Published December 11, 2015

RESEARCH

Effect of Planting Date and Starter Fertilizer on Soybean Grain Yield

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Abstract

In the Midwest, soybean [*Glycine max* (L.) Merrill] is planted over a large window of time. Starter fertilizer may be beneficial at earlier planting dates when cool soils limit nutrient availability or at later planting dates when the growing season is shortened. The objective was to evaluate the effect of planting date and starter fertilizer on soybean nodulation, biomass, canopy closure, grain yield, and grain quality in high-yielding environments. A trial was conducted at the Western Agricultural Research Station (WARS) in 2013 and 2014 and the Northwest Agricultural Research Station (NWARS) in 2014. Treatments included three to four planting dates ranging from May through early July and five starter fertilizers (none, urea, triple superphosphate, urea + triple superphosphate, and diammonium phosphate) applied 2 inches below and 2 inches beside the seed at planting. Starter fertilizer had a very small effect on soybean nodulation, biomass, canopy closure, and grain quality. In 2013 and 2014 at the WARS location, yield decreased an average of 0.58 bu/acre per day from the first to last planting date. Fertilizer did not increase soybean yield at any of the site-years. All sites had soil phosphorus (P) levels greater than the critical level of 15 ppm. At soil P levels >15 ppm, a yield response to fertilizer is unlikely. Nitrogen fixation and mineralization were adequate to meet the crop demand. Planting in early May without starter fertilizer provides the greatest chance to consistently maximize soybean yield and profitability when N and P are not limiting.

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Abbreviations: DAP, diammonium phosphate; NWARS, Northwest Agricultural Research Station; TSP, triple super phosphate; WARS, Western Agricultural Research Station.

Published in Crop, Forage & Turfgrass Management
DOI: 10.2134/cftm2015.0178

PREVIOUSLY CONDUCTED SOYBEAN STARTER FERTILIZER STUDIES

Starter fertilizer use is uncommon in soybean production due to equipment limitations (i.e., difficulty applying starter fertilizer with a grain drill). However, starter fertilizer may be beneficial at early planting dates when the soil is often cool, which limits biological nitrogen (N) fixation and N mineralization (Agehara and Warncke, 2005; Osborne and Ridell, 2006; Stanford and Epstein, 1974). Starter fertilizer may also be

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
2.54	inch	centimeter, cm (10^{-2} m)
0.405	acre	hectare, ha
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
1	milliequivalents per 100 grams, meq/100 g	centimole per kilogram, cmol/kg (ion exchange capacity)
1	parts per million, ppm	milligram per kilogram, mg/kg

beneficial when soybeans are planted late, where yield is limited by reduced light interception due to lack of canopy closure (Beuerlein and Dorrance, 2005; Bhatia et al., 1999; Steele and Grabau, 1997). Nitrogen and phosphorus (P) starter fertilizer may improve soybean yield due to increased vegetative growth when soils are cool and N is limited (early planting) or when the growing season is short (late planting) (Egli and Cornelius, 2009; Starling et al., 1998; Taylor et al., 2005; Vitosh et al., 1995).

Most starter fertilizer studies on soybean have been conducted in the southern Coastal Plain (Starling et al., 1998; Taylor et al., 2005; Touchton and Rickerl, 1986) and northern Great Plains (Osborne and Ridell, 2006). In the southern Coastal Plain, starter N has been found to increase soybean yield by an average of 2.2 bu/acre (Starling et al., 1998). Taylor et al. (2005) recommended 53 to 63 lb N/acre to maximize soybean grain yield in late-planted soybean in the southern Coastal Plain. Additionally, in the southern Coastal Plain, starter fertilizer containing N, P, and potassium (K) increased soybean yield by 26% when residual P and K were high (Touchton and Rickerl, 1986). In the northern Great Plains, soybean grain yield was increased in two out of three years with the addition of starter N fertilizer (Osborne and Ridell, 2006). There is limited research examining the effect of starter fertilizer in high-yielding environments in the midwestern United States. The objective of this study was to evaluate the effect of planting date and starter fertilizer on soybean nodulation, biomass, canopy closure, grain yield, and grain quality.

EVALUATING SOYBEAN PLANTING DATE AND STARTER FERTILIZER

In 2013, a trial was conducted at the Western Agricultural Research Station (WARS) near South Charleston, OH. In 2014, the trial was repeated at the WARS location and an additional trial was established at the Northwest Agricultural Research Station (NWARS) near Custar, OH. At WARS, the trial was in a different field each year, but the soil series in both years was Kokomo silty clay loam (fine, mixed, superactive, mesic Typic Argiaquoll). At the NWARS location, soil was Hoytville clay loam (fine, illitic, mesic Mollic Epiaqualf). At all three site-years, the previous crop was corn (*Zea mays* L.). The WARS locations were minimally tilled in the fall, and the NWARS location was minimally tilled in the fall and the spring.

Table 1. Target planting date, actual planting date, and harvest date for soybean at the Western Agricultural Research Station (WARS) and Northwest Agricultural Research Station (NWARS) in 2013 and 2014.

Site-year	Target planting date	Actual planting date	Soil temperature at planting†	Harvest date
			°F	
WARS 2013	Before 1 May	1 May	59.0	25 Sept.
	1 May to 31 May	20 May	68.3	1 Oct.
	1 June to 30 June	12 June	73.4	14 Oct.
	After 30 June	2 July	73.0	6 Nov.
WARS 2014	Before 1 May	21 May	64.0	2 Oct.
	1 May to 31 May	3 June	72.9	3 Nov.
	1 June to 30 June	16 June	73.0	3 Nov.
	After 30 June	1 July	77.3	3 Nov.
NWARS 2014	Before 1 May	8 May	61.7	25 Sept.
	1 May to 31 May	27 May	71.7	27 Oct.
	1 June to 30 June	18 June	76.3	27 Oct.

† Average soil temperature at 2-inch depth recorded at each location by the Ohio Agriculture and Research Development Center Weather System.

The study was a split-plot, randomized complete block design with four replications of treatments. The main plot factor was target planting dates of April, May, June, and July, which are representative of the earliest through the latest planting dates for soybean production in Ohio (Beuerlein and Dorrance, 2005). Actual planting and harvest dates for each site are in Table 1. Due to excessive rainfall in both 2013 and 2014, April plantings at all sites were delayed until May. In 2014, a July planting at NWARS was not pursued due to the shorter growing season of the region. The subplot factor consisted of five starter fertilizer treatments: none, urea, triple super phosphate (TSP), urea + TSP, and diammonium phosphate (DAP). Urea was applied at 30 lb N/acre, TSP was applied at 40 lb P_2O_5/acre, and DAP was applied at 40 lb P_2O_5/acre and 16 lb N/acre.

Before planting, soil samples were collected at each site-year (Table 2). A minimum of 10 soil cores were collected to a depth of 8 inches and combined to form a composite sample. A John Deere planter was used at

Table 2. Initial soil test levels before planting soybean at the Western Agricultural Research Station (WARS) in 2013 and 2014 and the Northwest Agricultural Research Station (NWARS) in 2014.

	Site-year		
Soil property	WARS 2013	WARS 2014	NWARS 2014
pH	6.3	6.2	6.3
Organic matter (%)	4.0	4.5	3.6
CEC† (meq/100 g)	16.9	22.2	19.0
P (ppm)	33	38	84
K (ppm)	111	177	196
Ca (ppm)	2100	2650	2300
Mg (ppm)	450	580	405

† CEC, cation exchange capacity.

both locations to plant soybean at 145,000 seeds/acre at a depth of 1.5 inches. 'Asgrow 3231' (3.2 relative maturity) soybean seed was planted and was treated with Acceleron (active ingredients: pyraclostrobin, metalaxyl, fluxapyroxad, and imidacloprid). Each plot was 10 ft by 40 ft and consisted of four 30-inch rows. Starter fertilizer treatments were applied in a band 2 inches beside and 2 inches below the seed at planting. Appropriate preemergence and postemergence herbicides were applied to control weeds, and any weeds not controlled chemically were removed by hand. The center two rows from each plot were harvested with a plot combine, and reported yield was adjusted to 13.0% moisture content. A subsample of grain was collected from each plot at harvest and analyzed for protein and oil content. Analysis was determined by near-infrared transmittance technology using a Tecator Infratec whole grain analyzer (Foss, Eden Prairie, MN). Protein and oil content is reported as a percentage at 13.0% grain moisture content.

Soil temperature at a 2-inch depth was obtained from the Ohio Agricultural Research and Development Center weather stations located at WARS and NWARS. Biomass measurements were collected at the V2 (two unrolled trifoliolates) and R1 (initial flowering) growth stages. Nodulation measurements were conducted at the V2 (two unrolled trifoliolates) growth stage. Five consecutive plants from each plot were chosen at random and dug from the nonharvest rows. Excess soil was removed from the root mass, and the number of nodules on each plant was counted and recorded. Roots were separated from the shoots at ground level, and both were placed in an oven at 140°F for at least 48 h and biomass was subsequently determined.

Percent canopy closure was determined by measuring light interception with a LI-250A Light Meter (LI-COR, Lincoln, NE). In each plot, one reading was taken above the soybean canopy followed by three readings taken below the soybean canopy. The three below-canopy readings were averaged. Percent canopy closure for each plot was determined by dividing the average below-canopy readings by the above-canopy reading and multiplying by 100. A quadratic model was fit to the biweekly canopy closure measurements to determine the number of days from planting to reach 90% canopy closure.

Analysis of variance was conducted for soybean nodulation, root and shoot biomass, canopy closure, grain yield, and grain quality at each site-year using the PROC MIXED procedure in SAS 9.3 (SAS Institute, 2011). Planting date and starter fertilizer were treated as fixed effects and replication was treated as a random effect. Means were separated using LSD at $\alpha \leq 0.10$. Regression analysis was conducted using the PROC REG procedure to estimate daily yield reductions associated with planting date.

EFFECT OF PLANTING DATE ON SOYBEAN GRAIN YIELD

Soybean planting date influenced soybean yield at all three site-years (Table 3). At the WARS location in 2013 and 2014, soybean yield decreased with each planting date (Table 4). Soybean yield was reduced by 0.57 and 0.59 bu/acre per day after the first planting date at the WARS location in 2013 and 2014, respectively (Fig. 1). Soybeans were not able to be planted in April due to wet weather. Growers should be cautious of planting too early when the soil is cool and wet due to increased seedling disease and susceptibility to insect pests (Hamman et al., 2002; Witkowski and Echtenkamp, 1996).

At the NWARS location in 2014, grain yield was greatest when soybeans were planted on 8 May and 18 June and lowest when planting on 27 May (Table 4). However, yield was only reduced by 7% between the high-yielding planting date and the lowest-yielding planting date. In 2014, precipitation at the NWARS location was approximately 50% below normal in May, July, and August (data not shown), which likely contributed to the overall lower yielding conditions at NWARS and lack of per-day yield reductions (Fig. 1).

EFFECT OF STARTER FERTILIZER ON SOYBEAN NODULATION, BIOMASS, CANOPY CLOSURE, AND YIELD

Starter fertilizer influenced the number of nodules per root at the WARS 2013 and NWARS 2014 locations (Table 3). Although starter fertilizer influenced the number of nodules per root at the WARS 2013 location, none of the starter fertilizers resulted in a different number of nodules compared with the control (no fertilizer) treatment (Table 5). At the NWARS 2014 location, the number of nodules/root was reduced when urea was applied compared with the control. The other fertilizer treatments were not statistically different from the control treatment. Overall, differences in the number of nodules per plant were quite small among the starter fertilizers and may not be biologically significant. Other studies have found N fertilizer reduces the number of nodules per plant (Streeter and Wong, 1988). However, nodulation of leguminous plants is more sensitive to N in the

Table 3. Analysis of variance for the fixed effects of soybean planting date, fertilizer, and planting date × fertilizer interaction at the Western Agricultural Research Station (WARS) in 2013 and 2014 and the Northwest Agricultural Research Station (NWARS) in 2014 (α = 0.10).

Source	Number of nodules at V2	Root biomass at V2	Shoot biomass at V2	Days from planting to 90% canopy closure	Grain yield	Grain protein	Grain oil
WARS 2013							
Date (D)	<0.0001	<0.0001	0.0054	<0.0001	<0.0001	<0.0001	<0.0001
Fertilizer (F)	0.0337	0.3915	0.0592	0.9920	0.1454	0.7710	0.7509
D × F	0.3390	0.1794	0.6231	0.9611	0.6849	0.8737	0.4131
WARS 2014							
Date (D)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fertilizer (F)	0.5943	0.5776	0.4219	0.4761	0.3462	0.8260	0.7772
D × F	0.1235	0.8826	0.8348	0.8473	0.2388	0.9256	0.9378
NWARS 2014							
Date (D)	0.0845	<0.0001	<0.0001	0.3544	0.0019	0.0134	<0.0001
Fertilizer (F)	0.0002	0.6128	0.0066	0.4254	0.9998	0.0314	0.0884
D × F	0.2001	0.9163	0.4266	0.3641	0.9479	0.6234	0.7346

Table 4. Average number of nodules per soybean root, root and shoot biomass at the V2 growth stage (two unrolled trifoliolates), days to 90% canopy closure, grain yield, and grain quality by the main effect of planting date at the Western Agricultural Research Station (WARS) in 2013 and 2014 and the Northwest Agricultural Research Station (NWARS) in 2014.

Planting date	Average no. of nodules/root	Root biomass at V2	Shoot biomass at V2	Days from planting to 90% canopy closure	Grain yield	Grain protein	Grain oil
		——— oz ———			bu/acre	——— % ———	
WARS 2013							
1 May	25.1 b[†]	0.0235 a	0.0573 a	72.9 a	94.4 a	34.5 b	18.3 a
20 May	29.7 a	0.0234 a	0.0558 ab	66.0 b	82.8 b	35.2 a	18.2 a
12 June	14.5 c	0.0202 b	0.0518 b	56.5 c	67.6 c	35.2 a	17.9 b
2 July	16.4 c	0.0142 c	0.0464 c	52.4 d	58.5 d	35.0 b	17.3 c
WARS 2014							
21 May	9.7 b	0.0067 b	0.0140 c	57.3 a	70.1 a	35.8 b	18.3 a
3 June	21.2 a	0.0137 a	0.0284 b	44.7 c	64.7 b	36.2 a	18.2 a
16 June	23.0 a	0.0143 a	0.0424 a	41.4 d	60.9 c	36.2 a	17.9 b
1 July	10.7 b	0.0054 c	0.0160 c	49.4 b	45.5 d	35.6 c	17.3 c
NWARS 2014							
8 May	19.8 b	0.0092 b	0.0144 b	67.4 a	54.3 a	34.3 a	18.2 a
27 May	20.5 b	0.0056 c	0.0186 a	69.2 a	51.9 b	34.0 b	18.3 a
18 June	22.7 a	0.0120 a	0.0183 a	66.8 a	55.5 a	34.4 a	17.5 b

[†] Values followed by different letters are significantly different at the $P \leq 0.05$ level.

form of nitrate than to ammonium and urea (Ralston and Imsande, 1983; Silsbury et al., 1986).

Root biomass at the V2 growth stage was not influenced by starter fertilizer (Table 3). Shoot biomass at the V2 growth stage was influenced by starter fertilizer at the WARS 2013 and NWARS 2014 locations. At the WARS 2013 location, DAP fertilizer resulted in a greater shoot biomass compared with the control (Table 5). The other fertilizer treatments were not different from the control treatment. At the NWARS 2014 location, when urea, urea + TSP, and DAP were applied, shoot biomass was greater than the nonfertilized treatment. Phosphorus fertilizer has been found to increase shoot biomass of soybean while P deficiency symptoms include a reduction in leaf expansion and leaf surface area (Borkert and Barber, 1984). Despite some early-season differences, there was no difference in R1 root and shoot biomass among the starter fertilizer treatments (data not shown).

Grain quality was influenced by the main effect of starter fertilizer at the NWARS location (Table 3). At the NWARS location, grain protein was 0.4% greater when urea was used as a starter fertilizer than the control treatment (Table 5). Grain oil content was reduced by 0.1 to 0.2% with applications of urea, TSP, and DAP

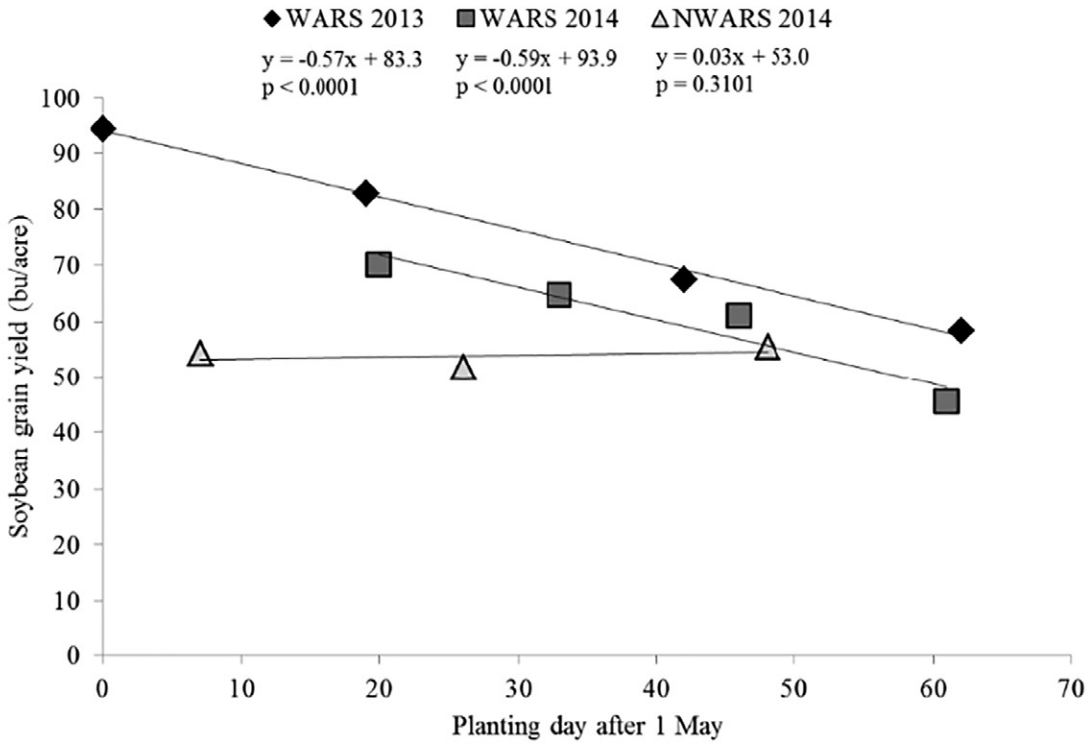

Figure 1. Linear regression analysis for soybean grain yield by planting day after 1 May (i.e., Day 35 = 5 June) at the Western Agricultural Research Station (WARS) in 2013 and 2014 and the Northwest Agricultural Research Station (NWARS) in 2014.

Table 5. Average number of nodules per soybean root, root and shoot biomass at the V2 growth stage (two unrolled trifoliolates), days to 90% canopy closure, grain yield, and grain quality by the main effect of starter fertilizer at the Western Agricultural Research Station (WARS) in 2013 and 2014 and the Northwest Agricultural Research Station (NWARS) in 2014.

Fertilizer†	Avg. no. of nodules/root	Root biomass at V2	Shoot biomass at V2	Days from planting to 90% canopy closure	Grain yield	Grain protein	Grain oil
		oz			bu/acre	%	
WARS 2013							
None	22.1 ab‡	0.0196 a	0.0482 b	62.1 a	73.6 a	35.0 a	17.9 a
Urea	18.8 b	0.0199 a	0.0535 ab	62.1 a	76.1 a	35.0 a	17.9 a
TSP	24.3 a	0.0202 a	0.0514 b	61.6 a	77.2 a	35.0 a	17.9 a
Urea + TSP	18.7 b	0.0203 a	0.0520 b	61.9 a	74.8 a	34.9 a	17.9 a
DAP	23.1 a	0.0216 a	0.0589 a	62.1 a	77.2 a	35.0 a	17.9 a
WARS 2014							
None	16.5 a	0.0099 a	0.0239 a	49.6 a	58.0 a	35.9 a	16.8 a
Urea	15.3 a	0.0103 a	0.0265 a	46.9 a	59.5 a	36.0 a	16.8 a
TSP	17.5 a	0.0096 a	0.0247 a	47.7 a	60.1 a	36.0 a	16.8 a
Urea + TSP	16.5 a	0.0105 a	0.0247 a	47.9 a	61.8 a	36.0 a	16.7 a
DAP	15.0 a	0.0098 a	0.0266 a	48.8 a	62.1 a	35.9 a	16.8 a
NWARS 2014							
None	23.0 ab	0.0088 a	0.0154 b	69.7 a	54.0 a	34.1 bc	18.1 a
Urea	16.2 c	0.0087 a	0.0184 a	67.7 a	53.9 a	34.5 a	17.9 b
TSP	24.8 a	0.0092 a	0.0155 b	67.8 a	53.8 a	34.3 ab	18.0 b
Urea + TSP	20.5 b	0.0095 a	0.0180 a	65.3 a	53.8 a	33.9 c	18.1 a
DAP	20.7 b	0.0090 a	0.0181 a	68.3 a	53.9 a	34.4 ab	17.9 b

† Urea and triple super phosphate (TSP) were applied at 30 lb N/acre and 40 lb P_2O_5/acre, respectively. Diammonium phosphate (DAP) was applied at 40 lb P_2O_5/acre and 16 lb N/acre.

‡ Values followed by different letters are significantly different at the $P \leq 0.05$ level.

compared with the control treatment. Starter fertilizer did not influence grain quality at the WARS location.

Although there were some differences in the number of nodules/root and shoot biomass at the V2 growth stage among the starter fertilizer treatments, soybean grain yield was not influenced by starter fertilizer (Table 3). Canopy closure and yield were the same regardless of starter fertilizer treatment at all three site-years (Table 5). The soil P level at all three site-years was >15 ppm, which is the established P critical level for Ohio (Vitosh et al., 1995). If the soil P levels were <15 ppm, a yield response to P starter fertilizer would have been much more likely to occur. In previously conducted studies, yield response to N application in soybean was variable and generally occurred under high-yielding conditions when biological N fixation and soil residual N does not supply sufficient N to meet crop demand (Salvagiotti et al., 2008). Soil organic matter was 3.6 to 4.0% for the three site-years, which may have resulted in sufficient N mineralization to meet crop demand causing the lack of yield response to starter N fertilizer (Sawyer et al., 2006). At the WARS 2013 location, soybean yield was 94 bu/acre when planted on 1 May; however, starter N fertilizer did not increase soybean yield, indicating that biological N fixation and soil residual N supplied were adequate.

IMPLICATIONS OF USING STARTER FERTILIZER IN SOYBEAN PRODUCTION

In this three-site-year study, starter fertilizer did not increase soybean grain yield, and there was no planting date × starter fertilizer interaction. Each site-year had soil P levels greater than the critical level of 15 ppm. The WARS location in 2013 yielded 94 bu/acre when soybeans were planted on 1 May (Table 4); however, even at high yields, there was no yield response to starter N or P fertilizer. Soybean yield decreased by 0.57 and 0.59 bu/acre per day when soybeans were planted after the first planting date at the WARS location in 2013 and 2014, respectively (Fig. 1). Grain protein and oil were slightly influenced by starter fertilizer at one out of three site-years. Timely planting is much more important to maximizing soybean yield than the use of starter fertilizer, which had no yield benefit when soil P levels were adequate according to state fertility guidelines. Starter N fertilizer is not likely to increase soybean yield when biological N fixation and soil residual N is adequate.

Acknowledgments

The authors thank Ohio Soybean Council for funding this study as well as Monsanto for donating the soybean seed. Salary and research provided in part by state and federal funds appropriated to the Ohio Agricultural Research and Development Center and The Ohio State University. Thanks are extended for field assistance from JD Bethel, Chris Kroon Van Diest, John McCormick, Joe Davlin, Matt Davis, Grace Bluck, Aaron Brooker, Stephanie Verhoff, and Sin Joe Ng.

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