CROP EMERGENCE WITH ALTERNATIVE SDI DESIGNS IN A PULLMAN CLAY LOAM SOIL

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ABSTRACT

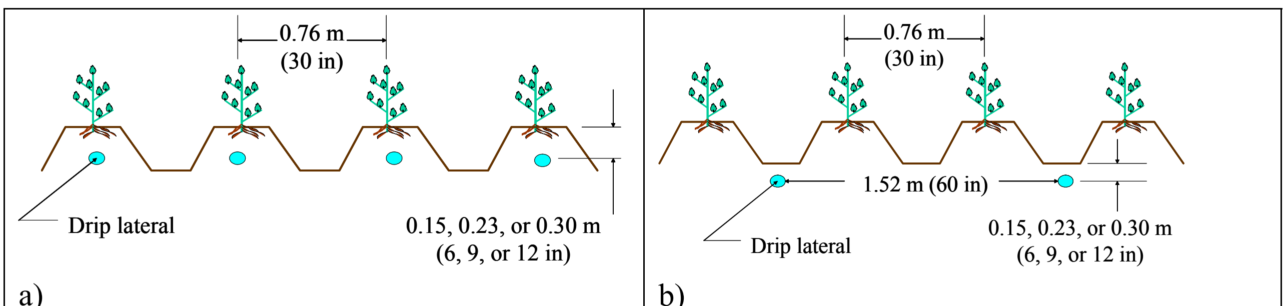
Subsurface drip irrigation (SDI) is gaining popularity with producers in the Southern and Central Great Plains region of the United States. Drip laterals are commonly installed in alternate furrows because it is cost prohibitive to install laterals in every bed for low value crops; however, crop germination can be difficult if preseason precipitation is inadequate. We evaluated soybean emergence and grain yield with laterals installed in wide beds containing two seed rows and compared this to laterals installed in alternate furrows and in every bed. The wide bed design requires the same number of laterals as the alternate furrow design, but the seed row is closer to the lateral. For each bed design, lateral burial depth was 6-, 9-, and 12-in., and irrigation amounts were 33, 66, and 100% of full crop evapotranspiration (ETc). The wide bed design generally resulted in greater plant emergence early in the season than standard beds; however, bed design and lateral installation depth did not usually result in significant differences in final grain yield. This implied that for sparser plant populations, greater water and nutrient availability per plant may have been compensating factors for final yield. This paper reports data for a single soybean crop season, and this experiment will continue for additional seasons and different crops.

INTRODUCTION

Subsurface drip irrigation (SDI) is seeing increased adoption by producers in the Texas High Plains, notably in the cotton producing area around Lubbock where water resources (mainly irrigation wells) are extremely limited. Among farmers, there is a general premise that SDI results in greater crop yields, greater water use efficiency, better cotton fiber quality, and enhanced crop earliness relative to other types of irrigation systems, and this is thought to be related to reduced evaporative cooling and the ability to maintain warmer soil temperatures during crop establishment. Colaizzi et al. (2004; 2005) found that SDI resulted in greater crop yield than LEPA or spray irrigation at small irrigation amounts (i.e, ≤ 50% or less of full crop ET) for grain sorghum and cotton, and preliminary data reported by Colaizzi et al. (2006) indicated that SDI resulted in greater near-surface soil temperatures than LEPA or spray for a Pullman clay loam soil in Bushland, TX. For some producers, these factors have justified the much greater cost, maintenance, and management requirements inherent in SDI. Producers using SDI also face potential difficulties in crop germination for most High Plains soils if precipitation is inadequate prior to planting. Although SDI represents less than 1% of the 4.0 million acres irrigated area in the Texas High Plains as of 2000 (TWDB, 2001), the recent northward expansion of cotton into areas where corn was traditionally produced, but which are thermally-limited for cotton, may stimulate additional adoption of SDI.

Drip laterals comprise two-thirds or more of the SDI system installation costs when laterals are installed beneath each planted row (Fig. 1a). For lower value row crops such as cotton and corn, drip laterals are commonly installed in alternate furrows (Fig. 1b), which can reduce initial capital costs by 30-40% as well as the frequency of repairs due to mechanical or animal damage (Henggeler, 1995; Camp et al., 1997; Enciso et al., 2005). The alternate-furrow installation, however, requires the wetting front to travel much further from the lateral to the seed bed. This poses considerable risk for crop establishment if the near-surface soil profile is dry and if soil conditions are unfavorable for the horizontal or upward movement of water, such as in the presence of cracks (Howell et al., 1997; Bordovsky and Porter, 2003), soil compaction (Enciso et al., 2005), or relatively low capillary potential (Thorburn et al., 2003). Dry soil conditions at planting have been increasingly common in recent years due to widespread drought throughout much of the Central and Western US, and excessive irrigation water is sometimes required to germinate crops using SDI, especially for cracking soils commonly found in the Texas High Plains, defeating the purpose of SDI.

The wide bed, or twin row design (Fig 1c) has been used successfully in the Southeastern U.S. for corn (Phene, 1974; Phene and Beale, 1979), in Israel for cotton (Oron, 1984), and by producers in Arizona for numerous crops. This design has the same number of SDI laterals and plant rows per unit area as standard beds with laterals in alternate furrows (Fig. 1b), but the seed bed is much closer to the lateral, motivating the hypothesis that better crop establishment and yield would result. The objective of this research was to compare crop emergence and final yield for the alternative SDI designs shown in Fig. 1 for three lateral installation depths (6, 9, and 12 in.).



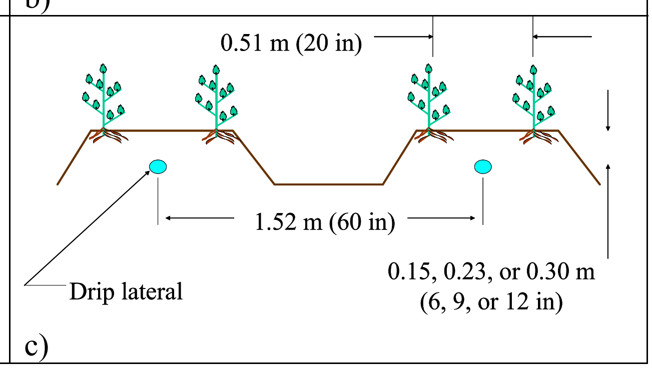


Figure 1. SDI bed and lateral spacing and installation depths, a) laterals in each bed with 30-in. spacing; b) laterals in alternate furrows with 60-in. spacing; c) wide bed (twin row) with laterals centered in each bed with 60-in. spacing.

MATERIALS AND METHODS

The experiment was conducted in 2005 at the USDA Conservation and Production Research Laboratory at Bushland, Texas (35° 11′ N lat., 102° 06′ W long., 3,510 ft elevation MSL). The climate is semi-arid with a high evaporative demand of about 102 in. per year (Class A pan evaporation) and low precipitation averaging 18 in. per year. Most of the evaporative demand and precipitation occur during the growing season (May to October) and average 61 and 13 in., respectively. The climate is also characterized by strong regional advection from the south and southwest, with average daily wind runs at 6-ft height exceeding 280 mi, especially during the early part of the growing season. The soil is a Pullman clay loam (fine, superactive, mixed, thermic torrertic Paleustoll; USDA-NRCS, 2005), with slow permeability due to a dense B21t layer that is 6- to 15-in. below the surface. A calcic horizon begins about 47 in. below the surface.

A subsurface drip irrigation (SDI) system was installed at the study location with east-west oriented raised beds in a randomized complete block design replicated three times with subplots. Main plot factors consisted of the irrigation treatment (I0, I33, I66, and I100) and bed design (Fig. 1), and the subplot factor was the SDI lateral installation depth (6-, 9-, and 12-in. below the soil surface). The I100 irrigation treatment was sufficient to prevent yield-limiting soil water deficits from developing, and was based on soil water measurements with neutron scattering to the 8-ft depth. Integer values in treatment codes (i.e., I0, I33, I66) indicate the percentage of irrigation applied relative to full (I100) irrigation. From planting to the vegetative growth stage, irrigation water was applied when soil water measurements indicated a deficit of 1 in. less than field capacity over the 5-ft deep root zone in the I100 treatment, after which the appropriate irrigation amount was applied on a weekly basis to replenish soil water to field capacity. The different irrigation treatments were used to estimate production functions, and to simulate the range of irrigation capacities typical in the Texas High Plains. The I0 treatment received only sufficient irrigation to ensure crop emergence. The bed designs included SDI laterals in alternate furrows (Fig. 1b) and wide beds (Fig. 1c) for the I33, I66, and I100 treatments. The design with laterals installed in every bed (Fig. 1a) was used for the I0 plots. This design was also used for three additional plots along the south boundary of the field, which were irrigated identically to the I100 treatment but were outside the randomized complete block design. SDI laterals (commonly termed “drip tape”) were Netafim model Typhoon 990[1], 13 mil thickness, with 0.25-gal hr^{-1} emitters spaced 12-in. apart (24-in. apart for laterals in every bed), resulting in an application rate of 0.08 in. hr^{-1} (35 gal min^{-1} ac^{-1}) for all plots. Irrigation treatments were therefore imposed by varying the duration of each irrigation event. Main plots were 285-ft long and were divided into three 85-ft-long subplots along the row direction, separated by a 15-ft transition area to change the SDI lateral installation depth. Each plot had 12 rows for the standard bed design (Figs 1a and 1b, 30-in. bed centers) and 6 rows for the wide bed design (Fig. 1c, 60-in. bed centers).

Agronomic practices were similar to those in the Texas High Plains for irrigated corn and soybean production (Table 1). Preplant herbicide (Laymaster) was applied at 1 qt ac^{-1} on 14 April, and corn (*Zea mays L.*, cv. Pioneer 33B54) was planted on May 11, 2005 at 34,000 plants per acre, but was destroyed by two severe hail storms on 10-11 June. Liquid nitrogen (32-0-0) was injected into the subsurface drip irrigation (SDI) system and totaled 60 lbs ac^{-1} for all plots when the hail storms occurred. The hail-damaged corn was removed 20 June, and the field was replanted in soybeans (*Glycine max* cv. Pioneer 94M90) on 22 June at 180,000 plants per acre. No other chemicals or fertilizer were applied for the remainder of the season.

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[1]The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by the USDA-Agricultural Research Service.

Table 1. Agronomic and irrigation parameters for 2005 corn and soybean season.

Corn Planting Date	5/11/05		
Corn Variety	Pioneer 33B54		
Plant Density	34,000	Plants ac^{-1}	
Nitrogen	60.0	lbs ac^{-1}	
Herbicide (Laymaster)	1.0	qt ac^{-1}	
Hail Storms	6/10-6/11/05		
Corn Removed	6/20/05		
In-season rain (corn)		4.5	in.
In-season irrigation (corn)	I0	1.3	in.
	I33	2.2	in.
	I66	2.8	in.
	I100	3.6	in.
Soybean Planting Date	6/22/05		
Soybean Variety	Pioneer 94M90		
Plant Density	180,000	Plants ac^{-1}	
Harvest Date	10/26/05		
In-season rain (soybeans)		5.5	in.
In-season irrigation (soybeans)	I0	0.0	in.
	I33	3.1	in.
	I66	6.4	in.
	I100	9.3	in.

The number of plants emerged were counted at four locations in each subplot (rows 3, 4, 9, and 10 in a 39-in. distance) on 29 June, 5 July, 14 July, and 21 July. Volumetric soil water was measured in the top 6-in. soil layer at the same time and location of the plant emergence counts using a portable Time-Domain Reflectometry (TDR) system (Evett et al., 2005). Soil water was also measured on a weekly basis in the 8-ft profile using a Campbell Pacific Nuclear (Martinez, CA) model 503DR neutron moisture meter, but only in subplots with the 9-in. lateral installation. The neutron moisture meter was calibrated according to procedures described by Evett and Steiner (1995), and a depth control stand was used for calibration, measurement, and standard counts (Evett, 2003). The depth control stand was required to achieve a calibrated accuracy of ≤ 0.01 ft^3 ft^{-3}, which included the top 4-in. soil layer (Hignett and Evett, 2002). The profile measurements were used to compute seasonal water use (irrigation + rainfall + change in soil water) and to verify that irrigation was sufficient so that no water deficits developed in the I100 treatment. Plants were harvested by hand in two 21.5-ft^2 areas of each subplot (rows 3-4 and 9-10) on 17 Oct to determine grain yield, seed weight, harvest index, plant height, and plant density; the remainder of the field was harvested by machine on 26 Oct.

Plant emergence at 13 and 29 days after planting (DAP) (5 and 21 July, repsectively) and grain yield were tested for differences for each bed design and lateral depth using the SAS mixed model (PROC MIXED, Littell et al., 1996). In PROC MIXED, fixed and random effects are specified separately. Fixed effects were bed design, irrigation treatment, and lateral depth. Random effects were block replicates, block by bed design, block by irrigation treatment, and block by bed design by irrigation treatment. Differences of fixed effects were tested using least square means ($\alpha \leq 0.05$) within each irrigation treatment (i.e., the level slice option was used for irrigation treatment). The PROC MIXED procedure was also used to test for differences in grain yield, seasonal water use, water use efficiency (WUE), and irrigation water use efficiency (IWUE) among bed designs and irrigation treatments for each subplot with the 9-in. lateral depth (since available resources restricted soil water profile measurement to these subplots only). Here, WUE was defined as the ratio of grain yield (GY) to seasonal water use (WU) or WUE = GY WU^{-1}. IWUE was defined as the increase in irrigated yield (Y_i) over dryland yield (Y_d) due to irrigation (IR), or IWUE = $(Y_i - Y_d)\ IR^{-1}$ (Bos, 1980).

RESULTS AND DISCUSSION

The number of plants emerged at 13 and 29 days after planting (DAP) were compared for each lateral installation depth and bed design among irrigation treatments (Table 2; Fig. 2). For the I33 and I66 irrigation treatments at 13 DAP, the wide bed design (WIDE) resulted in significantly greater emergence than standard beds with laterals in alternate furrows (STD-af) at the 9- and 12-in. lateral depths, and numerically greater emergence than standard beds with 6-in. laterals. For the I100 treatment at 13 DAP, the wide beds resulted in significantly greater emergence than the standard beds with 12-in. lateral depths, although emergence for the standard bed 6-in. lateral depth was largest at 3.9 plant ft^{-1}. Trends were similar by 29 DAP, but differences tended to be more numerical. The I100 treatment with laterals in every bed (I100, STD-eb) resulted in the greatest emergence for both 13 and 29 DAP; however, these plots were not randomized and so could not be compared on a statistical basis. Furthermore, producers in the Texas High Plains perceive it cost prohibitive to install laterals in every bed at 30-in. centers for most low-value crops, despite the obvious advantages in plant emergence (Enciso et al., 2005). As expected for standard beds, the 6-in. lateral depth resulted in greater emergence than deeper laterals for all irrigation treatments, but we experienced much greater mechanical and rodent damage with this shallow lateral depth. For the wide bed design by 29 DAP, emergence was slightly greater for the 9-in. lateral depth than the 6- or 12-in. depths for all irrigation treatments (Fig. 2b), which may reflect a tradeoff between providing adequate water without excessive seed bed cooling. We have not completed the analysis of the near-surface soil water measurements using the portable Time Domain Reflectometry (TDR) system. We may see a greater emergence response during the 2006 growing season as conditions have been extremely dry since the end of the 2005 season.

Final grain yield was compared for each lateral installation depth and bed design among irrigation treatments in a manner similar to plant emergence (Table 2, Fig. 3). Grain yield was not as responsive to the bed design or lateral depth factors as plant emergence. Yield differences were numerical among all irrigation treatments except for I33, where yield for the wide bed with a 9-in. lateral depth (28.8 bu ac^{-1}) was significantly less than that for the wide bed with the 12-in. lateral depth (36.2 bu ac^{-1}). This result was not expected, as this treatment had the greatest plant emergence by 29 DAP for the I33 treatment (Fig. 2b). Yields for the 6- and 12-in. lateral depths were nonetheless numerically greater than those for the standard beds. For the I66 treatment, yields for all standard bed lateral depths were numerically greater than the wide bed 6- and 12-in. lateral depths, also unexpected considering early plant emergence trends (Fig. 2). The greater yield for sparser plant populations may have resulted from greater water and nutrient availability per plant. For the I100 treatment, yields were greater for all wide bed lateral depths than those for the standard beds, and the 12-in. lateral depth resulted in the largest yield (47.0 bu ac^{-1}) observed for the 2005 season (Fig. 3).

Table 2. Plants emerged at 13 and 29 days after planting (DAP), and final grain yield for 2005 soybean season.

Bed design	Irrigation treatment	Drip lateral depth (in.)	13 DAP Plant emergence (ft^{-1})		29 DAP Plant emergence (ft^{-1})		Grain yield (bu ac^{-1*})	
STD30	I0	6	2.7	a	3.1	a	28.0	a
STD30	I0	9	2.2	a	2.3	a	26.0	a
STD30	I0	12	2.4	a	2.8	a	27.4	a
STD60	I33	6	2.5	bc	2.8	bcd	28.3	ab
STD60	I33	9	1.8	c	2.1	d	29.9	ab
STD60	I33	12	1.7	c	2.5	cd	29.0	ab
WIDE60	I33	6	3.3	ab	3.3	abc	34.5	ab
WIDE60	I33	9	3.5	ab	3.7	a	28.8	b
WIDE60	I33	12	3.6	a	3.5	ab	36.2	a
STD60	I66	6	2.5	a	3.2	a	40.1	a
STD60	I66	9	1.3	b	2.2	b	41.1	a
STD60	I66	12	0.4	b	2.1	b	37.2	a
WIDE60	I66	6	3.2	a	3.4	a	36.8	a
WIDE60	I66	9	3.4	a	3.8	a	40.3	a
WIDE60	I66	12	2.9	a	3.4	a	36.3	a
STD60	I100	6	3.9	a	3.8	a	36.4	a
STD60	I100	9	3.0	ab	3.4	a	40.5	a
STD60	I100	12	2.5	b	3.2	a	35.7	a
WIDE60	I100	6	3.8	a	3.6	a	42.2	a
WIDE60	I100	9	3.8	a	3.7	a	43.3	a
WIDE60	I100	12	3.7	a	3.4	a	47.0	a
STD30	I100	6	4.8		4.4		45.0	
STD30	I100	9	4.2		4.3		37.8	
STD30	I100	12	4.3		4.6		42.4	

* 13% moisture basis.

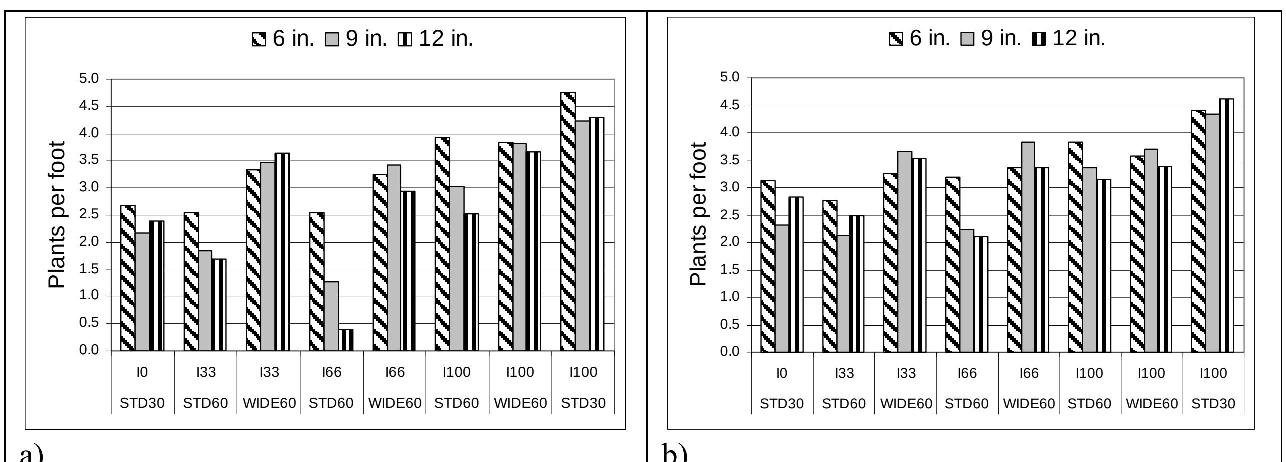

Figure 2. Plants emerged after a) 13 days after planting; b) 29 days after planting.

Seasonal water use, grain yield, water use efficiency (WUE), and irrigation water use efficiency (IWUE) were compared between irrigation treatments and bed designs for subplots with the 9-in. lateral installation depth. Seasonal water use varied by irrigation treatment but did not appear sensitive to bed design (Table 3). A significant linear relationship between grain yield and seasonal water use was observed for the I0, I33, and I66 treatments, but not for the I100 treatment (Fig. 4). The range of grain yield vs. seasonal water use observed here was similar to that reported by Payero et al. (2005) for soybeans under solid set and surface drip irrigation at North Platte and Curtis, NE. But yields were approximately 25% less than those for full SDI irrigation for flat-planted soybeans at the same location observed by Evett et al. (2000) in 1996 and 1998, possibly due to the shorter growing season for the present study. No significant differences were observed for WUE and IWUE, but these were numerically greatest for the I66 treatment (Table 3). WUE values were similar to those reported by Evett et al. (2000).

Table 3. Seasonal water use, yield, water use efficiency (WUE), and irrigation water use efficiency (IWUE) for 2005 soybean season (9-in. drip lateral depth subplots only).

Bed design	Irrigation treatment	Seasonal water use (in.)		Grain yield (bu ac^{-1*})		WUE (bu ac^{-1} in.$^{-1}$)		IWUE (bu ac^{-1} in.$^{-1}$)	
STD30	I0	14.3	b	23.9	b	1.7	a	----	
STD60	I33	16.6	b	29.6	b	1.8	a	15.0	a
WIDE60	I33	17.3	b	29.7	b	1.7	a	16.5	a
STD60	I66	20.0	ab	41.9	a	2.0	a	24.4	a
WIDE60	I66	20.1	ab	41.7	a	2.0	a	24.6	a
STD60	I100	24.1	a	41.8	a	1.8	a	17.2	a
WIDE60	I100	25.2	a	41.7	a	1.7	a	16.8	a
STD30	I100	24.6		37.8		1.5		13.0	

* 13% moisture basis.

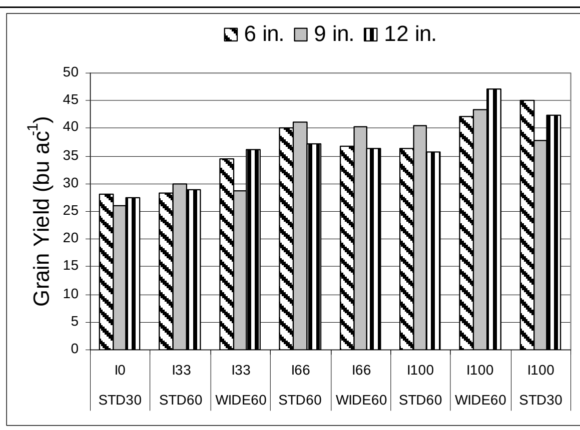

Figure 3. Soybean yield for irrigation rates, bed designs, and drip lateral installation depths for the 2005 season.

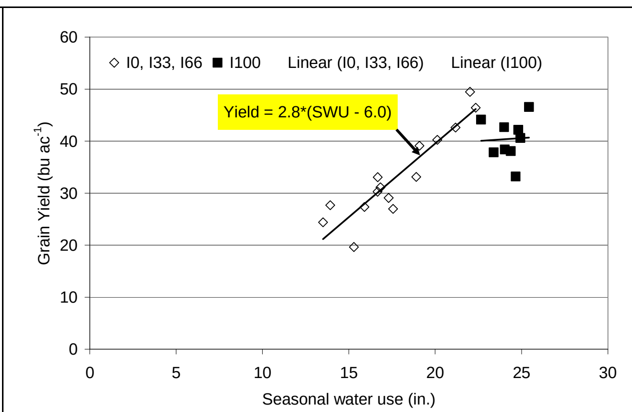

Figure 4. Production functions for 2005 soybean season.

CONCLUSIONS

Plant emergence and soybean grain yield were evaluated for alternative subsurface drip irrigation (SDI) designs and lateral installation depths among a range of irrigation treatments. Although the wide bed design generally resulted in greater plant emergence early in the season than that for standard beds (with SDI laterals in installed in alternate furrows), bed designs and lateral installation depths usually did not result in significant differences in final grain yield. For the I33 and I100 treatments, grain yield was numerically greater for the wide beds, with the exception of the wide-bed I33 treatment with the 9-in. lateral installation depth, for which grain yield was significantly less than that for the 12-in. lateral depth. For the I66 treatment, grain yield was similar between the wide and standard bed designs, although early season plant emergence was often significantly less for the standard beds. This implied that for sparser plant populations, greater water and nutrient availability per plant may have been compensating factors for final yield. No consistent correlation between lateral installation depth and final yield was observed for the single season of data reported here. Although these results suggest there are no advantages to the wide bed design, this study will continue for additional seasons and different crops, which may have vastly different responses than the single season of soybean data presented here.

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