

## EVAPOTRANSPIRATION OF DEFICIT IRRIGATED SORGHUM AND WINTER WHEAT

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### ABSTRACT

Deficit irrigation commonly is used in regions with reduced or limited irrigation capacity to increase water use efficiency (WUE). This research measured winter wheat (*Triticum aestivum* L.) and sorghum (*Sorghum bicolor* L. Moench) water use (ET) and yields so WUE could be determined. Two precision weighing lysimeters were used to accurately measure the crop ET from fully irrigated (FULL) fields and deficit irrigated (DI) fields. The DI wheat was an irrigation cutoff at the jointing growth stage as might be used if available irrigation water was being shifted to summer crops while the sorghum DI used a reduced irrigation rate (~50% FULL irrigation) as might occur with a lower irrigation capacity. Both crops were irrigated by a lateral-move sprinkler system at Bushland, Texas. Wheat ET was decreased by 20% from 849 to 677 mm with a 76% decline in irrigation. Sorghum ET decreased 10% from 621 mm to 560 mm with a 48% decline in irrigation. WUE of sorghum for both grain and dry matter increased slightly with DI but seed mass, and harvest index were unaffected. DI irrigated wheat extracted soil water to a depth of 1.7 m in the Pullman soil with some apparent root extraction to the 2.3-m depth. Sorghum extracted soil water mainly above 1.2 m in the Pullman soil profile if well watered, but DI sorghum extracted soil water to 1.7 m. Sprinkler DI of sorghum beginning with a nearly full soil water content profile permitted the crop to better exploit the soil profile water and minimize soil water deficit effects on crop yield in a year with typical summer rainfall for Bushland (~210 mm) such that yield was not reduced by DI. Cutting off winter wheat irrigation in early spring with a near full soil water profile at jointing, permitted the wheat crop to fully exploit the soil water reservoir when rainfall was normal.

### INTRODUCTION

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 (DI) and concluded that the level of the DI 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

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only increase water productivity but also farm profit. Deficit irrigation 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 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  $1.46 \text{ kg m}^{-3}$  at Bushland, Texas 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.

The purpose of this paper is to present and briefly discuss and describe the ET of deficit and more fully irrigated grain sorghum and wheat measured at Bushland, Texas 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.

## PROCEDURES

This study was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, Texas (35° 11' N lat.; 102° 06' W long.; 1,170 m elev. above MSL) in 1991 to 1993. Crop ET was measured with two weighing lysimeters (Marek et al., 1988) each located in the center of two 4.4-ha 210 m E-W by 210 m 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 0.3 to 0.5 m below the surface. The two east lysimeter fields were used for this experiment. The plant available water holding capacity within the top 2.0 m of the profile is approximately 240 mm (Tolk and Howell, 2001) and ~200 mm to the 1.5-m depth. A calcareous layer at about the 1.4 m depth somewhat limits rooting and water extraction below this depth, depending on the crop. Variations of this soil series are common to more than 1.2 million ha of land in this region and about 1/3 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 1 km. 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. (1998), Howell et al. (2004), and Evett et al. (2000).

### **Agronomic Methods**

Winter wheat (*Triticum aestivum* L.; CV TAM-107) was seeded on 27-28 September 1991 (DOY<sup>6/</sup> 269-270) in E-W rows 0.25-m apart with a conventional grain drill on the two east lysimeter fields. Previous crops were irrigated corn (*Zea mays* L.) in 1990 and fallow until fall 1991 (8 months). Plant density was 192 plants m<sup>-2</sup>. Fertilizer rate was 11.2 g (N) m<sup>-2</sup> applied on 29 August 1991 (DOY 241). The fields were uniformly irrigated on 29 September 1991 (DOY 272) with 20 mm for germination and uniform emergence. Plant emergence was on 7 October 1991 (DOY 280). The NE field had some lodging on about DOY 135 in 1992 (14 May). The SE lysimeter was hand harvested on 17 June 1992 (DOY 169) and the NE lysimeter was hand harvested on 29 June 1992 (DOY 181).

Sorghum (*Sorghum bicolor* L. Moench; CV, DK-56<sup>7/</sup> (Dekalb, Monsanto Co., St. Louis, Missouri), was planted in the field on 27 May 1993 (DOY 147) in E-W rows 0.76 m apart with a six-row conventional farm planter. Previous crops were fully irrigated corn in 1990, the wheat described above, and fallow from wheat harvest until sorghum planting (10 months). The six rows at each lysimeter [about 10 m 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 (16 mm) was applied uniformly on 28 May (DOY 148) for seed germination and uniform emergence. The final mean emerged field plant stand was 22 plants m<sup>-2</sup> in the two fields. Harvest plant density counts averaged 20-21 plants m<sup>-2</sup> for both fields and lysimeters. The fields and lysimeters were fertilized on 8 May (DOY 159) at the rate of 11.2 g (N) m<sup>-2</sup> 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.

### **Lysimeter Measurements**

Lysimeter mass was determined using a Campbell Scientific CR-7X data logger to measure and record the lysimeter load cell (Interface SM-50) signal at 0.5-Hz (2 s) frequency. The load cell signal was averaged for 5 min and later reported as 30-min means (reported on the mid point of the 30 min, i.e. data were averaged from 0-30 minutes and reported at 15 min). The lysimeter mass resolution was 0.01 mm, and its accuracy exceeded 0.05 mm (Howell et al., 1995a). Daily ET was determined as the difference between lysimeter mass losses (from evaporation and transpiration) and lysimeter mass gains (from irrigation, precipitation, or dew) divided by the lysimeter area (9 m<sup>2</sup>). A pump regulated to -10 kPa provided vacuum drainage, and the drainage effluent was held in two tanks suspended from the lysimeter (their mass was part of the total lysimeter mass) and independently weighed by load cells (drainage rate data are not reported here). ET for each 24-h period was divided by 1.02 to adjust the lysimeter area to the mid point

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<sup>6/</sup> DOY – Day of Year.

<sup>7/</sup> 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.

between the two walls (10 mm air gap; 9.5 mm wall thickness; 9.18-m<sup>2</sup> area instead of 9.00-m<sup>2</sup> area). This correction would be applicable for full-cover crops, but it would not be necessary for bare soil conditions. Nevertheless, it was applied to all data uniformly.

### **Irrigation Treatments**

Wheat: The east lysimeter fields were irrigated with a lateral-move sprinkler system with the north field (NE) and south field (SE) irrigated similarly until early spring 12 March (DOY 72) at the jointing stage when irrigations were ceased on the SE field to simulate the common deficit irrigation practice of switching irrigations to preplant irrigations for summer crops like corn or sorghum. Irrigations were applied with a 10-span lateral-move sprinkler system (Lindsay Manufacturing, Omaha, Nebraska) with an end-feed hose. The NE field and lysimeter (designated as the FULL treatment) continued to be irrigated to minimize soil water deficits to maintain non water stressed. The SE lysimeter and field were allowed to deplete the soil water reserves until harvests (DI treatment).

Sorghum: 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 treatment) and the south half (SE) being DI with approximately 50% of the FULL rate by using smaller nozzles. This simulated a reduced irrigation capacity on the SE field and lysimeter. The FULL treatment was managed to meet the water demand of the crop. 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, Florida) with concaved spray plates on drops located about 1.5 m above the ground and 1.52 m apart. Each spray head was equipped with a 100-kPa pressure regulator and a 1-kg polyethylene drop weight. Irrigations were scheduled to meet the ET water use rate and were typically applied in one to two 25-mm applications per week. Irrigations were managed on the FULL treatment to minimize soil water deficits with the available irrigation capacity allowing 25-30 mm for rainfall storage. The DI treatment allowed the soil water profile to gradually deplete.

### **Soil Water Measurements**

Soil water contents were measured periodically using a neutron probe (model 503DR Hydroprobe. CPN International, Inc., Martinez, California) at 0.2-m depth increments beginning with the 0.10-m depth using 60-s counts. Two access tubes were located in each lysimeter (read to 1.9 m depth) and four tubes were located in the field surrounding each lysimeter (read to 2.3-m depth). The probe was field calibrated for the Pullman soil using a method similar to that described by Evett and Steiner (1995).

### **Plant and Yield Sampling**

Plant samples from three separate 1.5-m<sup>2</sup> areas were obtained periodically to measure crop development. These field samples were taken at sites about 10 to 20 m away from the lysimeters in areas of the field representative of the lysimeter vegetation. Leaf area index (LAI), crop

height (CH), and aboveground dry matter (DM) were measured from three samples. Final yield was measured by harvesting the lysimeter grain and aboveground plant matter from each lysimeter (9 m<sup>2</sup>), and dry matter and yield at harvest were measured from three adjacent 1.5-m<sup>2</sup> plant samples.

### **Water Use Efficiency**

Water use efficiency (WUE) was computed based on Viets (1962) and Zwart and Bastiaanssen (2004) [see also Farre and Faci (2006) and Tolk and Howell (2003)].  $WUE_g$  (in kg m<sup>-3</sup>) was the ratio of grain yield (dry) ( $GY_d$ ; in g m<sup>-2</sup>) to ET (in mm);  $WUE_{dm}$  (in kg m<sup>-3</sup>) was the ratio of DM (in g m<sup>-2</sup>) to ET (in mm); and harvest index (HI) was the dimensionless ratio of  $GY_d$  to DM.

## **RESULTS**

### **Wheat**

The crop emerged on 7 October 1991 (DOY 280). The rainfall received from crop planting until harvest was 507 mm above average for a wheat season but not greatly different from the annual precipitation at Bushland, Texas [~480-500 mm long-term annual mean]. The FULL irrigation treatment received 502 mm of seasonal irrigation and the DI treatment received 119 mm of irrigation. Measured drainage was 61 mm for the FULL treatment and 88 mm for the DI treatment. The drainage was mainly from remaining soil water following the 1990 irrigated crop, the 1990-91 winter precipitation, and the 1991 spring rainfall. Total net water applied (rain plus irrigation) was 1,009 mm for FULL and 626 mm for DI from planting and 962 mm for FULL and 582 for DI from the emergence date (Fig. 1).

### **Sorghum**

The crop emerged on 3 June (DOY 154). The rainfall received from crop planting until harvest was 211 mm typical for a normal summer rainfall season at Bushland, Texas [~480-500 mm long-term annual mean]. Almost one-third of the growing season rain (70 mm) was received on 14 and 15 July (DOYs 195 and 196). The FULL irrigation treatment received 369 mm of season irrigation and the DI treatment received 171 mm of irrigation. Measured drainage was 46 mm for the FULL treatment and 29 mm for the DI treatment. Total net water applied (rain plus irrigation) was 586 mm for FULL and 388 mm for DI from planting and 563 mm for FULL and 365 for DI from the emergence date (Fig. 2).

### **Crop Evapotranspiration**

The seasonal ET rates are shown in Fig. 3 for the winter wheat, and the cumulative seasonal ET was shown in Fig. 1 for comparison with the rainfall and applied water. The FULL ET [ $ET_{FULL}$ ] was 849 mm and the DI ET [ $ET_{DI}$ ] was 677 mm (Fig. 1; Table 1) from emergence. The wheat daily ET deficit ratio [ $ET_{DI} ET_{FULL}^{-1}$ ; Fig. 3] was somewhat erratic during the early season due to the usually smaller ET rates, except following rain or irrigation when the deficit ET ratio was

near 1.0 then declined after heading (DOY 118, DAE<sup>8/</sup> 203, 28 April) to 0.3-0.4 at physical maturity for the DI treatment (DOY 161, DAE, 245, 9 June). Wheat daily ET rates were

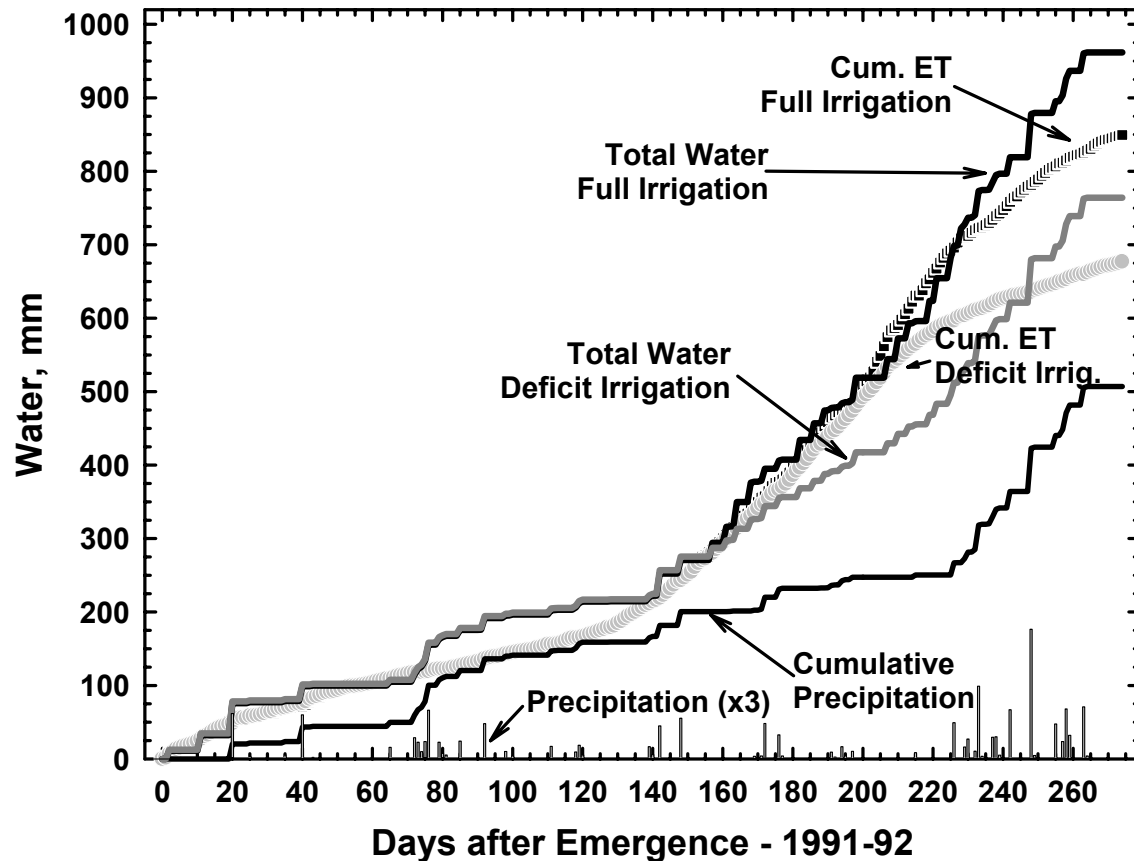


Figure 1. Water balance parameters for the 1991-92 winter wheat growing season (note the rainfall bars were multiplied by 3 to be more visible on the scale).

maximum near heading at  $8\text{--}9\text{ mm d}^{-1}$  with three days having maximum daily ET rates from 12 to  $13\text{ mm d}^{-1}$  under strong regional advection (Fig. 3).

Sorghum seasonal ET amounts were 621 and 560 mm for the FULL and DI treatments from emergence (Fig. 2). The sorghum FULL ET ( $ET_{\text{FULL}}$ ) was about 40 mm less than that reported by Tolk and Howell (2003) for their 100% ET treatment in 1998 and 85 mm more than their reported 100% ET in 1999. It was about 30 mm less than the 100% ET treatment in 1995 for sorghum in Spain (Farre and Faci, 2006). The DI sorghum ET ( $ET_{\text{DI}}$ ) was about 20 mm more than that reported by Tolk and Howell (2003) for their 50% ET treatment in 1998 and 100 mm more than their reported 100% ET in 1999. The Bushland sorghum  $ET_{\text{DI}}$  was about mid way between the T-1 ET (588 mm) and T-2 ET (544 mm) reported by Farre and Faci (2006) for 1995 in Spain from a line source experiment. The sorghum daily ET deficit ratio [ $ET_{\text{DI}} ET_{\text{FULL}}^{-1}$ ;

<sup>8/</sup> DAE – Days after emergence.

Fig. 4] was somewhat erratic during 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, the sorghum 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

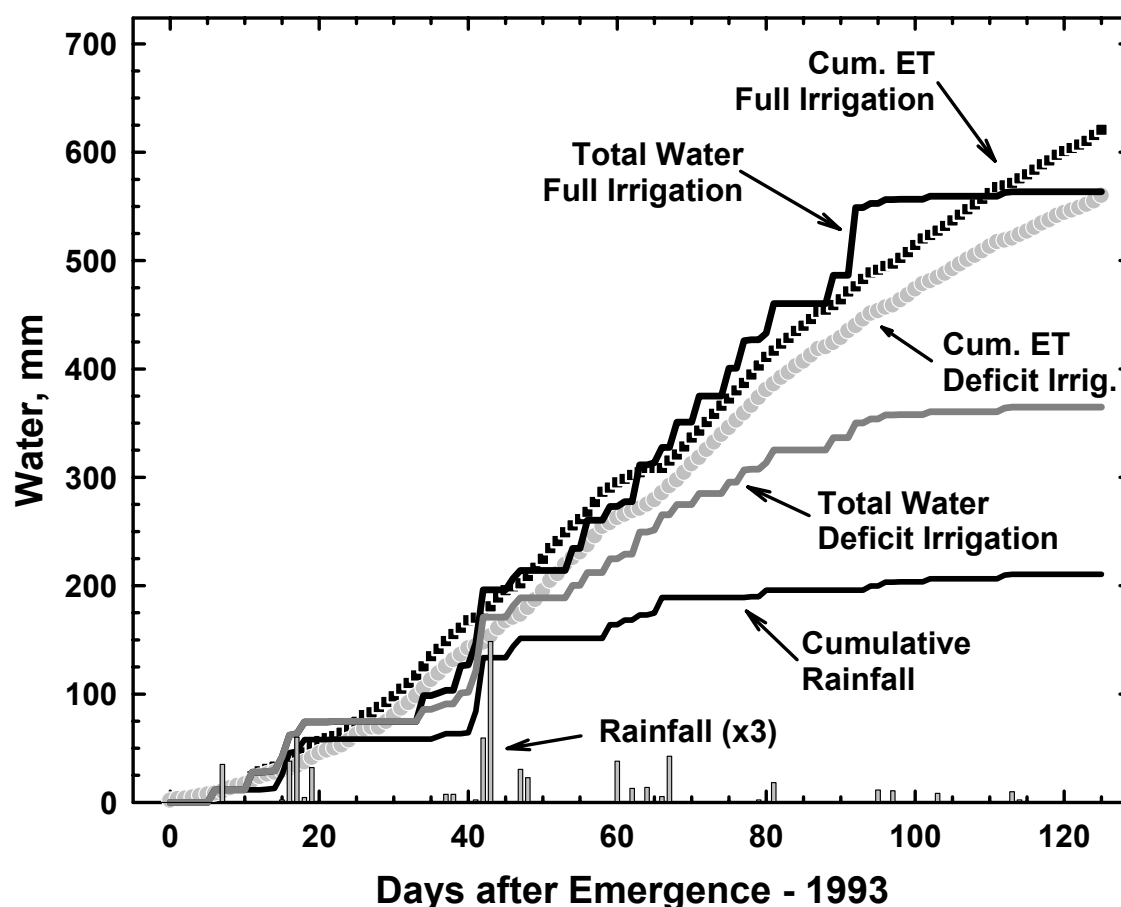


Figure 2. Water balance parameters for the 1993 sorghum growing season (note the rainfall bars were multiplied by 3 to be more visible on the scale).

further. The deficit ET ratio never was less than 0.75 after full cover until near crop maturity. Daily sorghum ET rates were about  $7\text{--}8\text{ mm d}^{-1}$  with full cover [after the boot growth stage at  $\sim 60$  DAE] with a few days with ET rates of  $8\text{--}10\text{ mm d}^{-1}$  (Fig. 4) likely due to stronger regional advection.

### Crop Development

Figure 5 shows the wheat crop development in 1991-92, and Fig. 6 shows sorghum crop development in 1993. The wheat crop height (CH) was similar for both the FULL and DI treatments until heading (DOY 118, DAE 203; Fig. 5A). The taller FULL wheat did lodge on the lysimeter following early grain development affecting the resulting lysimeter grain yields and

crop ET to an unknown extent. The wheat LAI was similar until the irrigation was ceased for DI (DAE 200, DOY 95; Fig. 5B) at jointing indicating the sensitivity in leaf area development to soil water deficits; and dry matter was similar for FULL and DI irrigated wheat until boot (DAE 190, DOY 105; Fig. 5C).

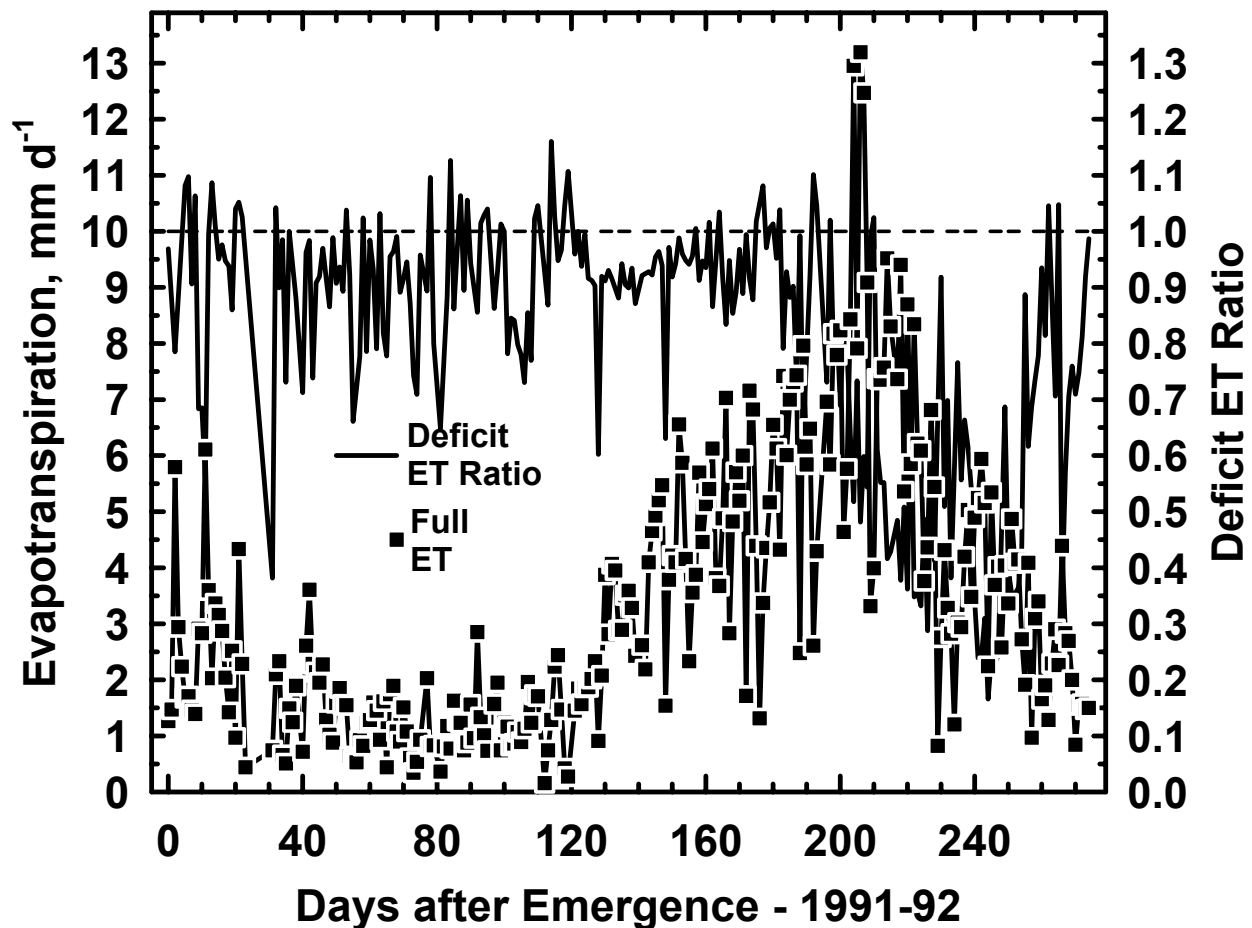


Figure 3. Daily ET rates and the daily deficit ET ratio [ $ET_{DI} ET_{FULL}^{-1}$ ] (right axis scale) for the 1991-92 winter wheat.

Neither crop height (CH) nor dry matter (DM) were different (based on the standard deviations of the sample observations) between the FULL and DI sorghum treatments (Fig. 6A, 6C). Leaf area index (LAI) was essentially the same for the FULL and DI fields until about 90 DAE when the soil water profile had greater depletion (Fig. 8B). Sorghum LAI peaked near  $5.0\text{--}5.2\text{ m}^2\text{ m}^{-2}$ , which was less than the sorghum maximum of the T-1 treatment LAI (100% ET; Farre and Faci, 2006) of  $6.4\text{ m}^2\text{ m}^{-2}$  in Spain. Maximum sorghum DM was near  $1,800\text{--}2,000\text{ g m}^{-2}$  which was similar to that reported by Farre and Faci (2006) [dry matter of  $1,838\text{ g m}^{-2}$ ] in Spain for their T-1 treatment (100 % ET).



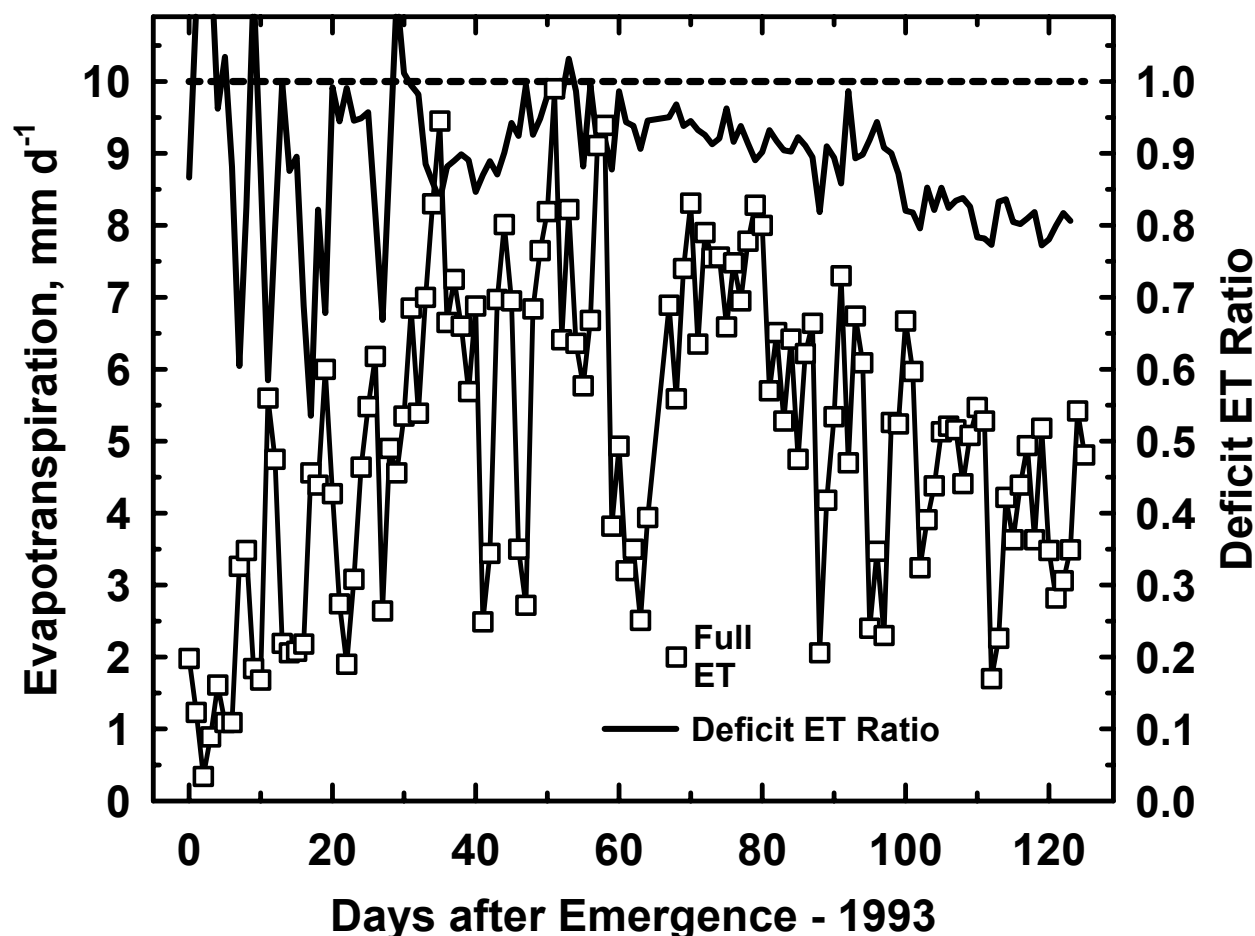


Figure 4. Daily ET rates and the daily deficit ET ratio  $[ET_{DI} ET_{FULL}^{-1}]$  (right axis scale) for the 1993 sorghum.

### Soil Water

Figure 7 shows the mean field soil water content profiles for the two wheat fields, and Fig. 8 shows the mean field soil water content profiles for the two sorghum fields. Fig. 7A shows wheat soil water extraction to the 1.2-m depth prior to jointing (DAE 176, DOY 91) and minimal root extraction from the caliche layer at 1.2-1.7-m depths. After heading, the DI wheat extracted a significant amount of soil water to the 1.7-m depth with apparent root uptake by wheat in the Pullman soil to the 2.3-m depth (Fig. 7B).

The sorghum lysimeter and field soil water profiles did not differ significantly, except the lysimeters only permitted measuring to the 1.9-m depth (data not given here). Most sorghum root extraction in the Pullman soil occurred above the 1.2-m depth for the FULL field and the DI field before boot (Fig. 8 A and B), but DI sorghum extracted some soil water to the 1.7-m depth

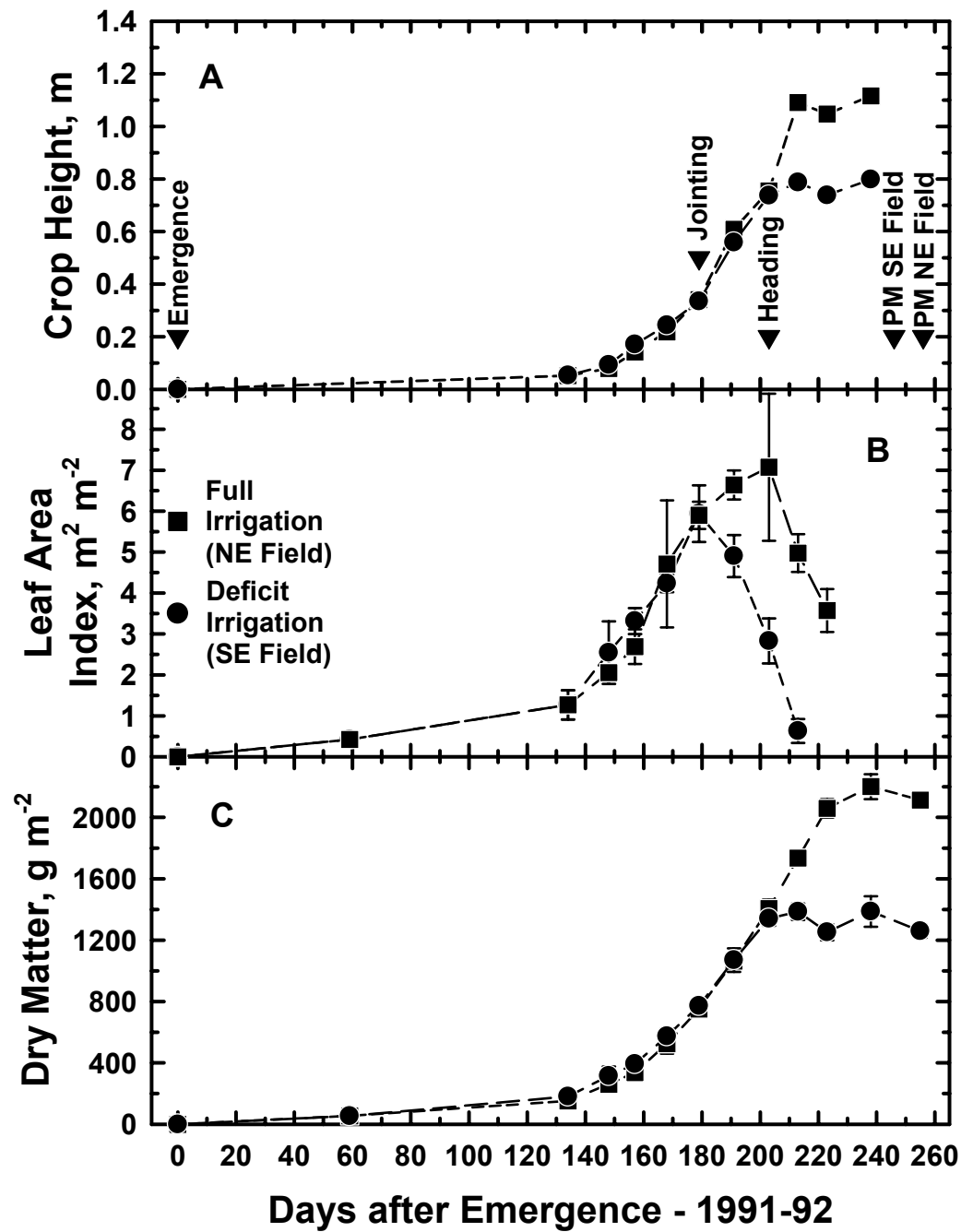


Figure 5. Crop development for 1991-92 winter wheat. Top (A) is crop height; middle (B) is leaf area index; and bottom (C) is dry matter. PM is physical maturity.

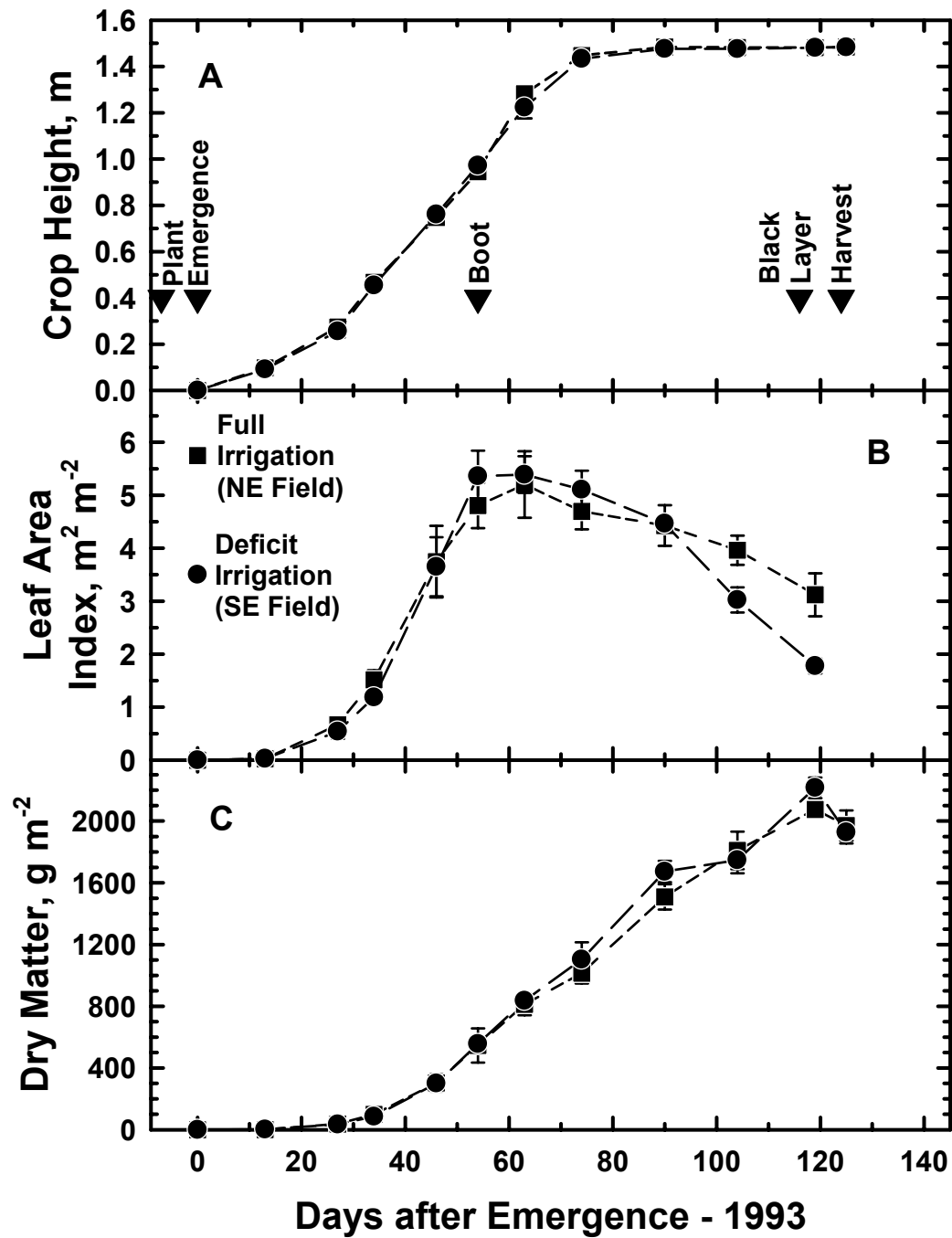


Figure 6. Crop development for 1993 sorghum. Top (A) is crop height; middle (B) is leaf area index; and bottom (C) is dry matter.

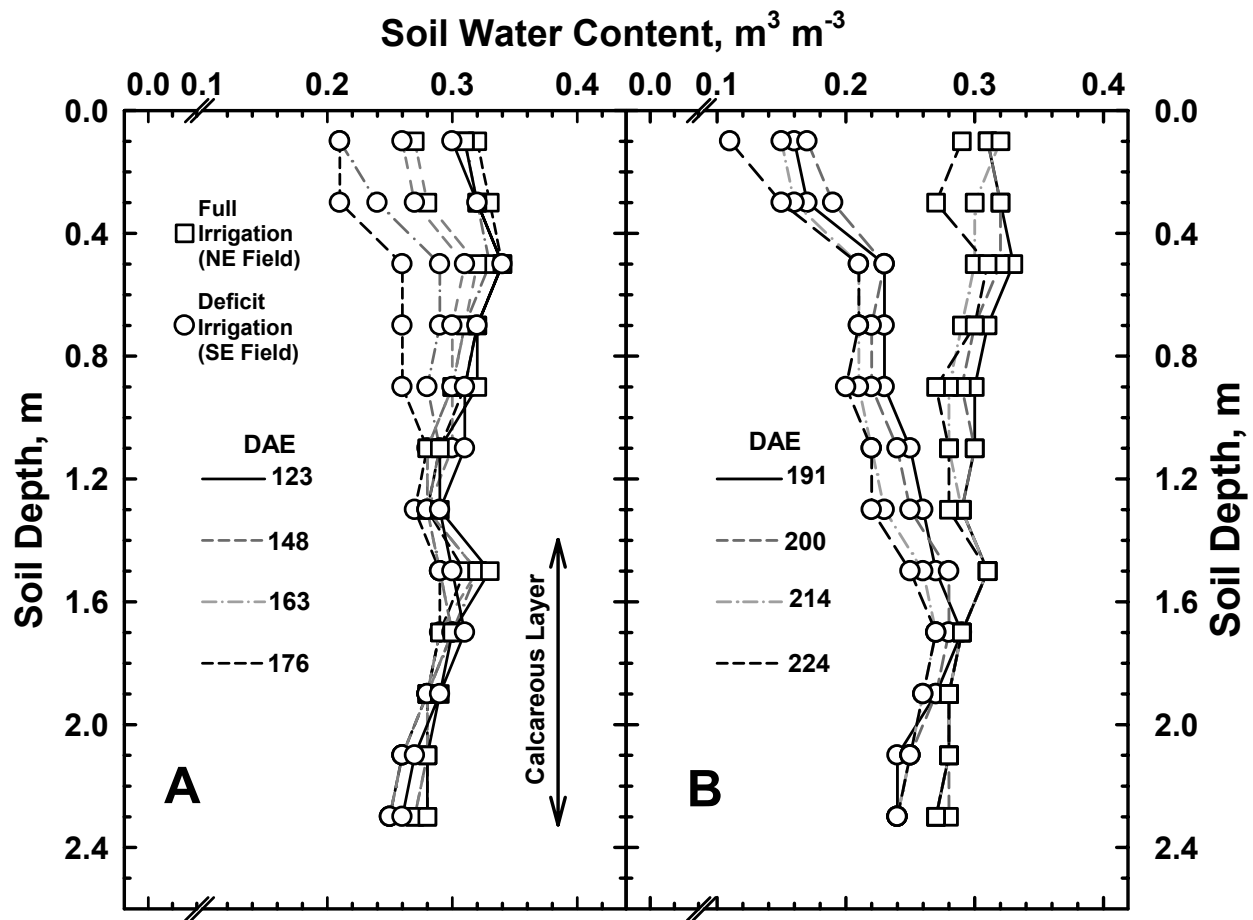


Figure 7. Soil water content profiles (mean of four neutron tube sites) in each treatment field in 1991-92 for winter wheat for emergence to joint (A) and joint to maturity (B).

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 for the wheat, and Table 2 summarizes the WUE and yield data for the sorghum. Since the SE lysimeter stems weren't harvested for a follow-up experiment on residue effects on soil water evaporation a complete analysis isn't possible, here. The NE lodging apparently affected the lysimeter yields, especially for the NE lysimeter (FULL treatment). The NE (FULL treatment) field had a DM yield of  $2,113 \pm 42 \text{ g m}^{-2}$ ; grain yield of  $669 \pm 48 \text{ g m}^{-2}$ ; a HI of  $0.32 \pm 0.03$ ; and a grain mass of  $29.7 \pm 0.3 \text{ mg seed}^{-1}$ . The SE (DI treatment) field had a dry matter yield of  $1,258 \pm 48 \text{ g m}^{-2}$ ; grain yield of  $373 \pm 34 \text{ g m}^{-2}$ ; a HI of  $0.296 \pm 0.017$ ; and a grain mass of  $24 \pm 2 \text{ mg seed}^{-1}$ . The lysimeter wheat yields were similar to regional wheat

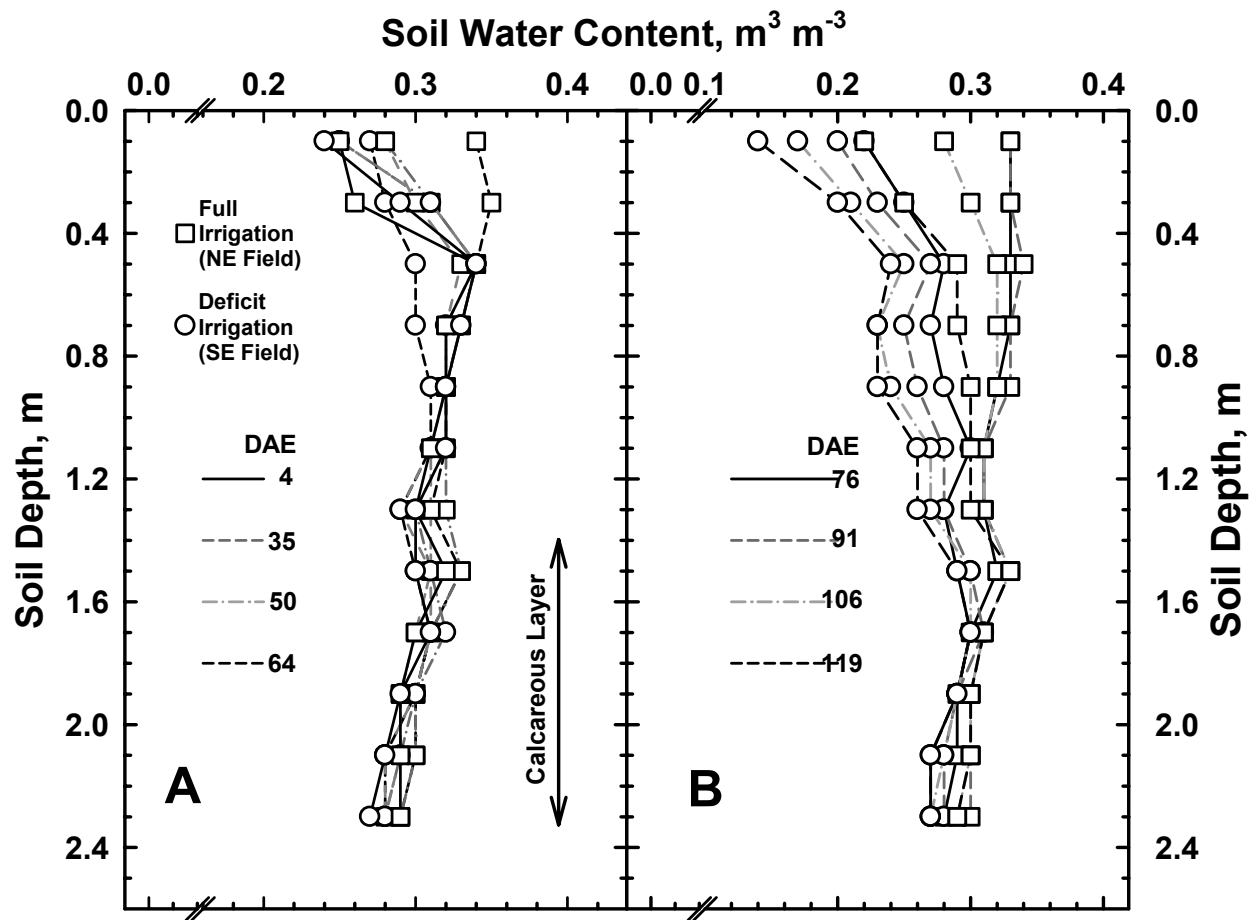


Figure 8. Soil water content profiles (mean of four neutron tube sites) in each treatment field for 1993 sorghum for emergence to boot (A) and boot to maturity (B).

yields, but affected by the lodging on the FULL lysimeter. The field yield samples are more similar to other experiment plot yields, although both the lysimeter and field HI values seemed somewhat lower than might be expected. The wheat  $WUE_g$  was  $0.38 \text{ kg m}^{-3}$  for the FULL treatment and  $0.61 \text{ kg m}^{-3}$  for the DI treatment.

The sorghum DM, grain yield, HI, 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  $25 \text{ mg seed}^{-1}$ , and HI averaged 0.45. The HI was somewhat lower than that reported for the T-1 treatment (100% ET) by Farre and Faci (2006) of 0.49. Mastrorilli et al. (1995) reported well-watered sorghum seed mass of  $26 \text{ mg seed}^{-1}$  in Italy. Grain yield of the FULL lysimeter ( $898 \text{ g m}^{-2}$ ) was slightly greater than the yield reported for the T-1 treatment (100% ET) by Farre and Faci (2006) of  $854 \text{ g m}^{-2}$  in Spain or the 100% ET treatment yield reported by Tolk and Howell (2003) for the Pullman soil at Bushland of  $865 \text{ g m}^{-2}$  in 1998 and  $879 \text{ g m}^{-2}$  in 1999. Mastrorilli et al. (1995) reported well watered sorghum yield of  $634 \text{ g m}^{-2}$  in Italy in 1991.

Table 1. Summary of ET, yield, and WUE data for the winter wheat treatments in 1991-92. Numbers in parenthesis are standard deviations of the individual row (12) yields in a lysimeter.

Category	Treatments	
	FULL	DI
ET (mm)	849	677
Grain Yield ( $\text{g m}^{-2}$ ) (dry)	326 <sup>**</sup> (37)	412 <sup>**</sup> (54)
Dry Matter ( $\text{g m}^{-2}$ )	1,317 (160)	na <sup>¶</sup>
Seed Mass ( $\text{mg seed}^{-1}$ )	23.5 <sup>*</sup> (1.4)	24.2 <sup>*</sup> (0.9)
HI	0.248 (0.021)	na
WUE <sub>g</sub> ( $\text{kg m}^{-3}$ )	0.38	0.61
WUE <sub>dm</sub> ( $\text{kg m}^{-3}$ )	1.55	na
<sup>**</sup> Significant difference ( $P < 0.05$ ) <sup>¶</sup> The DI field residue wasn't harvested for a fallow evaporation experiment in 1992-93. <sup>*</sup> n.s. Difference by t Test for Differences between FULL and DI.		

Harvest DM of  $2006 \text{ g m}^{-2}$  at Bushland was greater than that reported for the T-1 treatment (100% ET) by Farre and Faci (2006) of  $1,838 \text{ g m}^{-2}$  in Spain. Mastrorilli et al. (1995) reported sorghum DM of  $2,040 \text{ g m}^{-2}$  in Italy for non-stressed sorghum. WUE<sub>dm</sub> at Bushland was  $3.23 \text{ kg m}^{-3}$  for FULL and  $3.65 \text{ kg m}^{-3}$  for DI. Farre and Faci (2006) did not report WUE<sub>dm</sub>, but their data for the T-1 treatment (100% ET) were used to compute WUE<sub>dm</sub> as  $3.12 \text{ kg m}^{-3}$ . Mastrorilli et al. (1995) reported WUE<sub>dm</sub> of  $4.85 \text{ kg m}^{-3}$ . WUE<sub>g</sub> was  $1.45 \text{ kg m}^{-3}$  for the FULL lysimeter and  $1.64 \text{ kg m}^{-3}$  for the DI lysimeter. Tolck and Howell (2003) reported WUE<sub>g</sub> that varied from  $1.31 \text{ kg m}^{-3}$  in 1998 to  $1.64 \text{ kg m}^{-3}$  in 1999 for WUE<sub>g</sub> of  $1.46 \text{ kg m}^{-3}$  for their T-1 treatment (100 % ET). WUE<sub>g</sub> was reported as  $1.51 \text{ kg m}^{-3}$  for non-stressed sorghum in Italy (Mastrorilli et al., 1995). WUE<sub>g</sub> increased at 50% ET in both years on the Pullman soil as reported by Tolck and Howell (2003) but decreased with greater ET deficits in Spain (Farre and Faci, 2006).

Table 2. Summary of ET, yield, and WUE data for the 1993 sorghum treatments. Numbers in parenthesis are standard deviations of the individual row (4) yields in a lysimeter.

Category	Treatments	
	FULL	DI
ET (mm)	621	560
Grain Yield ( $\text{g m}^{-2}$ ) (dry)	898* (43)	919* (45)
Dry Matter ( $\text{g m}^{-2}$ )	2,006* (77)	2,042* (91)
Seed Mass ( $\text{mg seed}^{-1}$ )	24.9* (1.0)	24.6* (0.5)
Harvest Index (HI)	0.448* (0.018)	0.450* (0.005)
$\text{WUE}_g$ ( $\text{kg m}^{-3}$ )	1.45	1.64
$\text{WUE}_{dm}$ ( $\text{kg m}^{-3}$ )	3.23	3.65
* n.s. Difference by t Test for Differences between FULL and DI.		

## CONCLUSIONS

Deficit irrigation of wheat with typical precipitation had greater yields on the lysimeters but not based on field sampling likely due to the lodging that occurred with the FULL treatment. 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, 20003; 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 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 USDA-ARS Soil and Water Research Unit at Bushland, tEXAS. Their tireless efforts were required to obtain these data, and we sincerely recognize their dedication.

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