Proceedings of the 27th Annual Central Plains Irrigation Conference, Colby, Kansas, February 17-18, 2015
Available from CPIA, 760 N.Thompson, Colby, Kansas

Corn and Sorghum Performance As Affected by Irrigation Application Method: SDI versus Mid-elevation Spray Irrigation

Steven R. Evett, Research Soil Scientist

David K. Brauer, Research Leader

Paul D. Colaizzi, Research Agricultural Engineer

Susan A. O'Shaughnessy, Research Agricultural Engineer

USDA-ARS, Conservation & Production Research Laboratory
Bushland, Texas

Voice: 806-356-5775, Email: steve.evett@ars.usda.gov
Voice: 806-356-5769, Email: david.brauer@ars.usda.gov
Voice: 806-356-5763, Email: paul.colaizzi@ars.usda.gov
Voice: 806-356-5770, Email: susan.o'shaughnessy@ars.usda.gov

ABSTRACT

It is known that irrigation application method can impact crop water use and water use efficiency, but the mechanisms involved are incompletely understood, particularly in terms of the water and energy balances during the growing season from pre-irrigation through planting, early growth and yield development stages. Grain corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) were grown on four large weighing lysimeters at Bushland, Texas in 2013 (corn) and 2014 (sorghum). Two of the lysimeters and surrounding fields were irrigated by subsurface drip irrigation (SDI) and the other two were irrigated by mid elevation spray application (MESA). Crop evapotranspiration (ETc) was measured using the weighing lysimeters and soil water content was measured using the neutron probe and electromagnetic sensors. Periodic measurements of plant height, width, leaf area index and biomass were made, and final biomass and yield were measured. Micrometeorological measurements included incoming and outgoing short and long wave radiation, soil heat flux, precipitation, air temperature and humidity and wind speed. Irrigation amounts were metered. Compared with MESA irrigation, using SDI saved from 2.5 to 2.2 inches of water that was lost to evaporation early in the season (pre-plant to 25 days after planting) in 2013 and 2014, respectively. While sorghum, particularly short season sorghum, is not a crop ordinarily considered for SDI, it was grown successfully using SDI with yields averaging 120 bu/acre, comparable to others reported for short season sorghum at Bushland. In the relatively dry 2013 season, SDI increased corn yields by 35 bu/acre (20%) compared with MESA irrigation, while reducing overall corn water use by 3.6 inches.

Introduction

Irrigation application method is known to affect crop performance, including yield and water use efficiency, with subsurface drip irrigation (SDI) having some advantages over spray sprinkler irrigation for corn, cotton and sorghum production (Colaizzi et al., 2004, 2005, 2009, 2011). For cotton, some of the SDI advantage is thought to be due to warmer soil temperatures in the bed due to a reduction in evaporative cooling under SDI as compared with spray sprinkler. Increased soil temperatures were reported by Colaizzi et al. (2010). The advantage of SDI is thought to be in part due to decreased loss of water to evaporation (*E*) from the soil surface since the soil surface is directly wetted by spray sprinklers but not with SDI. A 36% (3.2 inch) decrease in evaporative loss using SDI vs. surface irrigation was estimated using a mechanistic model (Evett et al., 1995), which would mean that more of the applied irrigation water would be available for transpiration (*T*) by plants. Because yield is directly tied to transpiration, this increase in the *T*/*E* ratio should result in relatively more yield per unit of water applied with SDI, and a corresponding increase in crop water use efficiency (WUE) (Howell, 2001). There are, however, very few direct measurements of differences in *E*, *T* and water and energy balances of crops grown using SDI compared with spray sprinkler irrigation.

Weighing lysimeters directly measure water losses from the soil due to evapotranspiration (ET) when there is no precipitation (*P*) or irrigation (*I*) occurring and when deep flux (*F*) and runoff (*R*) are negligible. And, the crop ET can be calculated as the residual of the soil water balance equation

$$\mathrm{ET} = P + I + R + F + \Delta S \qquad (1)$$

for periods during which *I*, *P*, *F* and *R* are known because the change in storage (ΔS) is known from the lysimeter mass change (Evett et al., 2012b). Because most of the difference in evaporative loss from SDI versus spray sprinkler occurs early in the season during pre-irrigation and the period before full cover is established (Evett et al., 1995), most of the difference is due to *E*, not *T* from the relatively small plants, and can be determined from weighing lysimeter measurements.

In order to more fully understand water and energy balance and flux differences under SDI compared with spray sprinkler irrigation, the large weighing lysimeter facility at Bushland Texas (Marek et al., 1988) was modified during 2012 and early 2013 so that the eastern two of the four monolithic lysimeters and their surrounding fields could be irrigated using SDI. Energy and water balances were measured on grain corn and sorghum grown in 2013 and 2014, respectively, to determine the differences in evaporative loss and energy balance, including radiation balance and soil heat flux, and corresponding differences in yield and water use efficiency, if any.

MATERIALS and METHODS

Site description

Grain corn (*Zea mays* L) was grown in 2013 and short season sorghum (*Sorghum bicolor* (L.) Moench) was grown in 2014 at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas [35° 11’ N, 102° 06’ W, 3838 ft (1170) m elevation above MSL] on a gently sloping (<0.3%) Pullman soil (fine, mixed, superactive, thermic Torrertic Paleustoll). The slowly permeable soil has a dense B22 horizon at 1 to 1.7 ft (0.3 to 0.5 m) depth and a caliche layer at approximately 4.6 ft (1.4-m) depth that restricts water movement in some seasons. The soil series is common to 3.0 million acres (1.2 million ha) of land and one third of the irrigated area in the Texas Panhandle (Musick et al., 1988). The plant available water holding capacity is approximately 8.3 inch (210 mm) in the top 4.6 ft (1.4 m) of the profile. The research location is situated in the Southern High Plains of the Great Plains and was thoroughly described by Evett et al. (2012a). Winds are predominantly from the south and southwest during the growing season and often carry advective energy from dryland and rangeland fields and pastures plus additional energy derived from their passage over the Chihuahuan Desert followed by descent with adiabatic heating along the eastern slope of the southern Rocky Mountains. Mean annual pan evaporation exceeds 95 inches (2400 mm) (Kohler et al., 1959).

Agronomy

The crops were managed for high yield using practices common for the northern Texas Panhandle. Fertilizer (N) was applied according to soil tests done by a commercial soil testing laboratory. No other inorganic fertilizers were recommended. In 2013, corn was planted in the NW and SW fields at 33,000 seeds/acre and fertilized with liquid N (32-0-0) to achieve a total of 260 lb/acre N (Table 1). The hybrid corn was bred and engineered for water-limited conditions and so a test of this was conducted by irrigating the NW field at 75% of full irrigation (Table 1).

Table 1. 2013 northwest (NW) and southwest (SW) lysimeter fields corn management. DOY is day of year.

Date	DOY	Action
23-Apr-13	113	Applied 32-0-0 fertilizer at a rate of 60 gal/acre (211lbs N/ac).
24-Apr-13	114	Ran disc to incorporate fertilizer
2-May-13	122	Ran disc bedder to build beds
16-May-13 17-May-13	136- 137	Planted Pioneer corn variety 1151HR Aqua Max[1] at a rate of 33,000 seeds per acre using row planter. Hand planted lysimeters are greater rate.
24-May-13	144	Corn fully emerged
28-May-13	148	Hail resulted in approximately 5% stand loss
7-Jun-13	158	Started treatment irrigations using Nelson nozzle #20 on the NW field to target applications at 75% of the full (100%) irrigation applied to the SW field using #23 nozzles
11-Jun-13	162	Sprayed west fields with Roundup Power Max and GMAX Lite (mixed) at rates of 20 oz and 32 oz per acre
12-Jun-13	163	Furrow diked west fields
30-Jul-13	211	Applied 34 oz/min of 32-0-0 using the #22 nelson nozzles for a uniform irrigation. Used 150 gal of 32-0-0 during the 9.0 hr irrigation, which is 24 lbs N/acre
31-Jul-13	212	Applied 34 oz/min of 32-0-0 using the #22 nelson nozzles for a uniform irrigation. Used 165 gal of 32-0-0 during the 10.5 hr irrigation, which is 26.4 lbs N/acre
15-Oct-13	288	Hand harvest of lysimeters and field
21-Oct-13	294	Combine harvested.

[1] The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Table 2. 2013 northeast (NE) and southeast (SE) lysimeter fields corn management. DOY is day of year.

Date	DOY	Action
25-Apr-13	115	Applied 44 gal. of 32-0-0/acre (154 lbs N/ac) on east field and incorporated using disc plow
24-Apr-13	114	Ran disc to incorporate fertilizer
2-May-13	122	Ran disc bedder to build beds
22-May-13 23-May-13	142-143	Planted Pioneer corn variety 1151HR Aqua Max at a rate of 33,000 seeds /acre
31-May-13	151	Rotary hoed east field to break up crust and allow emergence
2-Jun-13	153	Full emergence on lysimeters, spotty in field
21-Jun-13	172	Sprayed Roundup PowerMax at a rate of 20 oz. per acre
25-Jun-13 to 11-Sep-13	254	Staged plants and harvested for biomass six times
15-Oct-13	288	Hand harvest of lysimeters and field
23-Oct-13	296	Combine harvested Field

In 2014, cotton was planted but failed due to heavy rains during emergence (a total of 8 inches of rain in five days). A short-season sorghum (Channel variety 5c35) was planted on 20 June at a rate of 85,000 seeds/acre on all fields after the cotton was killed (Tables 3 and 4).

Table 3. Northwest and southwest field sorghum management, 2014. DOY is day of year.

Date	DOY	Action
5-Mar-14	64	Ran offset disc to incorporate stubble
16-Apr-14	106	Applied 25.5 gal/acre (90 lbs. N per acre) of 32-0-0 fertilizer using knife applicator. Did not apply any to spans 2 & 6 for reduced N trial.
18-Apr-14	108	Spread and disked in residue that had concentrated behind the combine.
13-May-14	133	Used disc bedder to bed the field.
14-May-14	134	Used cultipacker to break-up clods and pack beds.
15-May-14	135	Sprayed Charger Max at 1.3 pnts/acre for pre-emergent weed control.
2-Jun-14	154	Planted Delta-Pine cotton variety 1219b2RF at 83,000 seeds/acre
18-Jun-14	169	Ran rod weeder over beds to kill cotton due to crop failure
19-Jun-14	170	Ran cultipacker to break-up clods and pack beds.
20-Jun-14	171	Replanted with Channel sorghum variety NC+5C35 at a rate of 85,000 seeds/acre
25-Jun-14	176	Emergence
26-Jun-14	177	Full emergence
14-Jul-14	195	Furrow diked field
17-Aug-14	229	West Field Full Bloom
20-Oct-14	293	Harvest

Table 4. Northeast and southeast field sorghum management, 2014. DOY is day of year.

Date 2014	DOY	Action
5-Mar-14	64	Ran offset disc to incorporate stubble
10-Apr-14	100	Applied 25.5 gal/acre (90 lbs. N/acre) of 32-0-0 fertilizer using the knife applicator. Did not apply any to zones 3 & 4 or 11 & 12 for limited N trial.
18-Apr-14	108	Disked field to incorporate residue.
3-Jun-14	154	Planted Delta-Pine cotton variety 1219b2RF at a rate of 83000 seeds/acre
4-Jun-14	155	Sprayed Section 2ec at a rate of 10 oz/acre to burn down volunteer corn and Charger Max at a rate of 1.3 pints/acre for pre-emergent weed control.
20-Jun-14	171	Replanted Channel sorghum variety NC+5C35 at a rate of 85,000 seeds/acre
25-Jun-14	176	Emergence
26-Jun-14	177	Full emergence
8-Jul-14	189	Sprayed Strut herbicide at a rate of 9 oz/acre to kill cotton and weeds.
11-Jul-14	192	Furrow diked field
19-Aug-14	231	East Field in Full Bloom
20-Oct-14	293	Harvest

Lysimeter and soil water balance ET measurements

Crop water use (evapotranspiration, ET) is measured by the soil water balance of a control volume that includes the root zone: ET = $P + I + R + F + \Delta S$ where P is precipitation depth, I is irrigation depth, R is the sum of runon and runoff, F is deep soil water flux out of (deep percolation) or upward into the control volume, and ΔS is the change is soil water storage due to root water uptake, deep percolation, irrigation and precipitation. Weighing lysimeters define the control volume as the depth of the lysimeter (7.5 ft at Bushland). The lysimeter mass change is a direct measure of the change in soil water storage and thus of the water lost to evaporation and transpiration (ET) when P, I, R and F are zero. Lysimeter mass changes were converted to a depth of water by dividing the mass change by the density of water and by the effective surface area of the lysimeter.

The lysimeters were drained under vacuum equivalent to 40 inches (1 m) of hanging water column into tanks suspended by load cells from the lysimeter soil tanks so that drainage did not change the total mass of the lysimeter. Irrigations were metered, but sprinkler irrigation metered amounts were verified by measuring the change in lysimeter mass caused by each irrigation. Precipitation was measured with rain gages at each lysimeter and again verified (and corrected when precipitation events happened quickly) by observing changes in lysimeter mass (Marek et al., 2014). The field was furrow diked to inhibit runoff and runon into the lysimeters, and the lysimeter soil boxes had approximately 2 inches of freeboard that prevented runoff and runon for all irrigation events and almost all precipitation events.

Soil profile water content was determined to 7.9 ft depth using a neutron probe for measurements centered at 4-inch depth and at depths in 8-inch increments below that. The neutron probe was field calibrated to 0.01 ft^3/ft^3 accuracy using methods described by Evett et al. (2008), and a depth control stand (Evett et al., 2003) was used to ensure repeatedly accurate probe depth placement.

The water content as a depth for each 8-inch thick measured soil layer was calculated by multiplying the volumetric water content by the layer depth. Profile water content as a depth was calculated by summing the water contents for each 8-inch thick measured soil layer. The change in storage for each period between neutron probe readings (typically weekly) was calculated as the difference in profile water contents, the precipitation and irrigation amounts were taken as those measured by the lysimeters for each field, the value of *R* was assumed equal to zero since the fields were furrow diked, and the soil water flux at the bottom of the 7.9-ft deep control volume for the neutron probe was estimated using soil water contents at the 6.9 and 7.5-ft depths to estimate the hydraulic conductivity and hydraulic gradient using methods described in detail by Evett et al. (2012b).

Irrigation systems and management

Spray sprinkler irrigation was applied to the NW and SW fields using a ten-span linear irrigation system (Lindsay Manufacturing, Inc.) moving in the E-W direction with spray plates at 5-ft height (mid-elevation sprays, MESA) on weighted drops with 10 psi pressure regulators on each drop. Drops were spaced at 5-ft intervals. Irrigations were typically ¾ to 1 inch depth, occasionally as much as 1.5 inch. Nozzling was such that a 1-inch irrigation took approximately 12 hours. Proximal lateral end pressures were typically 35 psi and distal lateral end pressures were typically 25 psi, ensuring that the pressure regulators set and operated correctly after system startup.

The SDI system was installed in the NE and SE fields and lysimeters before the 2013 cropping season and featured 0.99-inch diameter tubing (model Typhoon 990, 13 mil wall thickness, Netafim, Inc.) spaced 5-ft apart and injected at 12-14 inch depth in the E-W direction. Emitters were spaced 12-inches apart and had 0.18 gph discharge at the 10 psi regulated line pressure. Sand filters were used to remove sediment and algae from reservoir water. Lines were 690 ft long and designed for a EU% of 98.6. The field was divided into 20 zones, with each zone valved, metered and pressure regulated separately. The system applied 1 inch of irrigation in approximately 14 hours. Water from multiple wells was stored in a reservoir, then pumped through sand filters using a variable frequency drive to power a pump and provide constant supply line pressure downstream of the filters.

Irrigations were applied to replace soil water in the root zone to field capacity based on weekly neutron probe measurements. The NW and SW fields were managed together and separately from the common management applied to the NE and SE fields. In 2013, the SW field was managed for full (100%) irrigation, replacing soil water used back to field capacity, while the NW field was irrigated on the same dates but with nozzle size reduced to apply approximately 75% of full irrigation. In 2014, the NW field was managed for full irrigation while the SW field was managed for approximately 75% of full irrigation.

Yields were adjusted to standard % moisture (15% for corn and 14% for sorghum). Statistical calculations were performed using t-tests assuming unequal variances, and means were considered significantly different at the 5% level.

RESULTS and DISCUSSION

2013 corn

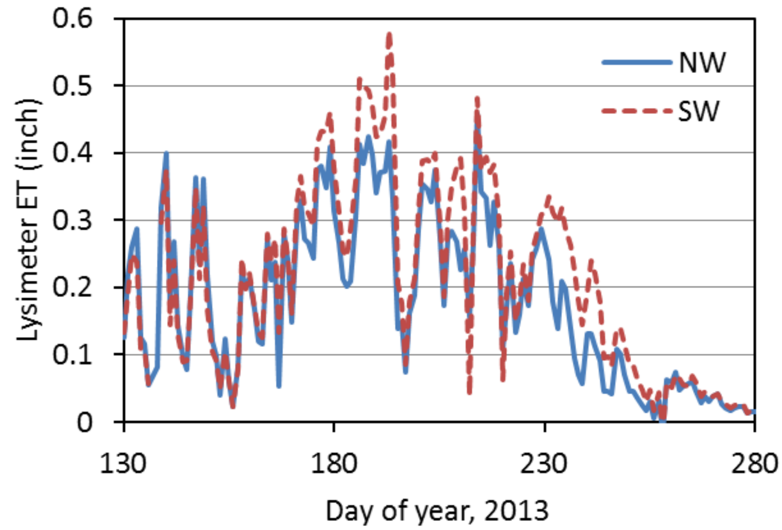
Despite a severe hailstorm during corn emergence, plant stand was 34,000 per acre in the SDI fields and 39,100 per acre in the MESA fields. The fully irrigated SW field received 23.2 inches of MESA irrigation, while the limited irrigated NW field received 18.0 inches of MESA irrigation. Corn fully irrigated using MESA yielded 174 bu/acre, which was significantly greater (27% greater) than the 136 bu/acre corn harvest resulting from limiting irrigation to 75% of full irrigation. Fully irrigated corn grown using SDI yielded 208 bu/acre, which was significantly greater (20% greater) than the yield of MESA fully irrigated corn.

Reasons for the differences in yield and water use are illustrated in Figure 1 and evaluated in Table 5. Once the crop covered the soil well, by day of year (DOY) 175, the SW field, which was fully irrigated using MESA, used water at rates much greater than did the deficit irrigated NW field (Fig. 1A). Daily ET exceeded ½ inch (12 mm) several times and exceeded 0.55 inch (14) mm once. In contrast, peak water use of deficit irrigated corn was 0.39 inch/day (10 mm/d). Water use of fully irrigated corn exceeded that of the deficit irrigated crop through seed filling and senescence up until DOY 255. In contrast, the fully irrigated SDI corn exceeded 0.39 inch daily water use only once, and in fact appeared to use water at daily rates very close to those exhibited by the MESA deficit irrigated corn until DOY 230 when SDI irrigated corn began to use more water than the MESA deficit irrigated corn and began to closely match the water use of the MESA fully irrigated corn (Fig. 1A, 1B). This was likely important for completing grain filling. Overall, fully MESA irrigated corn used the most water (32.5 inch), deficit MESA irrigated corn used 28.1 inch, while corn irrigated using SDI used 26.4 to 27.1 inch.

MESA irrigation wetted the soil surface, which resulted in much greater evaporative loss during pre-plant irrigations and in the first 25 days after planting (DAP) when the crop was emerging and not yet covering much of the soil surface (Fig. 1A and 1B). Total MESA irrigation water use in that period was 5.8 to 6.3 inch compared with the much smaller 4.4 to 4.5 inch water use of SDI irrigated corn (Table 5). Most of this water was lost to evaporation from the soil surface since the plants were not emerged or very small. The gross savings in evaporative loss from the use of SDI was 2.7 inch during this period. This is remarkably close to the savings estimated by Evett et al. (1995) who used the ENWATBAL simulation model to estimate an evaporative loss reduction of 3.2 inch for SDI compared with surface irrigation of corn.

Differences in water use did not always translate directly into differences in yield. The fully MESA irrigated corn yielded 173 bu/acre, significantly greater than the 136 bu/acre from the deficit irrigated MESA corn. However, the corn irrigated with SDI, which used less water than either MESA irrigated treatment, out yielded both significantly with a yield of 208 bu/acre. Overall yields were not as large as expected, partly due to corn earworms that invaded nearly every ear despite the Bt variety grown.

A



B

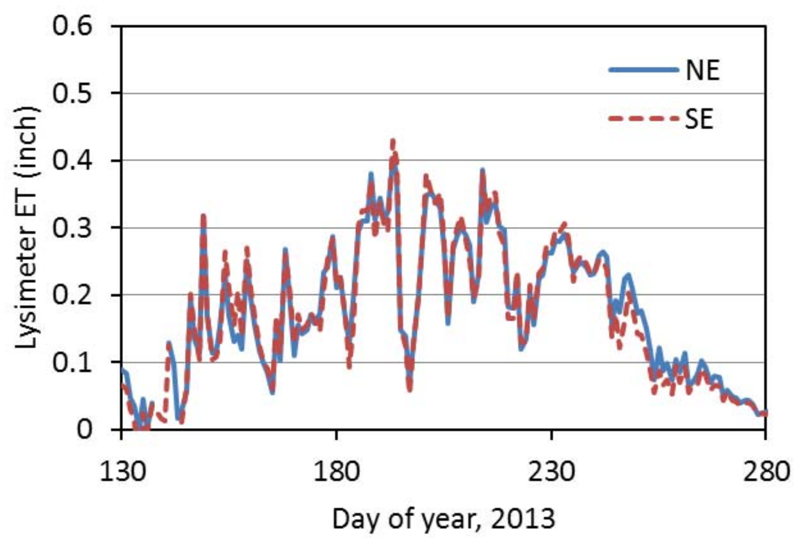


Figure 1. (A) Corn evapotranspiration (ET) in the northwest (NW) and southwest (SW) lysimeter MESA irrigated fields in 2013. (B) Corn ET in the northeast (NE) and southeast (SE) SDI fields.

Table 5. Soil water balance for corn in 2013 (inch). Lysimeters and fields are designated NE (northeast) and SE (southeast), which were irrigated by SDI, and NW (northwest) and SW (southwest, which were irrigated with mid elevation spray irrigation (MESA). The NE, SE and SW fields were fully irrigated. The NW field was irrigated at 75% of the SW field beginning on 6 June.

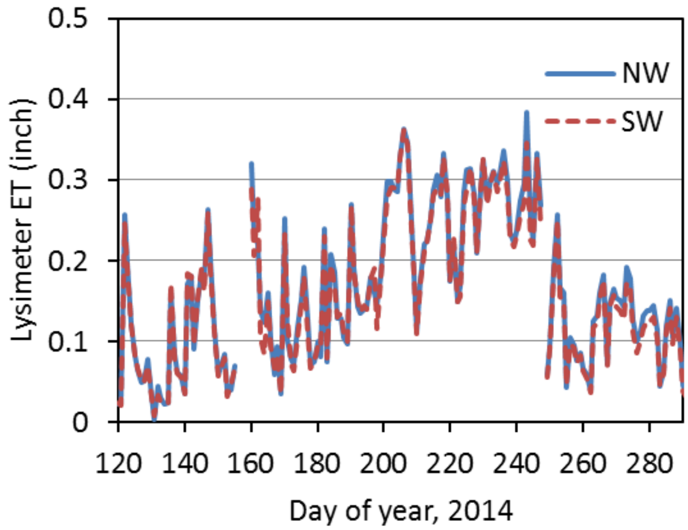
	NE	SE	NW	SW
Pre-plant Irrigation	0.4	0.4	1.1	1.0
Irrigation from planting to 6 June	8.7	8.7	4.3	4.4
Irrigation after 6 June	12.6	13.1	12.6	17.7
Total Irrigation	21.7	22.1	18.0	23.2
Pre-plant Precipitation	1.7	1.2	0.3	0.3
Precipitation from planting to 6 June	1.2	1.0	1.6	1.8
Precipitation after 6 June	7.3	7.1	7.4	7.8
Total Precipitation	10.2	9.3	9.4	9.9
Total Δ*S* (residual)	-4.8	-5.0	0.7	-0.6
ET from 1^{st} pre-plant irrigation to 25 DAP	4.5	4.4	6.3	5.8
Total evapotranspiration (ET)	27.1	26.4	28.1	32.5

2014 short season sorghum

Cotton was planned for the 2014 cropping season, but was replaced by sorghum after cotton failure. Cotton planting was preceded by ~4.7 inches of rain in the May 21-26 period, which delayed cotton planting until June 3. Two days after cotton planting, rains began that flooded the field with 4 inches of rain in four days and left a thick crust of soil. Cotton emergence in the following week was poor, and the crop was terminated by cultivation. Short season sorghum was planted on June 20 and emerged five days later. The deficit irrigation treatment on the SW field did not begin until August 1 and resulted in only a 2.9 inch reduction in total irrigation (Table 6), not enough to much influence crop yield given the full soil profile that resulted from the plentiful rains. Due to the full profile, only 1.3 inch of irrigation was required from planting to August 1. Hot, dry weather in July and August required 10.1 inch of irrigation for the fully irrigated treatment in the NW field to finish the season. A large rain (>2 in) on September 3 finished the irrigation season.

Despite the 2.9 inch difference in total irrigation, season long sorghum water use (ET) did not differ importantly or significantly between the fully MESA irrigated (27.3 inch) and deficit irrigated (26.4 inch) crops (Fig. 2, Table 6). Even though yield from deficit irrigated sorghum was 4.4% less than that for fully irrigated sorghum, yield was not significantly different (135 bu/acre for full irrigation and 129 bu/acre for deficit irrigation). Similar depression of yield when water is limited during grain filling has been reported previously. Yields were smaller for sorghum produced using SDI, 125 and 115 bu/acre in the NE and SE fields, respectively, which did not differ significantly. However, the SDI yields were significantly smaller (9% overall) than those obtained using MESA irrigation. For the same sorghum variety, O'Shaughnessy et al. (2014) reported 149 bu/acre for 21.0 inches of ET in 2009, but only an average 119 bu/acre for an average ET of 25.5 inches of ET in 2010 and 2011.

A



B

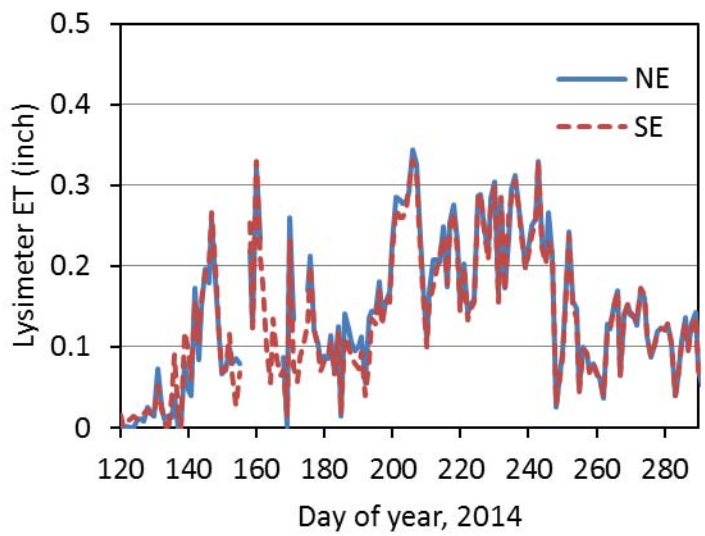


Figure 2. (A) Sorghum evapotranspiration (ET) in the northwest (NW) and southwest (SW) lysimeter fields irrigated with MESA in 2014. (B) Sorghum ET in the NE and SE SDI fields.

It is difficult to perceive a reason for the smaller sorghum yields with SDI, but the large rainfalls may have leached fertilizer from the already full soil profile in the SDI fields, further depressing yields. Supporting this idea is the fact that the lysimeters in the SDI fields drained considerably more water than did those in the MESA irrigated fields, indicating larger deep percolation losses in the SDI fields. Pre-plant irrigation with the SDI system was larger than that for the MESA system in order to bring water to the seed bed for cotton germination. This proved unnecessary due to the large rains just after cotton planting, but it did leave the soil profile full of water prior to the large rains. Despite the larger pre-plant irrigation, evaporative loss before planting and through 25 DAP was on average 2.2 inches smaller in the SDI fields compared with the MESA irrigated fields. Season long irrigation using SDI averaged 1 inch more than that for full irrigation using MESA. But, Season long water use for SDI sorghum averaged 4.3 inches less than that for MESA fully irrigated sorghum (Table 6), mostly due to 3.3 inches less irrigation in the SDI fields after August 1. It is possible that less irrigation in the SDI fields after August 1 combined with loss of nutrients due to deep percolation led to the 9% yield depression in SDI fields.

This result is in line with those of Colaizzi et al. (2004) who reported that yields for both long and short season grain sorghum were on average 12% less (~19 bu/ac) for SDI compared with MESA for 75 and 100% of full irrigation rates. They too attributed this yield depression to leaching of nutrients, which was supported by measurements of increasing volumetric water content deep (> 6 ft) in the soil profile. On the other hand, for 25 and 50% irrigation rates, Colaizzi et al. (2004) reported that SDI resulted in an average of 36% (43 bu/ac) greater grain yields compared with MESA. This implied that SDI resulted in greater partitioning of water to plant transpiration and less to soil evaporation, especially early in the season. The current study reported herein confirms their supposition of reduced evaporative loss with direct measurements.

Table 6. Soil water balance for sorghum in 2014 (inch). Lysimeters and fields are designated NE (northeast) and SE (southeast), which were irrigated by SDI, and NW (northwest) and SW (southwest, which were irrigated with mid elevation spray irrigation (MESA). The NE, SE and SW fields were fully irrigated. The SW field was irrigated at 75% of the NW field beginning on 1 Aug.

	NE	SE	NW	SW
Pre-plant Irrigation	7.6	7.0	3.5	3.7
Irrigation from planting to 1 Aug.	1.9	2.2	1.3	1.3
Irrigation after 1 Aug.	6.7	6.8	10.1	7.3
Total Irrigation	16.3	16.0	15.3	12.4
Pre-plant Precipitation	9.9	9.7	10.7	9.5
Precipitation from planting to 1 Aug.	5.4	5.3	5.1	4.6
Precipitation after 1 Aug.	7.0	6.6	7.3	7.3
Total Precipitation	22.3	21.7	23.1	21.5
Total ΔS + R (residual)	-15.8	-14.7	-11.0	-7.5
ET from 1st pre-plant irrigation to 25 DAP	6.1	6.8	8.8	8.6
Total evapotranspiration (ET)	22.8	23.0	27.3	26.4

SUMMARY

Despite a difficult 2014 season that included management problems caused by very large rains, it is clear that the SDI system saved from 2.5 to 2.2 inches of water that was lost to evaporation early in the season (pre-plant to 25 DAP) with the MESA irrigation system in 2013 and 2014, respectively. Between 25 DAP and mid season, another 2.6 to 2.1 inches of water was lost with the MESA irrigation system compared with the SDI system in 2013 and 2014, respectively. For corn grown in 2013, much of the water saved due to smaller evaporative losses was used during grain fill when

SDI corn used 3.3 inches more water than did MESA fully irrigated corn. In the relatively dry 2013 season, SDI reduced overall corn water use by 3.6 inches while increasing yields by 35 bu/acre (20%) compared with MESA irrigation. While sorghum, particularly short season sorghum, is not a crop ordinarily considered for SDI, it was grown successfully using SDI with yields comparable to others reported for short season sorghum at Bushland.

ACKNOWLEDGEMENTS

We gratefully acknowledge support from the USDA-ARS Ogallala Aquifer Program, a consortium between the USDA Agricultural Research Service, Kansas State University, Texas A&M AgriLife Research, Texas A&M AgriLife Extension Service, Texas Tech University, and West Texas A&M University, as well as the dedicated support of Karen Copeland, USDA-ARS Soil Scientist, and Brice Ruthardt, USDA-ARS Biological Scientist.

REFERENCES

Colaizzi, P.D., A. D. Schneider, S. R. Evett, and T. A. Howell. 2004. Comparison of SDI, LEPA, and spray irrigation performance for grain sorghum. Trans. ASAE Vol. 47(5): 1477-1492. Available at http://www.cprl.ars.usda.gov/pdfs/Trans%20ASAE%2047-5-1477-1492.pdf.

Colaizzi, P.D., S.R. Evett, and T.A. Howell. 2005. Comparison of Spray, LEPA, and SDI for Cotton and Grain Sorghum in the Texas Panhandle. Proc. 2005 Central Plains Irrigation Conference, Sterling, Colorado, Feb 16-17. pp. 123-136. Available at http://www.cprl.ars.usda.gov/pdfs/Central%20Plains%20Irrig%20Conf%202005%20Colaizzi.pdf.

Colaizzi, P.D., S.R. Evett, T.A. Howell and R.L. Baumhardt. 2009. Comparison of grain sorghum, soybean, and cotton production under spray, LEPA, and SDI. pp. 122-139 in Proc. 21st Annual Central Plains Irrig. Conf., Colby Kansas, February 24-25, 2009. CPIA, 760 N.Thompson, Colby, KS. Available at http://www.cprl.ars.usda.gov/Wmru/pdfs/Colaizzi%20CPIC%202009.pdf.

Colaizzi, P.D., S.R. Evett, T.A. Howell, and R.L. Baumhardt. 2010. Crop production comparison with spray, LEPA, and subsurface drip irrigation in the Texas High Plains. 5th Decennial National Irrigation Conf., 5-8 December 2010, Phoenix, Arizona. Paper No. IRR10-9704. ASABE, St. Joseph, Mich. http://www.cprl.ars.usda.gov/wmru/pdfs/Colaizzi%20et%20al%20%20(2010)%20Crop%20Production%20Comparison%20with%20Spray%20LEPA%20and%20SDI_5th%20Dec%20Irrig%20Conf_07-9704.pdf

Colaizzi, P.D., S.R. Evett and T.A. Howell. 2011. Corn production with spray, LEPA and SDI. Pp. 52-67 In Proc. 23rd Annual Central Plains Irrig. Conf., Burlington, CO, 22-23 Feb. 2011. Available at http://www.cprl.ars.usda.gov/wmru/pdfs/Colaizzi%20et%20al%20%20(2011)%20Corn%20production%20with%20spray-LEPA-SDI_CPIC%20meeting.pdf

Evett, S.R., T.A. Howell and A.D. Schneider. 1995. Energy and water balances for surface and subsurface drip irrigated corn. Pp. 135-140. In F. R. Lamm (ed.) Microirrigation for a Changing World: Conserving Resources/Preserving the Environment. Proc. Fifth International Microirrigation Congress. Am. Soc. Agric. Engr., St. Joseph, MI.

S.R. Evett, J.A. Tolk, and T.A. Howell. 2003. A depth control stand for improved accuracy with the neutron probe. Vadose Zone J. 2:642-649. http://www.cprl.ars.usda.gov/pdfs/Evett_Tolk_Howell_VZJ2003.pdf

Evett, S.R., L.K. Heng, P. Moutonnet and M.L. Nguyen (eds). 2008. Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation, and Sensor Technology. IAEA-TCS-30. International Atomic Energy Agency, Vienna, Austria. ISSN 1018–5518. http://www.cprl.ars.usda.gov/wmru/pdfs/Field%20Estimation%20of%20Soil%20Water%20Content%20TCS-30_web.pdf

Evett, S.R., W.P. Kustas, P.H. Gowda, J.H. Prueger, and T.A. Howell. 2012a. Overview of the Bushland Evapotranspiration and Agricultural Remote sensing EXperiment 2008 (BEAREX08): A field experiment evaluating methods quantifying ET at multiple scales. Adv. Water Resourc. 50:4-19. http://dx.doi.org/10.1016/j.advwatres.2012.03.010.

Evett, S.R., R.C. Schwartz, T.A. Howell, R.L. Baumhardt and K.S. Copeland. 2012b. Can weighing lysimeter ET represent surrounding field ET well enough to test flux station measurements of daily and sub-daily ET? Adv. Water Resour. 50:79-90. http://dx.doi.org/10.1016/j.advwatres.2012.07.023.

Howell, T.A. 2001. Enhancing water use efficiency in irrigated agriculture. Agron. J. 93(2):281-289. Available at http://www.cprl.ars.usda.gov/pdfs/howell%202001.pdf.

Kohler, M.A., T.J. Nordenson and D.H. Baker. 1959. Evaporation Maps for the United States. Technical Paper No. 37, U.S. Department of the Interior, Weather Bureau, Washington, D.C.

Marek, T.H., A.D. Schneider, T.A. Howell and L.L. Ebeling. 1988. Design and construction of large weighing monolithic lysimeters. Trans ASAE 31: 477-484.

Marek, G.W., S.R. Evett, P.H. Gowda, T.A. Howell, K.S. Copeland, and R.L. Baumhardt. 2014. Post-processing techniques for reducing errors in weighing lysimeter evapotranspiration (ET) datasets. Trans. ASABE 17(2):499-515. http://dx.DOI.org/10.13031/trans.57.10433.

Musick, J.T., F.B. Pringle and J.D. Walker. 1988. Sprinkler and furrow irrigation trends -Texas High Plains. Appl. Engr. Agric. 4(1):46-52. Available at http://www.cprl.ars.usda.gov/pdfs/musick%20pringle%20walker%2088.pdf

O'Shaughnessy, S.A.,S.R. Evett, P.D. Colaizzi, J.A. Tolk and T.A. Howell. 2014. Early and late maturing grain sorghum under variable climatic conditions in the Texas High Plains. Trans. ASABE 57(6):1583-1594. http://www.cprl.ars.usda.gov/wmru/pdfs/O'Shaughnessy%20et%20al%20%20(2014)%20Early%20and%20Late%20Maturing%20Sorghum%20in%20THP.pdf