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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).