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Crop evapotranspiration in Argentinean maize hybrids released in different decades

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ABSTRACT

Crop evapotranspiration (ET) is a major process influencing crop yield in water limited environments; and there is a lack of information on the influence of the breeding progress on crop ET. The objectives of this work were (i) to determine the seasonal crop ET and (ii) to characterize the soil water profile and pattern of soil water depletion along the season, in three Argentinean maize hybrids released in different decades. One old (DK2F10) and two modern (DK682RR and DK690MG) maize hybrids were sown during two seasons at Balcarce, Argentina under different water regimens (irrigated, rain-fed from silking and rain-fed). Soil water content was measurement weekly with a neutron probe and crop ET was estimated. Seasonal ET ranged from 646 mm to 284 mm depending on the water regime; and it was similar among hybrids at each water regime. Mean daily ET during the critical period for kernel set, however, was higher in the two modern hybrids than in the older hybrid. Differences in daily ET during this period were evident, in particular when AW was low (<57%). During the grain filling period, mean daily ET was similar among hybrids but soil available water was lower in the modern hybrids than in the old hybrid. A greater water extraction capacity, associated with greater soil water depletion at deeper soil layers (i.e. below 80 cm) in the modern hybrids than in the older maize hybrid, might have influenced daily ET differences among hybrids.

1. Introduction

Crop evapotranspiration (ET) is a major process influencing crop yield in water limited environments (Passioura, 1996; Blum, 2009). Although much research have been done on the improved yield and stress tolerance in maize hybrids released in different decades (e.g. Tollenaar and Wu, 1999; Echarte et al., 2004; Duvick and Donald, 2005); there is still little understanding on the influence of the breeding progress on maize crop ET. Edmeades et al. (2003 cited by Campos et al., 2004) showed that modern hybrids yielded more than older ones under conditions of low water availability during grain filling; but crop ET was not measured in those studies. In a modeling study, Hammer et al. (2009) assumed that crop ET increased concomitantly with grain yield and crop biomass in US hybrids released during the last 40 years; and suggested that the increased crop ET might have exposed newer maize hybrids under more frequent water stresses than older hybrids.

In addition to the little information on the crop ET of hybrids released in different decades worldwide; there is a lack of information on the pattern of soil water profile and depletion of modern compared with older maize hybrids. Depth, rate and timing of soil water depletion are mechanisms that could contribute to differences in crop ET in hybrids released in different decades. It was suggested that soil water depletion occurred at a greater rate in the upper soil layers in an old than in a modern maize hybrid before the critical period for kernel set which encompasses 30 days bracketing silking (Campos et al., 2004). Changes in maize root system architecture contributing to a faster and deeper root growth may have had a direct effect on the greater yield of newer US maize hybrids (Hammer et al., 2009).

The objectives of this study were (i) to determine the seasonal crop ET in modern and in older hybrids, and (ii) to characterize the soil water profile and pattern of soil water depletion along the season in maize hybrids released in different decades.

2. Materials and methods

2.1. Site and crop management

Maize crops were grown at Balcarce, Argentina (37°45′ S, 58°18′ W; elevation 130 m), during 2008–2009 (season 1) and 2010–2011 (season 2), on a silty clay loam soil (Typic Argiudoll; USDA Taxonomy) with a petrocalcic horizon between 140

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Table 1
Mean photosynthetically active radiation (PAR), air temperature, reference evapotranspiration (ET_0), cumulative rainfall and irrigation for irrigated (I) and rain-fed from silking (Rs) treatments, every month during season 1 (S1) and season 2 (S2); and their corresponding mean (PAR, temperature, ET_0) or median (rainfall) values for a 30 years of data (H) at Balcarce, Argentina.

	PAR (MJ m^{-2} d^{-1})			Mean air temperature (°C)			ET_0 (mm)			Rainfall (mm)			Irrigation (mm)		
	S1	S2	H	S1	S2	H	S1	S2	H	S1	S2	H	S1 I	S1 Rs	S2 I
October	8.8	7.7	7.6	13.9	13.5	13.1	92	92	90	29	45	91			
November	10.7	10.1	9.4	19.8	16.3	15.8	136	120	116	53	116	63			
December	11.6	12.5	10.2	20.7	20.9	18.6	162	175	145	31	33	100	121	121	153
January	12.3	11.4	10.3	22.5	22.3	20.3	188	159	151	25	185	103	72		51
February	10.2	10.2	9.3	22.2	20.1	19.5	138	116	117	64	33	71	24		58
March	7.2	8.2	7.2	20.3	19.9	17.8	107	111	95	66	22	75			19

and 160 cm depth (Calviño et al., 2003) and with 5.4% topsoil organic matter. A clayey layer (Bt) is always present in these soils between 40 cm and 90 cm depth. Maximum water holding capacity (511 mm) was determined according to Cassel and Nielsen (1986). Briefly, a plot of soil free of crops or weeds was covered with polyethylene and soil water content was measured after wetting the soil profile; the soil moisture was monitored from 2 days after wetting and until the water content rate of change was null (i.e. negligible drainage). The permanent wilting point (279 mm) to 140 cm soil depth was measurement by pressure plate apparatus at 1500-kPa suction (Richards and Weaver, 1943). Experiments were conducted under conventional tillage and were fertilized at sowing with 45 kg P ha^{-1} and at stage V6 (Ritchie and Hanway, 1982) with 150 kg N ha^{-1}. Weeds and insects were mechanically and chemically controlled. Table 1 summarizes weather conditions and irrigation for the two seasons. Mean photosynthetically active radiation, mean air temperature and reference ET values were in general higher than the historic values (Table 1). Accumulated rain from sowing to physiological maturity (i.e. growing season) was 47 and 14% lower than the median historic value, for seasons 1 and 2, respectively. In addition, rainfall distribution pattern differed between years (Table 1). As such, rainfall during January which is the most critical month for kernel number determination in the South east of Buenos Aires, Argentina (Andrade et al., 1996) was 76% lower and 80% higher than the median value, for seasons 1 and 2, respectively.

2.2. Plant material and experimental design

Maize hybrids DK2F10 (year of release 1980; old hybrid) and DK682RR (year of release: 2004; modern hybrid) were sown in seasons 1 (2008–2009) and 2 (2010–2011); and an additional modern maize hybrid DK690MG (year of release 2004) was sown in season 2. These hybrids were selected because they are single and they had been extensively planted by farmers at the time they were released. Hybrids were sown on October 23 and October 20, during seasons 1 and 2, respectively; at a plant density of 7.5 pl m^{-2}, which is the recommended plant density for current hybrids in this area and it has been shown to be an optimum plant density for older hybrids (Echarte et al., 2000). Plots were over sown and thinned to the desired plant densities at V3 Water regime treatments included: rain-fed (R) and irrigated (I) during seasons 1 and 2, and rain-fed from silking (Rs) during season 1. Irrigation was performed by a drip irrigation system, and it started at V10 and V8 in seasons 1 and 2, respectively. Irrigation was stopped at physiological maturity in the I treatments and it was stopped at approximately 15 days before silking in the Rs treatment. Irrigation was performed to maintain soil water availability above 50% of soil available water during the critical period for kernel set in the irrigated treatments. Table 1 indicates moments and amounts of irrigation for the different treatments. The experimental design was a split plot randomized complete-block design with three replications, with water regimes as main plots and hybrids as subplot. Subplots comprised 7 rows, 0.7 m apart and 14 m long.

2.3. Measurements

Soil water content was measured (i) gravimetrically from 0 to 140 cm depth in 6 experimental units at sowing, and an average soil water content value was used as the soil initial water content for all the treatments, (ii) with a neutron probe (Troxler 103 A, Troxler Electronic Lab, NC) in each experimental unit from 40 to 50 days after sowing (DAS) to physiological maturity. The method combined gravimetric measurements between 0 and 10 cm depth and the use of the neutron probe in 10 cm increments between 10 and 40 cm depth and in 20 cm increments from 40 to 140 cm depth in each experimental unit. One access tube per experimental unit was placed midway between the two harvest rows and soil water was measured every 7 days, except for a 50 (season 1) or 42 (season 2) day interval at the beginning of the growing seasons.

Shoot biomass was determined at physiological maturity in samples of 10 plants. In all cases, the samples were taken from the central rows of each subplot and were oven-dried (forced air at 60 °C) to constant weight and weighed.

A meteorological station from the Instituto Nacional de Tecnología Agropecuaria, situated less than 1 km from the field experiment, recorded the rainfall data and the meteorological variables needed to estimate reference evapotranspiration (ET_0) Reference evapotranspiration is defined as the ET rate from a hypothetical grass reference crop with specific characteristics and without water deficits; and it was calculated according to Allen et al. (1998) as:

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,(900/(T + 273))\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad (1)$$

where ET_o (mm day^{-1}), R_n net radiation at the crop surface (MJ m^{-2} day^{-1}), G soil heat flux density (MJ m^{-2} day^{-1}), T mean daily air temperature at 2 m height (°C), u_2 wind speed at 2 m height (m s^{-1}), e_s saturation vapour pressure (kPa), e_a actual vapour pressure (kPa), $e_s - e_a$ saturation vapour pressure deficit (kPa), Δ slope vapour pressure curve (kPa °C^{-1}), γ psychrometric constant (kPa °C^{-1}).

In order to elucidate if soil evaporation was a factor influencing ET differences among hybrids; soil evaporation was measured during season 2 (at 51, 62, 89, 99, 110 and 128 DAS) using mycrolysimeters. The mycrolysimeters consisted of a plastic pipe (inside diameter 0.1 m, 0.15 m long with a wire mesh at the bottom) filled with non-disturbed soil samples taken from the inter-row. The mycrolysimeters were weighed and placed in the same spot soil from where the soil samples were taken. Mycrolysimeters were weighted again after 48 h. Previous evaporation measurements indicated that soil within the mycrolysimeter was representative of real evaporation for up to 48 h (Valenzuela, 2000). This time period is in agreement with Boast and Robertson (1982); Allen (1990).

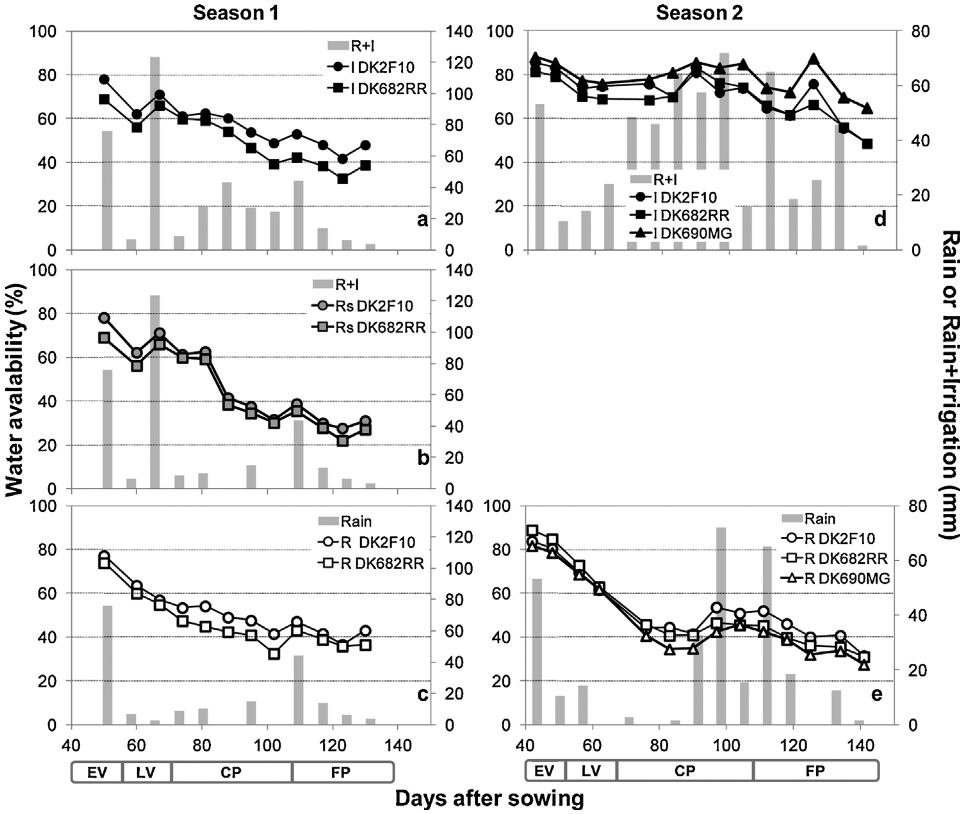

Fig. 1. Soil available water (AW) expressed as percentage of total soil available water from 0 to 140 cm and rain or rain and irrigation during seasons 1 (left) and 2 (right) for one old (DK2F10) and two modern (DK682RR and DK690MG) maize hybrids, under three water regimes: irrigated (a, d), rain-fed from silking (b) and rainfed (c, e) and during four periods: early vegetative (EV), late vegetative (LV), critical period for kernel set (CP) and grain filling (FP).

Table 2
Seasonal crop evapotranspiration (ET) and soil available water (AW, %) during season 1 (S1) and season 2 (S2) for one old (DK2F10) and two modern (DK682RR and DK690MG) maize hybrids, under three water regimes: irrigated (I), rain-fed from silking (Rs) and rain-fed (R) at four periods during the growing season: early vegetative (EV), late vegetative (LV), critical period for kernel set determination (CP) and grain filling (GF).

		ET (mm d^{-1})				AW (%)			
		EV	LV	CP	GF	EV	LV	CP	GF
									S1
I	DK2F10	1.9	4.9	4.9	3.6	87	67	57	48
	DK682RR	2.2	3.6	5.4	3.6	82	61	52	38
Rs	DK2F10	1.9	4.9	2.5	2.7	87	67	45	34
	DK682RR	2.2	3.6	2.7	2.9	82	61	42	28
R	DK2F10	2.0	3.1	1.7	3.4	86	60	49	42
	DK682RR	2.1	3.1	1.9	2.7	84	57	42	39
Hybrid		**		**	ns	**	**	**	**
Water regime		ns		**	**	ns	ns	*	ns
H × W		ns	**	ns	ns	ns	ns	ns	ns
S2									
I	DK2F10	1.9	7.0	7.7	4.3	88	74	75	63
	DK682RR	2.1	7.3	7.2	4.5	85	70	75	62
	DK690MG	1.8	7.1	7.2	3.8	90	77	82	75
R	DK2F10	2.0	3.9	5.0	2.7	86	66	47	42
	DK682RR	1.8	4.1	5.6	2.2	90	68	44	38
	DK690MG	2.1	4.0	5.5	2.3	85	65	40	35
Hybrid		ns	*	ns	ns	ns	ns	ns	ns
Water regime	ns	**	**	**	ns	ns	**	**	
H × W		ns	ns	ns	ns	ns	ns	ns	ns

ns indicates not significant difference.

* Significant at $P < 0.1$.

** Significant at $P < 0.05$

2.4. Calculations and statistical analysis

Soil water content in each experimental unit was expressed either in mm or as a percentage of soil available water (AW), which was calculated as:

$$\mathrm{AW}\,(\%) = \frac{\mathrm{SW} - \mathrm{PWP}}{\mathrm{SAW}} \times 100 \qquad (2)$$

where SW is soil water content (i.e. the sum of the water content in all layers for each date of measurement expressed in millimeters), PWP (mm) is permanent wilting point, and SAW is soil available water (i.e. the difference between maximum water holding capacity and permanent wilting point expressed in millimeters).

Crop ET (mm) was calculated as rainfall plus irrigation minus the change in soil water storage between two observation dates minus runoff. The water balance for the first ET estimation included a 40–50 day period after the gravimetric soil water content determination at sowing. Runoff was estimated using a soil water balance model locally calibrated for maize (Della Maggiora et al., 2002). Briefly, the input variables for the model are rainfall, irrigation, $\mathrm{ET_o}$, crop coefficient (Kc), soil depth, water holding capacity, wilting point and initial soil moisture. The model calculates ET as maximum ET (i.e. the product between $\mathrm{ET_o} \times \mathrm{Kc}$) when soil water is readily available; and it assumes a linear decline from maximum ET when fraction of soil available water was below a critical value. Water excess was evidenced when soil water content minus ET plus rainfall and irrigation was above the water holding capacity.

Mean daily ET and mean AW were calculated for (i) an early vegetative growing period (i.e. from sowing to 50 days after sowing; EV), (ii) a late vegetative growing period (i.e. 50 days after sowing to 15 days before silking; LV), (ii) the critical period for kernel set (i.e. 15 days before silking to 15 days after silking; CP), and (iii) the grain filling period (i.e. 15 days after silking to physiological maturity; GF).

Water use efficiency was calculated as the quotient between crop biomass and crop ET.

Daily soil evaporation was calculated as:

$$\mathrm{Evaporation}\,(\mathrm{mm\ day^{-1}}) = \frac{\Delta W \times \mathrm{Vs} \times 150\,\mathrm{mm}}{\rho_\mathrm{b}} \times 2 \qquad (3)$$

Where ΔW is the difference between weight of the mycrolysimeter at the beginning and at the end of the period, Vs is soil volume, 150 mm is the length of the tube, ρ_b is bulk density of the soil layer (1.20 gr $\mathrm{cm^{-3}}$) and 2 days.

Analysis of variance, using the proc mixed procedure (SAS v9), was used to test the effect of water regimes, hybrids and their interactions on seasonal crop ET, mean daily ET and mean soil water availability at three periods during the growing season. The least significant difference test (LSD) was used to determine significant differences among means.

3. Results

3.1. Soil available water, seasonal crop ET and crop biomass

The water regime treatments influenced the soil available water (AW; Fig. 1). Mean seasonal AW was 57% (season 1) and 75% (season 2) for the irrigated treatments; whereas it ranged from 50% for the rain-fed from silking treatment to 52% (season 1) and 56% (season 2) for the rain-fed treatments. Soil available water at the end of the growing season reached values as low as 40–30% for the rain-fed treatments (for seasons 1 and 2; Fig. 1c and e) and as low as 29% for the rain-fed from silking treatment (Fig. 1b). Available water was lower in the modern hybrids than in the older one in season 1 (Fig. 1 and Table 2).

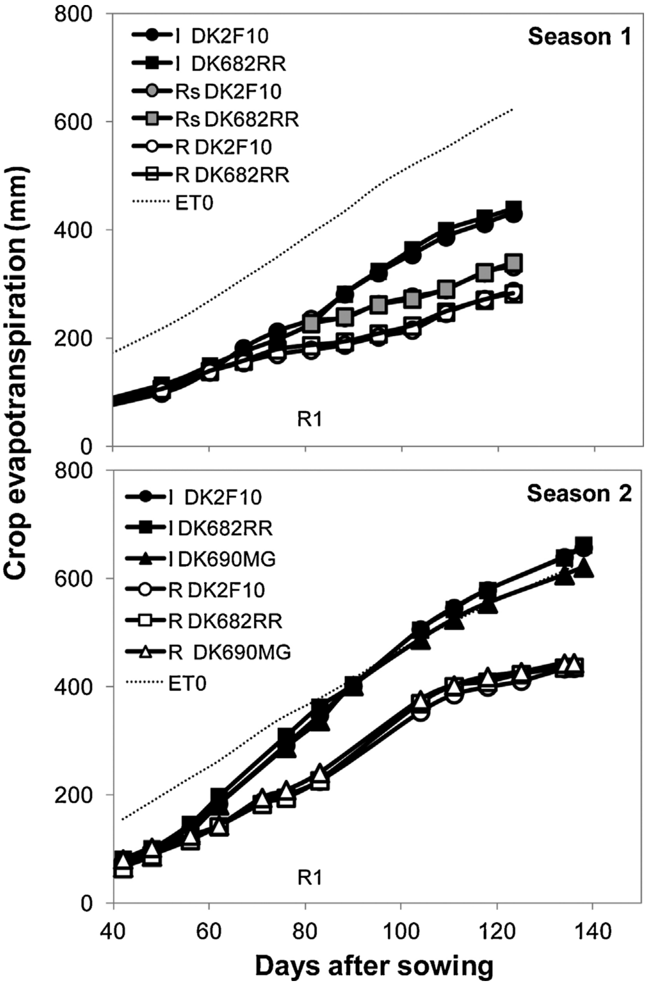

Fig. 2. Seasonal crop evapotranspiration accumulated during seasons 1 (upper figure) and 2 (lower figure) for one old (DK2F10) and two modern maize hybrids (DK682RR and DK690MG) under three water regimes: irrigated (I), rain-fed from silking (Rs) and rain-fed (R). $\mathrm{ET_0}$ is reference evapotranspiration accumulated during each season.

Seasonal crop ET was higher for irrigated crops and lower for rain-fed crops in both seasons ($P < 0.05$), while it was intermediate for the rain-fed from silking treatment (Fig. 2). Seasonal crop ET was greater during season 2 than during season 1 (Fig. 2a). This was associated mainly with a greater water supply during season 2 (i.e. irrigation + rainfall; Table 1); and also it was attributed to a longer cycle duration (i.e. 14 days longer during season 2 than during season 1). Seasonal ET was not different between modern and older hybrids at any water supply in the two seasons (Fig. 2, $P > 0.05$); in agreement, length cycle duration was similar among hybrids during each season. As such, physiological maturity occurred 123 (season 1) and 137 (season 2) days after sowing in the *R* treatment; and 127 (season 1) and 139 (season 2) days after sowing in the I treatment ($P > 0.05$) (average for the older and the newer hybrids).

Final biomass was similar among hybrids during both seasons ($P > 0.05$) and it was greater for I than for R and Rs treatments ($P < 0.05$ and $P < 0.06$ for seasons 1 and 2, respectively). As such, mean biomass production across hybrids was 16,405, 13,994 and 11,559 kg $\mathrm{ha^{-1}}$ for I, Rs and R, respectively, in season 1; and 29,897 and 21,028 kg $\mathrm{ha^{-1}}$ for I and R treatments respectively, during season 2. Biomass was closely associated with seasonal ET across hybrids and seasons ($R^2 = 0.92$, $P < 0.05$; Fig. 4) with a slope of 44.6 kg $\mathrm{mm^{-1}}$.

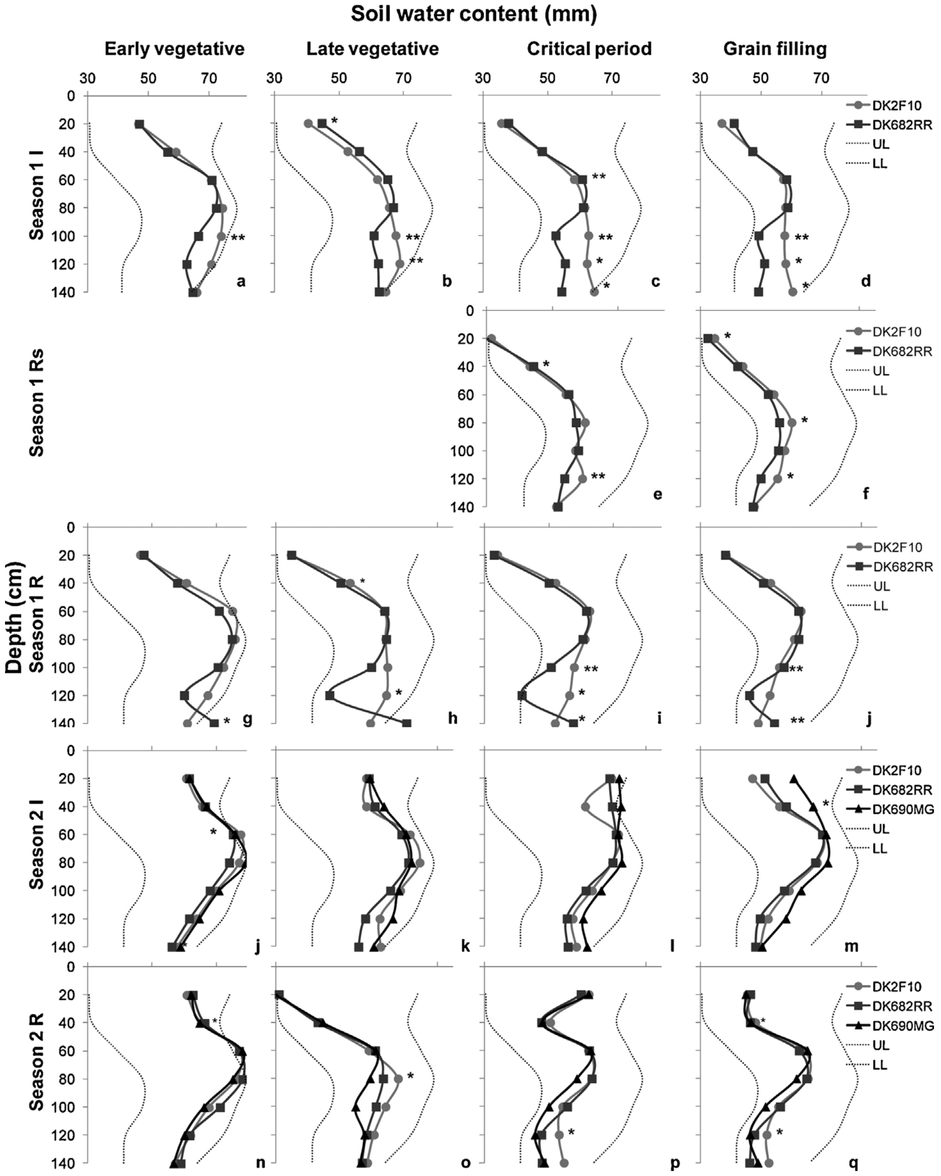

Fig. 3. Soil water content profile from 0 to 140 cm, at the end of (i) the early vegetative period (a, g, j, n), (ii) the late vegetative period (b, h, k, o), (iii) the critical period for kernel set (c, e, i, l, p), and (iv) the grain filling period (d, f, j, m, q); for an old (DK2F10) and two modern maize hybrids (DK682RR and DK690MG) during seasons 1 and 2, under three water regimes: irrigated (I), rain-fed from silking (Rs) and rain-fed (R). UL is the maximum water holding capacity (i.e. upper limit), and LL is the permanent wilting point (i.e. lower limit) through the soil profile. * and ** indicate differences among hybrids at each soil layer depth significant at $P < 0.10$ and $P < 0.05$, respectively.

3.2. *Mean daily ET and evaporation*

Mean daily ET during the early (EV) and late (LV) vegetative periods did not show a clear trend with the year of the hybrid release (Table 2). However, mean daily ET during the critical period for kernel set was higher in the modern hybrids than in the older one at low AW (i.e. AW below 57% in the irrigated and rain-fed treatments in season 1 and rain-fed treatment in season 2; Table 2). At higher AW during this period (i.e. AW above 75%, Table 2), mean daily ET did not show a clear trend with the year of the hybrid release. Mean daily ET during the grain filling period was similar among hybrids in the two seasons (Table 2, $P > 0.05$); but AW was lower in the two modern than in the older maize hybrid (significant during season 1, $P < 0.05$).

Daily soil evaporation ranged from 0.39 to 1.07 mm d^{-1} among hybrids, water regimes and moment during the growing cycle (data not shown). These values are in close agreement with previous reports for maize crops (Fernandez et al., 1996; Liu et al., 2002; Sharratt and McWilliams, 2005). Soil evaporation was similar among hybrids at each water regime ($P > 0.05$).

3.3. *Soil water profile*

Soil water profile differences among hybrids were evident in 15 out of 18 situations evaluated that combined growing periods, water regimes and seasons; and most of the soil water content differences among hybrids occurred at soil depths below 80 cm (Fig. 3). In addition, differences among hybrids were clearer during periods with low water supply from rain; as such, lower soil water content in the modern hybrids than in the older one at soil layers below 80 cm were evident in all the water regimes during season 1 and in the rain-fed treatment during season 2 (Fig. 3; $P < 0.05$). Soil water content between 80 and 140 cm was 8% lower in the modern than in the older hybrid at the end of the late vegetative period (Fig. 3b; $P < 0.05$); and the difference increased at the end of the critical period for kernel set (i.e. soil water content was 14% lower in the modern than in the older hybrid; Fig. 3c, $P < 0.05$) for the irrigated treatment during season 1. Similar trends were found for the same two growing periods at a soil depth between 80 and 120 cm in the rain-fed treatment during season 1 (Fig. 3h, i; $P < 0.05$). Differences among hybrids in the soil water content profile were not that clear during season 2, associated probably with more frequent rainfall during that season than during season 1 (Fig. 1). In addition, lower soil water content in the modern than in the older hybrid was evident as early as 50 days from sowing at a soil layer between 80 and 100 cm in the irrigated treatment during the drier season 1 (Fig. 3a; $P < 0.05$); the same trend occurred at a deeper soil layer (i.e. 100–120 cm) in the rain-fed treatment (Fig. 3g).

The relative contribution of different soil layers to total water depletion was analyzed for a drying period during the critical period for kernel set in season 1 (not shown). A drying period (i.e. no rainfall recorded between two soil water content measurements) was selected for this analysis to minimize the redistribution of water other than that influenced by root activity (Kirkham et al., 1998). The contribution of the deeper soil layer (80–140 cm) to the total water depletion was larger for the newer (49%) than for the older maize hybrid (20%) in the Rs treatment ($P < 0.05$). Similar trends were found for the same period in the R treatment.

4. Discussion

The combination of quantity and distribution of rainfall and irrigation during the seasons resulted in distinctive soil water availability situations (Fig. 1). Seasonal crop ET increased with water availability and was similar among hybrids released at different decades for each water regime (Fig. 2). Water use efficiency for biomass production was also similar for the old and new hybrids (Fig. 4). Hammer et al. (2009) assumed, for modeling purposes, that ET increased with the year of the hybrids release. The assumption was based on the shoot biomass increments observed along the decades (e.g. Duvick and Donald, 2005; Tollenaar and Lee, 2011) and on a similar water use efficiency in C4 species (Tanner and Sinclair, 1983; Hammer et al., 1997). By contrast, in this study, shoot biomass was similar among the old and the newer maize hybrids. In agreement with this observation, Echarte and Andrade (2003), Luque et al. (2006), Echarte et al. (2013) found no clear trend in biomass production for Argentinean maize hybrids released between 1965 and 1993.

Although seasonal crop ET was similar among maize hybrids, results of this work showed that mean daily ET of the two modern maize hybrids were higher than that of the old hybrid during the critical period for kernel set at low soil water availability (i.e. AW < 57%, Table 2). Water extraction capacity might contribute to explain differences in daily ET among hybrids during this period. Major differences in soil water content profile among hybrids occurred at soil depths below 80 cm (Fig. 3). As such, at deep soil layers soil water content was, in general, lower in newer than in older maize hybrids; and differences between hybrids were broadened during the critical period for kernel set (Fig. 3). In accordance, the contribution of deeper soil layers (80–140 cm) to total water depletion was larger in newer than in the older maize hybrid. The greater soil water extraction capacity could be influenced by a larger root system density and/or growth rate. Interestingly, lower soil water content at deep soil layers in the modern than in the old hybrid was evident early in the season (Fig. 3a, g); which is probably indicating a faster root growth rate in modern hybrids. The increased soil water depletion early in the season with the year of the hybrid release is in contrast with Campos et al. (2004); who indicated greater soil water depletion in an older than in a modern maize hybrid before silking. Hybrid effects could underlie differences between works in the pattern of soil water depletion.

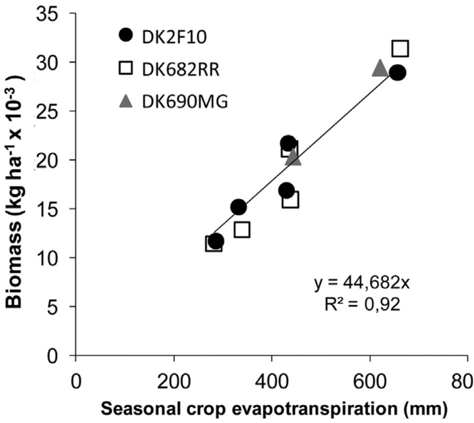

Fig. 4. Biomass production as a function of seasonal crop evapotranspiration for one old (DK2F10, circles) and two modern maize hybrids (DK682RR and DK690MG, squares and triangles, respectively) at three water regimes (irrigated, rain-fed from silking and rain-fed), during seasons 1 and 2. The fitted equation was forced through zero.

Greater daily ET in modern than in older hybrids during the critical period for kernel set could be associated also with differences among hybrids in leaf area and stomata function. Nevertheless, leaf area at silking did not follow a clear trend with the year of the hybrid release; as such leaf area index at silking ranked DK690 (5.47) > DK682 (4.91) = DK2F10 (4.91) during season 2 ($P < 0.05$). Stomata closure, however, might have been delayed in modern hybrids in response to the water stress; as such, leaf rolling was evident in the two modern hybrids but not in the older hybrid (visual observation). In agreement, instantaneous leaf transpiration and photosynthesis rates were greater in a modern than in an older maize hybrid exposed to a short period of water stress at tasseling in a greenhouse study (Nissanka et al., 1997). In addition, although minimum rates of evaporation are expected during the critical period for kernel set, evaporation during this period was not an additional factor influencing ET values. Differences in daily crop ET among hybrids at the critical period for kernel set were diluted as the season progressed (Table 2), resulting in no difference in seasonal crop ET (Fig. 2).

Soil available water influences daily ET; and ET reductions can be expected when soil available water is below 50–55% for maize (Allen et al., 1998). As discussed above, mean daily ET of modern hybrids was higher than that of the older hybrid during the critical period for kernel set at low soil water availability (i.e. AW < 57%). Under these conditions of low AW, however, mean AW across water regimes was lower in the modern (44%) than in the old hybrid (50%, Table 2). During the grain filling period, AW was even lower in the modern (36%) than in the older hybrid (42%), however daily ET was similar between hybrids. Similar trends were found between the older and the two modern maize hybrids for the rain-fed treatment during season 2 (Table 2). Thus, the greater or similar daily ET at lower AW under conditions of low soil water availability probably indicates lower AW thresholds below which actual ET is reduced respect to its maximum in modern compared with older maize hybrids.

5. Conclusions

Seasonal crop ET was similar between the old and the modern maize hybrids at all soil water availabilities. However, a larger daily crop ET was evident in the modern hybrids during the critical period for kernel set at low soil available water. The larger daily ET was associated mainly with a greater water extraction capacity at deeper soil layers, and probably with a delayed stomata closure in modern than in older hybrids. In addition, during the grain filling period, daily crop ET was similar among hybrids in spite of the lower soil available water in the modern hybrids than in the old one. Therefore, daily crop ET of modern hybrids was less sensitive to low soil water availability than that of the older hybrid.

Acknowledgments

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