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SDI Bed Design Comparison for Soybean Emergence and Yield

Paul D. Colaizzi, Agricultural Engineer

USDA-ARS Conservation and Production Laboratory, P.O. Drawer 10, Bushland, TX 79012-0010, pcolaizzi@cprl.ars.usda.gov.

Steven R. Evett, Soil Scientist

USDA-ARS Conservation and Production Laboratory, P.O. Drawer 10, Bushland, TX 79012-0010, srevett@cprl.ars.usda.gov.

Terry A. Howell, Research Leader (Agricultural Engineer)

USDA-ARS Conservation and Production Laboratory, P.O. Drawer 10, Bushland, TX 79012-0010, tahowell@cprl.ars.usda.gov.

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Abstract. Subsurface drip irrigation (SDI) use is increasing in the Southern and Central Great Plains region of the United States. Drip laterals are commonly installed in alternate furrows because installing laterals in every bed for low value crops is typically too expensive; however, crop germination can be difficult if preseason precipitation is inadequate with the alternate-furrow SDI configuration. We evaluated soybean emergence and grain yield with laterals installed in wide beds containing two seed rows and compared this with 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 15-, 22-, and 30-cm, 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.

Keywords. Subsurface drip irrigation, germination, crop emergence, lateral, soybean.

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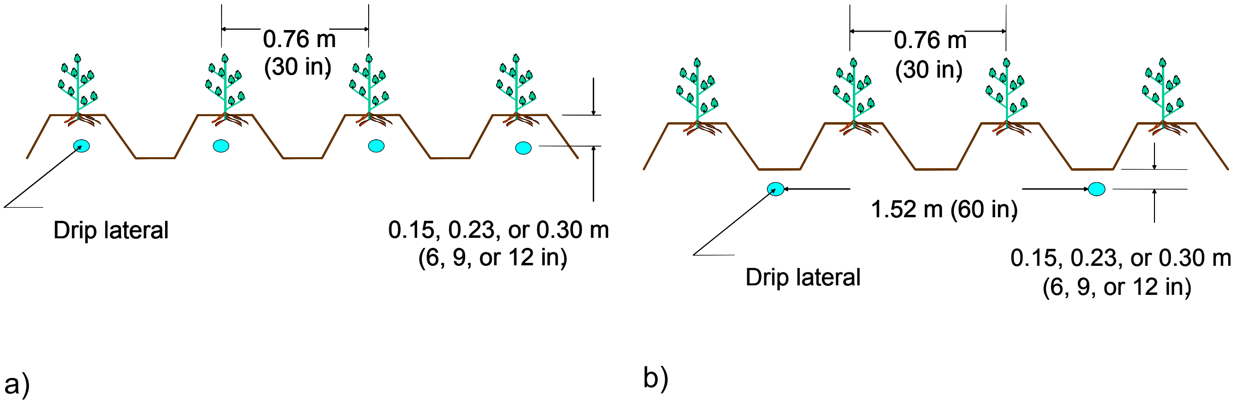
Introduction

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 1.62 million ha 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.

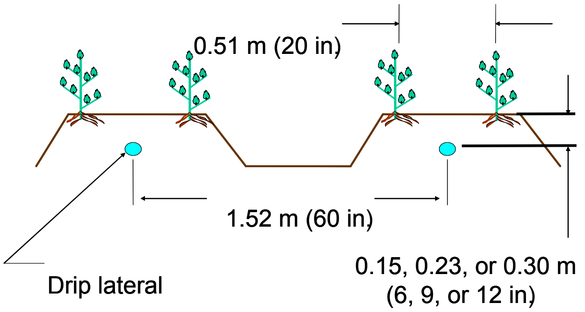
Drip laterals comprise two-thirds or more of the SDI system installation costs when laterals are installed beneath each planted row (Fig. 1a). For lower value row crops such as cotton and corn, drip laterals are commonly installed in alternate furrows (Fig. 1b), which can reduce initial capital costs 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 (15, 22, and 30 cm).



a)

b)



c)

Figure 1. SDI bed and lateral spacing and installation depths, a) laterals in each bed with 0.76-m spacing; b) laterals in alternate furrows with 1.52-m spacing; c) wide bed (twin row) with laterals centered in each bed with 1.52-m 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., 1,070 m elevation MSL). The climate is semi-arid with a high evaporative demand of about 2,600 mm per year (Class A pan evaporation) and low precipitation averaging 460 mm per year. Most of the evaporative demand and precipitation occur during the growing season (May to October) and average 1,550 and 330 mm, respectively. The climate is also characterized by strong regional advection from the south and southwest, with average daily wind runs at 2-m height exceeding 460 km, 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 0.15- to 0.40-m below the surface. A calcic horizon begins about 1.2 m 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 (*I*0, *I*33, *I*66, and *I*100) and bed design (Fig. 1), and the subplot factor was the SDI lateral installation depth (15-, 22-, and 30-cm below the soil surface). The *I*100 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 2.4-m depth. Integer values in treatment codes (i.e., 0, 33, 66) indicate the percentage of irrigation applied relative to full (e.g., 100% or *I*100) irrigation. From planting to the vegetative growth stage, irrigation water was applied when soil water measurements indicated a deficit of 25 mm less than field capacity over the 1.5-m deep root zone in the *I*100 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 *I*0 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 *I*33, *I*66, and *I*100 treatments. The design with laterals installed in every bed (Fig. 1a) was used for the *I*0 plots. This design was also used for three additional plots along the south boundary of the field, which were irrigated identically to the *I*100 treatment but were outside the randomized complete block design. SDI laterals (commonly termed "drip tape") were Netafim model Typhoon 990, 13 mil thickness, with 1.0-L h^{-1} emitters spaced 0.30-m apart (0.60-m apart for laterals in every bed), resulting in an application rate of 2.0 mm h^{-1} for all plots. Irrigation treatments were therefore imposed by varying the duration of each irrigation event. Main plots were 86.9-m long and were divided into three 25.9-m-long subplots along the row direction, separated by a 4.6-m transition area to change the SDI lateral installation depth. Each plot had 12 rows for the standard bed design (Figs 1a and 1b, 0.76-m bed centers) and 6 rows for the wide bed design (Fig. 1c, 1.52-m 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 2.3 L ha^{-1} on 14 April, and corn (*Zea mays L.*, cv. Pioneer 33B54) was planted on May 11, 2005 at 8.4 plants m^{-2}, but the corn 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 67.3 kg ha^{-1} for all plots when the hail storms occurred. The hail-damaged corn was removed 20 June, and the field was replanted to soybean (*Glycine max* cv. Pioneer 94M90) on 22 June at 44.5 plants m^{-2}. No other chemicals or fertilizer were applied for the remainder of the season.

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

Corn Planting Date	5/11/05		
Corn Variety	Pioneer 33B54		
Plant Density	8.4	Plants m^{-2}	
Nitrogen	67.3	kg ha^{-1}	
Herbicide (Laymaster)	2.3	L ha^{-1}	
Hail Storms	6/10-6/11/05		
Corn Removed	6/20/05		
In-season rain (corn)		114	mm
In-season irrigation (corn)	*I*0	33	mm
	*I*33	55	mm
	*I*66	72	mm
	*I*100	92	mm
Soybean Planting Date	6/22/05		
Soybean Variety	Pioneer 94M90		
Plant Density	44.5	Plants m^{-2}	
Harvest Date	10/26/05		
In-season rain (soybeans)		140	mm
In-season irrigation (soybeans)	*I*0	0	mm
	*I*33	80	mm
	*I*66	164	mm
	*I*100	236	mm

The number of plants emerged were counted at four locations in each subplot (rows 3, 4, 9, and 10 in a 1.0-m distance) on 29 June, 5 July, 14 July, and 21 July. Volumetric soil water was measured in the top 15-cm 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 2.4-m profile using a Campbell Pacific Nuclear (Martinez, CA) model 503DR neutron moisture meter, but only in subplots with the 22-cm 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 m^3 m^{-3}, which included the top 10-cm 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 *I*100 treatment. Plants were harvested by hand in two 2.0-m^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.

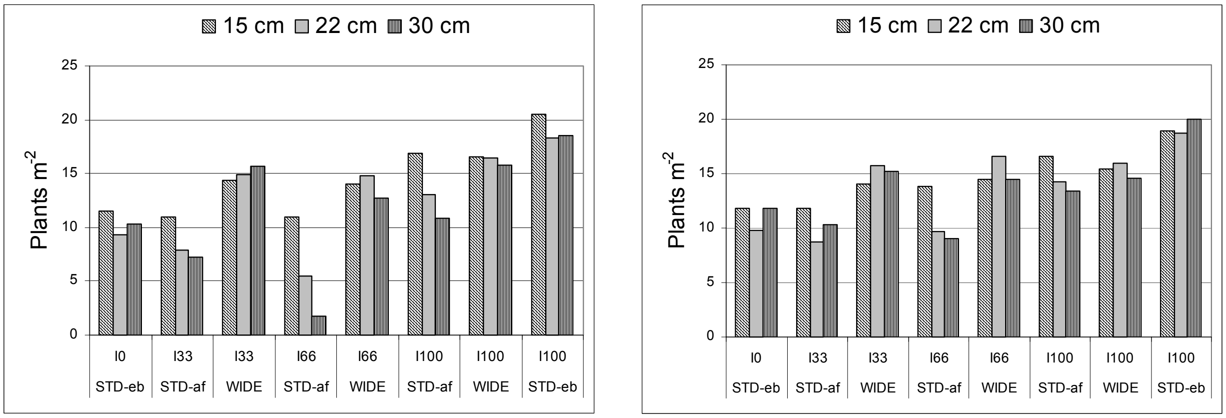
Plant emergence at 13 and 29 days after planting (DAP) (5 and 21 July, repsectively) and grain yield were tested for differences for each bed design and lateral depth using the SAS mixed model (PROC MIXED, Littell et al., 1996). In PROC MIXED, fixed and random effects are specified separately. Fixed 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 22-cm 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 *I*33 and *I*66 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 22- and 30-cm lateral depths, and numerically greater emergence than standard beds with 15-cm laterals. For the *I*100 treatment at 13 DAP, the wide beds resulted in significantly greater emergence than the standard beds with 30-cm lateral depths, although emergence for the standard bed 15-cm lateral depth was largest at 17.0 plant m^{-2}. Trends were similar by 29 DAP, but differences tended to be more numerical. The *I*100 treatment with laterals in every bed (*I*100, STD-eb) resulted in the greatest emergence for both 13 and 29 DAP; however, these plots were not randomized and could not be directly compared on a statistical basis. Furthermore, producers in the Texas High Plains perceive it cost prohibitive to install laterals in every bed at 0.76-m centers for most low-value crops, despite the obvious advantages in plant emergence (Enciso et al., 2005). As expected for standard beds, the 15-cm 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 22-cm lateral depth than the 15- or 30-cm 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 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.

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 (cm)	13 DAP Plant emergence (m^{-2})		29 DAP Plant emergence (m^{-2})		Grain yield (kg ha^{-1})	
STD-eb	*I*0	15	11.6	a	11.8	a	1,892	a
STD-eb	*I*0	22	9.4	a	9.8	a	1,755	a
STD-eb	*I*0	30	10.4	a	11.8	a	1,852	a
STD-af	*I*33	15	11.0	bc	11.8	bcd	1,914	ab
STD-af	*I*33	22	7.9	c	8.8	d	2,022	ab
STD-af	*I*33	30	7.3	c	10.3	cd	1,958	ab
WIDE	*I*33	15	14.4	ab	14.0	abc	2,330	ab
WIDE	*I*33	22	14.9	ab	15.8	a	1,944	b
WIDE	*I*33	30	15.7	a	15.2	ab	2,443	a
STD-af	*I*66	15	11.0	a	13.8	a	2,712	a
STD-af	*I*66	22	5.5	b	9.6	b	2,774	a
STD-af	*I*66	30	1.7	b	9.0	b	2,515	a
WIDE	*I*66	15	14.0	a	14.5	a	2,489	a
WIDE	*I*66	22	14.8	a	16.6	a	2,726	a
WIDE	*I*66	30	12.7	a	14.5	a	2,454	a
STD-af	*I*100	15	16.9	a	16.6	a	2,458	a
STD-af	*I*100	22	13.1	ab	14.3	a	2,737	a
STD-af	*I*100	30	10.9	b	13.4	a	2,413	a
WIDE	*I*100	15	16.6	a	15.5	a	2,850	a
WIDE	*I*100	22	16.5	a	16.0	a	2,925	a
WIDE	*I*100	30	15.8	a	14.6	a	3,176	a
STD-eb	*I*100	15	20.5		19.0		3,043	
STD-eb	*I*100	22	18.3		18.8		2,556	
STD-eb	*I*100	30	18.5		20.0		2,866	



a)

b)

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

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 was not statistically different among irrigation treatments except for *I*33, where yield for the wide bed with a 22-cm lateral depth (1,944 kg ha^{-1}) was significantly less than that for the wide bed with the 30-cm lateral depth (2,443 kg ha^{-1}). This result was not expected, as this treatment had the greatest plant emergence by 29 DAP for the *I*33 treatment (Fig. 2b). Yields for the 15- and 30-cm lateral depths were nonetheless numerically greater than those for the standard beds. For the *I*66 treatment, yields for all standard bed lateral depths were numerically greater than the wide bed 15- and 30-cm 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 *I*100 treatment, yields were greater for all wide bed lateral depths than those for the standard beds, and the 30-cm lateral depth resulted in the largest yield (3,176 kg ha^{-1}) observed for the 2005 season (Fig. 3).

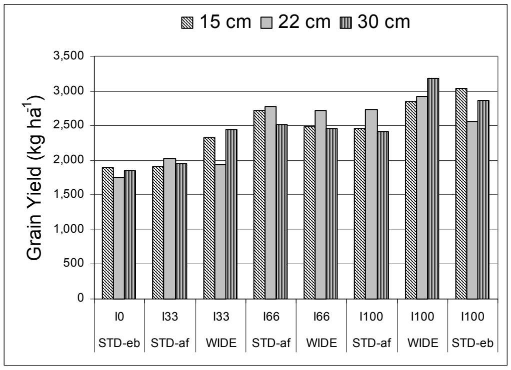


Figure 3. Soybean dry grain yield for irrigation treatments, bed designs, and drip lateral installation depths for the 2005 season.

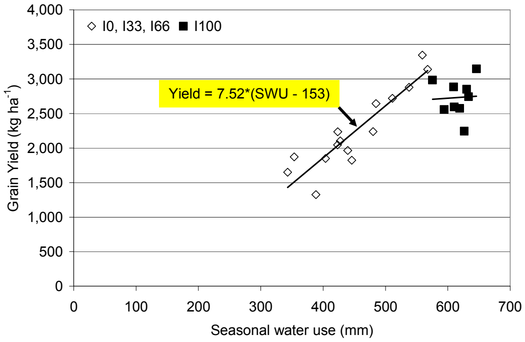


Figure 4. Production function for the 2005 soybean season.

Table 3. Seasonal water use, yield, water use efficiency (WUE), and irrigation water use efficiency (IWUE) for 2005 soybean season (22-cm drip lateral depth subplots only).

Bed design	Irrigation treatment	Seasonal water use (mm)		Dry grain yield (kg ha^{-1})		WUE (kg m^{-3})		IWUE (kg m^{-3})	
STD-eb	*I*0	365	c	1,616	b	0.45	ab	----	
STD-af	*I*33	421	bc	1,999	b	0.48	ab	4.00	ab
WIDE	*I*33	439	bc	2,008	b	0.46	ab	4.38	ab
STD-af	*I*66	503	b	2,833	a	0.54	a	6.48	a
WIDE	*I*66	508	b	2,821	a	0.53	a	6.55	a
STD-af	*I*100	617	a	2,821	a	0.47	ab	4.56	ab
WIDE	*I*100	643	a	2,816	a	0.45	ab	4.48	ab
STD-eb	*I*100	625		2,556		0.41		3.46	

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 22-cm 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 *I*0, *I*33, and *I*66 treatments, but not for the *I*100 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 *I*66 treatment (Table 3). WUE values were similar to those reported by Evett et al. (2000).

Conclusion

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 *I*33 and *I*100 treatments, grain yield was numerically greater for the wide beds, with the exception of the wide-bed *I*33 treatment with the 22-cm lateral installation depth, for which grain yield was significantly less than that for the 30-cm lateral depth. For the *I*66 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.

Acknowledgements

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