Early Planting, Full-season Cultivars, and Seed Treatments Maximize Soybean Yield Potential

Jacob P. Vossenkemper,* Emerson D. Nafziger, Jeff R. Wessel, Matt W. Maughan, Michael E. Rupert, and John P. Schmidt

Abstract
Recent findings in the midwestern United States have shown that planting soybean [Glycine max (L.) Merr.] by early May often increases yield compared to planting in mid- to late May. These findings have encouraged earlier planting, but raise questions about how planting date might interact with other management factors. In 58 on-farm trials in Illinois and Indiana in 2011 and 2012, we found that seed treatment (fungicide + insecticide + rhizobia inoculant) increased plant stand by 4200 plants per acre, with greater effects from early planting than with later planting. Seed treatment also increased yield, by an average of 1.2 bu/acre, but did not interact with planting date or maturity. Planting in late April increased yield only slightly (0.9 bu/acre) compared to planting in mid- to late May, and full-season cultivars yielded 3.8 bu/acre more than short-season cultivars. Full-season cultivars yielded 5.5 bu/acre more than short-season cultivars with early planting, but only 2 bu/acre more planted later. Yield of full-season cultivars dropped by 2.7 bu/acre from early to normal planting, but those of short-season cultivars remained unchanged. Although seed treatments may improve stands more with early planting, stands were adequate regardless of planting date or seed treatment, and the decision to use seed treatment can be made independently of cultivar or planting date. These results show that planting full-season cultivars before short-season ones, and perhaps choosing slightly fuller season cultivars in general, may improve soybean yields.

Within the last decade university researchers in the midwestern United States soybean production regions have updated their soybean planting date recommendations (Bastidas et al., 2008; De Bruin and Pedersen, 2008; Robinson et al., 2009; Vonk, 2013). These recommendations now suggest soybean yield reaches a maximum when planting takes place in late April to early May. These recommendations are updates because prior experiments conducted in the Midwest from the 1960s to the early 2000s either did not test April and early-May planting dates, or found no clear yield advantage to planting dates earlier than mid- to late May (Egli and Cornelius, 2009). To gain a...
clarity understanding of why the optimum planting date is earlier now, Rowntree et al. (2013) tested the hypotheses that newly released cultivars produce more grain when planted in early May as opposed to early June when compared with cultivars released across the eight previous decades. The results from Rowntree et al. (2013) confirmed this hypothesis, finding that roughly 80 years of genetic improvement has nearly doubled the effect planting date has had on soybean grain yields within Maturity Group III cultivars (Rowntree et al., 2013).

The general consensus that soybean produces maximum yield when planted in late April to early May, and the affirmation that genetic improvement has enhanced soybean’s response to planting date suggests early planting is a management strategy that often will increase soybean yield in the soybean growing regions of the Midwest. Although the potential for increased profitability from earlier spring planting exists, it is unknown how some common management decisions may influence soybean’s response to planting date, particularly at earlier planting dates, that are now recommended. Some of the recent experiments used to support earlier soybean planting have had multiple objectives, focusing not only on planting date’s general effect on soybean yield but investigating the interaction between planting date and seeding rate (De Bruin and Pedersen, 2008), or planting date, seeding rate, and row spacing’s effect on soybean yield (Vonk, 2013). However, published literature investigating planting date and cultivar maturity selection effects on soybean yield is scant, and the few recent reports that do exist have a small inference space, encompassing few cultivars and locations over just 2 years (Setiyono et al., 2007; Robinson et al., 2009).

One physiological mechanism that is commonly associated with greater soybean grain yield is extending all or parts of the reproductive growth duration. Crop scientists, soybean breeders, and molecular biologists have independently demonstrated that when the duration of reproductive growth increases grain yields also increase (Kantolic and Sláfer, 2005; Bastidas et al., 2008; Kantolic and Sláfer, 2007; Preuss et al., 2012; Rincker et al., 2014; Rowntree et al., 2014). One of the few recently published reports investigating the effect of cultivar maturity on soybean grain yields at different planting dates suggest early planting coupled with full-season cultivars maximizes the duration of the critical seed-filling period (R5–R7) (Robinson et al., 2009). When averaged over the two site-years in Robinson et al. (2009), the difference in the critical seed-filling period between the fullest- and the shortest-season cultivars tested diminished as planting was delayed. At the mid-April planting date, the seed-filling period for the fullest-season cultivar was 12% longer than for the shortest-season cultivar, but by the early June planting date the difference in the seed-filling period between these two groups was <5%. In the 2007 growing season of Robinson et al. (2009), grain yields tended to follow the observed pattern in the seed-filling period, with the fullest-season cultivar producing greater yields at the late-March and mid-April planting dates relative to the mid- and short-season cultivars. At the late-April through early-June planting dates, however, cultivars differing in maturity had similar yields. In the 2006 growing season, all cultivars differing in maturity had similar yields regardless of planting date.

Besides cultivar maturity selection, seed treatments are another common management decision growers must consider. Since 1994 the percentage of soybean seed treated with either a fungicide or a fungicide plus an insecticide seed treatment has risen from 8% (Munkvold, 2009) to >70% in some regions (Adam Kaufman, personal communications, 2015). During this period there has been a myriad of research investigating the ability of seed treatments to protect soybean stands, and increase soybean yield and grower profitability (Poag et al., 2005; Bradley, 2008; Schulz and Thelen, 2008; Dorrance et al., 2009; Esker and Conley, 2012; Cox and Cherney, 2014; Gaspar et al., 2014). The overwhelming conclusion from this body of research is that the ability of seed treatments to provide these services are environment (year/location) (Bradley, 2008; Schulz and Thelen, 2008; Cox and Cherney, 2014; Gaspar et al., 2014) and cultivar dependent (Dorrance et al., 2009; Esker and Conley, 2012). Environments where seed treatments tend to protect soybean stands and increase yield more consistently appear to be when soybeans are planted into cold wet soils or when a significant rain event occurs shortly after planting (Bradley, 2008; Schulz and Thelen, 2008; Dorrance et al., 2009).

Given the evidence that full-season cultivars have a longer seed-filling period relative to mid- and short-season cultivars at early planting dates, and that seed treatments appear to be most effective at protecting soybean stands and increasing yield when planted in cold wet soil conditions (i.e., planted early), we hypothesize that adopting a management system that combines the use of seed

### Table A. Useful conversions.

<table>
<thead>
<tr>
<th>To convert Column 1 to Column 2, multiply by</th>
<th>Suggested Unit</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.609</td>
<td>mile, mi</td>
<td>1</td>
<td>kilometer, km (10⁻³ m)</td>
</tr>
<tr>
<td>0.405</td>
<td>acre</td>
<td>0.1</td>
<td>hectare, ha</td>
</tr>
<tr>
<td>67.19</td>
<td>60-lb bushel per acre, bu/acre</td>
<td>0.740</td>
<td>kilogram per hectare, kg/ha</td>
</tr>
<tr>
<td>0.454</td>
<td>pound, lb</td>
<td>0.453</td>
<td>kilogram, kg</td>
</tr>
<tr>
<td>2.96 × 10⁻²</td>
<td>ounce (liquid), oz</td>
<td>0.000865</td>
<td>liter, L (10⁻³ m³)</td>
</tr>
<tr>
<td>0.304</td>
<td>foot, ft</td>
<td>0.304</td>
<td>meter, m</td>
</tr>
</tbody>
</table>
treatments with a full-season cultivar and an early planting date will result in maximum soybean yield. With later planting dates, however, the difference in the seed-filling period between cultivars differing in maturity appears to become more similar, and seed treatments may not be effective at protecting stands or increasing yields because the soil environment is less favorable for soil-borne diseases. Therefore, cultivar maturity selection and seed treatments may not be important management decisions for maximizing soybean yields at delayed planting dates. Our objectives were to quantify the effects of cultivar maturity and seed treatments (fungicide + insecticide + rhizobia inoculant) on soybean grain yields and early-season stand establishment at early and normal planting dates using on-farm strip trials distributed throughout the soybean growing regions of Illinois and Indiana.

ON-FARM STRIP TRIALS, DATA COLLECTION, AND ANALYSIS

In the growing seasons of 2011 and 2012, 20 and 38 on-farm strip trials were conducted throughout Illinois and Indiana. These strip trials were a collaborative project between DuPont Pioneer technical field personnel, DuPont Pioneer independent sales representatives, and volunteer grower participants. DuPont Pioneer provided the seed and protocol for the field experiments, and volunteer grower participants implemented the experiments with guidance from DuPont Pioneer representatives. The experimental design at each location was a randomized complete block in a split-plot arrangement. The whole plots were two planting dates and subplots were a full- and short-season cultivar with and without seed treatments, for a total of eight treatments per location.

Grower participants were asked to plant the first planting date in the last half of April and the second planting date about 30 days later, targeting the last half of May. From this point forward, the first and second planting dates will be referred to as the “early” and “normal” planting dates. The full- and short-season cultivars used at each location were relative to the latitude of the experiment. Some of the common cultivar combinations representing the full- and short-season cultivars in the northern, central, and southern regions, respectively, of these states were 92Y51 and 93Y40, 92Y80 and 93Y82, and 93Y40 and 94Y01, although other cultivar combinations were used. Each location followed one or several years of corn (Zea mays L.), and almost all locations had a recent history of soybean in the rotation. The seed treatments used in this study were applied at DuPont Pioneer production facilities and consisted of Trilex (trifloxystrobin) at 0.32 fl oz/100 lb seed, Allegiance (metalaxyl) at 0.75 fl oz/100 lb seed, Gaucho (imidacloprid) at 1.6 fl oz/100 lb seed, and Optimize 400 (lipo-chitoooligosaccharide promoter + Bradyrhizobium japonicum) at 2.8 fl oz/100 lb seed. In 2012 DuPont Pioneer changed their seed treatment formulation and Optimize 400 was replaced with PPST 120 + (Bradyrhizobium japonicum) and PPST 2030 (Bacillus spp. biological growth promoter). PPST 120 + and PPST 2030 were applied to the seed at 2.25 and 2.0 fl oz/100 lb seed.

The experimental unit dimensions varied by location in accordance with grower equipment, although a common approach was to complete one or two passes across an entire field with a commercial planter, which equated to one experimental unit. In addition, grower participants were asked to keep the experimental unit lengths >300 ft and to report their seeding rates verified via the readout on their planting monitor. Between V2 and R1, DuPont Pioneer technical field personnel recorded the number of plants in 10 ft of row in three random spots within each treatment. Treatments were harvested with commercial combines, and either the entire treatment was harvested or a single combine header’s width from the center of each treatment was harvested. Treatments were weighed with grain carts or seed tenders equipped with digital scales. Samples of each treatment were collected and tested for moisture with portable moisture meters, so that grain yields could be adjusted to a standard moisture of 13%.

Data were analyzed using a mixed statistical model analysis of variance in SAS via the PROC MIXED statement (SAS Institute, 2014). The dependent variables were early-season stands and grain yield. The fixed-effect class variables were planting date, cultivar maturity, and seed treatment. The random class variables were year, replicates nested within year, and planting date by replicates nested within year to form the split-plot error term. Because the treatments were not replicated at an individual location, a combined analysis was performed using locations as replicates. Tillage (some tillage or no-tillage into standing corn residue), seeding rate, and the Palmer Drought Severity Index (PDSI) were collected at each location for inclusion in the model as possible covariates. After model simplification using the Bayesian information criteria seeding rate was found to be a significant covariate ($P < 0.001$) and left in the model for the dependent variable early-season stands. For the dependent variable grain yield, PDSI ($P < 0.001$), PDSI by planting date ($P = 0.036$), PDSI by cultivar maturity ($P = 0.010$), and tillage by seed treatment ($P = 0.024$) were found to be significant covariates and left in the model.

For further exploration of the interaction between early-season stands and seed treatment, planting date was treated as a continuous predictor variable and early-season stands were regressed against planting dates. An $\alpha$ level of $P \leq 0.10$ was used for determining statistical significance of the model main effects, interaction effects, and for separating means. Means separations were performed using the PDIFF statement in SAS.

WEATHER

Because detailed meteorological information was not collected at each location, the PDSI was used to estimate the
effects of weather. In brief, the PDSI is a water balance model that uses monthly temperature and precipitation averages plus potential soil water holding capacity to compute abnormally wet or dry conditions when compared with historical norms for a given location (Alley, 1984). The seven PDSI rankings are as follows: extremely dry, severely dry, moderately dry, near normal, moderately wet, very wet, and extremely wet. Because PDSI rankings are heavily weighted on the previous month’s PDSI rankings, it is a good predictor of seasonal trends and potential soil moisture supply when new predictions are made (Mika et al., 2005). In a general sense, the growing season of 2011 was characterized by near-normal temperatures and a wetter than normal April, May, and June, followed by a dry late summer and early fall. During the 2012 growing season the southern two-thirds of Illinois and Indiana experienced a significant drought and well above normal temperatures throughout the majority of the growing season. These conditions lasted until August when near-normal temperatures and precipitation returned to the majority of the two-state region.

Figures 1 and 2 show the geographic distribution of the PDSI ranking predictions made in the last week of August for the 2011 and 2012 growing seasons as well as the geographic positions of each field location. These figures were created in ArcMap (Environmental Systems Resource Institute, 2013) by obtaining rasterized PDSI rankings from the United States Forest Service (Raymond, 2012). Despite the significant drought in 2012, the locations were well distributed across PDSI rankings. Of the combined 58 locations in 2011 and 2012, 39 were classified as moderately dry to moderately wet, 18 as severely dry or very dry, and 1 as very wet according to the PDSI rankings. While on average the locations (replications) experienced slightly dryer than normal conditions, nearly 70% were between the moderately dry to moderately wet PDSI rankings.
TREATMENT EFFECTS ON GRAIN YIELDS

Across years and locations the median early and normal planting dates occurred on 22 April and 18 May; however, these ranged from 11 April to 14 May and from 6 May to 3 June. At individual locations the planting dates differed from as few as 6 days to as many as 44, although the most frequent number of days between planting dates was 21 (Fig. 3). Across locations and years the minimum and maximum observed yields were 17 and 97 bu/acre. The lowest yielding location averaged 25 bu/acre and was located in west-central Illinois in 2012. This location normally receives 14.5 inches of rain from May through August but received only 3.5 inches during this same period in 2012. The highest yielding location occurred in 2011 in north-central Illinois. Average yield here was 89 bu/acre and was classified as moderately wet, according to the PDSI rankings.

In this study the main effect of cultivar maturity and seed treatments had a significant effect on grain yield; however, planting date did not. Full-season cultivars and seed treatments increased grain yield 3.8 and 1.2 bu/acre, respectively, relative to short-season cultivars and nontreated seed (Table 1). In addition, there was a highly significant cultivar maturity \times planting date interaction; however, there was not a planting date \times seed treatment interaction or three-way interaction between these factors. Full-season cultivars were responsive to planting date, producing 2.7 bu/acre more grain for the early planting date than for the normal planting date. Short-season cultivars had similar yield irrespective of planting date (Fig. 4). At both the early and normal planting dates full-season cultivars produced more grain than short-season cultivars, although the difference in yield between full- and short-season cultivars for the normal planting date was only 2 bu/acre compared with 5.5 bu/acre for the early planting date.
Our hypothesis was that seed treatments and full-season cultivars would be required for maximum yields for early planting dates, and that these factors may not be important to yield determination at delayed planting dates. The finding that full-season cultivars and seed treatments increased soybean yields at the early planting date agrees with our hypothesis. However, these factors were also important to yield for the normal planting date. The fact that greater yield was observed for full-season cultivars at both the early and normal planting dates is not completely unexpected given that Setiyono et al. (2007) and Robinson et al. (2009) found full-season cultivars grew longer reproductively (R1–R7) than short-season ones from planting dates as early as 27 March to as late as 7 June. In our study we observed that short-season cultivars had similar yields at both the early and normal planting dates. In Robinson et al. (2009) the shortest-season cultivar tested spent a similar amount of time in the seed-filling period irrespective of planting date, and may help explain our observations.

Table 1. Type III analysis of variance and the effect of early and normal planting, full- or short-season cultivars, and treated or nontreated seed on soybean grain yield and early-season stands at 58 on-farm locations distributed throughout Illinois and Indiana in the growing seasons of 2011 and 2012.

<table>
<thead>
<tr>
<th>Main effects</th>
<th>Grain yield</th>
<th>F value</th>
<th>Pr &gt; F</th>
<th>Early-season stand</th>
<th>F value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/acre</td>
<td></td>
<td></td>
<td>plants/acre x 1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting date (PD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>61.6</td>
<td>2.6</td>
<td>0.114</td>
<td>127.8</td>
<td>4.2</td>
<td>0.043</td>
</tr>
<tr>
<td>Normal</td>
<td>60.7</td>
<td></td>
<td></td>
<td>122.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivar maturity (CM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-season</td>
<td>63.1</td>
<td>37.0</td>
<td>&lt;0.001</td>
<td>124.3</td>
<td>2.5</td>
<td>0.108</td>
</tr>
<tr>
<td>Short-season</td>
<td>59.3</td>
<td></td>
<td></td>
<td>125.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed treatment (ST)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated</td>
<td>61.8</td>
<td>6.14</td>
<td>0.013</td>
<td>127.2</td>
<td>16.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nontreated</td>
<td>60.6</td>
<td></td>
<td></td>
<td>123.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANOVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD × CM</td>
<td>23.4</td>
<td>&lt;0.001</td>
<td></td>
<td>1.1</td>
<td>0.286</td>
<td></td>
</tr>
<tr>
<td>PD × ST</td>
<td>0.07</td>
<td>0.793</td>
<td></td>
<td>6.6</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>PD × ST × CM</td>
<td>0.2</td>
<td>0.886</td>
<td></td>
<td>0.2</td>
<td>0.599</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Distribution of the early and normal planting dates as a percentage of the 58 locations in the growing seasons of 2011 and 2012.
TREATMENT EFFECTS ON EARLY-SEASON STANDS

The average seeding rate selected by growers was 160,100 seeds per acre, ranging from 110,000 to 256,000 seeds per acre. Growers using 30- and 15-inch row planters, respectively, planted 152,800 and 158,820 seeds per acre, whereas growers using grain drills (10- to 7-inch rows) planted 197,900 seeds per acre. In this study planting date and seed treatments had a significant effect on the early-season stands; however, cultivar maturity did not affect early-season stands (Table 1). Averaged across these 58 locations, the early and normal planting dates resulted in early-season stands of 122,400 and 127,800 plants per acre, suggesting that at the average grower-selected seeding rate (160,100 seeds per acre), 37,700 and 32,300 seeds per acre failed to produce plants by mid-vegetative growth stages at the early and normal planting date. Seed treatments increased early-season stands by 4200 plants per acre when compared with nontreated seed. In addition to a significant main effect of planting date and seed treatment there was a significant planting date × seed treatment interaction. To further explore this interaction early-season stands were regressed against each planting date observation with and without seed treatments. The results revealed that seed treatments are more likely to significantly increase early-season stands at planting dates before 10 May (Fig. 5). Moreover, the difference in the early-season stands between treated and nontreated seed increased from 3580 to 8685 plants per acre between the 10 May and 10 April planting dates.

We hypothesized that seed treatments would be more effective at protecting plant stands at early planting dates than at normal planting dates, and our results support this hypothesis. Despite the fact that seed treatments did protect early-season plant stands more at early planting dates than at normal planting dates, seed treatments increased yields irrespective of planting date. Moreover, when seed treatments increased early-season stands, there was not a corresponding increase in grain yield (results not shown). Therefore, we can conclude that stand protection is not the primary mechanism by which seed treatments often increase soybean yields. De Bruin and Pedersen (2008) found that on average 99,162 plants per acre at harvest often produces 95% of maximum yield and that this harvest stand could be achieved by planting 112,325 seeds per acre. In our study, growers seeded on average 160,100 seeds per acre and our early-season stands were 117,910 plants per acre with nontreated seed and at mid-April planting dates, indicating that even under conditions where we would expect considerable stand loss, growers were planting more than enough seeds to produce close to maximum yields.

IMPLICATIONS FOR GROWERS AND RECOMMENDATIONS FOR FUTURE WORK

This study indicates that full-season cultivars achieve maximum yield potential when planted in late April to early May, and that full-season cultivars in general may yield more than short-season cultivars at planting dates.
through at least mid-May. This finding, and the fact that short-season cultivars had no yield penalty for delayed planting in this study, suggest full-season cultivars should be planted before short-season ones, although this does tend to go against the strategy of using different maturities to spread harvest out over time. Sound management, however, would not include planting excessively long maturing cultivars relative to the latitude of production (i.e., not adapted for the area). The cultivars used in this study were well-adapted full-season cultivars, meaning they had been thoroughly tested by DuPont Pioneer to be sold and grown on many commercial acres in these regions.

The combination of seed treatments used in this study (fungicide + insecticide + rhizobia inoculant) are likely to increase grain yields, and the decision to use seed treatments can be made independent of planting date or cultivar maturity. For planting dates in April and early May, seed treatments are also likely to increase early-season plant stands; however, the grower-selected seeding rates (160,100 plants per acre on average) used in this study resulted in a sufficient number of plants to produce close to maximum yields without the need for added stand protection from seed treatments.

This study adds significantly to our current understanding of planting date and cultivar maturities effect on determining soybean grain yield; however, the physiological mechanisms associated with the increased yields observed with full-season cultivars and the lack of response to planting date for short-season cultivars are still not clear. Because only full- and short-season cultivars were used in this study, we do not know if full-season cultivars are more responsive to early planting dates than midmaturity cultivars, and it is also unclear at what point shorter-season cultivars do not respond to early planting. Future studies using a comprehensive range in cultivar maturities are thus needed to resolve these questions.

Acknowledgments
The authors would like to thank the many DuPont Pioneer technical field personnel, DuPont Pioneer independent sales representatives, and volunteer grower participants who generously volunteered their time to implement these experiments.

References

Figure 5. Early-season stand (V2 to R1) for treated or nontreated soybean seed regressed against planting dates (early-season stand × seed treatment Pr > F 0.084) from 11 April to 3 June at 58 on-farm locations distributed throughout Illinois and Indiana in the growing seasons of 2011 and 2012. Early-season stands between treated and nontreated seed left (10 May or earlier planting dates) of the vertical red line are different at an α level of P ≤ 0.10.


