWUE, and net returns above total specified costs, *F*-values were small compared with the planting date and maturity group interaction values. Therefore, a second analysis was conducted with year serving as a component of error. In the second analysis, planting date and maturity group served as fixed effects and year, replication within year, year by planting date, replication by planting date within year, year by maturity group within planting date, and planting date by variety within year by maturity group 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 $\alpha = 0.05$.

## Seasonal Rainfall

Seasonal rainfall varied by year during the study as compared with the 10-yr average rainfall (YAR) amounts (Table 4). The 2015 growing season was characterized as hot and dry and had 13.5, 22.1, and 73.7% less rainfall during the months of June, July, and August, respectively, as compared with

Table 3. Total specified expenses per acre by treatment for a maturity group by planting date study conducted at Stoneville, MS from 2015 through 2017.

| Treatment | Total specified costs† |
|---|---|
| | $/acre |
| Early/III | 240.63 |
| Early/IV | 250.70 |
| Early/V | 252.70 |
| Mid/III | 254.43 |
| Mid/IV | 259.98 |
| Mid/V | 255.12 |
| Late/III | 251.81 |
| Late/IV | 249.61 |
| Late/V | 273.38 |

† Total specified costs include costs for soybean planting ($7.93 $/acre), cultivation (6.43 $/acre), broadcast spraying (7.44 $/acre, times two), irrigation setup (72.10 $/acre), combining soybeans (18.09 $/acre), soybean seed (63.00 $/acre), herbicides applied (46.17 $/acre), and irrigation water lifting (1.82 $/acre-in). Water applied to each treatment is as follows; Early/III = 10.70 acre-in, Early IV = 16.23, Early/V = 17.33, Mid/III = 18.28, Mid/IV = 21.33, Mid/V = 18.66, Late/III = 16.84, Late/IV = 15.63, Late/V = 24.57.

Table 4. Rainfall (inch) amounts for March through October and the 10-yr average for all years of a maturity group by planting date study conducted at Stoneville, MS from 2015 to 2017.

| Month | 2015 | 2016 | 2017 | 10-year average |
|---|---|---|---|---|
| | | | inch | |
| March | 7.3 | 18.5 | 2.9 | 5.6 |
| April | 6.3 | 4.3 | 6.6 | 5.6 |
| May | 6.9 | 3.3 | 4.9 | 5.2 |
| June | 2.6 | 5.1 | 7.6 | 2.9 |
| July | 3.2 | 6.5 | 4.3 | 4.1 |
| August | 0.8 | 5.5 | 10.7 | 2.9 |
| September | 0.8 | 0.3 | 1.7 | 3.8 |
| October | 5.5 | 0.2 | 0.2 | 5.3 |
| Total | **33.4** | 43.7 | 38.1 | 35.3 |

## Irrigation Water Use Efficiency

The interaction of planting date and MG had an effect on IWUE ($P \leq 0.0001$) (Table 6). Depending on planting date, the IWUE of MG III was 4.8 to 77.1% greater than that of MG IV and V. Compared with the early planting date, IWUE for MG III decreased 27.9 and 41.9% for the mid- and late planting date, respectively. Irrigation water use efficiency for MG IV did not change due to planting date. Compared with the early planting date, IWUE for MG V decreased 34.0% from early to mid-planting but did not change from mid- to late planting.

A primary objective of this research was to determine how to maximize IWUE for soybean without adversely affecting yield and net returns above total specified costs. Presently, Mid-Southern United States producers primarily plant MG IV soybean varieties during the early and mid-planting window and MG IV or V during the late window (T. Irby, personal communication, 2016). However, planting date and MG interacted to have an effect on yield and IWUE while both planting date and MG had an effect on net returns above total specified costs, indicating that to maximize IWUE without adversely affecting yield and net returns above irrigation total specified costs, a MG IV soybean should be seeded across all planting dates.

For all MGs, net returns above total specified costs and IWUE were greater during early rather than later planting dates. Others noted that net returns were maximized for MG III, IV, and V when planted at mid-April in the Mid-Southern United States (Salmeron et al., 2014). Higher yields and net returns for these MGs planted early rather than later is attributed to an increased photoperiod (Chen and Wiatrak, 2010; Purcell et al., 2002), increased leaf area index and radiation interception (Egli et al., 1987), reduced risk of late-season effects caused by insect pests (Baur et al., 2000; Gore et al., 2006), and improved drought avoidance (Heatherly et al., 1998; Boykin, 2002; Heatherly and Spurlock, 2002). Aside from August 2015, rainfall amounts during critical reproductive periods for soybean planted in April were equivalent or exceeded the 10 YAR amounts, and the greater IWUE during

the 10 YAR. These conditions resulted in water deficits during critical reproductive growth stages for soybean planted during early and mid-planting dates, and the frequency of irrigation requirements reflect this (Table 5). In contrast, the 2016 and 2017 growing seasons had higher amounts of rainfall than the 10 YAR, with the months of June, July, and August averaging 112, 32.5, and 188% more rainfall, respectively, across both years.

## Soybean Grain Yield

The interaction of planting date and MG had an effect on soybean grain yield ($P \leq 0.0001$) (Table 6). For the early planting date, yield for MG IV and V was at least 15.9% greater than MG III. Maturity Group IV yielded 30.3% and 33.9% greater than MG III and V, respectively, for the mid-planting date. In the late planting date, yield was not different among MGs. Yield for MG III and IV was stable through the mid-planting window, but delaying planting until the late window reduced yield by at least 19.9% as compared with the early planting. Yield for MG V decreased 32.5% from the early to mid-planting date but did not change from mid- to late planting.

## Net Returns above Total Specified Costs

The interaction of planting date and MG had no effect on net returns above total specified costs ($P = 0.0861$). However, planting date and MG both affected net returns above total specified costs individually ($P \leq 0.0390$) (Table 7). Across all MGs, net returns above total specified costs were reduced up to 192% when planting was delayed until the late planting date while net returns above total specified costs were not different between the early and mid-planting dates. Regardless of planting date, selecting a MG IV soybean increased net returns above total specified costs by at least 21% compared with MG III and V.

Table 5. Irrigation water applied (acre-inch) at specific growth stages by year for a maturity group by planting date study conducted in Stoneville, MS from 2015 to 2017.

| | | 2015 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Planting date | MG† | Growth stage | | | | | | | Total |
| | | VN | R1 | R2 | R3 | R4 | R5 | R6 | |
| Early | III | | | | | 4.0 | 4.0 | | 8.0 |
| | IV | | | | | | 8.0 | 12.0 | 20.0 |
| | V | | | | | 4.0 | 20.0 | 4.0 | 28.0 |
| Mid | III | | | 4.0 | 4.0 | 4.0 | 16.0 | 4.0 | 32.0 |
| | IV | | | | 4.0 | 12.0 | 16.0 | 12.0 | 44.0 |
| | V | | | | 4.0 | 4.0 | 16.0 | 8.0 | 32.0 |
| Late | III | | | 4.0 | | 16.0 | 16.0 | 4.0 | 40.0 |
| | IV | | | | 8.0 | 8.0 | 8.0 | 8.0 | 32.0 |
| | V | | | 4.0 | 16.0 | 12.0 | 12.0 | 4.0 | 48.0 |
| | | 2016 | | | | | | | |
| Planting date | MG | Growth stage | | | | | | | Total |
| | | VN | R1 | R2 | R3 | R4 | R5 | R6 | |
| Early | III | | | | 4.0 | 4.0 | 8.0 | 4.0 | 20.0 |
| | IV | | | 4.0 | 4.0 | 4.0 | 8.0 | | 20.0 |
| | V | | | 4.0 | | | 8.0 | | 12.0 |
| Mid | III | | | 4.0 | | | 8.0 | | 12.0 |
| Mid | IV | | 4.0 | | | 8.0 | | | 12.0 |
| | V | | 4.0 | | | 8.0 | 4.0 | | 16.0 |
| Late | III | 4.0 | | | | | 4.0 | | 8.0 |
| | IV | | | 4.0 | | 4.0 | | 4.0 | 12.0 |
| | V | 8.0 | | 4.0 | 4.0 | 4.0 | | 4.0 | 24.0 |
| | | 2017 | | | | | | | |
| Planting date | MG† | Growth stage | | | | | | | Total |
| | | VN | R1 | R2 | R3 | R4 | R5 | R6 | |
| Early | III | | | | | | 4.0 | | 4.0 |
| | IV | | | | | | 8.0 | | 8.0 |
| | V | | | | | | 8.0 | | 8.0 |
| Mid | III | | | | | | 4.0 | | 4.0 |
| | IV | | | | | | 8.0 | | 8.0 |
| | V | | | | | | 8.0 | | 8.0 |
| Late | III | | | | | 4.0 | | | 4.0 |
| | IV | | | | 4.0 | | | | 4.0 |
| | V | | | 4.0 | | | | | 4.0 |

† Maturity group.

the early planting date reflect this (Table 5). Yet, as planting date progressed, yield, net returns above total specified costs, and IWUE were adversely affected for all MGs.

During the early planting window, the strategy that maximizes IWUE for soybean without having an adverse effect on yield and net returns above total specified costs is to plant MG IV rather than MG III or IV cultivars. The IWUE for MG III was superior to that of all later-maturing varieties but should not be planted during the early window due to adverse effects on net returns above total specified costs (Kay et al., 2015). Others noted similar yield potentials among early planted, indeterminate MG IV and V cultivars, and that these cultivars have a greater yield potential than that of MG III cultivars (Wegerer et al., 2015; Popp et al., 2006; Salmeron et al., 2014). The superior yield and net returns for early planted, later-maturing cultivars relative to MG III cultivars is due to greater interception of solar radiation during reproductive growth in the former (Egli and Bruening, 2000; Kantolic et al., 2013). Thus MG IV cultivars should be seeded in the ESPS to maximize IWUE without having an adverse effect on economics.

During the mid-season planting window, the strategy that maximizes IWUE for soybean without having an adverse effect on yield and net returns above total specified costs is to plant MG IV rather than MG III or V cultivars. As in the early planting window, the IWUE for MG III was greater than that of MG IV, but the net returns above total specified costs were $139/acre less than that of MG IV. Others noted superior yields and economic benefits for MG IV cultivars relative to earlier- or later-maturing cultivars when planted in May (Heatherly, 2005; Salmeron et al., 2014; Salmeron et al., 2016; Popp et al., 2006). Greater yields and net returns for MG IV relative to other MGs within the mid-planting window

Table 6. Mean ± SEM soybean grain yield (bu/acre) and irrigation water use efficiency (bu/acre-inch) for a maturity group by planting date study conducted in Stoneville, MS from 2015 to 2017.

| Planting date | MG† | Yield | IWUE‡ |
|---|---|---|---|
| | | bu/acre | bu/acre-in |
| Early | III | 59.2 (1.9)§ bc¶ | 8.6 (1.0) a |
| Early | IV | 70.8 (2.4) a | 5.2 (0.5) cd |
| Early | V | 68.6 (2.3) a | 5.3 (0.5) cd |
| Mid | III | 47.6 (1.4) c | 6.2 (1.0) b |
| Mid | IV | 62.0 (2.1) ab | 4.6 (0.4) cd |
| Mid | V | 46.3 (1.3) d | 3.5 (0.4) e |
| Late | III | 45.1 (1.7) d | 5.0 (0.6) c |
| Late | IV | 56.7 (2.1) d | 4.5 (0.4) d |
| Late | V | 51.7 (2.1) d | 3.7 (0.5) e |

† Maturity group.

‡ Irrigation water use efficiency.

§ Values in parenthesis are the standard error of the mean.

¶ Values in a column followed by the same letter are not significantly different at $P \le 0.05$.

Table 7. Mean net returns above total specified costs ($/acre) for a maturity group by planting date study conducted in Stoneville, MS from 2015 to 2017.

| Planting date | Net returns |
|---|---|
| | $/acre |
| Early | 950 a† |
| Mid | 664 a |
| Late | 325 b |
| Maturity group | |
| III | 735 a |
| IV | 608 b |
| V | 596 b |

† Values in a column followed by the same letter are not significantly different at $P \le 0.05$.

are attributed to better synchronization of reproductive growth with optimum environmental conditions (Chen and Wiatrak 2010; Purcell et al., 2002; Egli et al., 1987). These data indicate that during the mid-season planting window, Mid-Southern United States producers should continue seeding MG IV cultivars in place of MG III and V cultivars.

During the late-season planting window, the strategy that maximizes IWUE for soybean without having an adverse effect on yield and net returns above total specified costs is to plant MG IV rather than MG III or V cultivars. As noted by others, we did not observe yield differences among MG III, IV, and V cultivars when planted in the late window (Heatherly 2005; Salmeron et al., 2016); however, economic analysis indicates that planting a MG III or V would reduce net returns above total specified costs by at least $127/acre. Maturity Group III cultivars did return more yield per acre-inch of water applied than the later-maturing cultivars, which is consistent with the literature (Wegerer et al., 2015; Heatherly 2005; Edwards et al., 2003), but cultivars which provide greater yield potential must be developed before being implemented in Mid-Southern United States soybean production systems. The greater IWUE for MG III cultivars is due to their shorter seed-fill duration, which enables them to reach physiological maturity at least 10 days earlier than the later-maturing varieties (Table 1) (Wegerer et al., 2015; Edwards et al., 2003).

## Conclusion

The objective of this study was to determine which soybean MG should be seeded in specific planting windows to maximize IWUE without having an adverse effect on grain yield and net returns above total specified costs. Currently, Mid-Southern United States producers primarily plant MG IV soybean cultivars during the early and mid-planting window and MG IV or V during the late window to maximize yield and net returns. Planting date and MG interacted to affect yield and IWUE while net returns above total specified costs were affected by planting date and MG individually. Specifically, our data indicate that the maximum IWUE that can be attained without having an adverse effect on yield and net returns above total specified costs is achieved by planting MG IV across all planting dates. This research demonstrates that by optimizing soybean planting date and MG selection, Mid-Southern United States producers can maintain or improve their yields and profitability while reducing demand for groundwater.

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