Maize Evapotranspiration and Water-Use Efficiency in Response to Row Spacing

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ABSTRACT

Reduced row spacing has shown to increase maize (*Zea mays* L.) yield; however there are conflicting results on whether narrow rows increases maize crop evapotranspiration and/or water use efficiency. This work analyzes the response of maize yield, crop evapotranspiration (ET) and water use efficiency to reduced row spacing under different water and N regimes. Maize crops were grown at Balcarce, Argentina, during two seasons. Treatments included two water regimes (rain-fed and irrigated), two rows spacing (35 and 70 cm) and two rates of N (i.e., 180 kg N ha^{-1} or nonfertilized). Soil water content was measured through the growing seasons using a neutron probe, grain yield and shoot dry matter were determined at physiological maturity. Grain yield response to narrow rows ranged from 0 to 23%; it was higher for water limited (i.e., rain-fed crops) and/or N deficient crops (i.e., nonfertilized crops) and lower for crops with high N fertilization and irrigation. Narrow rows consistently increased (8%) crop ET during the initial stages of crop growth; and N fertilization did not influence ET response to reduced row spacing during this period. Initial differences in ET between row spacing treatments were diluted as the season progressed, and seasonal crop ET was not influenced by row spacing. Reduced row spacing increased water use efficiency for grain production up to 17%; increments were larger in N deficient crops and/or with water limitations but were negligible in N fertilized and irrigated crops.

Crop Economics, Production & Management

Positive maize yield responses to reduced row spacing were reported in well watered crops (Fulton, 1970; Ottman and Welch, 1989; Barbieri et al., 2000; Andrade et al., 2002). Yield response to reduced row spacing was related to a greater intercepted radiation (Ottman and Welch, 1989; Andrade et al., 2002). In general, crop ET and/or yield per unit ET (water use efficiency for grain production, WUE_g) responses to reduced row spacing were not quantified; and there are conflicting results whether narrow rows increases crop ET. As such, in well-watered maize crops, greater grain yields at narrow compared with wide row spacing were associated with lower (Yao and Shaw, 1964b) or with higher (Sharratt and McWilliams, 2005) crop ET. In other crops, like soybean [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.), there is agreement on that reduced row spacing did not influence ET in environments without soil water limitations (Mason et al., 1982; Reicosky et al., 1985; Eberbach and Pala, 2005).

Maize crop ET and WUE_g responses to reduced row spacing might be greater in N deficient or water-limited crops than in crops without N or water limitations, because of the reduction in fractionally intercepted photosynthetically active radiation (PAR) at low N or water supply (e.g., Boomsma et al., 2009; Earl and Davis, 2003). However, to the best of our knowledge, evidence to test these expectations is scarce in maize. As such, Alessi and Power (1976) reported similar ET at different row spacing for maize exposed to water stress during the grain-filling period. In soybean, reduced row spacing increased crop ET early in the season in environments with water limitations (Alessi and Power, 1982; Reicosky et al., 1985). The enhanced early season ET could result in greater water stress during critical periods for grain production in crops subjected to progressive drought (Alessi and Power, 1982).

The objective of this study was to assess maize yield, crop ET, and water use efficiency in response to reduced row spacing under different water and N regimes.

MATERIALS AND METHODS

Site and Crop Management

Maize crops were grown at Balcarce, Argentina (37°45′ S, 58°18′ W; elevation 130 m), during 2001–2002 (Season 1) and 2002–2003 (Season 2). The soil was a complex of a fine, mixed Typic Argiudoll and a fine, thermic Petrocalcic Paleudoll (petrocalcic horizon at 80-cm depth), with a loam texture at the surface layer (0–25-cm depth), loam to clay-loam at subsurface layers (25–110-cm depth) and sandy-loam below 110-cm depth (C-horizon) with 5.4% topsoil organic matter. The area was under no-till management since 1994; previous crop was maize and ground cover by maize residues ranged from 80 to 90%. The petrocalcic horizon at 80-cm depth might limit crop ET (Calviño et al., 2003). Maximum water holding capacity (288 mm) and permanent wilting point (158 mm) to 80-cm soil

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Published in Agron. J. 104:939–944 (2012)
Posted online 30 Apr 2012
doi:10.2134/agronj2012.0014

Abbreviations: DAS, days after sowing; ET, crop evapotranspiration; ET_0, reference evapotranspiration; PAR, photosynthetically active radiation; RS, row spacing; WUE_b, water use efficiency for shoot biomass production; WUE_g, water use efficiency for grain production.

Table 1. Mean photosynthetically active radiation (PAR), mean air temperature, cumulative rainfall, irrigation and reference evapotranspiration (ET_0) every month during the 2001–2002 (S1) and 2002–2003 (S2) growing seasons and their corresponding mean or median of a 30 yr of data (H) at Balcarce, Argentina.

Month	PAR S1	PAR S2	PAR H	Mean air temperature S1	Mean air temperature S2	Mean air temperature H	Rainfall S1	Rainfall S2	Rainfall H	Irrigation S1	Irrigation S2	ET_0 S1	ET_0 S2	ET_0 H
	MJ m^{-2} d^{-1}			°C			mm							
October	5.3	8.1	7.6	14.6	14.8	13.1	156	276	91			63	99	90
November	10.2	8.7	9.4	15.5	16.8	15.8	198	169	63			108	111	116
December	11.2	11.2	10.2	18.8	19.5	18.6	123	39	100	40	56	136	140	145
January	10.5	11.1	10.3	20.8	21.5	20.3	152	124	103	28	96	133	155	151
February	8.8	9.2	9.3	19.1	20.4	19.5	71	91	71	46		101	112	117
March	6.4	7.2	7.2	17.5	19.1	17.8	147	167	75			78	99	95

depth were determined in a previous experiment according to Cassel and Nielsen (1986). Experiments were conducted under no-till management. Crops were fertilized with 30 kg P ha^{-1} before sowing (P source: triple superphospate, 0–46–0). Weeds and insects were effectively controlled.

Table 1 summarizes weather conditions and irrigation for the two seasons of the study and the mean PAR, air temperature, and ET_0 and the median rainfall values for a series of 30 yr. Cumulative photosynthetically active radiation and mean air temperature during the growing seasons were close to the mean values both seasons. Water input from rain accumulated 846 mm in Season 1 (i.e., 46% higher than the median value) and 865 mm in Season 2 (i.e., 49% higher than the median value); however, rainfall distribution during the growing season differed between years (Table 1). As such, rainfall during December, a critical month for kernel number determination, was 23% higher but 60% lower than the median value, for Seasons 1 and 2, respectively.

Plant Material and Experimental Design

Maize hybrid DK 615 was sown on 2 November (Season 1) and 25 October (Season 2). Treatments included two water regimes (rain-fed and irrigated), two row spacings (35 and 70 cm) and two rates of N (i.e., 180 kg N ha^{-1} or nonfertilized). Maize plant density was 7.6 plants m^{-2} for irrigated conditions and 6.6 plants m^{-2} for rain-fed conditions. As such, distance between plants in a row was 18.8 and 37.6 cm for irrigated crops at 70- and 35-cm row spacing, respectively; and it was 21.6 and 43.3 cm for rain-fed crops at 70- and 35-cm row spacing, respectively. Plots were oversown and thinned to the desired plant densities at V3 (Ritchie and Hanway, 1982). The treatments were arranged in a split-split plot design with three replications; irrigation treatments were assigned to the main plots, row spacing treatments were assigned to the subplots and fertilizer treatments were assigned to the sub-subplots. Sub-subplots comprised seven rows 14 m long. Sprinkler irrigation was applied starting a few days before silking as required to supplement rainfall in the irrigation treatments during the growing season. In the N fertilized treatments, N was applied broadcast at sowing, which is the typical fertilization management in this region (N source: urea, 46–0–0).

Measurements

Soil water content was measured in the inter-row, where differences between row spacing treatments are expected to be maximal (Sharratt and McWilliams, 2005). Measurements were done (i) gravimetrically from 0 to 80 cm right before sowing only in six experimental units, 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., Research Triangle Park, NC) in each experimental unit from 50 to 55 d after sowing (DAS) and until 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 80-cm depth. Total soil water content in each experimental unit was determined as the sum of the water content in all layers. One access tube per experimental unit was placed midway between the two harvest rows and soil water was measured approximately every 7 to 15 d, except for (i) the 50- to 55-d interval at the beginning and (ii) the 30-d interval at the end, of the growing seasons. Physical constrains at the petrocalcic horizon depth did not allow deeper installation of the access tubes for soil water content measurements; thus, the quantification of root water extraction or drainage below that horizon was not possible and they were assumed to be null.

A meteorological station from the National Institute of Agriculture, situated <1 km from the field experiment, recorded the precipitation data and the meteorological variables for the reference evapotranspiration (ET_0) estimates using the Penman–Monteith equation (Allen et al., 1998). The ET_0 is defined as the ET rate from an hypothetical grass reference crop with specific characteristics and not short of water (Allen et al., 1998).

Grain yield and shoot dry matter were determined at physiological maturity in samples of 10 plants. In all cases, the samples were taken from the central rows of each subplot. All shoots and grain were oven-dried (forced air at 60°C) to constant weight and weighed.

Calculations and Statistical Analysis

Crop ET was calculated as precipitation plus irrigation minus the change in soil water storage between two observation dates and minus runoff. Runoff was estimated as water excess using a soil water balance model locally adjusted for maize (Della Maggiora et al., 2002). Drainage was considered negligible.

Water use efficiency for grain production and for biomass production (WUE_b) were estimated by dividing grain yield or shoot biomass at physiological maturity by the accumulated seasonal crop ET.

Analysis of variance, using the PROC MIXED procedure (SAS v9), was used to test the effect of season, row spacing, water regime,

Table 2. Yield, harvest index (HI), and shoot biomass for two water regimes (rain-fed and irrigated), two rows spacing (RS, 35 and 70 cm) and two rates of N addition (nonfertilized [0] and fertilized with 180 kg N ha^{-1} [180]). Results of ANOVA indicating *P* values on main effects and interactions are also shown; when interactions were significant, means were separated by test of contrasts.

Effects	Water regime	N addition	Row spacing	Yield	HI	Shoot biomass
				kg ha^{-1}		kg ha^{-1}
W × RS × N†	Irrigated	180	35	8660 ns‡	0.48	18,310
			70	8730	0.47	18,710
		0	35	5510 *	0.48	11,450
			70	4490	0.42	10,770
	Rain-fed	180	35	9050 *	0.51	17,770
			70	7740	0.47	16,470
		0	35	4160 *	0.49	8,510
			70	3480	0.42	8,350
					ANOVA	
S				ns	0.011	0.030
W				0.027	ns	<0.0001
S × W				ns	ns	ns
RS				<0.0001	0.006	ns
S × RS				ns	ns	ns
W × RS				ns	ns	ns
S × W × RS				ns	ns	ns
N				<0.0001	0.008	<0.0001
S × N				ns	ns	ns
W × N				0.007	ns	0.030
S × W × N				0.045	ns	ns
RS × N				ns	0.03	ns
S × RS × N				ns	ns	ns
W × RS × N				0.008	ns	ns

* Indicates differences significant at $P < 0.05$.

† W, water supply; RS, row spacing; N, nitrogen addition, S, season.

‡ ns indicates not significant differences between row spacing treatments within each water regime and nitrogen addition combination.

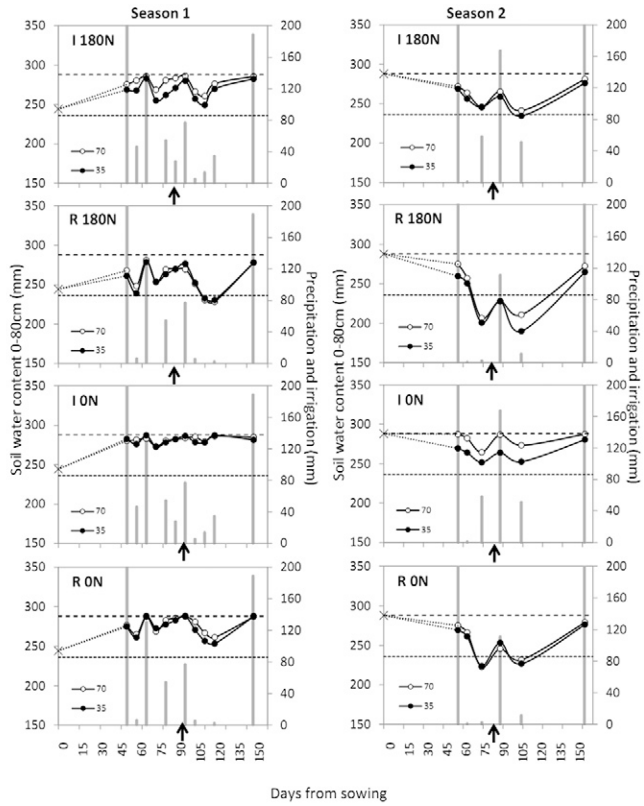

Fig. 1. Soil water content to 80-cm depth (mm) from sowing to physiological maturity during Season 1 (left) and Season 2 (right), at wide (open circles) and narrow (closed circles) row spacing. Crosses are the mean value of the first water content measurement, which was done in just a few plots before sowing. Bars are the accumulated precipitation between two soil moisture measurements. Upper dashed lines are the soil water content upper limit and lower dashed lines indicate 60% of the available water (i.e., 60% of water content in between the upper and lower limit). Arrows indicate silking date for each treatment. Each figure represents one combination of water × N addition; I180N is irrigated fertilized, R180 is rain-fed fertilized, I0N is irrigated nonfertilized and R0N is rain-fed nonfertilized.

N addition and their interactions on grain yield, its determinants (i.e., harvest index and shoot biomass), and crop ET and efficiency in the use of water. Class values were season (S), block, water (W), N addition (N), and row spacing (RS). The model statement was parameter = S|W|N |RS; using block (season), water × block(season) and season × water × row spacing × block(season) in the random statement. When interactions were significant, means were separated by test of contrasts.

RESULTS

Grain Yield, Harvest Index, and Shoot Biomass

The eight combinations of row spacing, water, and N addition produced ranges of shoot biomass from 8 to 18 t ha^{-1} and yield from 3.5 to 9.1 t ha^{-1} (Table 2). There was a significant yield response to the interaction of water regime × row spacing × N addition (Table 2). Yield response to narrow rows ranged from 0 to 23%; it was higher for rain-fed and/or nonfertilized crops, and became negligible when maize crops were fertilized and irrigated (Table 2). There was a significant interaction of season × water regime × N addition for yield (Table 2); irrigation increased yield in fertilized crops only during Season 2, in agreement with the lower precipitation that occurred during this season compared with Season 1 (Table 1). The lower precipitation during Season 2 was particularly evident from 60 to 80 d after sowing (see December in Table 1) and in correspondence with a decrease in soil water content below 60% of soil water availability during that period (Fig. 1).

Grain yield response to reduced row spacing was associated with harvest index ($R^2 = 0.74$; $P < 0.05$; $n = 8$; data of two seasons, not shown) and weakly associated with shoot biomass ($R^2 = 0.38$; $P > 0.1$; $n = 8$; data of two seasons, not shown). Harvest index increased in response to reduced row spacing only in N deficient crops (Table 2). Shoot biomass tended to increase with reduced row spacing in rain-fed and/or non-N fertilized crops, but differences were not statistically significant (Table 2). Yield and kernel number increments in response to narrow rows were closely associated ($R^2 = 0.84$; $P < 0.05$; $n = 8$; not shown).

Seasonal Crop Evapotranspiration and Water Use Efficiency

Seasonal crop ET ranged from 389 to 486 mm and it was increased by irrigation and N fertilization (Table 3). Seasonal crop ET increment due to irrigation was larger during Season 2 (25%) than during season 1 (17%, not shown; significant season × water regime × N addition interaction, Table 3). This was probably related to the lower precipitation in some periods

Table 3. Seasonal crop evapotranspiration (ET), water use efficiency for shoot biomass (WUE_b) and for grain production (WUE_g), for two water regimes (rain-fed and irrigated), two rows spacing (35 and 70 cm) and two rates of N addition (non-fertilized [0] and fertilized with 180 kg N ha^{-1} [180]). Results of ANOVA indicating P values on main effects and interactions are also shown; when interactions were significant, means were separated by test of contrasts.

Effects	Water regime	N addition	Row spacing	ET	WUE_b	WUE_g
				mm	g mm^{-1}	
W × RS × N†	Irrigated	180	35	486	3.8	1.79 ns‡
			70	482	3.8	1.82
		0	35	466	2.5	1.18§
			70	460	2.5	1.01
	Rain-fed	180	35	398	4.5	2.28 *
			70	394	4.2	1.97
		0	35	391	2.2	1.05 ns
			70	389	2.1	0.90
					ANOVA	
S				<0.0001	ns	ns
W				<0.0001	ns	ns
S × W				0.0002	ns	ns
RS				ns	ns	0.006
S × RS				ns	ns	ns
W × RS				ns	ns	ns
S × W × RS				ns	ns	ns
N addition (N)				<0.0001	<0.0001	<0.0001
S × N				0.014	ns	ns
W × N				0.0006	<0.0001	<0.0001
S × W × N				0.030	ns	ns
RS × N				ns	ns	ns
S × RS × N				ns	ns	ns
W × RS × N				ns	ns	0.030

* Indicates differences significant at $P < 0.05$.

† W, water supply; RS, row spacing; N, nitrogen addition, S, season.

‡ ns indicates not significant differences between row spacing treatments within each water regime and nitrogen addition combination.

§ Indicates differences significant at $P < 0.1$.

during Season 2 (Table 1). As well, N fertilization slightly increased seasonal crop ET, and the increment was larger in irrigated (5%) than in rain-fed crops (2%; significant water regime × N addition; Table 3).

Reduced row spacing did not influence seasonal crop ET (Table 3) but it increased WUE_g (significant water regime × row spacing × N addition interaction, Table 3). Increments of WUE_g due to reduced row spacing averaged 17% in N deficient and/or water limited crops but were negligible in N fertilized and irrigated crops (Table 3). The WUE_g and kernel number increments in response to narrow rows were closely associated ($R^2 = 0.89$, $P < 0.05$; not shown). Water use efficiency for biomass production (WUE_b) ranged from 2.1 to 3.8 g m^{-2} mm^{-1} among treatments. As expected from the lack of effect of row spacing on either shoot biomass production or crop ET, WUE_b was not influenced by row spacing (Table 3).

Soil Water Content and Crop Evapotranspiration Dynamics through the Crop Growing Season

Accumulated crop ET from sowing to 50 to 55 DAS increased 8.4% with reduced row spacing (Table 4) and mean ET rate followed the same trend (Fig. 2). Evapotranspiration response to row spacing was similar for N fertilized and

Table 4. Crop evapotranspiration (ET) accumulated from sowing to 50 to 55 d after sowing (DAS) (Period 1, P1), from 50 to 55 DAS to silking (P2) and from silking to physiological maturity (P3), for two row spacing treatments (35 and 70 cm). Results of ANOVA indicating P values on main effects and interactions are also shown. Water regime was not evaluated for P1 since irrigation started at 75 DAS. Only averaged ET values through N addition, water regime and season at each row spacing treatment are shown, to maintain coherence among periods of analysis.

Effects	Row spacing	ET		
		P1	P2	P3
			mm	
	35	129 *	128	179
	70	119	129	176
			ANOVA	
Season (S)		<0.0001	0.028	0.008
Water supply (W)		–	<0.0001	<0.0001
S × W		–	<0.0001	<0.0001
Row spacing (RS)		0.020	ns†	ns
S × RS		ns	ns	ns
W × RS		–	ns	ns
S × W × RS		–	ns	ns
N addition (N)		0.0003	<0.0001	0.0007
S × N		0.012	ns	ns
W × N		–	ns	0.012
S × W × N		–	0.004	ns
RS × N		ns	ns	ns
S × RS × N		ns	ns	ns
W × RS × N		–	ns	ns

* Indicates differences significant at $P < 0.05$.

† ns indicate not significant differences, between row spacing treatments.

nonfertilized crops (i.e., N addition × row spacing interaction not significant; Table 4). In addition, crop ET accumulated during this period was influenced by a significant season × N addition interaction (Table 4). As such, N addition increased accumulated crop ET to a greater extent during Season 1 (8%) than during Season 2 (6%). Soil water content in the inter-row at 50 to 55 DAS averaged through N addition, water regime, and season, was lower in narrower (269 mm) than in wider row spacing (276 mm, $P < 0.05$; Fig. 1).

Crop ET from 50 to 55 DAS to silking and from silking to physiological maturity was not influenced by row spacing (Table 4); and crop ET rates during these periods did not follow a consistent trend (Fig. 2). From 60 to 75 DAS there was an evident drought under rain-fed conditions during Season 2 (Fig. 1), and soil water depletion in the inter-row through the soil profile was similar between narrow and wide row spacing ($P > 0.05$; not shown).

DISCUSSION

The significant grain yield response to reduced row spacing in treatments with no N fertilization (Table 2) is in agreement with Barbieri et al. (2008), who indicated a greater yield response to reduced row spacing in N deficient crops. Nitrogen recovery efficiency (i.e., N uptake per unit of available N) was increased under narrow rows in N deficient crops (Barbieri et al., 2008), probably because of an improved root distribution with a greater root length density in the inter-row (Sharratt and McWilliams, 2005). The greater N recovery efficiency would result in greater intercepted radiation and a better physiological

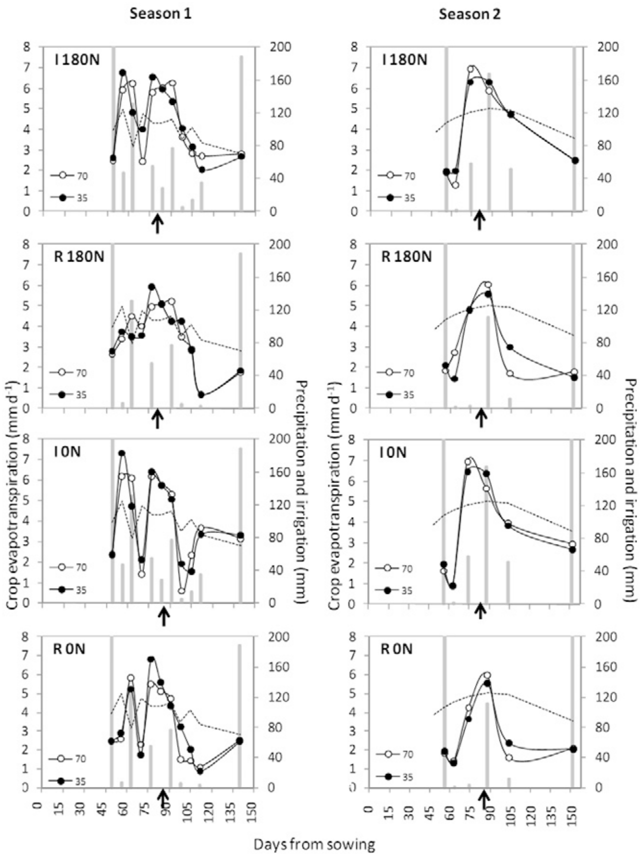

Fig. 2. Crop evapotranspiration rates (mm d^{-1}) from sowing to physiological maturity, during Season 1 (left) and Season 2 (right), at wide (open symbols) and narrow (closed symbols) row spacing. Bars are the accumulated precipitation between two soil moisture measurements. Dashed lines indicate the reference evapotranspiration. Arrows indicate silking date for each treatment. Each figure represents one combination of water × N addition; I180N is irrigated fertilized, R180 is rain-fed fertilized, I0N is irrigated nonfertilized and R0N is rain-fed nonfertilized.

condition during the critical period for kernel set compared with wide rows; as previously shown by Barbieri et al. (2000, 2008). In N fertilized and irrigated crops, grain yield responses to reduced row spacing were lower than in N deficient crops, probably because N was not limiting crop growth and greater N recovery would result in luxury N consumption. In accordance, intercepted radiation at silking was not improved by reduced row spacing in maize crops without water or N limitations (Andrade et al., 2002). Reduced row spacing, however, significantly increased grain yield in N fertilized crops when water supply was restricted (Table 2); which could be associated with (i) an improved root distribution under narrower row spacing (Sharratt and McWilliams, 2005) that may offset the limited nutrient transport to the root surface in dry soils (Buljovcic and Engels, 2001), and (ii) an improved intercepted radiation at the critical period for kernel set (Andrade et al., 2002). Similar trends as those found for yield response to reduced row spacing were expected for shoot biomass; since previous works showed that reduced row spacing increased initial plant growth (Barbieri et al., 2008) and intercepted radiation (Andrade et al., 2002). However, experimental errors might have masked shoot biomass significant differences between row spacing treatments.

Narrow rows consistently increased soil water depletion in the inter-row (Fig. 1) and crop ET during the initial stages of crop growth (i.e., from sowing to 50–55 DAS; Table 4, Fig. 2). This finding supports the greater N recovery with reduced row spacing reported by Barbieri et al. (2008); since N transport to the roots is mainly mediated by mass flow and it could be favored by the increased soil water depletion with reduced row spacing. The increased water depletion in the inter-row and crop ET under narrow row spacing up to 50 to 55 DAS were most likely related to (i) a more uniform and deeper root system (Raper and Barber, 1970; Sadras et al., 1989, Sharratt and McWilliams, 2005), and (ii) the relative change of the ET components, that is, transpiration and evaporation from soil. As such, many studies indicated intercepted radiation increased with reduced row spacing (Kasperbauer and Karlen, 1994, Barbieri et al., 2000; Andrade et al., 2002; Sharratt and McWilliams, 2005; Drouet and Kiniry, 2008) that would result in greater biomass production during the initial growth and thus in an increased crop transpiration. In addition, greater intercepted radiation might contribute to decreased soil evaporation as less radiation reaches the soil surface (Eberbach and Pala, 2005; Sauer et al., 2007; Yao and Shaw, 1964a). However, some authors did not find a consistent influence of row spacing on soil evaporation (Yunusa et al., 1993; Sharratt and McWilliams, 2005), since this effect depends on the moisture content in the upper soil layers (Allen et al., 1998). Moreover, the residue cover under the no-till management of this study might have decreased soil evaporation and thus, the influence of narrow rows on the ET component. Later in the growing season (i.e., from 50–55 DAS to physiological maturity), crop ET was not different between row spacing treatments (Table 4). The greater influence of reduced row spacing on increasing crop ET at initial growth stages (Table 4) could be associated with greater canopy cover and root exploration differences between row spacing treatments at initial stages rather than later in the season. Differences in crop ET between row spacing treatments would have been partially reduced if soil water contents had been measured both in the inter-row and in the intra-row, as was observed for root length density by Sharratt and McWilliams (2005).

Differences in initial crop ET between row spacing treatments were diluted as the season progressed (Table 4) resulting in no difference in seasonal crop ET (Table 3). Sharratt and McWilliams (2005) reported higher seasonal crop ET under narrow (38 cm) than under wider (76 cm) row spacing in 1 of the 2 yr tested in their study. Discrepancies between their work and ours might be mainly related to the pattern of water availability (i.e., rainfall distribution and irrigation schedule). Results of our work also showed that N fertilization increased seasonal crop ET, and the increase was larger in irrigated than in rain-fed crops (Table 3). In agreement, crop ET increments with N fertilization have been previously reported (Abbas et al., 2005; Bennett et al., 1986; Ogola et al., 2002).

Water use efficiency for grain yield increased 17% with reduced row spacing in N deficient crops and/or with water limitations (Table 3). Contrarily, WUE_g response to reduced row spacing was negligible in the high yielding treatment with high N fertilization and irrigation (Table 3). Under the growing conditions of this experiment, where (i) crop growth did not entirely depend on stored water at the beginning of the season and (ii) transient drought did not last for more than 20 d, the greater soil water depletion under narrow than under wider row spacing up to 50 to 55 DAS (Table 4; Fig. 1) did not increase water deficit at critical stages that could have reduced WUE_g. In this work, greater WUE_g with reduced row spacing was mainly influenced by a greater kernel set. Previous reports associated kernel number response to reduced row spacing with a greater N recovery at initial growing stages and with an improved fraction of intercepted radiation at silking (Andrade et al., 2002; Barbieri et al., 2000, 2008).

CONCLUSIONS

Narrow rows consistently increased soil water depletion in the inter-row and crop ET during the initial stages of crop growth. Nitrogen fertilization did not influence the ET response to reduced row spacing during this period. Initial ET differences between row spacing treatments were diluted during the season; and seasonal crop ET was not influenced by row spacing. However, the greater soil water depletion at narrower row spacing might promote water stress earlier in the season in crops subjected to progressive drought. Narrower row spacing increased water use efficiency for grain production; and increments were larger in N deficient crops and/or with water limitations but were negligible in fertilized and irrigated crops.

ACKNOWLEDGMENTS

This work was supported by Instituto Nacional de Tecnología Agropecuaria (INTA) and the Research Council of Argentina (CONICET).

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