The Wetting Front

Soil And Water Management Research Unit News

USDA-ARS Conservation and Production Research Laboratory
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Evapotranspiration of Deficit Irrigated Sorghum

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Karen Copeland, and Don Dusek

Deficit irrigation as characterized by English et al. (1990) has the fundamental goal to increase water use efficiency (WUE). Fereres and Soriano (2006) recently reviewed deficit irrigation and concluded that the level of irrigation supply should be 60-100% of full evapotranspiration (ET) needs in most cases to improve water productivity. They indicated "regulated deficit irrigation" (RDI) was successful in several cases, especially with fruit trees and vines, to not only increase water productivity but also farm profit. Deficit irrigation (DI) is widely used in the Southern High Plains and Columbia Basin in the U.S. with their limited irrigation capacities (Musick et al., 1988, English, 1990). High irrigation frequencies have been reported by Miller (1977) and Miller and Aarstad (1976) to improve DI results with sugarbeet (*Beta vulgaris* L.) on sandy soils, but Faci and Fereres (1980) and English and Nakamura (1989) reported little or no effect of irrigation frequency on DI with cereal crops, especially on finer texture soils. Farre and Faci (2006) reported greater WUE with sorghum (*Sorghum bicolor* L. Moench) compared with corn (*Zea mays* L.) with DI in Spain on a loam soil. Tolk and Howell (2003) reported mean WUE for sorghum of 332 lbs ac^{-1} $in.^{-1}$ at Bushland, TX, on the Pullman clay loam soil, but they reported a greater WUE for the Amarillo sandy loam soil and smaller WUE for the Ulysses silt loam soil. They also reported differences in WUE in two seasons across four irrigation levels.

This article is a summary of a paper to be presented at the 2007 ASCE-EWRI World Environmental & Water Resources Congress 2007, 15-19 May 2007, Tampa, FL. Its purpose is to present and briefly discuss and describe the ET of deficit and more fully irrigated grain sorghum measured at Bushland, TX with precision weighing lysimeters (Marek et al., 1988; Howell et al., 1995a) and the resulting WUE (for both grain and biomass) computed from the ET and yield. The crops were produced in large fields that were sprinkler irrigated frequently (2-3 times per week if required) to maintain adequate soil water for the "well watered" crop ET.

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New Scientist . . . .

by Jose L. Chavez

The effect that water has on crop growth and yield first called my attention when I was about 12 years old. I used to listen to my grandfather's comments on his cotton and sugarcane fields production. He would say that yields were good one or two years, although three or even four years were not enough to cover operational costs. The problem was mainly due to cyclical rainfall variability, i.e. some years rainfall amounts would be plenty and timely to satisfy crop water needs but most of the time it was not enough, not when crops needed water the most or simply it rained too much. After school graduation, that

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experience influenced my decision to move from the sub-tropical low lands of Eastern Bolivia to the semi-arid north-eastern region of Brazil, to become educated in irrigation engineering. The year was 1987.

In 1992 I graduated as an Agricultural Engineer and returned to Bolivia where my first professional Ag job was to advise farmers on the proper selection and use of agricultural machinery. The next year, I finally found a job where I was able to apply my newly acquired irrigation engineering knowledge. I was involved in designing pressurized irrigation systems, as well as pumping stations, both centrifugal horizontal axis and deep well turbine types.

With time, I became more interested in finding efficient technologies for the water management aspect of irrigation engineering. This was the moment when I decided to pursue a master degree in irrigation engineering. I moved to Logan, UT, in 1997 where I attended Utah State University (USU), Biological and Agricultural Engineering Department. At USU, I was exposed to the most recent developments in irrigation water management available at that time. Irrigation scheduling was based on the estimation of crop water use (evapotranspiration or ET) using weather station data and crop coefficients obtained with lysimeters. The subject was so appealing to me that I wanted to be more involved in ET research. I ended up staying at USU to pursue a doctorate degree in Biological and Agricultural Engineering. My Ph.D. research involved the evaluation of a remote sensing based algorithm utilized in the estimation of distributed ET and in the development and testing of a method to properly assign weights and integrate distributed ET values (pixels) for comparison with ET measured using eddy covariance stations.

I graduated in 2005 and started a postdoctoral program in Precision Irrigation with the Center for Precision Agricultural Systems (CPAS), Washington State University (WSU) at Prosser, WA, in March of 2005. The research at CPAS was aimed towards the remote control and monitoring of continuous move irrigation systems, namely Linear Moves and Center Pivots. The two main objectives were: to efficiently applied variable amounts of water by irrigation zones and to successfully transfer the site specific irrigation control system to a different Linear Move system/field configuration located in a different region of the United States. Research results indicated that it was possible to control and monitor the Linear Move through the internet to apply variable water amounts by location. Also, the system performed equally well when transferred to a Linear Move irrigation system in the Nesson Valley, ND, owned and operated by Dr. Robert Evans, USDA-ARS North Plains Agricultural Research Lab (Sidney, MT).

After concluding my research at WSU, I joined the USDA-ARS-CPRL Soil and Water Management Research Unit (SWMRU), at Bushland TX, as a postdoctoral research associate working with Dr. Prasanna H. Gowda.

The research project focuses mainly on finding a model to map crop ET accurately and consistently using satellite imagery for the Texas Panhandle. Several remote sensing based ET models are currently being evaluated using lysimetric data. In the near future, besides lysimeters, we will use ET data derived from scintillometer energy balance stations, spread throughout the Panhandle area. The ET maps will aid in the assessment of the spatio-temporal distribution of ET and in the identification of area-specific irrigation water management problems/recommendations for water savings.

I am excited to be part of the SWMRU research team and I am looking forward for a great time bringing new alternatives and solutions to the increasing water issue in the Texas Panhandle area. If you would like to contact me, my telephone number is (806) 356-5704 and my e-mail is

Measuring Latent heat flux (or evapotranspiration) with a Bowen ratio and an eddy covariance system over an alfalfa field near Richmond, UT in 2002.

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Procedures

This study was conducted at the USDA-ARS Laboratory at Bushland, TX, (35º 11' N lat.; 102º 06' W long.; 3,800 ft elev. above MSL) in 1993. Crop ET was measured with two weighing lysimeters (Marek et al., 1988) each located in the center of two 10 ac 700 ft E-W by 700 ft N-S fields. The soil at this site is classified as Pullman clay loam (fine, mixed, superactive thermic Torrertic Paleustoll) (Unger and Pringle, 1981; Taylor et al., 1963) which is described as slowly permeable because of a dense B22 horizon about 12 to 20 in. below the surface. The two east lysimeter fields were used for this experiment. The plant available water holding capacity within the top 6.5 ft of the profile is approximately 9.4 in. (Tolk and Howell, 2001) and ~7.9 in. to the 5-ft depth. A calcareous layer at about the 55-in. depth somewhat limits rooting and water extraction below this depth, depending on the crop. Variations of this soil series are common to more than 2.9 million ac of land in this region and about ⅓ of the sprinkler-irrigated area in the Texas High Plains (Musick et al., 1988). Weighing lysimeters offer one of the most accurate means to measure ET (Hatfield, 1990). Predominate wind direction is SW to SSW, and the unobstructed fetch (fallow fields or dryland cropped areas) in this direction exceeds 0.6 mi. The field slope is less than 0.3 percent. More descriptive information on the facility is provided in Howell et al. (1995b), Howell et al. (1997), Howell et al. (2004), and Evett et al. (2000).

The sorghum cultivar, DK-56[1/] (Dekalb, Monsanto Co., St. Louis, MO), was planted in the field on 27 May (DOY 147) in E-W rows 30 in. apart with a six-row conventional farm planter. The six rows at each lysimeter [about 30 ft total length] with four rows in the lysimeter were planted by hand with the same sorghum cultivar and later thinned to match the field plant population. The SE lysimeter was planted on May 27 (DOY 147), and the NE lysimeter was planted on 28 May (DOY 148). Irrigation (0.6 in.) was applied uniformly on 28 May (DOY 148) for seed germination and uniform emergence. The final mean emerged field plant stand was 89,000 plants ac^{-1} in the two fields. Harvest plant density counts averaged 81,000-85,000 plants ac^{-1} for both fields and lysimeters. The fields and lysimeters were fertilized on 8 May (DOY 159) at the rate of 100 lbs (N) ac^{-1} with granular urea (45-0-0) and disked to incorporate. The lysimeter fields were cultivated and furrow diked (both to retain rain and irrigation amounts as well as match the "free board" water retention by the lysimeter walls). The lysimeters were hand harvested on 5-6 Oct (DOYs 278-279), and the fields were combine harvested on the same dates.

Irrigation Treatments

The east lysimeter field was irrigated with a lateral-move sprinkler system with the north half (NE) being irrigated to meet the crop water use (FULL) and the south half (SE) being DI with approximately 50% of the FULL rate by using smaller nozzles. The FULL treatment was managed to meet the water demand of the crop. Irrigations were applied with a 10-span lateral-move sprinkler system (Lindsay Manufacturing, Omaha, NE) with an end-feed hose and aboveground, end guidance cable. The sprinkler system was aligned N-S, and irrigated E-W or W-E. The system was equipped with gooseneck fittings and spray heads (Senninger Super Spray, Orlando, FL) with concaved spray plates on drops located about 5 ft above the ground and 60 in. apart. Each spray head was equipped with a 15 psi pressure regulator and a 2.2-lb polyethylene drop weight. Irrigations were scheduled to meet the ET water use rate and were typically applied in one to two 1.0 in. applications per week. Irrigations were managed on the FULL treatment to minimize soil water deficits with the available irrigation capacity allowing 1.0-1.25 in. for rainfall storage. The DI treatment allowed the soil water profile to gradually deplete.

Other measurement procedures are described in the full ASCE/EWRI paper available from the senior author.

Results

The crop emerged on 3 June (DOY 154). The rainfall received from crop planting until harvest was 8.31 in. typical for a normal summer rainfall season at Bushland, TX [~19-20 in. long-term annual mean]. Almost one-third of the growing season rain (2.76 in.) was received on 14 and 15 July (DOYs 195 and 196). The FULL irrigation treatment received 14.47 in. of season irrigation and the DI treatment received 6.73 in. of irrigation. Measured drainage was 1.81 in. for the FULL treatment and 1.02 in. for the DI treatment. Total net water applied (rain plus irrigation) was 23.1 in. for FULL and 15.3 in. for DI from planting and 22.2 in. for FULL and 14.4 in. for DI from the emergence date (Fig.1).

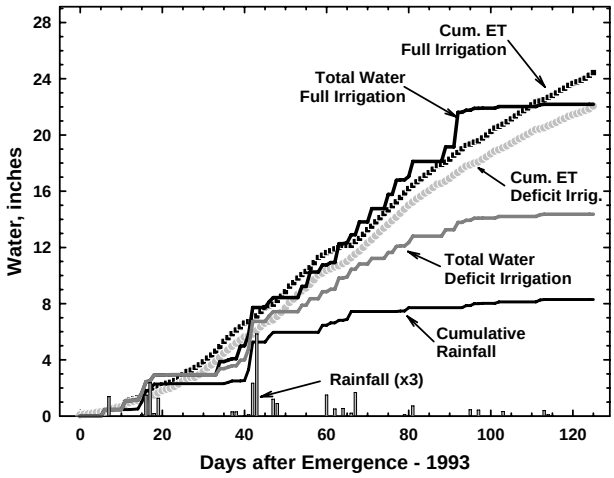

Figure 1. Water balance parameters for the 1993 sorghum growing season (note the rainfall bars were multiplied by 3 to be more visible on the scale).

Crop Evapotranspiration

The seasonal ET rates are shown in Fig. 2 and the cumulative seasonal ET was shown in Fig. 1 for comparison with the rainfall and applied water. Seasonal ET amounts were 24.4 in. and 22.0 in. for the FULL and DI treatments from emergence. The daily ET deficit ratio [$ET_{DI}\,ET_{FULL}^{-1}$; Fig. 2] was somewhat erratic dur-

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

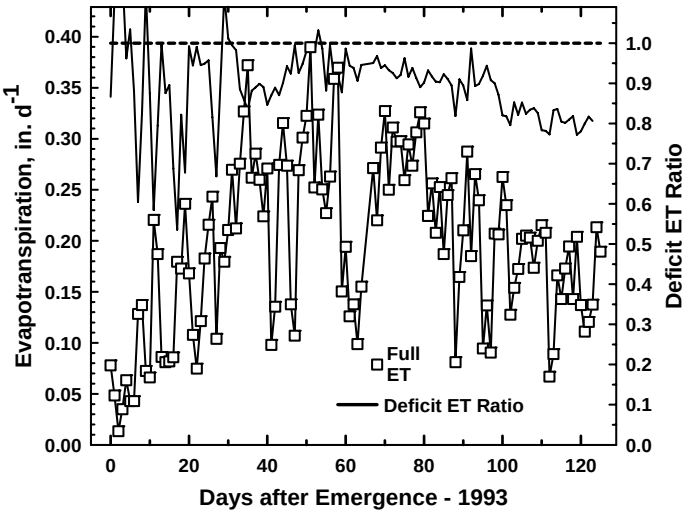

Figure 2. Daily ET rates and the daily deficit ET ratio [$ET_{DI}\ ET_{FULL}^{-1}$] (right axis scale) for the 1993 sorghum.

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ing the early season due to the usually smaller ET rates, except following rain or irrigation when the deficit ET ratio was near 1.0. Following full crop development (~60 days after emergence) with still a minor decline in profile soil water (Fig. 3A), the deficit ET ratio gradually declined below 1.0 likely due to less soil water evaporation from the smaller irrigations until the soil water profile gradually depleted further (Fig. 3B), but it never was less than 0.75 after full cover until near crop maturity. Daily ET rates were about 0.28-0.31 in. d^{-1} with full cover [after the boot growth stage at ~60 days after emergence] with a few days with ET rates of 0.31-0.39 in. d^{-1} (Fig. 2) likely due to stronger regional advection.

Soil Water

Figure 3 shows the mean field soil water content profiles for the two fields. The lysimeter and field soil water profiles did not differ significantly, except the lysimeters only permitted measuring to the 6.25 ft (75 in.) depth (data not given here). Most sorghum root extraction in the Pullman soil occurred above the 4 ft (48 in.) depth for the FULL field and the DI field before boot (Fig. 3 A and B), but DI sorghum extracted some soil water to the 5.5-ft (66-in.) depth in the Pullman soil after the boot stage well below the interface with the calcic horizon, showing that sorghum roots will penetrate the calcareous soil if water is available there and if overlying horizons become dry.

Water Use Efficiency

Table 1 summarizes the WUE and yield data. The DM, grain yield, harvest index, and seed mass were not statistically different on the two lysimeters between the FULL and DI treatments based on a t-Test. Seed mass averaged 18,300 seeds lb^{-1}, and HI averaged 0.45. Grain yield of the FULL lysimeter was 9,535 lbs ac^{-1} (170 bu ac^{-1}), and harvest DM was 17,894 lbs ac^{-1}. Grain yield of the DI lysimeter was 9,759 lbs ac^{-1} (174 bu ac^{-1}), and harvest DM was 18,215 lbs ac^{-1}. WUE_{dm} for the FULL treatment was 732 lbs ac^{-1} $in.^{-1}$ and 827 lbs ac^{-1} $in.^{-1}$ for the DI treatment. WUE_g was 329 lbs ac^{-1} $in.^{-1}$ for the FULL lysimeter and 372 lbs ac^{-1} $in.^{-1}$ for the DI lysimeter.

Conclusions

Deficit irrigation of sorghum at Bushland in a year with typical summer rainfall did not reduce yield but increased water use efficiency. Sorghum is widely known as a drought tolerant crop (Krieg and Lascano, 1990; Farre and Faci, 2006; Tolk and Howell, 2003; Mastrorilli et al., 1995; etc.) so planned water deficits (Lamm et al., 1994) can be an effective irrigation management strategy to reduce irrigation applications, especially with lower capacity center pivot sprinkler systems. DI does impose greater risk of reduced yields from water deficits when rainfall deficits are greater than occurred here or when irrigation capacity is reduced more than 50% of that required for

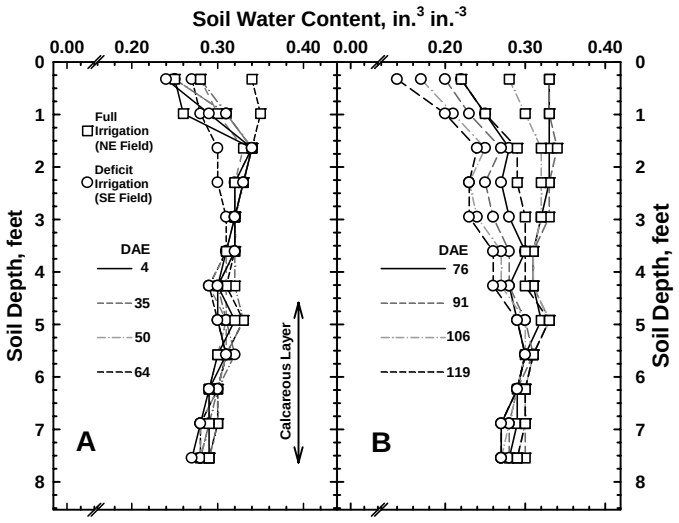

Figure 3. Soil water content profiles (mean of four neutron tube sites) in each treatment field for emergence to boot (A) and boot to maturity (B).

Table 1. Summary of ET, yield, and WUE data for the treatments. Numbers in parenthesis are standard deviations of the individual row yields in a lysimeter.

Category	Treatments	
	FULL	DI
ET (in.)	24.4	22.0
Grain Yield (lbs ac^{-1}) (dry)	8,010* (384)	8,197* (401)
Grain Yield (lbs ac^{-1}) (14% wc wb)	9,536* (457)	9,759* (478)
Dry Matter (lbs ac^{-1})	17,894* (687)	18,215* (812)
Seed Mass (seeds lb^{-1})	18,217*	18,439*
HI	0.448* (0.018)	0.450* (0.005)
WUE_g (lbs ac^{-1} $in.^{-1}$)	329	372
WUE_{dm} (lbs ac^{-1} $in.^{-1}$)	732	827
* n.s. Difference by t Test for Differences between FULL and DI.		

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non-stressed production largely in agreement with the conclusion of Fereres and Soriano (2006).

Acknowledgements:

These data were obtained through the dedicated and meticulous work of numerous technicians in the Soil and Water Research Unit at Bushland. Their tireless efforts were required to obtain these data, and we sincerely recognize their dedication.

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On December 8, Louis Baumhardt was interviewed on the KGNC 710 AM radio Agribusiness news Program CREET-BEAT about "Long-term effects of deep plowing on crop yields and soil properties." He discussed results from a long-term (31+ year) deep plowing test.

Terry Howell was interviewed by KGNC Ag Radio, CREET Beat, on April 20th on Deficit Irrigation in the Texas High Plains and the Ogallala Aquifer.

On January 29 and 30, Louis Baumhardt was invited to discuss his work on "Adapting the dryland Wheat-Sorghum-Fallow rotation for use with deficit irrigated cotton" at the 10th Annual National Conservation Systems Cotton & Rice Conference in Houston, TX.

Steve Evett traveled to Amman and the Jordan Valley, Jordan on 30 March-14 April 2007 to work with colleagues with the National Centre for Agricultural Research and Technology Transfer on construction of a large weighing lysimeter for crop water use and crop coefficient research.

Louis Baumhardt and others are helping Jackie Rudd, TAES, organize the Small Grains Field Day to be held on May 24th at the Texas A&M Research Center in Etter, TX.

SWMRU Group has started weekly unit seminar series on Thursday afternoons.

May 24	MS SharePoint Primer presented by Jerry Ennis
May 30	Cotton Irrigation presented by Paul Colaizzi
June 7	MODTRAN, Procedures to Calibrate Thermal Imagery by Jose Chavez
June 14	Lysimeters in Jordon Steve Evett
June 28	Soil Hydraulic Characteristics: Models to Reality by Robert Schwartz

* A tentative date of Wednesday, August 8th, has been set for the Bushland Summer Crops Field Day.

MEETINGS & PRESENTATIONS

Robert Schwartz and Steve Evett reported progress to the W1188 Soil Physics Multi-State Research Committee "Characterizing Mass and Energy Transport at Different Scales" January 2-4, 2007, at the Desert Research Institute, Las Vegas, NV.

Steve Evett was detailed for four months as Acting Laboratory Director of the USDA-ARS Cropping Systems Research Laboratory at Lubbock, TX, January 8, 2007. He can be reached at 806-749-5560, Fax: 806-723-5272, E-mail: srevett@cprl.ars.usda.gov.

Susan O'Shaughnessy, Terry Howell, Kim Bush, Grant Johnson, Jennifer Childers and Jourdan Bell attended the High Plains Conference, January 17, 2007, at the Amarillo Civic Center

Prasanna Gowda attended a 2-Week course "Seminar for New Managers: Leading People" offered by the U.S. Office of Personnel Management at the Western Management Development Center, Aurora, CO, on January 22 – February 2, 2007.

Susan O'Shaughnessy, Paul Colaizzi, Jim Cresap, Kim Bush, Jennifer Childers, and Kelli Bird participated in the WTAMU Spring Career Fair Exposition, in Canyon, TX, February 22, 2007. It was an opportunity to talk with students regarding summer employment and careers with ARS.

Steve Evett presented "Comparison of Soil Water Sensing Methods for Irrigation Management and Research" at the 19th Annual Central Plains Irrigation Conference & Exposition, February 27-28, 2007, Holiday Inn, Kearney, NE.

Louis Baumhardt presented an invited paper entitled "Adapting the dryland Wheat-Sorghum-Fallow rotation for use with deficit irrigated cotton" at the 10th Annual National Conservation Systems Cotton & Rice Conference held January 29-30, 2007 in Houston, TX.

Susan O'Shaughnessy and Brice Ruthardt attended NRCS-ARCGIS Spatial Analyst, Fort Worth, TX, January 29-February 1, 2007.

Steve Evett was awarded the Editors' Citation for Excellence in Manuscript Review by the Soil Science Society of America March 1, 2007.

Terry Howell attended the Oregon State Univ. NRI Project Advisory Board Meeting in San Francisco, CA, March 2-4, 2007.

Robert Schwartz, Jourdan Bell and Kim Bush attended the Datalogger Training at Campbell Scientific, titled "CR1000/ LoggerNet Training", in Logan, UT, March 5-8, 2007.

Jose Chavez took the GIS training program, "Working with ArcGIS Spatial Analyst." USDA-NRCS, National Cartography and Geospatial Center. Fort Worth, TX, March 5-8, 2007.

Terry Howell, Steve Evett, Susan O'Shaughnessy, Jose Chavez, Judy Tolk, Louis Baumhardt, Robert Schwartz, and Prasanna Gowda attended the Ogallala Aquifer Program Workshop, March 12-14, 2007, Lubbock, TX. Topics discussed were research results and potential research topics.

Steve Evett presented "An Overview of Soil Water Sensing Technology and Problems" to the "Soil Moisture Sensing Technology Conference: Current and future research directions in soil moisture sensing" at Honolulu, Hawaii, March 19-21, 2007. Dr. Evett was one of the conference organizers and moderated sessions V: Remote Access, Telemetry and New Technologies, and VII: Soil Water Sensor Improvements – Panel Discussion with Audience Participation.

Susan O'Shaughnessy, Chad Ford and Brice Ruthardt attended the Waveforum 2007 by Maxstream, Salt Lake City, UT, March 19-21, 2007.

Louis Baumhardt presented a paper entitled "Modeling to evaluate irrigation management strategies that maximize cotton yield and water use efficiency" at the 37th Biological Systems Simulation Group Conference held April 17-19, 2007, in Beltsville, MD.

Judy Tolk, Rick Todd, Louis Baumhardt and Brian Vick were exhibitors at Earth Fest 2007, April 28 at Wildcat Bluff Nature Center in Amarillo, TX.

Publications

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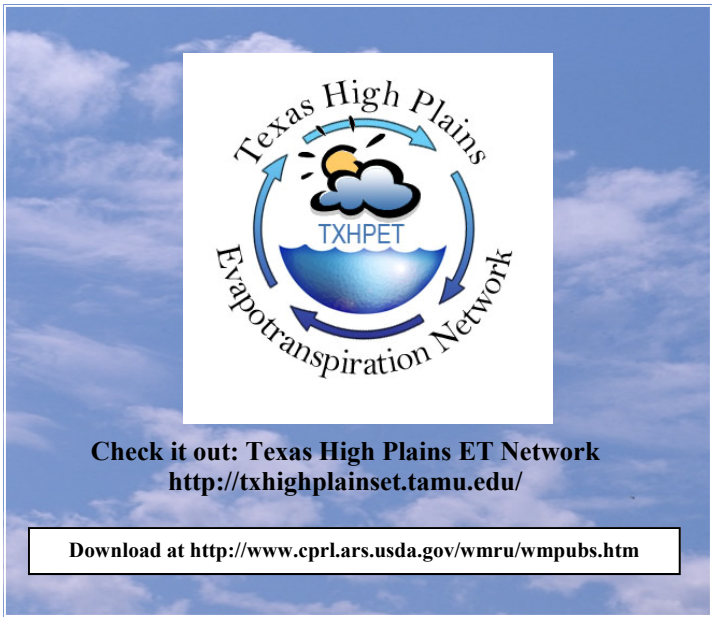

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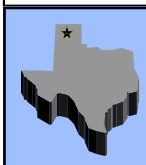

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