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Evapotranspiration, Yield, and Water Use Efficiency of Corn Hybrids Differing in Maturity

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ABSTRACT

Short-season corn (*Zea mays* L.) hybrids may reduce irrigation requirements and permit earlier harvest. We measured and compared evapotranspiration (ET) of a short-season (SS, Pioneer 3737) and full-season (FS, Pioneer 3245) hybrid under full irrigation in 1994 at Bushland, TX, and examined differences in growth, yield, and water use efficiency (WUE). Both hybrids were planted the same day in contiguous 4-ha fields (each field with a weighing lysimeter to measure ET directly), were irrigated simultaneously until the SS hybrid reached mid grain fill (R5 dent stage), and were managed for high productivity. Harvest was at the normal field-dried grain water content of 136 g kg^{-1} for the region. Rainfall was 320 mm; 465 and 577 mm of irrigation was applied to the SS and FS hybrid fields, respectively. Seasonal ET was reduced with the SS hybrid (SS, 673 mm; FS, 802 mm), with the primary reduction after SS anthesis. Peak daily ET rates (some >10 mm d^{-1}) were not affected by hybrid type. Grain yields (dry basis) declined from 1322 to 1130 g m^{-2}, but grain water use efficiency (WUE$_g$ = grain yield/ET) was similar across hybrids: SS, 1.68 kg m^{-3}; FS, 1.65 kg m^{-3}. Dry matter (DM) was reduced by >390 g m^{-2} for the SS hybrid, but DM water use efficiency (WUE$_d$ = DM/ET) was identical for the two hybrids, at 3.02 kg m^{-3}. The SS hybrid reached physiological maturity 12 d earlier than the FS hybrid and was harvested 11 d sooner. Leaf area index was >5.5 m^2 m^{-2} for the FS hybrid, but barely >4 m^2 m^{-2} for the SS hybrid. The WUE$_d$, WUE$_g$, and peak daily ET rates were not appreciably different for the two hybrids when fully irrigated, although seasonal ET was less with the SS hybrid. A shorter-maturity hybrid can reduce ET and seasonal irrigation requirement, but it will not reduce the needed irrigation capacity (flow per unit area) by more than 5 to 10%, as that is largely dictated by the near-maximum daily ET rate needed to avoid soil water deficits and a corresponding yield reduction. With prevailing regional pumping and production costs, the reduced production income with a SS hybrid would be more than six to eight times the saving in irrigation water cost, but this could be offset by higher grain marketing prices with an earlier harvest and by the opportunity for grazing income from a winter wheat (*Triticum aestivum* L.) double-crop.

CORN, a major irrigated crop on the Texas High Plains (Musick et al., 1990), has a high seasonal irrigation requirement. An important regional transition, the shift from graded furrow to sprinkler irrigation, predominantly center-pivot sprinklers (Musick et al., 1988), has reduced water applications and has contributed to sustained irrigated production in this region (Musick and Walker, 1987). Center-pivot sprinkler irrigation (Splinter, 1976) is well suited to this region, where water is a far more restricted resource for irrigated agriculture than land. Widespread growth of the use of center-pivot sprinkler systems in this area has made knowledge about crop-water use for management and system design even more critical, since the area is dependent on a declining groundwater resource and on low, highly variable precipitation. Irrigated corn has been grown on a wide-scale commercial basis for only about 25 yr in the Texas High Plains—a relatively short history, compared with irrigated cotton (*Gossypium hirsutum* L.) and sorghum [*Sorghum bicolor* (L.) Moench]. Table 1 summarizes the range of evapotranspiration (ET) and grain yields reported from several corn irrigation experiments in the Southern High Plains and elsewhere. The variability in maximum yields is quite large owing to many factors including environment and specific cultivar responses. Recent yields have often exceeded 1200 g m^{-2}; however, more significant is the considerably higher ET for fully irrigated corn in the Texas High Plains compared with other sites in the Great Plains, the USA, and around the world.

Although much information is known about corn responses to irrigation (Rhoads and Bennett, 1990; Doorenbos and Kassam, 1979), few reports are available that contrast water use and water use efficiency as related to corn maturity classification. Colville et al. (1964) investigated irrigated corn responses for six hybrids in Nebraska in relation to plant density. Rutger and Crowder (1967) studied effects of differing plant densities on a range in corn hybrids in New York. Bennett and Hammond (1983) measured yields and irrigation response of nine corn hybrids with differing maturities in Florida. Dwyer et al. (1994) investigated effects of corn maturity class on many yield-related parameters in Canada. None of these studies reported water use information as influenced by the hybrid-maturity class.

Because full-season corn has a large irrigation requirement and normally does not mature and dry down for harvest early enough to permit double-cropping to winter wheat (especially for winter grazing) in the Southern High Plains, the use of shorter-maturity corn hybrids has become more widespread in this region. Double-cropping of wheat following corn is more common under center pivots. Pivots can be managed to

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Abbreviations: DM, dry matter; DOY, day of year; ET, evapotranspiration; FS, full season; LAI, leaf area index; PAR, photosynthetically active radiation; SS, short season; VPD, vapor pressure deficit; WUE, water use efficiency; WUE$_d$, dry matter water use efficiency; WUE$_g$, grain water use efficiency.

Table 1. Range of water use and grain yield of fully irrigated corn, from selected reports.

Region and reference	Water use	Grain yield
	mm	g m^{-2}
Southern High Plains		
Texas		
Musick and Dusek (1980)	667–789	952–1085
Eck (1984)	783–984	766–1321
Unger (1986)	571–746	555– 936
Howell et al. (1989)	838	1170
Steiner et al. (1991)	683–785	1150–1230
Lyle and Bordovsky (1995)	—	1130–1390
Howell et al. (1995b)	786–973	1236–1550
Kansas		
Hattendorf et al. (1988)	551–597	670– 926
Lamm et al. (1995)	574–597	1050–1490
Nebraska		
Schneekloth et al. (1991)	609–634	1060–1330
Other		
Hillel and Guron (1973)	486–544	850–1080
Stewart et al. (1975)	632–658	977
Hanks et al. (1978)	550–650	630– 760
Stegman (1982)	431–549	953–1156

apply smaller irrigations needed for crop establishment. Also, no-till drills can permit wheat seeding into the higher amounts of crop residues commonly produced under irrigation (Schneekloth et al., 1991). However, the irrigation response of the shorter-maturity hybrids, the potential for reducing irrigation needs, and the effect of hybrid maturity on water use efficiency have not been studied. The purpose of this study, therefore, was to measure the water use of two corn hybrids, a full-season and a shorter-season hybrid, under typical irrigation regimes managed for full production and to examine the differences in crop growth patterns, yield, evapotranspiration, and water use efficiency.

MATERIALS AND METHODS

This study was conducted at the Conservation and Production Research Laboratory, Bushland, TX (35°11′ N, 102°06′ W; elevation 1170 m above mean sea level) on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) (Unger and Pringle, 1981; Taylor et al., 1963). This soil is slowly permeable, because of a dense B22 horizon beginning about the 0.2- to 0.5-m depth, and has a water-holding capacity of approximately 250 mm of plant-extractable water to the 2.0-m depth. A calcic layer at about 1.5 m significantly limits water extraction by corn below this depth (Musick and Dusek, 1980). This soil is common to >1.2 million ha of land in this region, including about one-third of the sprinkler-irrigated area in the Texas High Plains (Musick et al., 1988). Ground slope at the site is less than 0.003 m m^{-1}.

The ET of fully-irrigated corn was measured with weighing lysimeters (Marek et al., 1988) during the 1994 season. The lysimeters have an ET accuracy and resolution approaching 0.02 to 0.05 mm (Howell et al., 1995a), and lysimeters are recognized as a primary ET measurement method (Hatfield, 1990). The lysimeters, 3 by 3 m in surface area and 2.3 m deep, containing monoliths of the Pullman soil, and situated in the center of two contiguous 4-ha fields (each 210 m E–W by 210 m N–S), were under continuous vacuum drainage. Two corn hybrids, Pioneer 3737 (short season, SS) and Pioneer 3245 (full season, FS), were seeded and grown in the two fields. (The north field, with the SS hybrid, was designated as northeast, NE; the south field, with the FS hybrid, was designated as southeast, SE.) The hybrid maturity is classified as 115 d for FS and 98 d for SS. The predominant wind direction is SW to SSW, and the unobstructed fetch in this direction exceeds 1 km, so the lysimeter ET data should have been largely unaffected by localized heat advection. The previous lysimeter crop was sorghum in 1993; in that year, the SE lysimeter field was deficiently irrigated, and the NE field was fully irrigated. Surface soil water was similar in the two lysimeter fields at planting of the 1994 corn crops, due to winter and spring precipitation, but two irrigations totaling 46 mm were applied to the SE field and FS hybrid on DOY 158 and 160 (Table 2), to minimize profile differences in soil water.

Our objective was to compare two hybrids side-by-side under as nearly identical environments as possible and to measure the ET as accurately as possible. Plot sizes must be large to provide uniform fetch and environments for each lysimeter. Classical experimental designs are not feasible or practical for this type of agronomic research. However, since the purpose was more relative comparison (and not absolute difference comparison, which would require statistical analysis), this approach should be acceptable, although it is admittedly a large compromise due to space, facilities, and labor constraints. Replication in temporal environments also is difficult for this

Table 2. Cultural parameters and crop phenology for two corn hybrids differing in maturity (1994, Bushland, TX).

Parameter	Pioneer 3737 (short-season)	Pioneer 3245 (full-season)
Planting date	DOY 105 (15 Apr.)†	DOY 105 (15 Apr.)
Emergence date	DOY 124 (4 May)	DOY 124 (4 May)
First neutron readings	DOY 125 (5 May)	DOY 125 (5 May)
Silking date	DOY 187 (6 July)	DOY 196 (15 July)
Physiological maturity date	DOY 237 (25 Aug.)	DOY 249 (6 Sept.)
Final neutron readings	DOY 257 (14 Sept.)	DOY 257 (14 Sept.)
Harvest date	DOY 259 (16 Sept.)	DOY 270 (27 Sept.)
Fertility		
NH$_4$	26.2 g N m^{-2}	26.2 g N m^{-2}
Liquid (10–34–0)	3.3 g N m^{-2}, 11.2 g P m^{-2}	3.3 g N m^{-2}, 11.2 g P m^{-2}
Tillage		
Cultivate	DOY 151 (31 May)	DOY 151 (31 May)
Furrow dike	DOY 152 (1 June)	DOY 152 (1 June)
Irrigation		
Date, DOY (amount, mm)	110 (22); 154 (17); 157 (20); 158 (0); 160 (0); 162 (21); 164 (23); 167 (26); 171 (27); 174 (37); 178 (30); 181 (32); 185 (28); 187 (31); 189 (18); 192 (29); 202 (24); 206 (28); 209 (24); 213 (27); 221 (0); 224 (0); 227 (0); 230 (0)	110 (21); 154 (16); 157 (17); 158 (21); 160 (25); 162 (20); 164 (22); 167 (27); 171 (28); 174 (31); 178 (29); 181 (29); 185 (25); 187 (28); 189 (19); 192 (27); 202 (22); 206 (25); 209 (22); 213 (24); 221 (28); 224 (21); 227 (26); 230 (24)
Total amount, mm	465	577

† DOY, day of year; calendar date equivalents are given in parentheses.

research, owing to the large expense for the experiments. The year-to-year climatic variations may affect the seasonal values of ET and yield, but differences between hybrid maturities should be more conservative (i.e., they should remain similar over time).

Agronomic and management details are summarized in Table 2. Corn was sown on 15 April (DOY 105) in 0.76-m wide rows (E–W) at plant densities of about 8 plants m^{-2}. Each lysimeter contained four rows, and the area immediately surrounding the lysimeters (30 m^2, six rows wide by 6.5 m in length) was hand-seeded and cultivated. The field was bedded and furrow diked, to minimize surface water movement. All field operations were performed with standard 4.6-m wide (6 row) field equipment. Furrow dikes were installed following the lay-by cultivation, using a Bigham Brothers[1] (Lubbock, TX) trip-roll diker in each furrow at about 2- to 3-m spacing, to impound about 50 mm of rainfall. Fertilizer and pest control were applied uniformly to both field areas. Irrigations were applied to both fields simultaneously, using a 10-span lateral-move sprinkler system with an end-feed hose and aboveground, end-guidance cable. The sprinkler system is aligned N–S and irrigated E–W or W–E. The system was equipped with gooseneck drops located about 2.0 m above the ground and 1.52 m apart, with spray heads (Nelson Irrigation Corp., Walla Walla, WA) with medium grooved spray plates.

Irrigations were scheduled to maintain the soil water profile adequately supplied with water to prevent soil water deficits from reducing ET or yield. Soil water contents were measured periodically using a neutron probe (Model 503 DR Hydroprobe, Campbell Pacific Nuclear, Martinez, CA) at 0.2-m depth increments over the 2.0 to 2.4-m profile depths with 32-s counts. Two access tubes were located in each lysimeter (measured to 2.0 m), and four tubes were located in the field surrounding each lysimeter (measured to 2.4 m). The probe was field-calibrated for the Pullman soil, using a method similar to that described by Evett and Steiner (1995).

Plant samples from 1.0-m^2 areas were obtained periodically during the season to measure crop growth and development. Three field samples were taken at sites about 10 m away from the lysimeters in areas of the field representative of the lysimeter vegetation. Leaf area index (LAI), aboveground dry matter (DM), and crop height were measured. Final grain yield and DM were measured by harvesting each row (4 rows) in the lysimeter (2.29 m^2) separately. Final grain yield and DM yield were also measured in the field using similar procedures for 4.57-m^2 samples (2 rows by 3.0 m). All grain yield data are reported on a dry basis (0 g kg^{-1} water content). Seed mass was determined by the mean mass of 500 kernels. Seed number and seeds per ear were computed using the plant density and ear density values. Harvest index was computed as the ratio of the grain to the aboveground dry matter at harvest. A *t*-test analysis was used to determine significant mean differences for the yield and yield component data between the two hybrids and between the field and lysimeter values.

Solar irradiance, wind speed, air temperature, dew-point temperature, relative humidity, rainfall, and barometric pressure were measured at an adjacent weather station (Dusek et al., 1987) situated on an irrigated cool-season grass surface (similar to a mowed lawn) (for additional information, see also Dusek et al., 1993). The weather station is 1520 m^2 in area, including the irrigation border surrounding the level plot. All transducers were measured at a frequency of 0.167 Hz (6 s) using a data logger (Model CR-7X, Campbell Scientific, Logan, UT), signals were averaged for 15 min, and two 15-min means were composited into 30-min means. Daily (24 h) averages, maximum, and minimum values were determined from the 0.167-Hz samples. Data were transferred daily via telephone modem from the data logger to a laboratory personal computer. Daily solar irradiance, maximum and minimum daily air temperature, average daily dew-point temperature, 2-m wind speed, and rainfall are reported.

Lysimeter mass was determined using the CR-7X data logger to measure and record the lysimeter load cell (Model SM-50, Interface, Scottsdale, AZ) signal at a frequency of 0.5-Hz (2 s). The load-cell signal was averaged for 15 min and composited to a 30-min mean. Data were transferred daily via telephone modem from the data logger to a laboratory personal computer, as was done with the weather data. Daily ET was determined as the difference between lysimeter mass losses (from water evaporation and transpiration) and lysimeter mass gains (from irrigation, precipitation, or dew) divided by the lysimeter surface area (9 m^2). No correction was applied for the wall gap (10-mm air gap; 9.5-mm steel wall thickness, total) between the inner and outer lysimeter walls, which is 2% of the lysimeter surface area (gross outside lysimeter area = 9.18 m^2).

The WUE for dry matter (WUE_d) was computed as DM/ET and WUE for grain (WUE_g) was computed as (grain yield)/ET. Both WUE_d and WUE_g were expressed in units of kg m^{-3}. (Note that 1 kg m^{-3} = 1 g m^{-2} mm^{-1}.) Grain water use efficiency, WUE_g, was computed on a dry grain basis (0 g moisture kg^{-1} grain).

RESULTS AND DISCUSSION

The 1994 growing season at Bushland was typical for the Southern High Plains, but June was warmer and drier than normal, while July was wetter than normal. Table 3 presents a summary of the monthly climatic data, and Fig. 1 shows the seasonal variations in daily climatic parameters for Bushland in 1994. June averaged 3°C warmer than the historical mean, with rainfall 43 mm below normal; however, July rainfall was 44 mm above the normal, and July is a more critical month for corn development in the Southern High Plains. The rainfall total during the corn growing season was 320

Table 3. 1994 climatic data for site at Bushland, TX, with long-term (20-yr) means.

Parameter	Apr.	May	June	July	Aug.	Sept.
Temperature, °C						
Mean maximum	20.9	24.9	33.3	31.3	30.7	28.6
Long-term mean maximum	21.1	24.9	30.2	32.1	31.0	27.3
Mean minimum	3.8	11.5	16.8	17.2	16.4	12.4
Long-term mean minimum	3.9	9.3	14.8	16.9	16.2	11.7
Mean dew point	0.1	10.6	12.5	14.5	14.5	9.5
Solar radiation, MJ m^{-2} d^{-1}						
Mean	20.5	21.2	25.8	25.9	21.4	19.4
Long-term mean	22.5	24.4	26.3	25.6	22.8	19.2
Mean PAR, mol m^{-2} d^{-1}†	43.0	44.0	55.2	49.7	44.7	39.3
Mean 2-m wind speed, m s^{-1}	5.3	4.5	3.6	3.1	3.1	3.6
Rainfall, mm						
Growing season total	35	49	35	109	61	41
Long-term mean	26	68	78	65	71	49

† PAR, photosynthetically active radiation.

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[1] Mention of trade or commercial names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

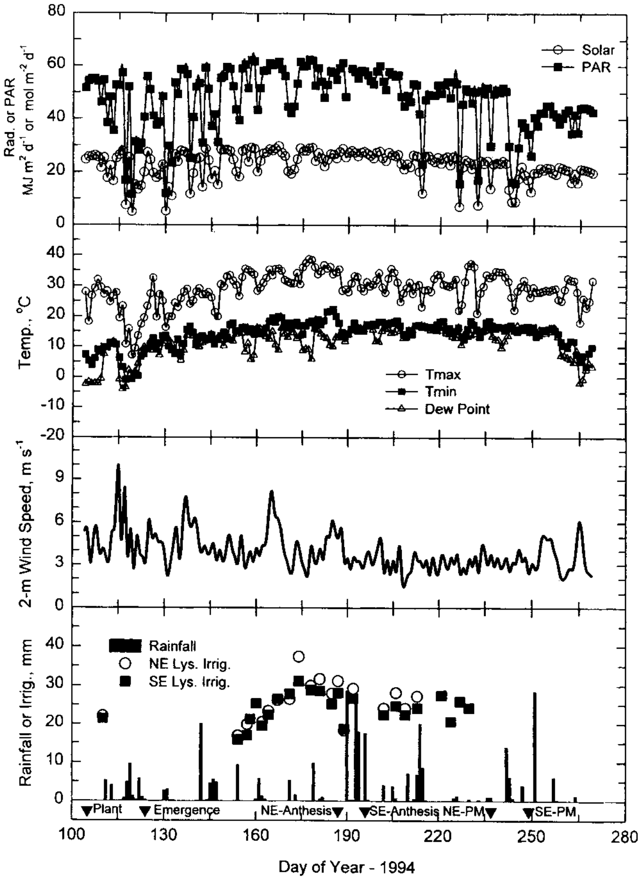

Fig. 1. Daily climatic parameters for the 1994 season at Bushland, TX.

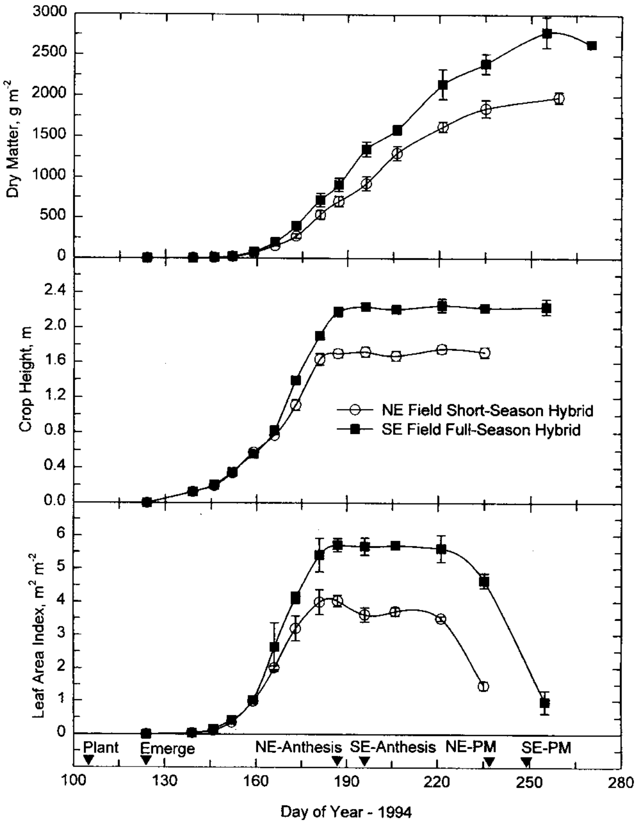

Fig. 3. Corn leaf area index (bottom), crop height (middle), and dry matter production (top) during the season. Error bars represent standard deviations; smooth curves are cubic splines.

mm, or 37 mm lower than the normal growing-season (April–September) rainfall of 357 mm.

Irrigations were applied uniformly except, for DOY 158 and 160, when the SS hybrid field was not irrigated in order to equalize the soil water contents from previous differences in the fields. These irrigations totaled 46 mm, but no appreciable soil water deficit occurred in the SS hybrid field while irrigation was withheld. Figure 2 shows the soil water profiles for both fields a few days after emergence (DOY 126) and near harvest (SS hybrid, DOY 258; FS hybrid, DOY 270). Since the SE field (FS hybrid) started with a relatively dry profile below 0.8 m, due to the previous 1993 cropping differences, the extra irrigations were applied on DOY 158 and 160, while avoiding any water shortages to the NE field and the SS hybrid. No irrigations were applied to the SS hybrid (NE field) after DOY 221, when this hybrid reached the early dent growth stage (R5 on the revised Hanway scale; Ritchie et al., 1992). Sufficient soil water remained in the profile to permit maximum grain fill. Likewise, irrigations for the FS hybrid (SE field) were terminated after DOY 230, when this hybrid reached the early dent growth stage.

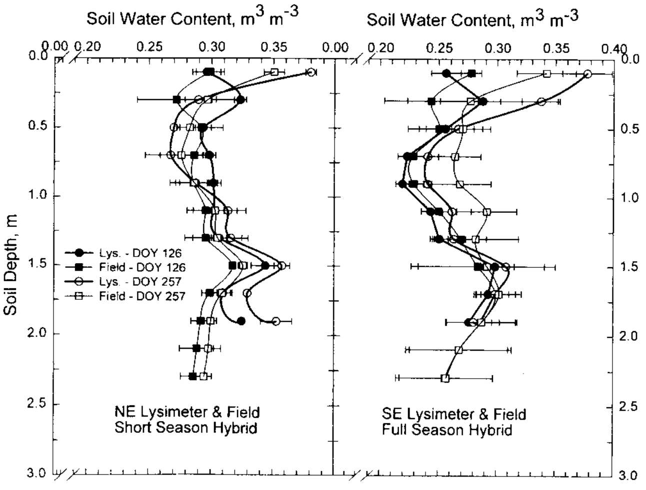

Fig. 2. Soil water content profiles for the lysimeters and fields at crop emergence and at physiological maturity. Error bars represent standard deviations; smooth curves are cubic splines.

Both hybrids emerged 19 d following seeding (Table 2). The emergence was delayed somewhat by cold weather, but these conditions are common in the Southern High Plains environment. The SS hybrid silked in 63 d after emergence, while the FS hybrid required 72 d to reach the silk and pollen shedding stage (R1 on the revised Hanway scale; Ritchie et al., 1992). The SS hybrid attained physiological maturity about 12 d before the FS hybrid and was harvested 11 d earlier. Figure 3 shows the seasonal trends in DM, LAI, and crop height. The FS hybrid was 0.55 m taller, produced 391 g m^{-2} greater DM at harvest, and had a greater maximum LAI by 1.7 m^{2} m^{-2}.

Lysimeter yields were similar to the field sample yields (Table 4), and field sample yields were similar to

Table 4. Corn yield, yield components, evapotranspiration, and water use efficiency data for two corn hybrids differing in maturity (1994, Bushland, TX).

	Pioneer 3737 (short-season)		Pioneer 3245 (full-season)	
Parameter	**Lysimeter†**	**Field‡**	**Lysimeter**	**Field**
Grain yield (0 g kg^{-1} moisture), g m^{-2}	1130 ± 59§	1132 ± 36	1322 ± 57	1430 ± 22
Biomass yield, g m^{-2}	2035 ± 94	1987 ± 68	2426 ± 74	2638 ± 42
Plant density, no. m^{-2}	7.87 ± 0.00	8.22 ± 0.22	7.98 ± 0.22	7.92 ± 0.13
Ears per plant, no. $plant^{-1}$	1.03 ± 0.03	1.04 ± 0.60	0.99 ± 0.03	1.01 ± 0.02
Harvest index, kg kg^{-1}	0.555 ± 0.009	0.570 ± 0.002	0.545 ± 0.011	0.545 ± 0.099
Seed mass, mg $seed^{-1}$¶	249 ± 6	260 ± 6	307 ± 7	326 ± 20
Seed number, no. m^{-2}	4356 ± 275	4553 ± 119	4307 ± 184	4404 ± 259
Seeds per ear, no. ear^{-1}	530 ± 25	535 ± 17	538 ± 23	550 ± 17
Evapotranspiration, mm				
Emergence to maturity	673		802	
Planting to harvest	741		841	
WUE_g (grain basis), kg m^{-3}#				
Emergence to maturity	1.68		1.65	
Planting to harvest	1.52		1.57	
WUE_d (dry matter basis), kg m^{-3}#				
Emergence to maturity	3.02		3.02	
Planting to harvest	2.75		2.88	

† Lysimeter data represent one row 3.0 m long (2.29 m^2) and averages of four rows.

‡ Field data represent two rows 3.0 m long (4.57 m^2) and averages of three samples.

§ Values ±1 SD.

¶ Seed mass data represent averages of three 500-kernel subsamples from harvested grain.

Water use efficiency (WUE) computed as lysimeter yield per unit evapotranspiration.

field combine yields (data not shown) indicating that the crop growing on the lysimeters reflected the field characteristics. No statistically significant ($P < 0.01$) differences were detected between the field and the lysimeter yield and yield component data. However, the grain yield, biomass yield, and seed mass were significantly different ($P < 0.01$) between the SS and FS hybrids. Grain yield for the SS hybrid was 192 to 298 g m^{-2} less than for the FS hybrid for the lysimeter and field samples, respectively, and approximately in proportion to the reduction in DM (Table 4). Grain water contents (wet basis) were nearly identical at harvest at 136 g kg^{-1}, reflecting common commercial harvesting ranges for corn in this region of the USA. (Actual mean values, ±1 SD, were 137 ± 11 g kg^{-1} for the FS hybrid and 136 ± 3 g kg^{-1} for the SS hybrid.) By harvesting at higher grain water contents, one could reduce the time for field dry down, but this practice might require special grain handling facilities for high-moisture corn. Ear density (number of ears per unit area) was not affected by maturity type for these hybrids under this full-irrigation regime and plant density of 8 plants m^{-2}. Harvest index (HI) was slightly higher (but not statistically different at the $P < 0.01$ level) for the SS hybrid than the FS hybrid, reflecting a higher partitioning of nonstructural carbohydrate assimilated to the grain. The harvest index was consistent with a nonstressed value for corn (Sinclair et al., 1990). Seed mass was 24% greater for the FS hybrid than the SS hybrid (seed mass may be a hybrid-specific characteristic), seed number was 1 to 3% lower for the SS hybrid than the FS hybrid, and seeds per ear was similar for the two hybrids, at about 535 seeds ear^{-1}.

Daily evapotranspiration (ET) rates for the two lysimeters are shown in Fig. 4. Rates of ET were essentially the same before DOY 160 (LAI < 1) and after DOY 260 (after physiological maturity of both hybrids—after senescence), although somewhat variable due to rainfall events and the lower evaporative demand at these times of the year. Peak daily ET rates exceeded 13 mm d^{-1} for both hybrids on only one day, while many days had ET rates exceeding 10 mm d^{-1}. The ET rates of the SS hybrid were consistently around 90 to 95% of the FS hybrid ET rate from DOY 160 until anthesis (DOY 187) for the SS hybrid (Fig. 5). The reduced ET rate could be due to two factors: the shorter crop height (and hence slightly smoother aerodynamic surface) and the lower LAI (see Fig. 3). These high daily ET rates support the conclusions of Howell et al. (1989) that the net irrigation capacity (i.e., system flow rate per unit area, which has the same units as ET: length per time, $l\,t^{-1}$) should exceed 8 mm d^{-1} for corn in this environment to avoid soil water deficits from inadequate rainfall

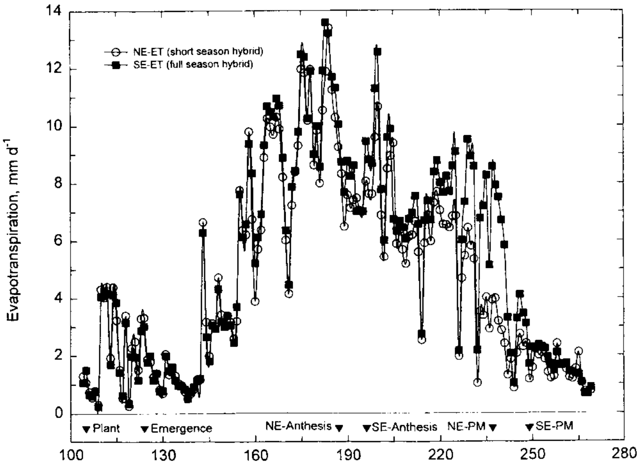

Fig. 4. Daily evapotranspiration rates for the short-season and full-season corn hybrids during the 1994 season at Bushland, TX.

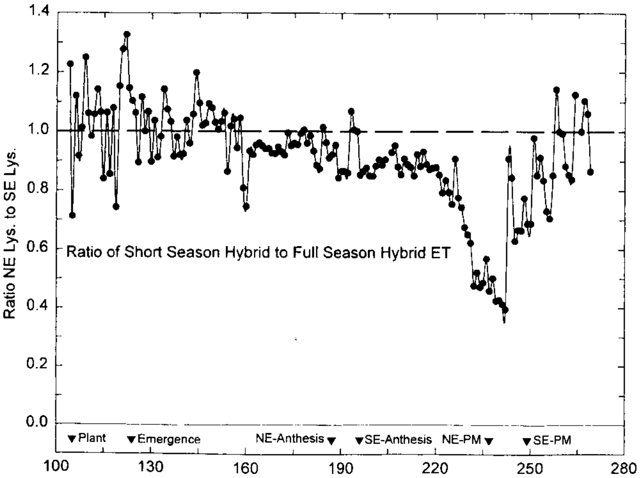

Fig. 5. Ratio of evapotranspiration in the short-season corn hybrid to that of the full-season hybrid for each day.

and a corresponding yield reduction. This needed irrigation capacity might be slightly lower for a SS hybrid, since the peak daily ET rates are lower, but it could not likely be reduced by more than the 5 to 10% by which daily ET rates were reduced. After anthesis of the SS hybrid, its ET rate declined to about 85 to 90% of the FS hybrid ET by the time the SS hybrid reached its early dent stage at DOY 220. During this period, for both hybrids, LAI was >3.0, which has been shown necessary for maximum ET in cotton and sorghum (Ritchie and Burnett, 1971). Corn is postulated to have a more open canopy for radiation penetration than either cotton or sorghum at the same LAI and, therefore, corn may require LAIs between 4 and 5 for near-maximum ET rates. In addition to the aerodynamic differences that may have resulted from the SS hybrid's shorter crop height, leaf resistance (not measured) may have differed between the two hybrids and increased the canopy resistance for the SS hybrid relative to the FS hybrid. After the SS hybrid reached the dent stage (DOY 220), its ET rate declined until DOY 240, when the FS hybrid was also near physiological maturity.

Seasonal ET amounts were 673 and 802 mm from emergence to physiological maturity for the SS and FS hybrids, respectively, while corresponding planting to harvest ET values were 741 and 841 mm (Table 4). These values are similar to previous reports at Bushland, but somewhat greater than other Great Plains locations (Table 1). The $\mathrm{WUE_g}$ values (Table 4) were similar for the two hybrids, at 1.68 kg $\mathrm{m^{-3}}$ for the SS hybrid and 1.65 kg $\mathrm{m^{-3}}$ for the FS hybrid for emergence to physiological maturity. The $\mathrm{WUE_g}$ values were lower when ET was characterized as planting to harvest. The $\mathrm{WUE_g}$ for the period from planting to harvest is perhaps more indicative of $\mathrm{WUE_g}$ measured by water balances (see Table 1). When the period from planting to physiological maturity was used, $\mathrm{WUE_d}$ was exactly the same (3.02 kg $\mathrm{m^{-3}}$) for both hybrids; when the planting to harvest period was used, however, $\mathrm{WUE_d}$ declined (to 2.75 kg $\mathrm{m^{-3}}$ for the SS hybrid and 2.88 kg $\mathrm{m^{-3}}$ for the FS hybrid).

The $\mathrm{WUE_d}$ measure reflects both genetic and environmental factors (Tanner and Sinclair, 1983; Stanhill, 1986). Tanner and Sinclair (1983) summarized several corn experiments within the range of 2.0 to 5.4 kg $\mathrm{m^{-3}}$ for total biomass (including estimated or measured root dry matter) per unit transpiration. Using their estimates for root biomass (total biomass/aboveground biomass = 1.20), $\mathrm{WUE_d}$ would be 3.6 kg $\mathrm{m^{-3}}$, which is about in the midrange of their summary from previous experiments. They reported a range from 8.2 to 12.0 Pa for their normalized WUE value, k, calculated as

$$k = (\mathrm{DM/ET})\ (\overline{\mathrm{VPD}}_\mathrm{d})$$

where $\overline{\mathrm{VPD}}_\mathrm{d}$ is the mean daytime vapor pressure deficit (expressed as Pa) and the DM and ET are expressed in units of kg $\mathrm{m^{-2}}$. The estimated k for this experiment was 8.5 Pa (with DM and ET expressed in the same mass per unit area units) using the mean daytime vapor pressure deficit of 2350 Pa for DOY 124 to DOY 249 based on the methods presented by Howell and Dusek (1995). Part of the disagreement is clearly due to differences between ET and transpiration, as discussed by Tanner and Sinclair (1983). But the experimental value of k determined here is within the range found for the previous research and would be expected to be at least 20 to 30% larger using transpiration instead of ET (assuming ET/transpiration = 1.20 to 1.30). With an assumed ET/transpiration ratio of 1.25 and a total DM/aboveground DM ratio of 1.2, k would be 10.7 Pa, which is about 10% lower than the 11.8 Pa valued derived theoretically by Tanner and Sinclair (1983).

In conclusion, short-season corn used water at almost the same peak daily rates as full-season corn. Therefore, the necessary irrigation capacity required to avoid yield suppression by water deficits could not be decreased appreciably (not by more than 5 to 10%) by using a SS hybrid without increasing the risk of yield reductions. The earlier harvest afforded by using a SS hybrid can facilitate double-cropping to winter wheat and may afford opportunities to market the crop at higher grain prices. The SS hybrid used in this study was dramatically shorter in crop height than the FS hybrid and produced less leaf area. The leaf area produced by the SS hybrid should be enough to support near-maximum photosynthetic activity and water use. The SS hybrid produced less biomass, but it did have a slightly higher harvest index than the FS hybrid. The higher grain yield by the FS hybrid over the SS hybrid at the population density used in this experiment (8 plants $\mathrm{m^{-2}}$) and under the full-irrigation regime was mainly due to the greater biomass accumulated during the longer period to anthesis and to a greater seed mass (possibly hybrid-specific), since the number of ears per plant, seed number, and seeds per ear were largely unaffected by hybrid maturity type. The FS hybrid produced 400 g $\mathrm{m^{-2}}$ more biomass on the lysimeter and >600 g $\mathrm{m^{-2}}$ more biomass on the field than the SS hybrid, and these yield differences would be a better reflection for silage production than just the grain yields alone.

Daily ET rates for corn in this environment exceeded 10 mm $\mathrm{d^{-1}}$ on several days. These ET rates were no greater than for irrigated winter wheat at this location (Howell et al., 1995c) despite corn being a much taller and aerodynamically rougher crop. The seasonal ET amounts of 673 mm for the SS hybrid and 802 for the FS hybrid were similar to the range in ET previously measured using water balance methods from many irrigation studies at Bushland, but considerably higher than reported for studies conducted in Kansas. The difference in ET values between the Texas High Plains and the plains of western Kansas is largely attributed to the higher vapor pressure deficit normally occurring at Bushland, and to the consistently strong winds in this region. The cost savings for the reduced irrigation using the SS hybrid is nearly six to eight times less than the value of the crop production sacrificed at prevailing local production and pumping costs, but these differences could be offset by opportunities to market the crop at higher prices and by income that could be realized from grazing winter wheat.

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