Final Report
OAES-OCES Water Grant

Title: Developing Management Strategies for Subsurface Drip Irrigation in the Oklahoma Panhandle

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Publications:

Abstracts:

1. Taghvaeian, S., J. Warren, J. Gatlin, R. Kochenower, C. Murley. 2014. Improving Agricultural Water Resources Management Using Ground-based Infrared Thermometry. Presented at the AGU Fall Meeting. San Francisco, CA, Dec. 15-19.

Field Tours:

1. Gatlin, J., and J. Warren. 2014. Subsurface Drip Technology & Research. Fall Crops Tour. Goodwell, OK 13 Aug.
2. Warren, J. Subsurface Drip Irrigation. Sorghum Tour. Goodwell, OK 25 July.

Student participation:

Student Status	Number	Disciplines
Undergraduate	1	Agronomy, PSU
M.S.	1	Plant and Soil Sciences, OSU
Ph.D.		
Post Doc		
Total	2	

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Problem and Research Objectives:

Various sources can be cited to demonstrate the fact that water availability in the Ogallala Aquifer is declining. For example, the USGS found that water levels had decline by as much as 100 ft under Texas County, OK between the 1940s and 1990s. The report went on to suggest that if withdrawal continued at the same rate as in 1996 that the water level would decrease by an additional 20-25 ft under Texas County, OK by 2020 (Luckey, et al. 2000). This declining water table is decreasing pumping capacity for agricultural producers in the Panhandle region. The adoption of new irrigation water management strategies are needed to improve water use efficiency in the region to offset this decline. Also, adoption of improved efficiency systems will be imperative if government restrictions on pumping are imposed in the future.

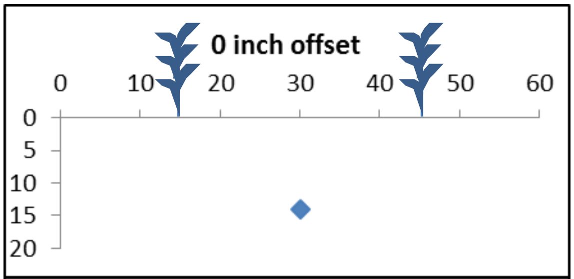
Previous research efforts in the High Plains Regions have shown that subsurface drip irrigation (SDI) provides superior water use efficiency compared to center pivot irrigation systems. In fact, Lamm and Trooien (2003) summarized 10 years of research in Kansas and concluded that irrigation water use for corn can be reduced by 35-55% using subsurface drip irrigation compared to commonly used irrigation systems in the region. Therefore research is not need to demonstrate the improved efficiency. However, research is needed to evaluate how variations in crop management will impact the performance of SDI in the region.

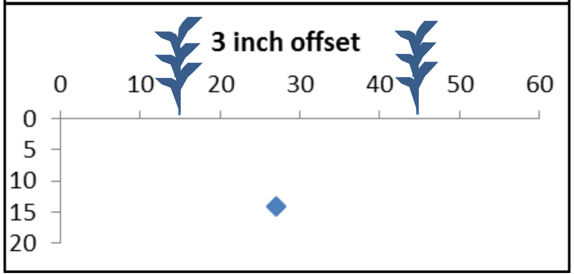
For the last two years we have been utilizing the subsurface drip irrigation system located at the Panhandle Research and Extension center to evaluate the yield response of corn compared to sorghum under limited irrigation water availability. This effort has provided opportunity for us to engage producers regarding the use of drip irrigation, which allows us to learn why producers are apprehensive in adopting this technology. In addition to its increased cost, producers are currently not certain that the technology will fit their production system. Specifically, information is needed on how crop row placement will impact crop performance under drip with respect to stand establishment and yield.

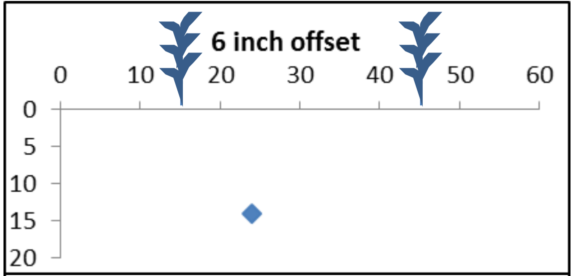
In order to minimize costs of SDI systems the drip tape buried at intervals such that one row of drip tape will irrigate two crop rows. Research on cotton row placement has previously been conducted in the Southern High Plains near Halfway, Texas. This research found that for cotton planted on 30 inch row spacing, yield was significantly reduced when the offset between the drip tape and crop rows was 15 inches. This yield reduction occurred at the “high” irrigation rate (approximately equal to daily evapotranspiration). At the “low” irrigation rate (approximately half of daily evapotranspiration) yield was reduced by 2% but this was not a significant reduction. The researchers evaluated yield in each row and found that at low irrigation the yield for the cotton row nearest the tape was equivalent to yields in the “high” irrigation treatments and that this compensated for the yield loss in the cotton row place 45 inches from the tape, making the average similar to the yield when rows were equidistance from the tape (each was 15 inches from the tape. In contrast, at “high” irrigation the cotton row placed 45 inches from the tape simply reduced the average of the two rows because the yield was not increased in the cotton row directly over the tape (Bordovsky et al. 2010). A similar analysis of the effect of crop row placement has not been conducted on corn or sorghum in the Southern Plains. Because the buried drip tape cannot seen from the surface, the potential for row placement error during planting is high. The use of high precision GPS systems can reduce this error, but research is needed to determine the accuracy required. Also, producers prefer to alternate row locations to improve ease of planting. This reduces the need to move root crowns out of the planting row. Producers need to know if this practice of alternating row locations from one year to the next will adversely impact crop performance. Sorghum and especially corn are more sensitive the water availability than is cotton. It is therefore expected that these crops will be more sensitive to row placement.

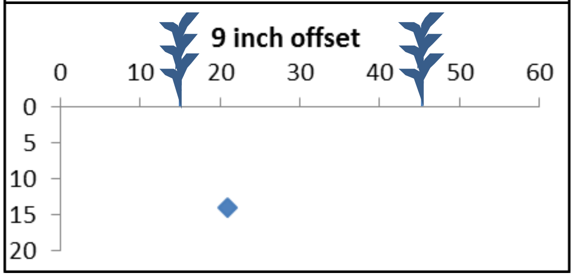
Objectives:

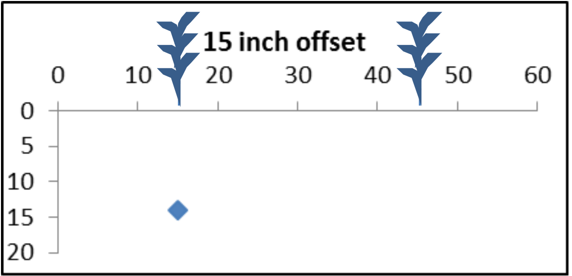
The objective of this project is to evaluate how crop row placement will influence corn and grain sorghum yield response at irrigation regimes of 50, 75, and 100% of full irrigation. A secondary objective was to evaluate canopy temperature measurements as a method to assess water stress in corn and sorghum. This will provide preliminary data needed to evaluate water stress thresholds and ultimately irrigation scheduling protocols.











Methodology:

This research utilized the SDI system at the Oklahoma Panhandle Research and Extension Center near Goodwell, OK. The study used 6 irrigation zones, each are 630 ft long and 60 ft wide. Within each zone subsurface drip irrigation tape is located 12 inches below the surface and spaced 60 inches apart such that each tape will supply water to two crop rows when planted 30 inches apart. The tape contained emmiters 24 inches apart along the length of the tape, designed to supply 0.18 gallons per hour at 10 psi allowing for 11 gallons per minute (GPM) being supplied to each zone. Pressure was adjusted to 12 psi at the inlet of each zone such that instantaneous flow rates of 15 GPM were achieved on each zone.

Within each zone, experiments were established to evaluate the impact of crop row placement on yield, soil moisture, and canopy temperature. The experimental design for each was a randomized complete block design with 4 replicates and 5 treatments. The treatments, as illustrated in figure 1 consisted of crop rows being planted at 0, 3, 6, 9, and 15 inch offsets (Figure 1) from the drip tape. These offset treatments were applied at planting using real time kinematic global positioning (RTK GPS) Guidance. Each plot was 15ft (6 rows) wide and 30 ft long.

On May 5th corn (hybrid Pioneer 1768AMX) was planted in 3 zones and on June 6th sorghum (Hybrid Pioneer 84G62) planted in 3 zones. One zone for each crop was designated to receive irrigation at a rate equal to evapotranspiration as estimated by the Aquaplanner (www.Aquaplanner.net) irrigation scheduling program. The remaining zones were designated to receive irrigation equal to 75 and 50% of this fully irrigated rate. Irrigation was applied when soil water deficit for the fully irrigated treatment dropped below 0.3 inches. At this threshold, irrigation was applied to the fully irrigated treatments to replace ET since the last irrigation event. When rainfall was anticipated irrigation was delayed. All Zones planted to corn received the same amount of irrigation water between planting and June 24th to ensure uniform soil profile moisture and crop emergence. Between June 24 and harvest the 75% and 50% irrigation regimes were imposed on the corn.

After emergences Apogee SI-111 Infra-Red Thermometers (IRTs) were installed and maintained one meter above the top of the canopy at a downward angle of 30° below horizon toward northeast to measure canopy temperature (Tc). Soil moisture was measured over 12-16 inch depth, using the Campbell Scientific CS-655 sensors. Data measurement and storage was performed by a CR1000 data-logger. A nearby Mesonet weather station provided required weather parameters on an hourly basis.

Figure 1: Drip tape offset from crop row. (Point indicates location of drip tape at each offset).

Three stress indexes were calculated using the canopy temperature data. The time-temperature threshold (TTT) was calculated as the total time when the canopy temperature was above the biologically identified threshold. In this study a temperature of 28 °C was used. The second stress index used was the degrees above non-stressed (DANS) threshold. This was calculated as the stressed canopy temperature minus the non-stressed canopy temperature. The Third threshold calculated was the canopy temperature ration which was calculated as the non-stressed canopy temperature divided by the stressed canopy temperature. The canopy temperature for the 100% irrigation treatment was used for the non-stressed canopy temperature and the 75 and 50% irrigation treatments were used as the stressed canopy temperatures in these threshold calculations.

Corn grain yield was collected at maturity for on Oct 8th and sorghum yields were collected at maturity on Oct. 15 using a small plot combine to harvest the center 2 rows from each plot. In addition, the 2nd and 5th rows from each plot were harvested individually. This allowed for an assessment of how distance from the drip tape influenced individual row yields.

Principal Findings and Significance:

Irrigation Applied

Figure 2 shows the resulting amounts of water applied to each of these corn zones. Soil moisture at planting of sorghum was sufficient to result in uniform emergence across all three zones, therefore on June 26 irrigation was initiated on the sorghum with the fully irrigated treatment being irrigated when the soil water deficit fell below 0.3 inches. As with corn, the remaining sorghum zones received 75 and 50% of this fully irrigated zone. Figure 2 shows the resulting amounts of water applied to each of these Sorghum zones.

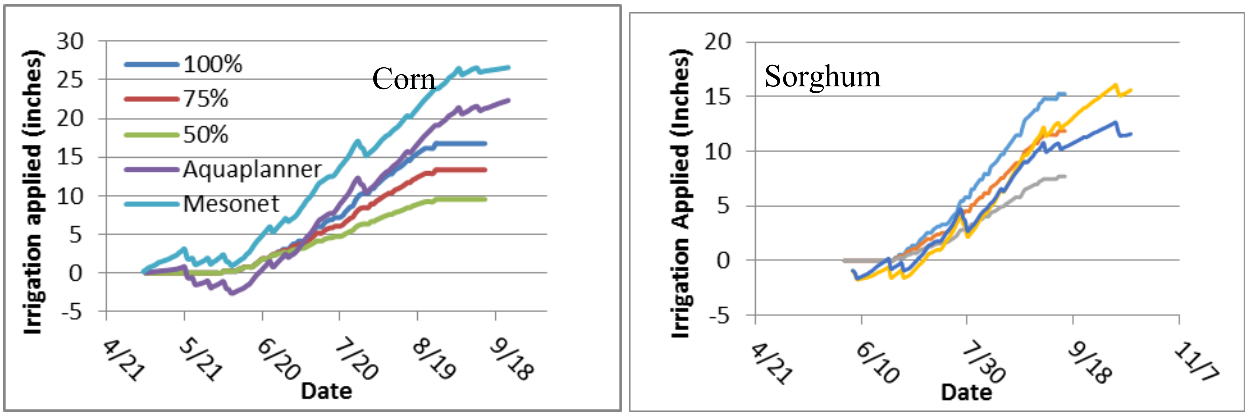


Figure 2: Cummulative Irrigation water applied during growing season for Corn (100%=16.5 inches, 75%=13.5 inchs and 50%=9.4 inches) and sorghum (100%=15.1 inches, 75%=11.7 inches and 50%=7.6 inches). The soil water deficit (ET-rainfall) as calculated by the mesonet and aquaplanner models are shown for each crop(When the water deficit is above an irrigation applied this idicates soil water depletion. When a water deficit is below an irrigation applied this indicates soil water recharge.)

According to the Mesonet station at Goodwell, the total amount of rainfall over the period between planting and harvest was 12.7 for corn. Furthermore the water deficit as calculated as the difference between ET and rainfall was 26.3 inches when the mesonet ET is used. In contrast, the water deficient was 22.2 inches when the aquaplanner ET estimate is used. The discrepancy between the two water deficit values results from the aquaplanner using a lower evaporation rate because it accounts for the decreased evaporation from drip irrigation. The reduced evaporation rate results from the subsurface application of water which prevents excessive wetting of the soil surface, this is particularly influential on ET estimates within the first 45 days after planting before canopy closure when Evaporation from the soil surface is large component of ET. The 100% irrigation treatment as applied was lower than required to replace 100% of ET experienced between planting and harvest because initially irrigation flow rates were overestimated, therefore each irrigation was 90% of the target application. Secondly, irrigation was terminated, with a final application on Aug. 26th, to allow the crop to senesce because physiological maturity had been achieved. During the period between this final irrigation event and termination of the simulation on Sept. 23. the mesonet estimated ET was 5.5 inches and the Aquaplanner estimated ET was 5.2. When these values are subtracted from the water deficits reported above of 26.3 and 22.2 the irrigation period targets of 20.8 and 17 inches can be determined. This shows that the actual water applied for the 100% treatment (16.5 inches) was 4.3 and 0.5 inches below the irrigation required when determined by the water deficits calculated by the mesonet and aquaplanner, respectively.

For sorghum, the total rainfall over the period from planting to harvest as determined by the mesonet were 10.6 inches. The water deficit as determined by the mesonet and aquaplanner during this period (June 6th through Oct. 15) was 11.6 and 15.6 inches, respectively. This suggest that the 100% and 75% irrigation sorghum received full irrigation during the study and the 50% irrigation received over 80% of its water requirement. This apparent over application of irrigation resulted from the assumption that rainfall water was lost from the system due to runoff/drainage during early season rainfall events. Specifically, the aquaplanner assumed that 2.3 inches were lost to drainage to below the rooting zone and that runoff reduced the effective rainfall to 6.5 inches. Yield data presented below showing no significant differences in yield between the 100 and 75% treatments suggest that these assumptions were not accurate and that both treatments were fully irrigated.

Corn Grain Yield

Table 2 shows average corn grain yields collected from the 2 center rows from each offset treatments within each irrigation regime. There were no significant yield differences within the irrigation regimes. However, when data was averaged across irrigation regimes significant differences were observed. Specifically, the yields measured in the 0 and 3 inch offset treatments were significantly higher than the yield observed in the 9 inch offset treatment. However there was no significant difference between the 6, 9 and 15 inch offset treatments. This data shows that driver accuracy is an important factor influencing corn yield when subsurface drip irrigation is used.

Table 1: Average corn grain yields from different row offsets within each irrigation regime as well as the average yield across irrigation regimes and within irrigation regimes.

Offset	50%	75%	100%	Average
Inches	--------------------Bu acre^{-1}--------------			
0	132	178	206	172a†
3	140	177	212	177a
6	131	172	208	170ab
9	119	151	204	158b
15	120	163	206	163ab
Average	129	168	207	

†means followed by the same letter are not significantly different at the 0.05 probability level

Figure 3 shows the corn grain yield harvested from the individual north and south rows for each offset treatment averaged across irrigation regimes. The data was averaged across irrigation regimes because no significant differences among offset treatments were found within any of the three irrigation regimes. The data in Figure 3 shows that row offset for the north row did not significantly influence yield. This shows that moving the row from 15 inches from the tape to 0 inches from the tape did not result in increased yields. Data from the south row reported in Figure 3 shows that yields declined as this row was moved from 15 to 30 inches (0 to 15 inch offset treatments, respectively) away from the drip tape. This decrease in yield is responsible for the yield declines reported in table 1. This is similar to the findings of Bordovsky et al. (2010) where whole plot yield for fully irrigated treatments declined because the yield in the row that was moved closer to the tape did not increase in proportion to the decreased yield observed in the row that moved away from the drip tape. However, under deficient irrigation Bordovsky et al. (2010) found that cotton lint yields in individual rows increased as the rows were moved closer to the drip tape for deficient irrigation. Furthermore, Bordovsky et al (2010) found that this increase in yield offset the decrease in yield found in rows moved further from the drip tape.

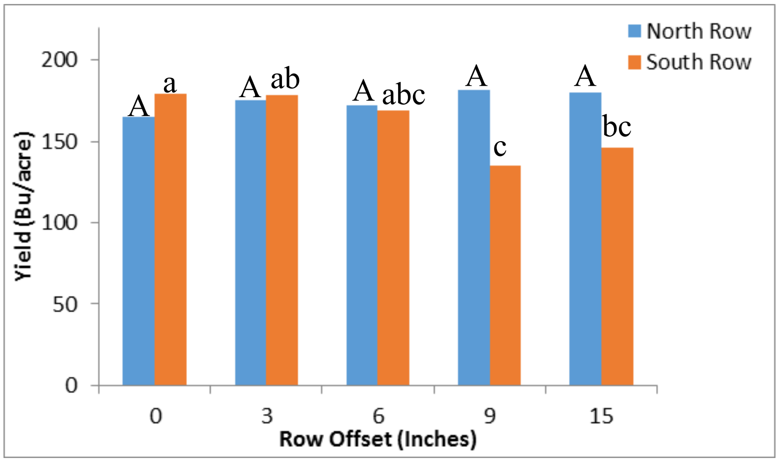


Figure 3: Corn grain yield from the north and south rows averaged across irrigation regimes (North row yields with the same capital letter are not significantly different at the 0.05 probability level, south row yields followed by the same lower case letters are not significantly different at the 0.05 probability level).

Grain Sorghum Yield

Table 2 shows average grain sorghum yields collected from the 2 center rows from each offset treatments within each irrigation regime. Grain sorghum yields were not significantly influenced by offset treatment within any of the irrigation regimes, nor was a significant difference found when data was averaged across irrigation regimes. This is similar to the findings presented by Bordovsky et al. (2010) for limited irrigation of cotton when evaluating the impact of row offset and irrigation rate on cotton lint yield. It is interesting to note that the 75% irrigation (12 inches) regime produced yields that are equivalent to that achieved with the 100% treatment (15 inches) indicating that the Aquaplanner over estimates irrigation water requirement for this crop.

Table 2: Average grain sorghum yields from different row offsets within each irrigation regime as well as the average yield across irrigation regimes and within irrigation regimes.

Offset	50%	75%	100%	Average
Inches	--------------------Bu acre^{-1}--------------			
0	120	150	152	141
3	127	164	149	147
6	128	154	152	145
9	133	146	152	144
15	126	151	154	144

Average	127	153	152

†means followed by the same letter are not significantly different at the 0.05 probability level

Analysis of individual row yield data found that offset treatments significantly influence yields in each irrigation regime (Figure 5). As expected in each irrigation regime the yield in the north row increased with increased offset as the row was moved closer to the drip tape and the yield in the south row decreased as it was moved further from the drip tape. In the 50% and 75% irrigation regime moving the north row closer to the drip tape dramatically increased the observed yield by 58 and 74 bushels, respectively. In contrast, yields in the 100% irrigation regime increased by 40 bushels. The grain yield in the south row decreased proportionally which resulted in the lack of yield differences presented in table 2, which represent the average yield of 2 rows. Recall that yields in the 100 % and 75% irrigation regime presented in table 2 are similar. With this in mind, it is interesting to note that individual row yields were maximized at 204 bushels in the 75% irrigation regime in the 15 inch offset treatment. Recall that this row was located directly over the drip line. Unfortunately, the south row in this treatment resulted in a yield of 78 bushels/acre. In contrast, the yields in the north and south rows in the 15 inch offset treatment were 165 and 114 bushels/acre, respectively, in the 100% irrigation regime. This shows that individual row yields are more sensitive to distance from drip tape in the 75% irrigation regime than in the 100% irrigation regime, presumably because water was more effectively delivered to the south row in the 100% regime. The yield of 204 bushels/acre observed in the north row in the 75% irrigation regime suggests that competition within rows did not limit yields to 152 bushels/acre yields reported in table 2 for fully irrigated sorghum suggesting that competition between rows limited yields.

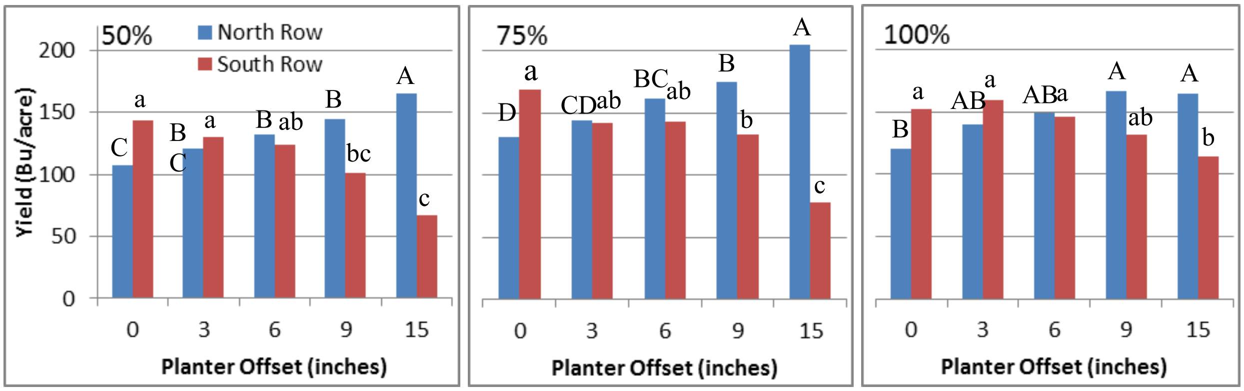


Figure 4: Grain sorghum yield from the north and south rows for the 50%, 75%, and 100% irrigation regimes (within each irrigation regime, the north row yields with the same capital letter are not significantly different at the 0.05 probability level, within each irrigation regime, south row yields followed by the same lower case letters are not significantly different at the 0.05 probability level).

The completion between rows observed in the sorghum data is interesting and may result from completion of nitrogen or water. Supplemental N was not applied after planting because soil analysis showed 170 lbs of nitrate nitrogen in the top 18 inches of soil, which has been found to be adequate to optimize productivity under overhead irrigation. This level of residual nitrate may be insufficient in a drip irrigated system because soil profile root exploration is limited to the portion of the profile wetted by the drip system.

Relationships between soil moisture and Yield

Figure 5 shows the relationship between 60 day average volumetric soil water content measured at a depth of 12-16 inches in the south rows of corn and sorghum in treatments with offsets of 0, 6 and 15 inches (sensors and crop rows were 15, 21 or 30 inches away from drip tape). This data demonstrates that corn grain yields are more sensitive to surface soil moisture than grain sorghum. This is somewhat contradictory to the observation that sorghum yields were more sensitive to row distance from drip tape. However, the strong correlations between VWC and corn yield in figure 5 can be explained by the substantial differences in corn yield between irrigation regimes. Specifically, the average corn yields were 129, 168 and 207, for the 50, 75, and 100% irrigation regimes, respectively. In contrast, the sorghum yields were 127, 153, and 152 bushels/acre, for the 50, 75, and 100% irrigation regimes, respectively. Although single row sorghum yields within an irrigation regime were sensitive to distance to the drip tape (Figure 4), the relationship in figure 5 is stronger for corn because of greater differences in corn yield between the three irrigation regimes.

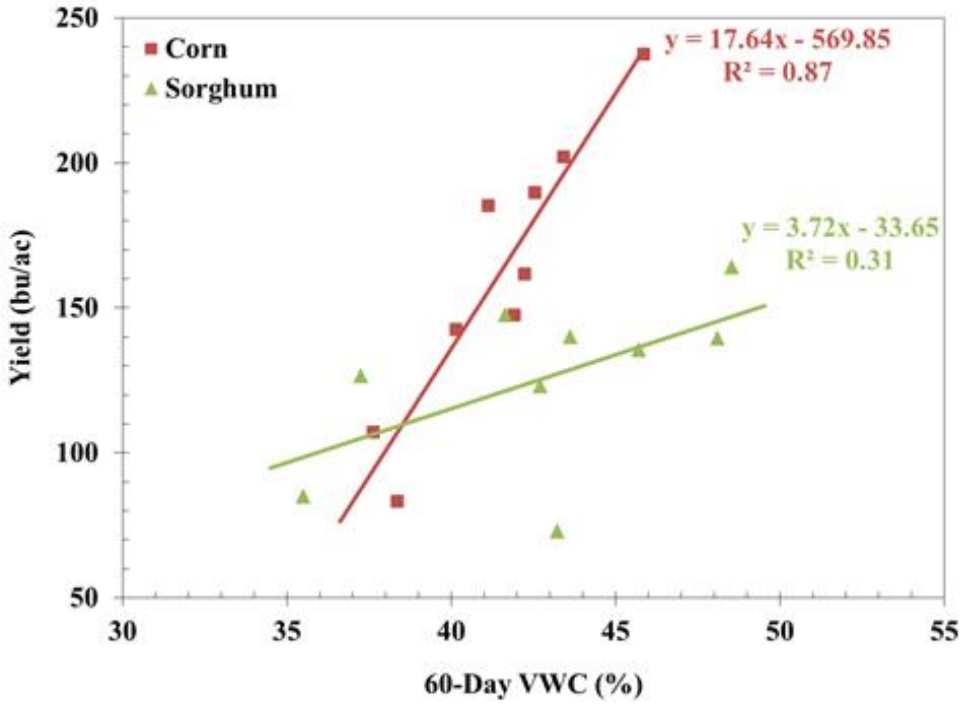


Figure 5: the relationship between yield observed in the south rows and the volumetric water content (VWC) measure within the south rows at 6 inches below the soil surface. The VWC data were averaged over a 2-month period which was Jul 9 to Sep 7 for corn and Jul 18 to Sep 15 for sorghum.

Stress indexes using Canopy Temperature

Time-Temperature Threshold (TTT)

Excluding the days when TTT was zero, the 2-month daily average TTT was 426, 419, and 447 minutes for 100%, 75%, and 50% irrigated corn, respectively (Figure 6). These values are similar to the 443 and 461 minutes estimates for 100% and 67% total ET replacement irrigation levels reported by Wanjura and Upchurch (2000). The maximum corn TTT was 660 minutes (11 hours), estimated on July 26th at both deficit irrigation levels.

Other studies have reported smaller TTT values for similar irrigation levels of corn. But this is mainly due to the fact that these studies used a larger solar radiation threshold in filtering TTT values, thus integrating the results over a shorter period of the day (mostly afternoons).

For sorghum, the average TTT was 324, 336, and 428 minutes for 100%, 75%, and 50% irrigation levels, respectively (Figure 7). The larger inter-treatment TTT difference for sorghum compared to corn could be attributed to larger water application and soil moisture difference for the sorghum. It may also indicate that this threshold is more sensitive for sorghum. The maximum TTT was 660 minutes at 50% irrigation level, measured on Sep. 3rd, 2014, when air temperature reached 37.2 °C (RH was 19%).

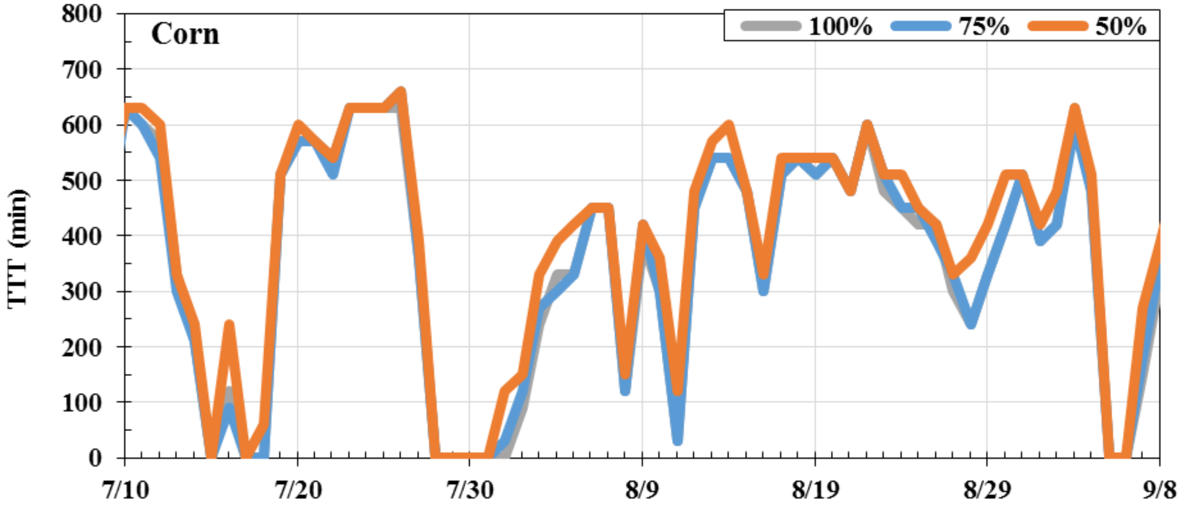


Figure 6: The time-temperature threshold for corn in the 100, 75, and 50% irrigation regimes.

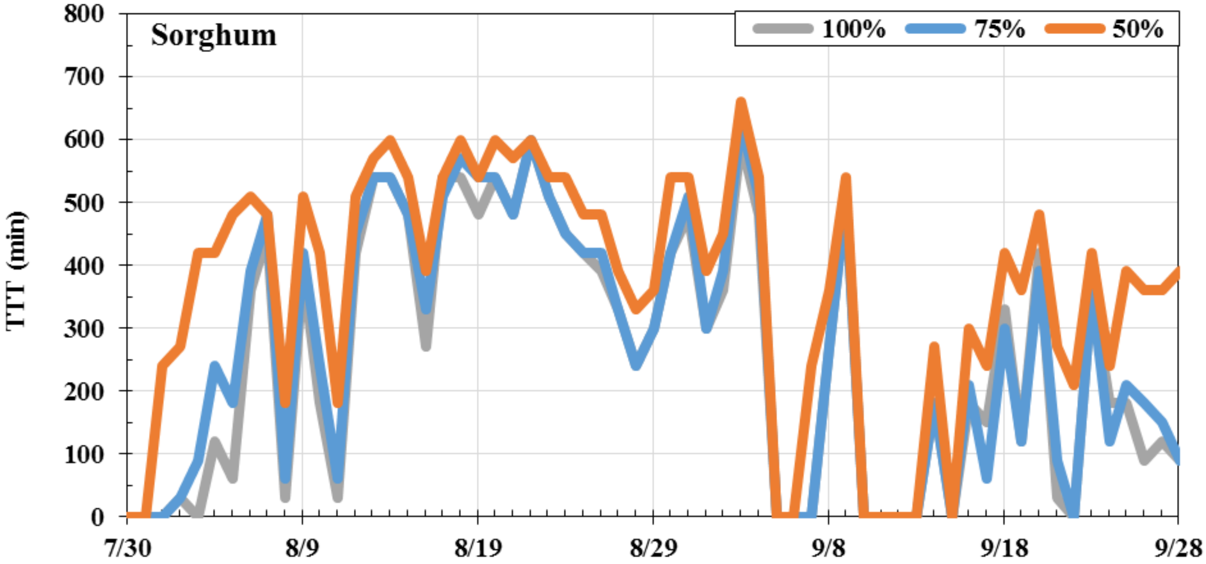


Figure 7: The time-temperature threshold for sorghum in the 100, 75, and 50% irrigation regimes.

Degrees Above Non-Stressed (DANS)

The 60-day average DANS was -0.1 and 1.4 °C for 75% and 50% irrigated corn, respectively. The average values were larger at 0.2 and 2.4 °C for the same irrigation levels of sorghum. The maximum DANS was 3.9 and 4.8 °C for corn and sorghum. Figures 8 and 9 represent daily variations in DANS for the canopy temperature measurements made during 1300-1400 hr. To assist with interpreting DANS dynamics (solid lines), the relative Volumetric Water Content (VWC) is also graphed in dashed lines for each irrigation treatment.
In case of corn, DANS had a rapid decline on Aug 27th, when 23 mm of rainfall was recorded by the adjacent weather station. This event was followed by another 36 mm of rain that fell during the next two days.

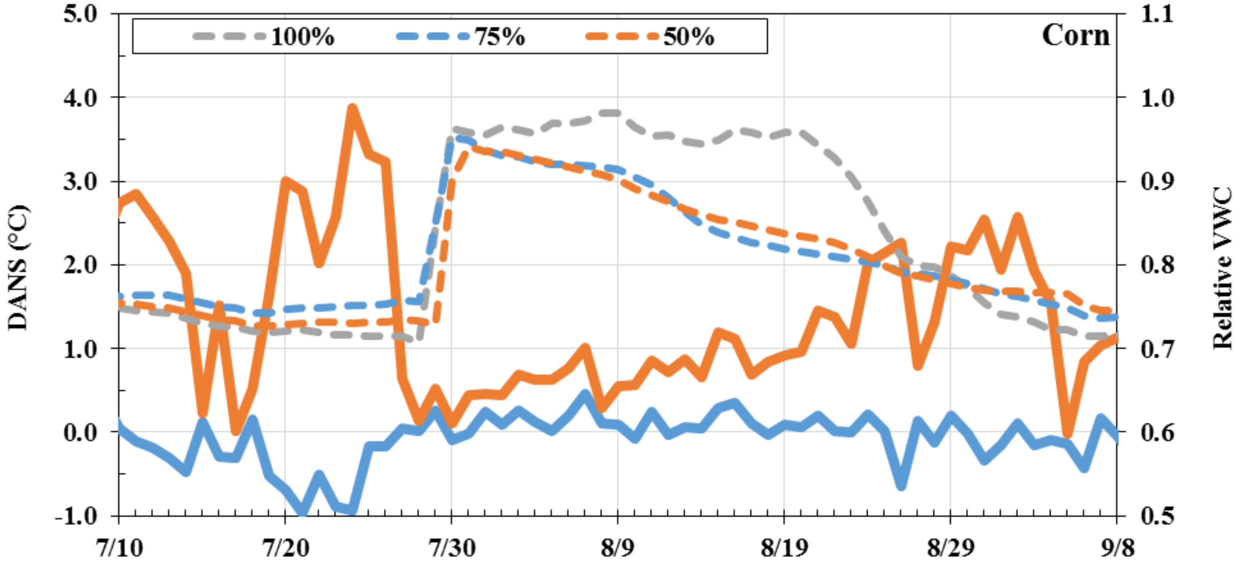


Figure 8: Daily variations in DANS for the corn canopy temperature measurements made during 1300-1400 hr

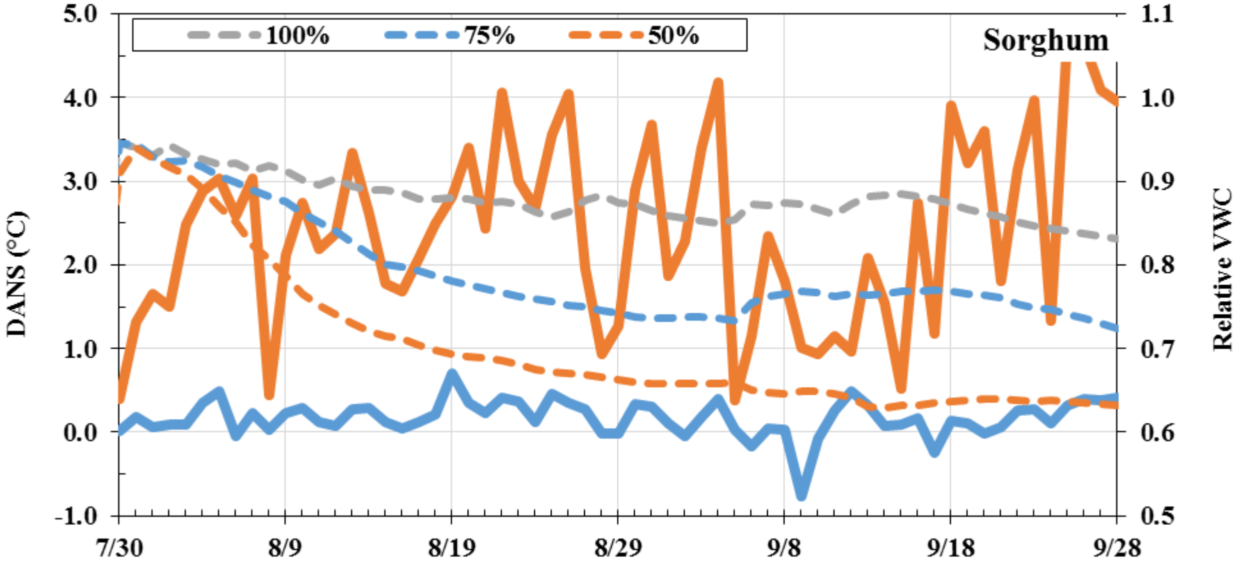


Figure 9: Daily variations in DANS for the Sorghum canopy temperature measurements made during 1300-1400 hr

Canopy Temperature ratio

The canopy temperature ratio had a small range of 0.99-1.03 for 75% irrigated corn, with an average of unity. The range was larger for 50% irrigated corn at 0.90-1.00, (average 0.96). For sorghum, the range was 0.95-1.02 and 0.85-0.98 for 75% and 50% irrigations, respectively. The average Tc ratio was 0.99 and 0.92 for the same two irrigation treatments.

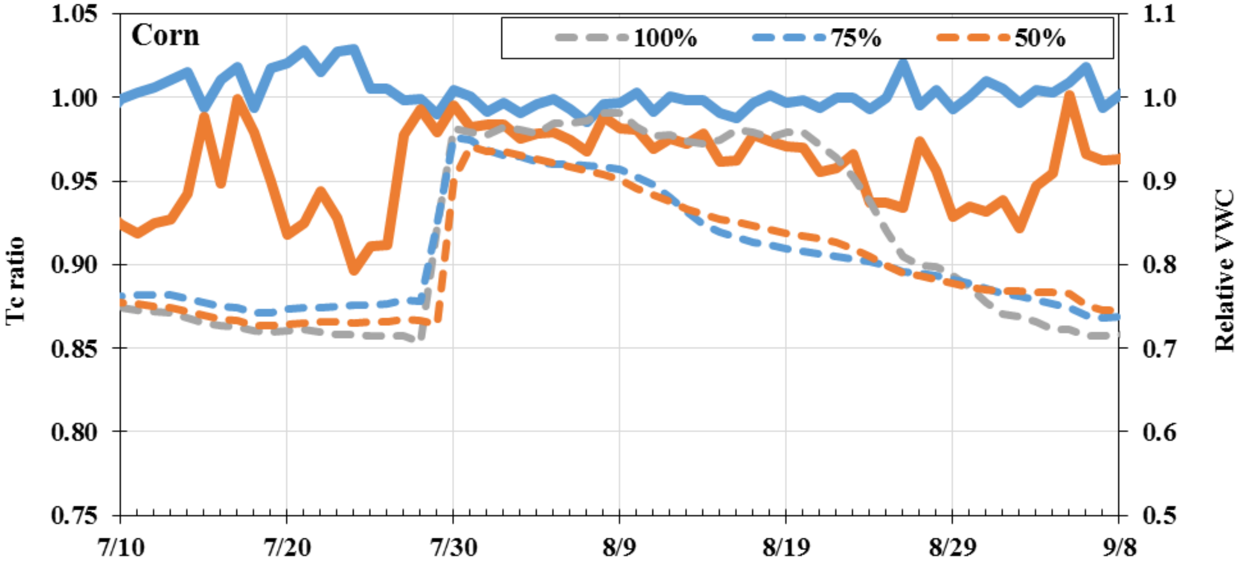


Figure 10: Daily variations in the temperature ratio for the corn canopy temperatures

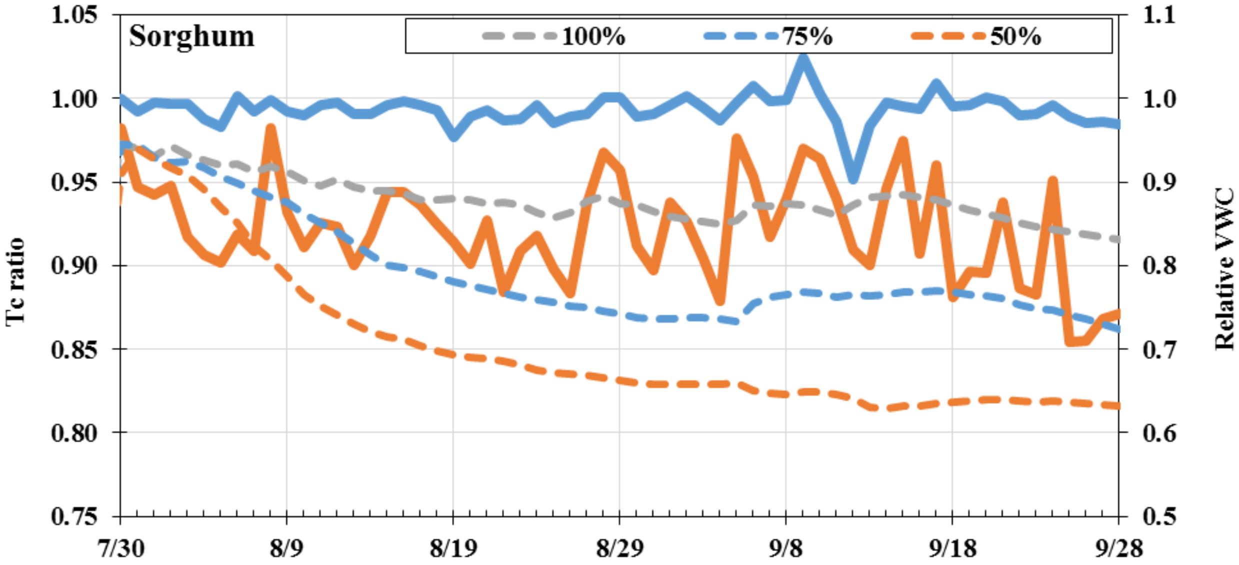


Figure 11: Daily variations in the temperature ratio for the grain sorghum canopy temperatures

The results showed that all SIs were sensitive to crop water stress and can be used for irrigation scheduling in Oklahoma Panhandle. The scatterplots below represent the relationships between Tc ratio/DANS and water availability in a shallow soil profile for all experimental treatments.

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