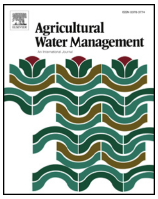
Agricultural Water Management 208 (2018) 357–362

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat



Short communication

Yield response of corn and grain sorghum to row offsets on subsurface drip laterals

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ARTICLE INFO

Keywords:
Subsurface drip irrigation
Corn
Grain sorghum
Lateral spacing offset
Semi-arid

ABSTRACT

Subsurface drip irrigation (SDI) is a micro-irrigation system that could be adopted by producers in the semi-arid regions around the world for efficient use of water. Yet, several crop management issues related to SDI system need to be addressed to assess the feasibility of SDI. One such issue is the impact of crop row placement on crop performance, irrigation water use efficiency and yield under SDI. A study was conducted in the Southern U.S. Great Plains, in which drip tape laterals were buried 30 cm deep at 153 cm spacing, with two crop rows planted at 76 cm spacing, and irrigated with one tape. Corn (*Zea mays* L.) and grain sorghum (*Sorghum bicolor* L.) rows were offset from equidistance from the drip tape by 0, 8, 15, 23, and 38 cm using high precision guidance system (real time kinematics). This resulted in 5 treatments and 4 replications. This treatment structure was imposed on three irrigation (high, medium and low) regimes. Analysis of Variance showed no interaction between offset treatments and irrigation or year in corn and grain sorghum yields. The row offset did not impact the overall yield as the yield loss in row farther from the tape was compensated by the increased yield in row moved closer to the tape. The yield distribution ranged from 50% in both rows for 0 cm offset to 59% in row closer to the tape for 38 cm offset. The findings of this study suggests that while driver accuracy is important to maintain equal yields in neighboring crop rows, the overall yields are affected more by irrigation and climatic conditions and not by the row offsets with respect to SDI tape. This data suggests that SDI can be successful regardless of access to high precision guidance systems.

1. Introduction

Subsurface drip irrigation (SDI) is a micro-irrigation method gaining popularity in arid and semi-arid regions around the world. In the United States of America (U.S.A.), Lamm et al. (2012) reported that acreage under SDI systems increased from 164,000 to 260,000 ha from 2003 to 2008. Ayars et al. (2015) reported increase in use of SDI systems on commercial horticulture farms in California, U.S.A. following recent droughts. Similarly, Bordovsky and Mustian (2010) reported increasing adoption of SDI systems for cotton production in the semi-arid Texas High Plains region of the United States. Yield response of crops to SDI has also been encouraging in the semi-arid regions. For example, Lamm and Trooien (2003) concluded from a 10-year research program conducted in semi-arid conditions of Kansas, U.S.A., that subsurface drip irrigation can reduce irrigation water requirement in corn (*Zea mays* L.) by 35–55% without compromising yields compared to center pivot spray irrigation systems. Ayars et al. (2015) reported that the yields either increased or did not change in SDI systems in horticultural crops. Colaizzi and Schneider (2005) reported highest grain sorghum (*Sorghum bicolor* L.) yields for SDI in comparison to center pivot LEPA, and spray irrigation systems under limited irrigation conditions. The authors concluded that SDI system was best suited for limited irrigation conditions of semi-arid Southern Great Plains of the United States. However, crop management, irrigation scheduling, and irrigation rates are important to achieve the greater yield goals at lower water usage (Bresler, 1978; Bozkurt et al., 2006; Payero et al., 2009; Bordovsky and Mustian, 2010), therefore, more agronomic research is required to perfect the SDI systems for individual crops (Lamm et al., 2012).

Some of the direct advantages of SDI system include efficient supply of water by eliminating runoff and deep percolation, sub-surface fertilization, reduced inter-row weed pressure, lower energy cost, and automation (Lamm and Camp, 2007). Conversely, disadvantages of SDI system include smaller wetting pattern, restricted root distribution, water filtration issues, rodent damage, difficulty in monitoring of irrigation, fewer tillage options, and high initial costs (Lamm and Camp, 2007). In SDI, water is applied underground and is seldom seen at the surface, therefore row placement becomes important to ensure plant roots have easy access to water (Bozkurt et al., 2006; Bordovsky and

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https://doi.org/10.1016/j.agwat.2018.06.038
Received 20 November 2017; Received in revised form 22 June 2018; Accepted 27 June 2018

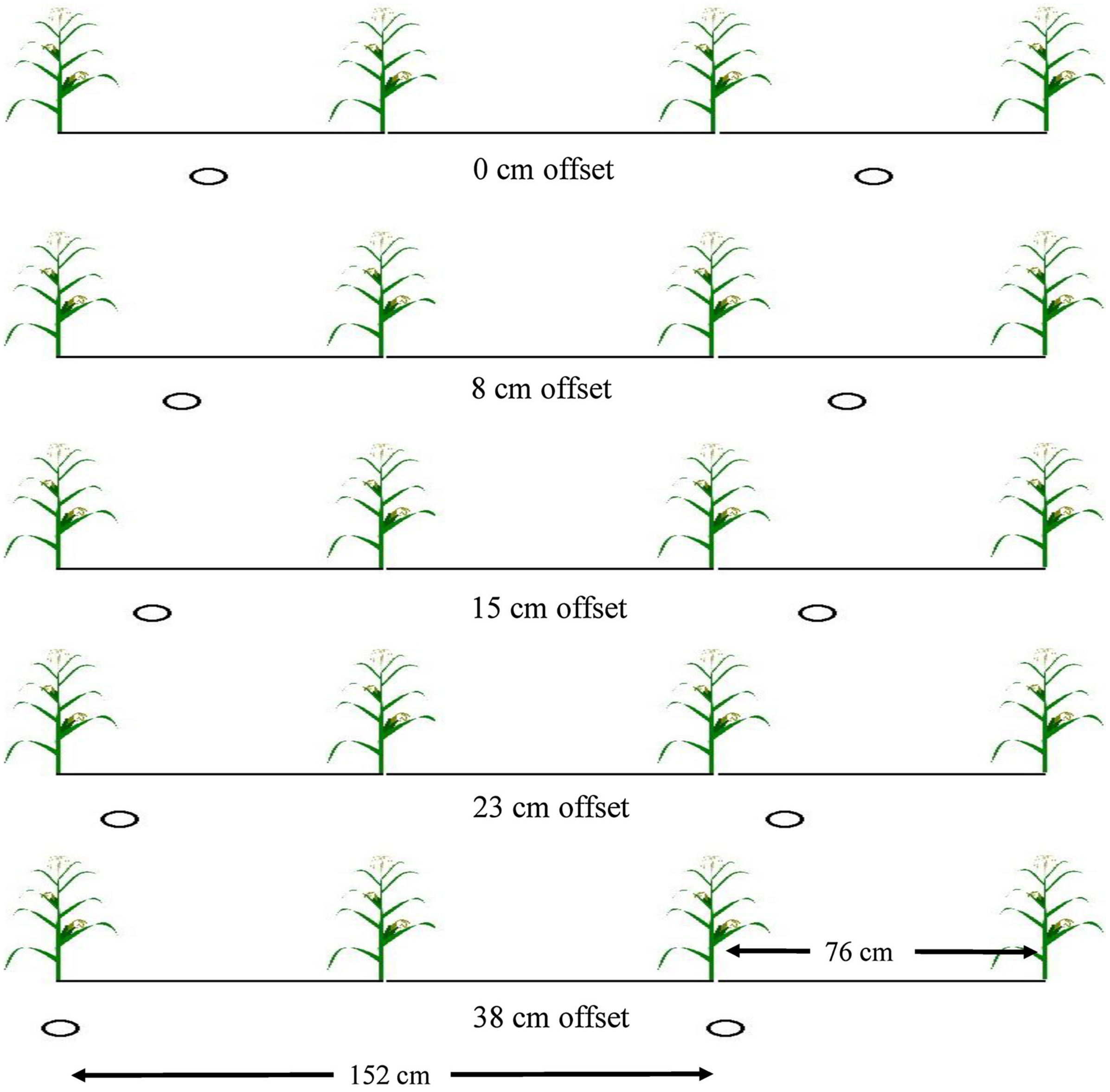

Fig. 1. Drip tape offsets from corn and grain sorghum rows. The drip tape was installed in east-west direction at 152 cm spacing which would supply water every alternate row. Therefore, the ideal placement for crop rows was equidistant from the drip lateral. Hence, the equidistant row placement was 0 cm offset and as the north row moved closer to the tape the offset increased until the north row was right above the tape at 38 cm offset.

Mustian, 2010). Bordovsky and Mustian (2010) noted that crop row placement relative to SDI drip tape can be difficult in a typical alternate row SDI drip tape installation. Bozkurt et al. (2006) reported significant effect of row spacing across lateral tape on corn yield in SDI. The authors reported increase in grain yield of corn as the rows were moved closer to the tape. In this study, yields were also proportional to the amount of irrigation supplied. Grabow et al. (2006) reported dampening of soil moisture to the crop row as the distance of crop row increased from the drip tape. An inadvertent shift in annual crop row relative to the drip tape could result in uneven distribution of water to neighboring crop rows due to smaller wetting patterns (Bordovsky and Mustian, 2010). Visual observation for consistent row placement above the drip tape in SDI cannot be relied upon for consistency of optimum crop row placement. This is important as the decision regarding spacing of drip tape has to be taken before planting and cannot be changed once the crop is growing.

Initial research conducted in the U.S. High Plains region by Lamm (2001) used permanent raised beds to maintain accurate placements of the crop row. However, this requires the beds to be maintained through tillage and presents challenges for narrow row crop production such as wheat which is commonly irrigated in rotation with row crops. Issues regarding installation of drip tape as well as planting of crop rows can be overcome by real time kinematics (RTK). The common utilization of RTK guidance allows for precision return accuracy but there is limited data to determine if this level of precision is needed for corn and grain sorghum. The main objective of this study was to evaluate the impact of offset row placement on yield of corn and grain sorghum over SDI tape under different irrigation conditions. The hypothesis of this research was that as the rows are moved from optimum placements, yields would decline as a function of distances away from this equidistance placement. The findings from this study will add to the understanding of corn and grain sorghum row spacing for SDI systems in similar agro-climatic conditions around the world.

2. Materials and methods

The experiment was conducted at Oklahoma Panhandle Research and Extension Center (36° 35′51″N, 101° 37′ 7″W), Oklahoma, U.S.A.

The 30-year (1981–2010) mean annual temperature and rainfall is 13.4 °C and 435 mm, respectively (US climate data website, 2017). About 70% of the total rainfall is received from May to September, which is also the main growing season in the region. The elevation of this site from the mean sea level is about 1006 m. The major soil type at the study site was Gruver clay loam (Fine, Mixed, Superactive, Mesic Aridic Paleustoll), which consists of a deep (about 2.0 m) soil profile.

The SDI system installed at the center was used for this study. The SDI tape was buried 30 cm below the surface and spaced 153 cm apart such that each tape was supplying water to two crop rows when planted at 76 cm row spacing. The tape contained emitters 60 cm apart along the length of the tape, designed to supply 0.68 l per hour at 68 kPa allowing for 41.6 l per minute (LPM) being supplied to each zone which are 192 m long and 18 m wide (0.35 ha). Pressure was adjusted to 89.6 kPa at the inlet of each zone such that instantaneous flow rates of 53 LPM were achieved on each zone which allowed for application rates of 153 LPM ha^{-1}. The instantaneous flow was evaluated periodically with manual observations of the flow meters (model # 36M251T, NetifimUSA, Fresno, CA, U.S.A.). The flow meters were installed at the inlet of each zone and included totalizers which were used to determine the total water applied during the season. The drip tape was installed using real time kinematic global positioning (RTK GPS) guidance. Therefore, all planting was conducted using this technology to place rows in desired locations relative to drip tape.

A total of 9 irrigation zones were involved in this study. Grain sorghum, corn, and wheat were rotated annually such that each crop was planted on three consecutive zones. Corn was planted into sorghum stubble, sorghum was planted into wheat stubble and wheat was planted immediately after corn harvest. This was done to allow for more successful no-till management to minimize pest pressure. However, as mentioned earlier, this study focused on corn and grain sorghum, and the wheat crop simply served as a rotation crop.

The experimental design was a randomized complete block design with 4 replicates and 5 treatments. The treatment structure was imposed in 3 zones planted to corn and 3 zones planted to grain sorghum. The zones received irrigation at high, medium, and low irrigation rates. Because irrigation was not replicated it was treated as an experimental condition and not a treatment factor in ANOVA analysis. Each plot was 4.57 m (6 rows) wide and 9.15 m long. The treatments consisted of crop row to drip lateral offsets of 0, 8, 15, 23, and 38 cm. Fig. 1 shows the crop row arrangement with respect to the drip tape. Normal row spacing where drip tape is in middle of two crops rows represent 0 cm offset. The crop rows ran parallel to drip tape in east-west direction. Therefore, the north row was getting closer to the tape with increasing offset.

Corn was planted on 5 May in 2014, 21 April in 2015 and 15 April in 2016 in three zones. Corn hybrid Pioneer 1768AMX was planted in 2014 and 2015, whereas corn hybrid Pioneer 1625 was planted in 2016. Grain sorghum was planted on 6 June 2014; 1 June 2015; and 8 June 2016 in 3 zones. Sorghum hybrid Pioneer 84G62 was planted during all three years of study. Figs. 2 and 3 show the irrigation applied rainfall received each month. All corn plots received 8 cm of pre-plant irrigation in 2014 and 2015; and 5 cm in 2016. Post planting irrigation was initiated for the corn on 5 June 2014; 4 June 2015; and 12 May 2016. Irrigation in sorghum was initiated on 19 June in 2014; 26 June in 2015; and 5 July in 2016. Irrigation was terminated at the development of black layer for both crops. Therefore, corn received the last irrigation of the season on 26 August 2014; 25 August 2015; and 24 August 2016. The last irrigation event of the season for grain sorghum was on 11 September in 2014; 28 September 2015; and 9 September 2016. In 2014 and 2015 evapotranspiration (ET) was estimated by the Aquaplanner [Amarillo, TX, U.S.A.] (available at: www.aquaplanner.net) irrigation scheduling program. The aquaplanner scheduling program utilizes a water balance approach to estimate soil water deficit and schedules irrigation events to minimize runoff and drainage while maintaining an allowable water deficient within the rooting zone if irrigation capacity is sufficient to do so. Although the details are proprietary, the commercially available product utilizes an FAO-56 ET model, soil hydraulic properties of the soil mapping unit as provided by SSURGO database and weather data from the U.S. National Weather Service.

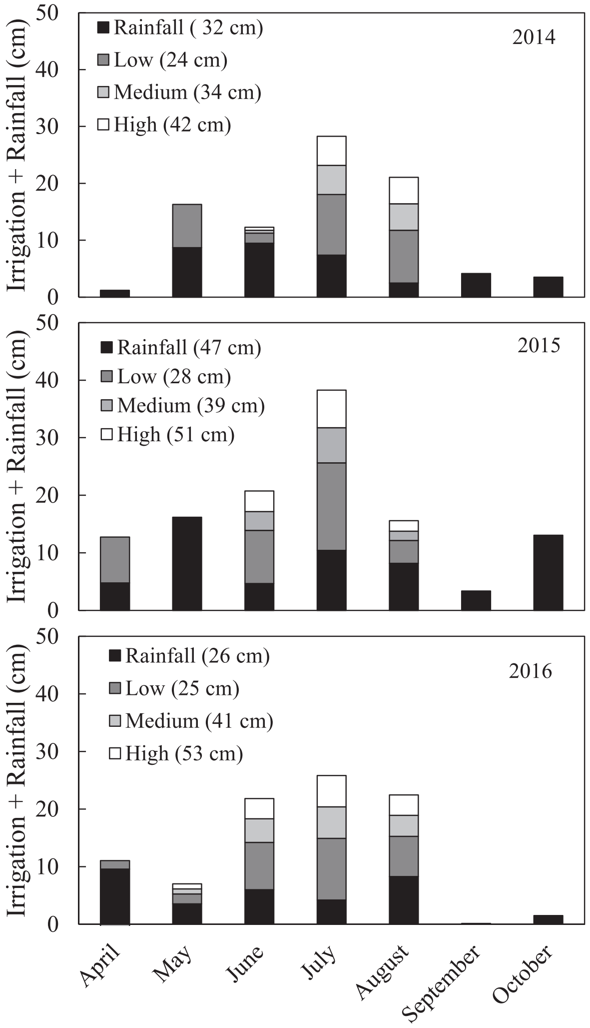

Fig. 2. The stacked bar graph represents cumulative monthly rainfall and irrigation supply in corn for three growing seasons. Irrigation supply includes high, medium and low regimes represented through different colored stacks in the bars. Values in parenthesis next to legend represent the total amount of water supplied during growing season through each irrigation regime and rainfall.

In 2016, the Mesonet (Oklahoma Mesonet, OK, U.S.A.) irrigation scheduling tool was used in combination with adjustments made based on work conducted by Gatlin (2014). The mesonet uses the ASCE Penman Monteith equation (ASCE, 2005) to calculate ET. The Specific details of the mesonet ET product description are provided by Sutherland et al. (2005). The minimum crop coefficient used by the mesonet during the initial growth phase for corn and sorghum is 0.48 and 0.36, respectively. These values were reduced to 0.04 during the initial phase (30 days after planting), because of the lack of surface wetting when using SDI.

In each year, the “high” irrigation regime was irrigated to replace daily ET or at a maximum irrigation rate of 1.0 cm per day in 2014 and 2015 and 0.9 cm in 2016. These maximum daily irrigation rates were used because irrigation capacities in the region are seldom above these daily rates. During the initial phase of the crop production period irrigation was applied when the soil water deficit was greater than 0.5 cm since the last irrigation event. The remaining two zones in each crop received irrigation equal to 75% (medium) and 50% (low) of the

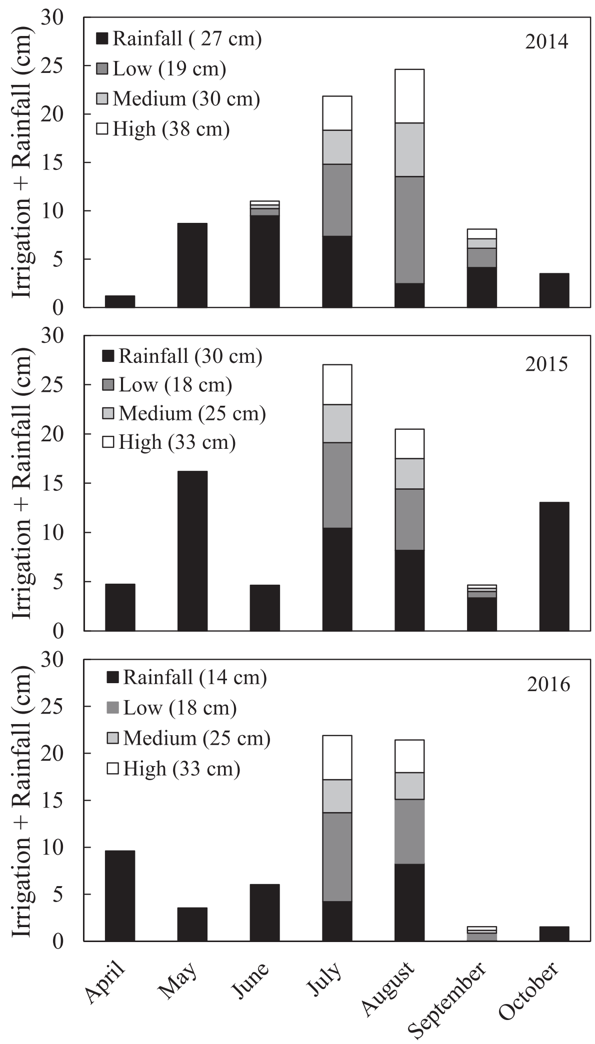

Fig. 3. The stacked bar graph represents cumulative monthly rainfall and irrigation supply in grain sorghum for three growing seasons. Irrigation supply includes high, medium and low regimes, which are represented through different colored stacks in each bar. Values in parenthesis next to legend represent the total amount of water supplied during growing season through each irrigation regime and rainfall.

maximum daily rate. Irrigation was delayed when rainfall was anticipated to allow for optimum rainfall capture. Prior to the growing season, 3 soil cores were collected from each irrigation zone to assess soil water status and pre irrigation water was applied to insure field capacity in the surface 100 cm prior to planting.

Both corn and sorghum received starter fertilizer of 3.3 L ha^{-1} of ammonium phosphate (10-34-0) in row at planting every year. Year 2014 did not receive in-season nitrogen applications because soil test NO_3-N plus NH_4-N in the surface 30 cm of soil was 200 kg N ha^{-1}. Both crops received in-season fertilization in 2015 and 2016. Corn received 34 kg N ha^{-1} as urea ammonium nitrate (UAN) (32-0-0) liquid fertilizer injected into the irrigation system weekly for 8 weeks starting on 15 June. Sorghum received 34 kg N ha^{-1} as UAN liquid fertilizer injected into the irrigation system weekly for 6 weeks starting on 8 July. Total seasonal application of N was 269 kg N ha^{-1} in corn and 202 kg N ha^{-1} in sorghum. In 2016, weekly fertigation of corn was initiated on 10 June and was applied for 8 weeks; and fertigation in grain sorghum was initiated on 30 June and applied for 6 weeks. Corn and sorghum both received pesticide applications to control weeds and insects in accordance with Oklahoma Cooperative Extension Service guidelines.

Corn grain yield was collected at maturity on 8 October 2014; 1 October 2015; and 5 October 2016. Sorghum yields were collected at maturity on 15 October 2014; 14 October 2015; and 29 October 2016. Harvesting was done using a Kincaid 8-xp small plot combine. In 2014 the combined harvest the center 2 rows simultaneously from each plot. In 2015 and 2016, the rows were harvested as individual rows such that the distribution of yield between rows could be utilized. Therefore, data presented allows us to look at the average yield for the two rows as effected by their place over the tape in each year of the study. However, the distribution of yield between the two rows can only be evaluated in 2015 and 2016. Irrigation water use efficiency (IWUE) was calculated by dividing grain yield with total irrigation supplied for the growing season. Analysis of variance (ANOVA) to evaluate treatment effects of whole plot yield and the distribution of yield to the northern row (row moving closer to tape as a function of offset) was conducted using SAS PROC GLIMMIX (SAS Institute, 2008).

3. Results and discussion

Analysis of variation for whole plot corn yield showed no interaction between the offset treatment and the irrigation regime or year. Therefore, offset treatment effects were analyzed across year and irrigation regime. This analysis showed no significant impact of offset on yield. Fig. 4 shows the treatment yields averaged across years for each irrigation regime. The lack of significant difference among treatments demonstrates that row placement is not critical consideration when growing corn on SDI.

Although irrigation was not a replicated treatment factor, its impact on yield in each year is presented in Fig. 5 which shows that in 2014 yields increased with increasing irrigation from low to high. This is similar to data reported by Payero et al. (2006) who found that more water yields larger biomass and larger biomass yields higher ET rates. In contrast, in 2015 and 2016 there was little or no difference between the high and medium irrigation treatments. The above average rainfall in 2015 (Fig. 2) resulted in similar yet excellent corn yields, especially at the medium and high regimes (Fig. 4). In 2016 rainfall was only slightly above average (Fig. 2), however, ET during reproductive growth of corn was above average. As a result, the corn yields were suppressed relative to the water available during this year from irrigation and rainfall. The similarity in yields for the medium and high regimes are likely explained by observation made by Traore et al. (2000) who found that the harvest index of corn is affected by water stress when the stress occurred at flowering and that yields are significantly reduced. Specifically, in 2016 the high irrigated treatment developed a large canopy under well-watered conditions prior to reproductive growth. This was followed by an increase in ET beyond the irrigation rate limit set for this treatment, which caused excessive stress on corn growing in this irrigation regime. In contrast, the corn grown in the medium irrigation regime endured water stress during vegetative

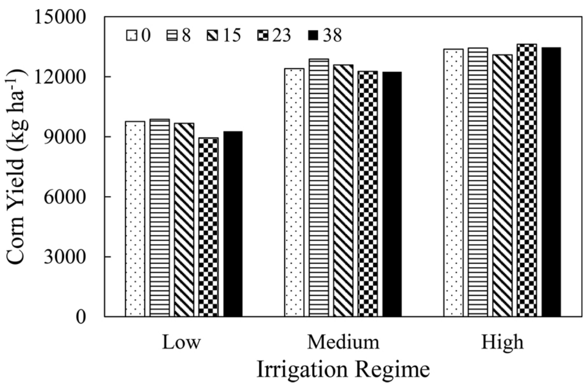

Fig. 4. Corn yield (kg ha^{-1}) averaged across years for each row offset (0, 8, 15, 23, 38 cm) treatment in low, medium and high irrigation regimes. Bars with similar lowercase letter are not significantly different at $p < 0.05$ or vice versa.

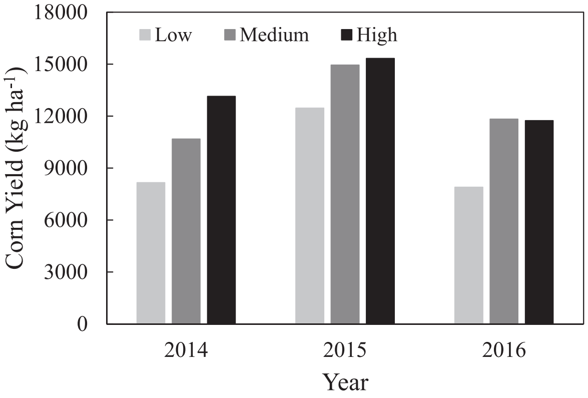

Fig. 5. Corn yield (kg ha^{-1}) averaged across treatments for each study year in low, medium and high irrigation regimes. Bars with similar lowercase letter are not significantly different at $p < 0.05$ or vice versa.

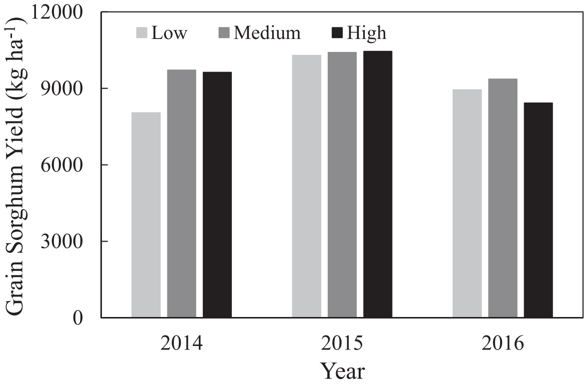

Fig. 7. Grain sorghum yield (kg ha^{-1}) averaged across treatments for each study year in low, medium and high irrigation regimes. Bars with similar lowercase letter are not significantly different at $p < 0.05$ or vice versa.

Table 1
Percentage increase in production of north row which with respect southern row for different offsets as the north row was moved closer to drip tape.

Offset cm	Corn 2015 %	 2016	Sorghum 2-year ave. %
0	51	50a[†]	51a[†]
8	50	50a	53ab
15	51	53a	53b
23	51	53a	54b
38	53	59b	54b

[†] Means followed by the same letter or no letter are not significantly different at the 0.05 probability level.

growth and therefore had a visibly small canopy which caused this crop to be more efficient at utilizing available water for grain production.

Analysis of variance for the grain sorghum yields resulted in no interaction between offset treatment, year, and irrigation regime. Furthermore, as was found in the corn data, no significant difference among offset treatments were observed. Fig. 6 shows the treatment means for each irrigation regime when averaged across years.

Although the irrigation regimes in this study were not replicated and served simply to provide alternative experimental conditions, it is noteworthy to mention similarities in grain sorghum yields among the regimes. Fig. 7 shows that the yields were often similar among the irrigation regimes. In 2014, the low treatment produced average yields that were 17% less than those produced by the medium irrigation regime. In 2015 and 2016, yields were similar among all irrigation regimes. This was certainly due to the above average rainfall in 2015. However, in 2016 the lack of yield response was in part due to greater bird damage in the high irrigation which was delayed in reaching physiological maturity. It is also likely due to its ability to more rapidly recover from water stress after rainfall or irrigation as well as its ability to scavenge soil moisture from greater depths under limited irrigation conditions (Gatlin, 2014). Specifically, early season water stress in the limited irrigation regimes (low and medium), allowed for more effective rooting and subsoil water extraction. This combined with timely rainfall allowed for comparable yields to the fully irrigated regime.

The offset treatments influenced the distribution of corn yield between the two rows harvested. The ANOVA analyses showed no interaction between offset treatment and irrigation regime, but there was an interaction between offset treatment and year. Therefore, means presented in Table 1 are separated by year for corn. At 0 cm offsets both north and south row (with respect to tape) contributed similar amount (50%) to total yield in both years. However, as the north corn row moved closer to the tape, the percentage of yield it produced increased to 59% in 2016. Significant differences were not observed in 2015, presumably because the above average rainfall reduced the importance of row placement in controlling water distribution in the soil.

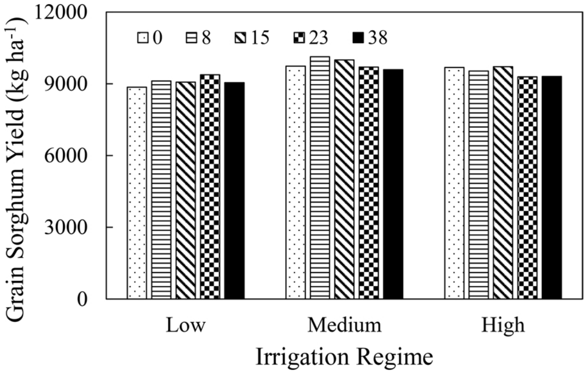

Fig. 6. Grain sorghum yield (kg ha^{-1}) averaged across years for each row offset (0, 8, 15, 23, 38 cm) treatment in low medium and high irrigation regimes. Bars with similar lowercase letter are not significantly different at $p < 0.05$ or vice versa.

ANOVA analysis of grain sorghum data found no interaction among offset treatment and year or irrigation. However, offset treatment did significantly impact the distribution of yield between the two rows. When averaged across year and irrigation regime the percentage of yield distributed to the northern grain sorghum rows increased as it moved closer to the tape (Table 1). This is similar to the observations made by Bordovsky and Mustian (2010) when irrigating cotton (*Gossypium hirsutum* L.) with rows offset from the tape. They found that cotton rows moved closer to the tape showed an increase in yield while the rows moving further away produced a declining yield. Although, soil moisture distribution data was not collected in this study, previous studies conducted on soil moisture distribution along SDI tape have reported decline in soil moisture distribution with increasing distance from tape and that the decline was prominent with reducing irrigation supply (Grabow et al., 2006; Badr and Abuarab, 2013). Therefore, the yield declines from the crop rows as they move away from the drip tape were expected.

Irrigation water use efficiency (IWUE) was calculated by dividing yield with irrigation supplied. Fig. 8 shows the average IWUE of different offset treatments for each irrigation regime across the years. Irrigation water use efficiency in our study was lower than what reported for corn in the Great Plains region of the United States. For example, Payero et al. (2009) reported IWUE efficiency of 7.09 kg m^{-3} for corn in Nebraska, U.S.A. In contrast, the IWUE values calculated for grain sorghum under the low and medium irrigation were greater than those

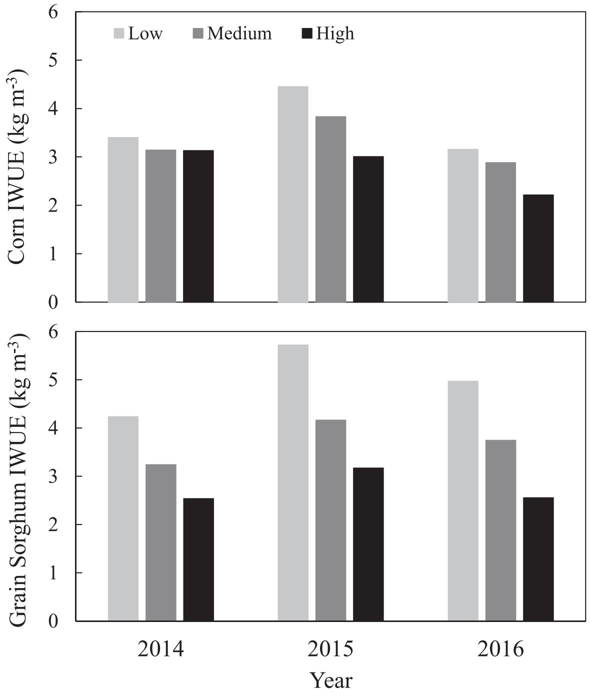

Fig. 8. Irrigation water use efficiency (IWUE) for corn and grain sorghum across row offset treatments for each irrigation regime in individual study year. The IWUE was calculated by dividing average grain yield in corn or grain sorghum across row offset treatments by total irrigation supplied to the corresponding irrigation regime during that growing season. Bars with similar lowercase letter are not significantly different at $p < 0.05$ or vice versa.

previously reported. In fact, Colaizzi and Schneider (2005) reported IWUE of 2.48 kg m^{-3} for grain sorghum under SDI systems in the Southern Great Plains of the United States. Higher IWUE in Nebraska could be attributed to lower ET demands in higher latitude region of the United States. Besides, IWUE for corn in this study was higher than those reported in other semi-arid areas of the world. For example, El-Hendawy et al. (2008) reported IWUE ranging from 1.2 kg m^{-3} for high irrigation to 0.73 kg m^{-3} in 60% ET irrigation treatment in Egypt. Bozkurt et al. (2006) reported IWUE for corn ranging from 1.12 to 1.41 kg m^{-3} in semi-arid region of Turkey. Vories et al. (2009) reported IWUE for corn ranging from 1.0 to 1.5 kg m^{-3} the Mid-South (Arkansas) region of the United States.

4. Conclusions

The study was conducted to evaluate the effect of different row offsets with respect to drip tape position under different irrigation regimes. The results of this study show that row placement does not significantly influence corn or grain sorghum yield regardless of irrigation rate. Harvest of individual row yield found that as the rows were moved, the yield in rows moved closer to the tape would increase, thereby offsetting the yield loss in the rows moved away from the tape. Overall, this study suggests that while driver accuracy is important to maintain equal yields in neighboring crop rows, the overall yields are affected more by irrigation and climatic conditions and not by the row offsets with respect to SDI tape.

Acknowledgements

This material is based on work supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-68007-25066. Opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the supporting agencies.

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