This is not a peer-reviewed article.
5th National Decennial Irrigation CD-ROM Proceedings
Phoenix Convention Center, 5 - 8 December 2010, Phoenix, AZ USA
M. Dukes ed. St Joseph Mich: ASABE
ASABE Publication Number 711P0810cd

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An ASABE Conference Presentation

Paper Number: IRR10-8598

Cotton Production Response to Crop Row Offset and Orientation to SDI Laterals in the Texas High Plains

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Written for presentation at the
5th National Decennial Irrigation Conference
Sponsored jointly by ASABE and the Irrigation Association
Phoenix Convention Center
Phoenix, Arizona
December 5 - 8, 2010

Abstract. *Production questions concerning subsurface drip irrigation (SDI) lateral position and orientation to crop rows in the Texas High Plains have been asked. Field experiments were conducted at Halfway, TX to evaluate row to lateral offsets of 0.0, 0.13 m, 0.25 m, and 0.38 m; perpendicular crop row to SDI laterals with spacing at 0.76 m, 1.02 m, and 1.52 m; and crop row widths of 0.76 m and 1.02 m. Cotton rows spaced at 0.76 m resulted in generally higher yield than 1.02-m rows and significantly higher yields at the high irrigation level. There were significant differences in yields from individual rows of adjacent row pairs irrigated with a single lateral when row offsets were greater than 0.25 m on 0.76-m row spacing. However, cotton plants from rows closest to the lateral largely compensated for yield losses of rows farthest from the SDI lateral. The perpendicular compared to traditional row-to-lateral orientation resulted in declines in cotton lint yield and irrigation water use efficiency, with significant yield declines at high irrigation. Irrigation water use efficiency (IWUE) resulting from rows perpendicular to laterals followed yield trends with higher IWUE values in treatments with closer SDI lateral spacing. Orienting rows perpendicular across drip laterals using 0.76-m row widths resulted in significantly higher yields and IWUE's than 1.02-m row widths at high irrigation capacity. These experiments will provide producers added information on how to install and manage existing SDI systems and whether to convert from traditional irrigation systems to SDI.*

Keywords. SDI, irrigation, cotton, lateral spacing, lateral orientation, drip irrigation, water use efficiency.

Introduction

The use of subsurface drip irrigation (SDI) systems for irrigating row crops in the Texas High Plains has increased due to their high water transfer efficiency in a region of rapid groundwater depletion. Of the 3.2 million hectares of cultivated farmland, approximately 50% is irrigated, mostly with center pivots and gravity (surface) methods. Interest in SDI for cotton production in the Southern High Plains has increased with successful demonstrations in the Garden City area (Henggeler, 1995) and the South Plains (HPUWCD No. 1, 1995). Currently, SDI installations in the area have exceeded 100,000 ha based on informal estimates of installers, dealers, and USDA-NRCS personnel. Conversion to SDI continues, primarily from gravity methods.

SDI system design for cotton production has been investigated. Drip laterals installed 0.2 to 0.3 m below the soil surface were successfully used in commercial cotton plantings in Arizona (Tollefson, 1985). Greater net returns from cotton occurred at lateral depths of 0.3 versus 0.2 m in the Texas Trans-Pecos region (Enciso, et al., 2005). Cotton yield was not different due to SDI lateral spacings of every row (1 m) compared to alternate furrow (2 m) spacing, in a 4-year study on a southeastern Coastal Plain soil (Camp, et al., 1997). Seed cotton yield and irrigation water use efficiency were not statistically different between dripline spacings of 0.9 m and 1.8 m on a Norfolk sandy loam soil in North Carolina (Grabow, et al., 2006). Cotton yields along SDI laterals were affected by design flow rate variations (Qvar's) between 5 and 27% in the Texas High Plains, however, total cotton lint yield within a treatment area was not significantly affected during a five-year evaluation (Bordovsky and Porter, 2008).

Crop bed design, or planted row location relative to drip tape laterals, has been investigated. Enciso-Medina, et al. (2002) compared ultra-narrow row (UNR) cotton at 0.25-m and 0.38-m plant spacing to those of 0.76-m and 1.02-m spacings irrigated with laterals at 0.76 m for UNR plantings and under each planted row for other treatments. Results showed crop row spacing had a moderate impact on water use efficiency. Colaizzi, et al. (2006) reported preliminary results of soybean germination and yield from wide beds (1.52 m) with 2 crop rows irrigated by one lateral centered in the bed and traditional arrangements of SDI laterals in alternate furrows (1.52-m crop row spacing) and one lateral under each 1.52-m crop row. One-year results showed no significant differences in final grain yield. Due to the high initial installation costs of SDI, most commercial producers in the South Plains use alternate furrow arrangements with single drip laterals delivering water to two crop rows.

Maintaining crop rows in SDI fields at precisely the same relative locations to the SDI laterals, year after year, can become very difficult. In typical alternate row SDI installations, unintended crop row offsets from drip laterals have resulted in one row of each pair receiving more water than its mate, causing significant differences in plant growth between adjacent rows, a common observation in the South Plains. Crop row position can impact seed germination as well as plant development, particularly in areas of limited irrigation capacity. Many new SDI systems are being installed with RTK-GPS guided tractors to achieve more uniform, parallel spacing of drip laterals compared to non-GPS guided installations. Commercially available tractor guided systems are advertised as being capable of repeatability within a few centimeters using their RTK systems (John Deere Starfire™ RTK, Trimble® AgGPS® Autopilot™, Autofarm RTK Autosteer™). Installing SDI with RTK-GPS guidance increased the probability of actual tape lateral positions being within 2.5 cm of target tape locations from 18%, without GPS guidance, to over 60%, with guidance (Bordovsky, 2006). Although GPS-guidance is commonly available, some SDI installations do not use this technique due to cost. The effects of crop-row-to-drip-tape horizontal distance on cotton production in alternate-furrow SDI areas has not been evaluated.

One method to eliminate the need for GPS precision in row crop production is planting rows perpendicular to the SDI lateral direction. In an effort to contain SDI installation costs and better capture rainfall, South Plains cotton producers have used long drip lateral lengths for economy, then contoured crop rows across laterals to optimize rainfall capture. Cotton production response and long-term lateral and soil structure deterioration caused by crop rows crossing subsurface laterals need to be documented and compared to traditional parallel plantings.

Important differences between the Northern and Southern Texas High Plains include crops grown, irrigation capacity, and planted crop row spacing. Producers in the Northern Plains have traditionally planted grains, have generally higher irrigation capacity, and commonly use 0.76-m planted row widths. The South Plains row crop area is typically planted in cotton, has low irrigation capacity, and uses row widths of 1.02 m. Past research has shown increased yield with narrower row spacings (Williford, 1992), however, closer crop row and SDI lateral spacing dramatically increases initial costs of SDI systems. Cotton yield and economic outcome resulting from SDI in 0.76-m versus 1.02-m crop rows need to be determined.

The objective of this report is to describe a SDI field experiment and present available cotton yield data resulting from 1) crop row offsets from their optimum position relative to SDI laterals; 2) crop rows crossing (perpendicular to) SDI laterals at different lateral spacings; and 3) two crop row widths irrigated by alternate furrow SDI.

Methods and Materials

A SDI system was installed on a 2-ha field at the Texas AgriLife Research and Extension Center, Halfway, TX (3514 ft elev., 340 10’ N, 1010 56’ W). The field was in a transitional soil changing from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) to an Olton loam (fine, mixed, thermic Aridic Paleustolls). Average annual rain at this site is approximately 460 mm with 300 mm occurring from May to September; however, precipitation amount and timing is extremely variable. This, as well as the high evaporative demand in this area, typically results in the need for supplemental irrigation.

Prior to SDI installation the treatment area was surveyed using mobile GPS equipment. From this survey, final crop row positions, all drip tape lateral positions, and corresponding GPS tractor guidance files were created using ArcMap™ 9.0 (ESRI, Redlands, California) software. The resulting guidance files (shape files) were transferred to a Trimble® AgGPS 214 system onboard a John Deere 7420 4WD tractor. The drip lateral installation plow was a three bar tool (100 cm x 100 cm w/full top mast, Bigham Brothers Inc. Manufacturing, Lubbock, TX) with two shanks and 50-mm tape installation tubes. The shanks were positioned so that the centers of the tape outlets were equidistant ($\pm$ 6 mm) from the centerline of the plow and tractor. The plow was mounted on the tractor using a standard Category III three-point hitch with auxiliary sway blocks that eliminated all visible side-to-side hitch movement with the plow in draft position. Prior to drip tape installation, the field was tilled 0.38 m deep with parabolic chisels on 0.5-m spacing in opposing diagonal paths, each path 45 degrees from the eventual direction of the drip laterals. The field was disked and then smoothed with a field cultivator.

Drip laterals were installed in alternating sections of east-west (EW), then north-south (NS) orientation. A detailed map and description of the SDI field layout is given by Bordovsky (2007). The experiment was designed as a two factor split plot with four replicates. The main factor was irrigation level with irrigation application based on estimated evapotranspiration (ET). In 2006, maximum daily irrigation treatments were limited to 5 mm d^{-1} (low level) and 7.5 mm d^{-1} (high level), and from 2007 to 2009 the high irrigation level was limited to 9 mm d^{-1} and the low level at 50% of the high. The sub-factor treatments were combinations of crop row orientation and location relative to drip tape position at 0.76-m and 1.02-m crop row widths. Within the 0.76-m crop rows, four treatments included rows planted parallel to SDI laterals with row offsets from their optimum position relative to SDI laterals of 0.0 m (traditional treatment, T1), 0.13 m (T2), 0.25 m (T3), and 0.38 m (T4), (Figure 1). Also included were rows crossing SDI laterals (perpendicular orientation) with laterals spaced at 0.76 m (T6), 1.02 m (T7), and 1.52 m (T8), (Figure 2). Within the 1.02-m crop rows, treatments included two planted rows irrigated by one SDI lateral located equidistant from the rows (T5, traditional orientation). Also included were three perpendicular row to SDI lateral orientation treatments with laterals spaced at 0.76 m (T9), 1.02 m (T10), and 1.52 m (T11). There were no offset treatments in the 1.02-m crop rows. Traditional and offset treatment plot sizes were 8 rows x 27.4 m and perpendicular row to lateral plot sizes were 8 rows x 9.1 m. The treatment designations and corresponding physical description of the field layouts are summarized in Table 1.

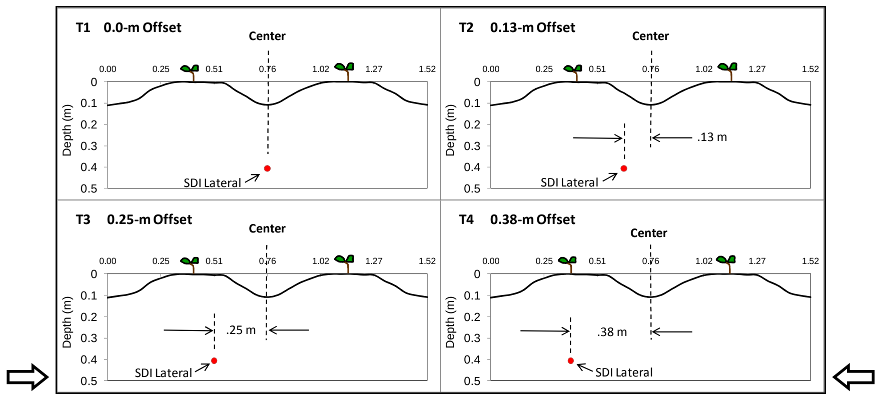

Figure 1. Illustration of treatments having row offsets from their optimum position relative to SDI laterals of 0.0, 0.13, 0.25, and 0.38 m, Texas AgriLife Research, Halfway, TX, 2006-2009.

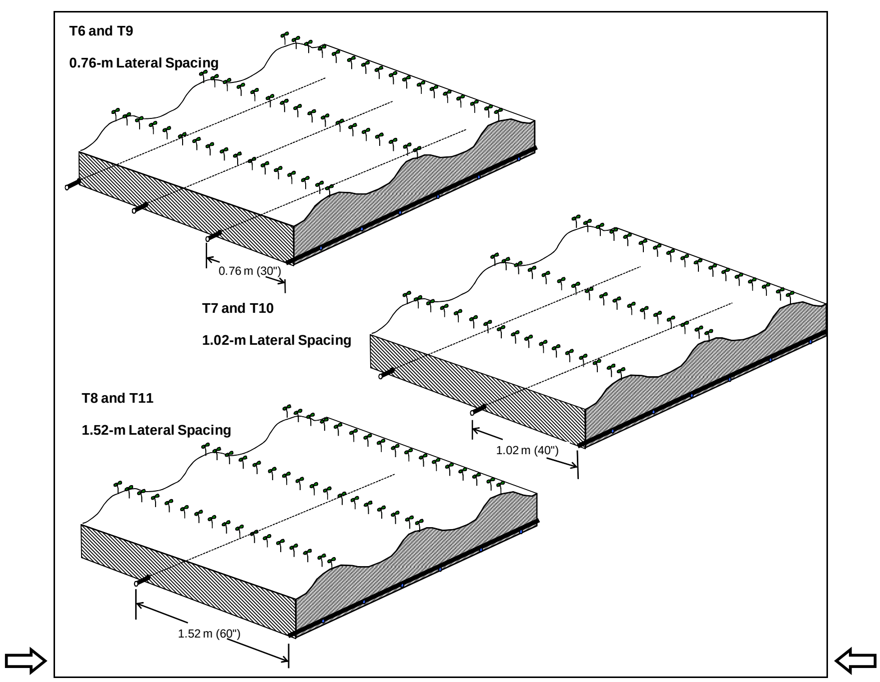

Figure 2. Illustration of three treatments with crop rows crossing SDI laterals with lateral spacings of 0.76, 1.02, and 1.52 m, Texas AgriLife Research, Halfway, TX, 2006-2009.

Table 1. Summary of SDI orientation treatments with different crop row widths, row offsets, and lateral spacing of treatments with rows perpendicular to SDI laterals in experiments conducted at Texas AgriLife Research, Halfway, 2006-2009.

	Treatment Designation										
Treatment Parameters	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Width between Crop Rows (m)	0.76	0.76	0.76	0.76	1.02	0.76	0.76	0.76	1.02	1.02	1.02
Row Offset Distance from SDI Lateral (m)	0.00	0.13	0.25	0.38	0.00						
Lateral Spacing with Rows Perpendicular to Laterals (m)						0.76	1.02	1.52	0.76	1.02	1.52

The installation was designed using 8 SDI irrigation control zones. Within an irrigation level, uniform irrigation depth per area was achieved by compensating for wider lateral spacing (1.52 m versus 2.04 m, parallel; and 0.76 m, 1.02 m, and 1.52 m, perpendicular) with closer emitter spacing. Specific information on the SDI emitter and laterals used are reported by Bordovsky (2007). Immediately following SDI installation in 2005, the entire field was smoothed with a sweep plow and further leveled with a field cultivator; and crop beds were formed and alternate furrows diked.

Field experiments were initiated in 2006 and continued through 2009. Cotton (*Gossypium hirsutum* L., *cv*. Fibermax 989B2R in 2006 and 2007; Fibermax 9063B2RF in 2008 and 2009) was planted at a density of approximately 13.3 plants m^{-2} using different sets of RTK-GPS guided equipment for 0.76-m and 1.02-m crop rows. All crop rows were oriented EW. Nutrients were applied based on laboratory analysis of soil samples. All phosphorus and one-third of the nitrogen was applied pre-plant with ground application equipment. The remainder of the nitrogen was applied in liquid form with irrigations in June and July. Planting, harvesting, and beginning and ending irrigation dates, as well as irrigation and rainfall amounts are given in Table 2. Crop germination and plant growth in the first three years was good. A hail event on 20 June 2008 reduced plant stands, however, remaining plants recovered over the growing season. Germination in 2009 was less than optimal due to low rain prior to planting compounded by the position of drip laterals relative to the seed drills in different treatments. Differences due to offset and perpendicular row-to-lateral treatments could easily be seen in the crop canopy during the growing season. Yield data were obtained by hand harvesting cotton samples from each individual row of adjacent row pairs (3 m x 1 row) in each offset treatment sub-plot (T1-T4). This allowed the analysis of contribution by row of the offset drip lateral treatments. In addition to hand samples, larger seed cotton samples (4-row x ~ 18 m) were obtained in all plots in 2008 and 2009 by using a weighing system on a 4-row John Deere 7445 cotton stripper. Two to three pound seed cotton sub-samples from the stripped sample at each location were ginned to determine lint turnout at the Texas AgriLife Research and Extension Center in Lubbock, Texas. HVI fiber analysis was performed on each lint sample at the Fiber and Biopolymer Research Institute at Texas Tech University in Lubbock.

Table 2. Significant dates, irrigation amounts, and rainfall for low and high irrigation levels in row to SDI lateral offset and orientation field experiment, Texas AgriLife Research, Halfway, TX, 2006-2009.

	2006		2007		2008		2009	
Operation	Low Irr.	High Irr.	Low Irr.	High Irr.	Low Irr.	High Irr.	Low Irr.	High Irr.
Planting date	2-May	2-May	14-May	14-May	13-May	13-May	7-May	7-May
Harvest date	1-Nov	1-Nov	9-Nov	9-Nov	20-Nov	20-Nov	20-Nov	20-Nov
First In-season Irr.	25-May	25-May	20-Jun	20-Jun	5-Jun	5-Jun	24-Jun	24-Jun
Last In-season Irr.	28-Aug	28-Aug	7-Sep	7-Sep	5-Sep	5-Sep	11-Sep	11-Sep
Irrigation amount (mm)								
Pre-plant	37	37	0	0	112	112	112	114
In-season	277	367	152	274	187	361	164	337
Total	314	404	152	274	298	472	276	451
Rainfall (mm)								
In-season	254	254	283	283	199	199	316	316
Calendar year	450	450	569	569	376	376	457	457

Results

The average cotton lint yields of the eleven treatments over the four year test period at low and high irrigation levels are given in Figure 3. It is important to note that, within an irrigation level the irrigation quantity and timing were the same for each treatment and yield differences are due to differences in the arrangement and spacing of SDI emitters relative to the location of cotton plants.

Spacing Between Crop Rows

The distance between crop rows had no significant effect on yield at the low irrigation level, but significantly decreased lint yield going from the 0.76-m row width (1.52-m lateral spacing) to 1.02-m row width (2.04-m lateral spacing) at high irrigation. At low irrigation in the traditional 0.76-m row installation with drip laterals installed parallel to and at 0-m offset from the center of row pairs ($T1_{Low}$), cotton lint yield was 1778 kg ha^{-1} versus 1731 kg ha^{-1} from the 1.02-m rows ($T5_{Low}$). However at high irrigation, the 0.76-m versus 1.02-m crop rows resulted in yields of 2091 kg ha^{-1}($T1_{High}$) versus 1930 kg ha^{-1}($T5_{High}$), respectively, or an 8% decrease in lint yield.

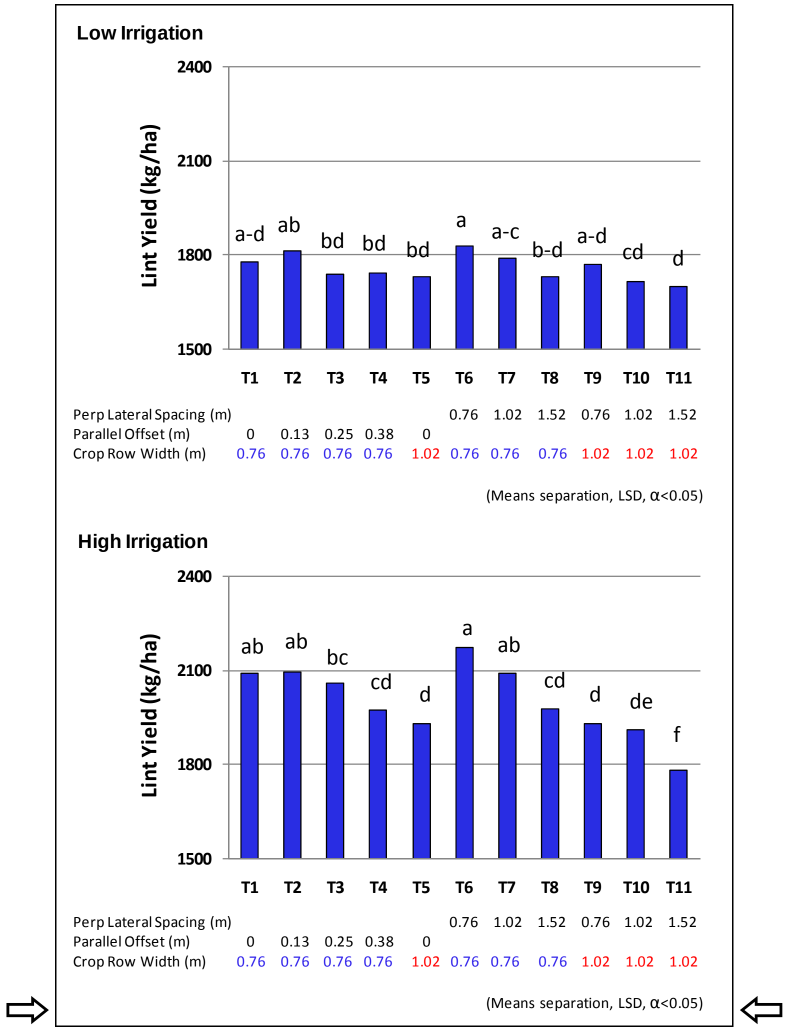

Figure 3. Average cotton lint yields from eleven crop row / drip lateral orientation treatments irrigated by SDI at low and high irrigation levels, Texas AgriLife Research, Halfway, TX, 2006-2009.

Drip Lateral Offsets from the Center of Paired Rows

With one exception ($T4_{High}$), row to SDI lateral offsets (T1- T4) did not significantly affect average cotton lint yield at either high or low irrigation levels. However, there were general yield declines as the row offsets increased from 0 m to 0.38 m. At low irrigation, four-year average yield decreased from 1778 to 1741 kg ha^{-1} (2.1%), and at high irrigation, the decline was from 2091 to 1975 kg ha^{-1} (5.6%) from 0-m (T1) to 0.38-m (T4) offsets. The 0.38-m offset yield at the high irrigation level was significantly lower than those with 0-m or the 0.13-m offsets.

The yield from each individual row of the two rows irrigated by single SDI laterals was significantly affected by increasing row offset from SDI laterals. Figure 4 contains average yield response due to row offset at low and high irrigation levels. Over the four years at low irrigation, the 0.13-m offset significantly reduced yield of the row farthest from the lateral compared to the adjacent row. More pronounced differences occurred as offsets increased. The 0.38-m offset resulted in a 775 kg ha^{-1} yield difference between the rows. At high irrigation significant differences between rows did not occur until the offset reached 0.25 m with differences of 446 and 473 kg ha^{-1} in 0.25-m and 0.38-m offset treatments, respectively. The effect of row offsets on fiber quality was minimal from 2006 to 2008 (data not shown). Within the Texas South Plains environment, cotton rows having access to more irrigation tended to compensate for adjacent rows having less.

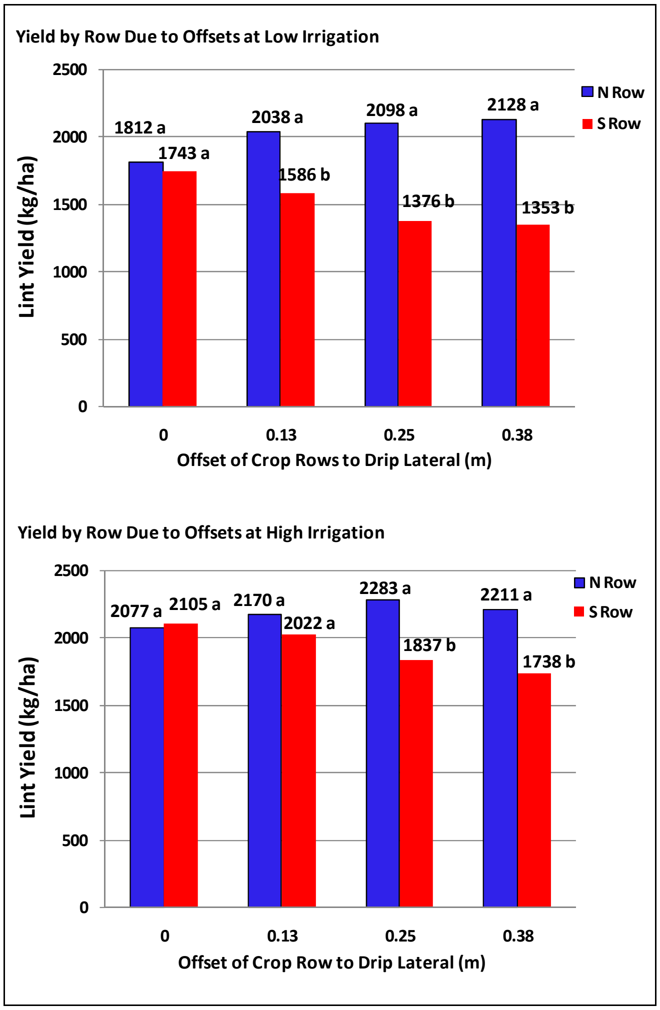

Figure 4. Yield from each individual row of row pairs irrigated by single SDI laterals with given row offsets from SDI lateral at low and high irrigation, Texas AgriLife Research, Halfway, TX, 2006-2009.

Crop Rows Perpendicular to Drip Laterals

Cotton yields were not significantly decreased by orienting rows perpendicular across SDI laterals (T8) compared to the traditional orientation with one lateral equidistant between two crop rows 0.76-m apart (T1) at the low irrigation level. T8 represents the identical crop row spacing, drip lateral spacing, emitter spacing, and emitter flow (and the same SDI installation cost) as T1 with the only difference being row orientation. $T1_{Low}$ and $T8_{Low}$ resulted in yields of 1778 and 1732 kg ha^{-1}, respectively (Figure 3). At high irrigation, lint yields were significantly different at 2091 and 1978 kg ha^{-1} for $T1_{High}$ and $T8_{High}$, respectively. Within the 0.76-m row width, perpendicular treatments (T8, T7 and T6), as the distance between drip laterals was reduced, yields increased from 1732 to 1829 kg ha^{-1} at low irrigation and 1978 to 2171 kg ha^{-1} at high irrigation with lateral distances of 1.52 m, 1.02 m and 0.76 m, respectively. Similar yield trends were seen in the 1.02-m wide crop rows oriented perpendicular to SDI laterals (T11, T10 and T9) with closer SDI lateral spacing resulting in numerically higher yields. Also, there were large differences in cotton yield resulting from 0.76-m crop rows compared to 1.02-m rows crossing laterals, particularly at the high irrigation level (Figure 3). The range in yield of the high irrigation, perpendicular treatments was from 2171 kg ha^{-1} with 0.76-m lateral spacing ($T6_{High}$) to 1783 kg ha^{-1} with 1.52-m lateral spacing ($T11_{High}$) or an 18% yield decline when using the same irrigation quantity and timing.

Irrigation Water Use Efficiency

The average irrigation water use efficiency (IWUE) was determined for each treatment and irrigation level (Figure 5). IWUE is a relative gauge of irrigation water value of all irrigation applied and is affected by weather, irrigation system, soil type, and overall production management. IWUE was calculated by reducing treatment lint yields by the non-irrigated yield from the same field and dividing this value by total annual irrigation, both pre- and in-season irrigation. IWUE was much higher at the low irrigation level averaging 0.57 kg m^{-3} than at the high level which averaged 0.42 kg ha^{-3}, indicating a reduction in per unit water value when irrigating for maximum yield. At the high water level, the traditional 0.76-m row spacing ($T1_{High}$) resulted in significantly higher IWUE than the 1.02-m spacing ($T5_{High}$). Except for the 0.38-m offset, offset treatments (T1 to T4) did not significantly affect IWUE, but tended toward lower efficiency with increased SDI offset from the center of paired irrigated rows. Water use efficiency resulting from rows perpendicular to laterals followed yield trends with higher IWUE values in treatments with closer SDI lateral spacing. This was generally the case for both 0.76-m (T6 - T8) and 1.02-m (T9 - T11) crop rows in both low and high irrigation treatments. As seen in both Figures 3 and 5, planting cotton across drip laterals with 0.76-m crop rows resulted in significantly higher yields and IWUE’s than using 1.02-m rows at the higher irrigation levels.

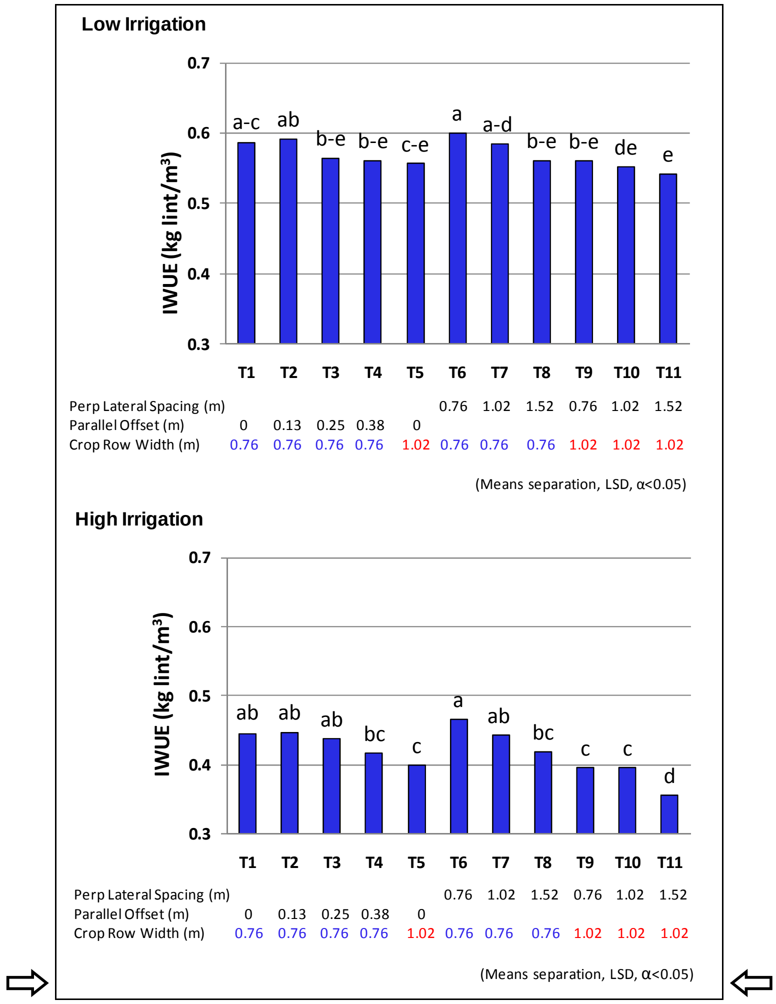

Figure 5. Average irrigation water use efficiency from eleven crop row / SDI lateral orientation treatments irrigated by SDI at low and high irrigation levels, Texas AgriLife Research, Halfway, TX, 2006-2009.

Summary and Conclusion

A SDI system was installed and managed to determine the effects on cotton production resulting from shifting crop rows from the optimum location relative to SDI lateral position and orienting crop rows perpendicular across laterals. Additional factors included levels of irrigation and the distance between crop rows. Crop rows spaced at 0.76 m resulted in generally higher yield than 1.02-m rows and significantly higher yields at high irrigation. There were significant differences in individual row yields as row pairs shifted away from their optimum position relative to SDI laterals by greater than 0.13 m at low irrigation and greater than 0.25 m at high irrigation. However, cotton plants from crop rows closest to the lateral largely compensated for reduced yield of rows farthest from the SDI lateral. This resulted in four-year yield declines of only 1778 kg ha^{-1} to 1741 kg ha^{-1} at low irrigation and 2091 to 1975 kg ha^{-1} at high irrigation as horizontal row offsets from optimum locations increased from 0.0 to 0.38 m, respectively. The perpendicular compared to parallel row to lateral orientation resulted in declines in cotton lint yield and irrigation water use efficiency, with significant yield declines at the high irrigation levels. Water use efficiency resulting from rows perpendicular to laterals followed yield trends with higher IWUE values in treatments with closer SDI lateral spacing. Planting cotton across drip laterals with 0.76-m crop rows resulted in significantly higher yields and IWUE's than those from 1.02-m rows at high irrigation capacity.

Acknowledgements

The authors would like to gratefully acknowledge the contributions of Andy Cranmer, Research Farm Manager, Douglas Nesmith, Former Research Farm Manager, and Cora Lea Emerson, Research Assistant, Texas AgriLife Research, Lubbock/Halfway. This project was supported by the USDA-ARS Ogallala Aquifer Initiative and the Texas State Support Committee, Cotton Incorporated.

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