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Impacts of Drought Stress and Planting Methods on Sweet Corn Yield and Water Use Efficiency

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Abstract
Seasonal drought is the most important factor to limit the production of maize in the world. Using a split plot design, a two year field experiment was conducted to determine the effect of limited irrigation regime on yield, yield components and water use efficiency of sweet corn (*Zea mays* var. saccharata). Responses of three sweet corn varieties KSC403, Merit and Obsession to three different water regimes were studied under two planting methods (raised bed and furrow planting). The three water levels (I_1: 100%, I_2: 80%, I_3: 60%) of the estimated crop evapotranspiration (ETc)) were arranged as main plots. Combination of the two planting methods and three sweet corn varieties were arranged in subplots. The evaluated traits were significantly affected by varieties ($p<0.01$). The highest ear length and diameter and biomass belonged to Merit. Fresh ear weight was significantly affected by the interaction of variety and irrigation level. The highest (19.7 ton/ha) and lowest (7.4 ton/ha) yields (fresh ear weight) belonged to Merit at 100% and KSC403 and obsession at 60% irrigation level, respectively. There was no difference between planting methods with respect to the measured traits. Results showed that limited irrigation significantly decreased kernel number per row by increasing the anthesis-silking interval, which decreased grain yield. Biomass decreased by decrement of water amount. The reduction in fresh ear yield and biomass decreased water use efficiency (WUE), but there was no significant difference between I1 and I2 irrigation levels for WUE.

Keywords: Furrow planting; Irrigation regime; Raised bed; Water use efficiency

Introduction

Seasonal drought is regarded as the most important factor to limit the production of maize in the world (Monneveux *et al*. 2006). Most of Iran's crop fields are located in arid and semi arid regions where water sources are limited (Sarmadnia 1993). Then efficient use of water has economical and environmental benefits for the farmers. One method to serve this purpose is the deficit irrigation. One of the irrigation methods applied by traditional farmers in arid regions of Iran is furrow planting. The assumption is that less water needed to grow plants because soil gets wet quicker than raised bed method (Khavari Khorasani 2009). Significant yield losses in maize from drought are expected to improve with advanced use of water and better planting methods. Water-use efficiency (WUE) is often considered an important determinant of yield under stress and even as a component of crop drought resistance (Blum 2005). Although WUE of maize is high, it is considered more susceptible to water stress than other crops due to its unusual floral structure with separate male and female floral organs. The near-synchronous development of florets on a single ear in each stem is the other reason for maize drought susceptibility (Huang *et al*. 2006). Drought stress is damaging grain yield if it occurs early in the growing season (when plant stands are establishing), at flowering, and during mid to late grain filling (Heisey and Edmeades 1999). During stem elongation (after floral initiation) leaves and stems grow rapidly, requiring adequate supplies of water to sustain rapid organ development (Muchow 1989). Plant water is one of the most important and readily manageable variables for producing a profitable crop (Kozlowski 1972; Taylor et al. 1983). To determine plant water status, measuring relative water content (RWC) of plant tissues has been widely accepted as a reproducible and meaningful index (Barrs 1968; Smart and Bingham 1974). The rate of RWC in plants with high resistance against drought is higher than others. In other words, plant having higher yields under drought stress should have high RWC. Under water deficit, the cell membrane is subjected to changes such as increase in penetrability and decrease in sustainability (Johnson and Tanner 1972; Blokhina *et al*. 2003). Water use efficiency of maize is a function of multiple factors, including physiological characteristics, genotype, soil characteristics such as soil water holding capacity, meteorological conditions and agronomic practices (Huang *et al*. 2006). Managing maize irrigation at the field scale can be improved by quantifying the water balance and using advanced techniques for irrigation scheduling for more effective and economic use of limited water supplies. Maximizing of crop yield per unit of water consumed by transpiration has long been a concern of both plant scientists and farmers. Increasing WUE could theoretically affect plant growth. The high WUE results in producing more dry matter by using little water amounts (Wright *et al*. 1993). Effect of water deficits on plant productivity and WUE have been studied by many researchers and different results are reported. WUE decreased by decreasing the water use amount (Ibrahim *et al*. 1995; Karimi *et al*. 2001; Al-Kaisi and Xinhua 2003). However, enhancing the water amount, results in WUE deficit (Ansari *et al*. 2006; Yi *et al*. 2010). Several studies have developed mathematical models to verify crop evapotranspiration (ETc) and use that to estimate WUE (Nairizi and Rydzewski, 1977; Doorenbos and Kassam 1979; Meyer *et al*. 1993).This study was conducted to investigate the effect of different irrigation levels on yield and yield components and also WUE of three sweet corn varieties at raised bed and furrow planting conditions.

Materials and Methods

Site description

The study was conducted from June to September of 2010 and 2011, in a cold-arid region with 286 mm precipitation per year in the Agricultural and Natural Resources Research Center of Khorasan Razavi in Mashhad, Iran. The station is at 35° 43´ N latitude and 59° 15´ E longitude. Soil analysis of experimental filed resulted in silt-loamy class by 29 percent of sand, 54 percent of clay and 17 percent of silt (USDA). The bulk density of soil was 1.42 g cm^{-3} with a field capacity of 28%

(determined gravimetrically), and a permanent wilting coefficient of 12% in 0-60 depth.

Experimental design

Response of three sweet corn varieties to three different water levels in two planting methods were studied. Water levels were I1:100, I2:80 and I3:60% ETc. The experimental design was a randomized complete block with four replications, with a split–plot arrangement. The main plot factor was three irrigation levels and subplot was a factorial arrangement (2 × 3) of two planting methods (raised bed and furrow planting), with three different sweet corn varieties (Merit, Obsession and KSC403). Each variety was hand-seeded in hills in 17.5 cm distance from each other. There were four rows in each plot, with 6 m length and 75cm row distance. The final plant population was 7 plants per square meter.

Methods

Irrigation

The irrigation time was fixed for all irrigation treatments. All plots irrigated after seven days at the same time, but the water amount was different for different water treatments. Drought stress imposed after the appearance of the fourth leaf.

A computer model which developed by agriculture ministry of Iran, used to estimate daily evapotranspiration under control water condition (ETo), using the procedures described in FAO-56 (Allen *et al*. 1998). Daily ETo calculated using the standardized Penman-Monteith method (ASCE-EWRI 2005) as:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\left[\frac{890}{T + 273}\right]U_2(e_s - e_d)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where:

ETo: reference evapotranspiration [mm day-1], Rn: 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], U2: wind speed at 2 m height [m s-1], es: saturation vapour pressure [kPa], ea: actual vapour pressure [kPa], es – ea: saturation vapour pressure deficit [kPa], Δ: slope vapour pressure curve [kPa °C-1], γ: psychrometric constant [kPa °C-1].

Inputs to the model included daily weather data, obtained from Mashhad weather station. ETc was calculated as:

ETc=ETo×Kc

Where Etc: Crop evapo-transpiration, ETo: reference crop evapo-transpiration and Kc: crop coefficient for sweet corn taken from Table 6-12 in FAO-56. In I_1 water was added to bring the soil to crop water requirement level. In I_2 and I_3treatments plots received 80% and 60% of water added to the I_1 treatment. The quantity of water for each irrigation time was measured using a 2-inch parshall flume. No precipitation occurred during planting season.

Water use efficiency

WUE can be expressed by different indicators resulting in different options. In this case WUE was calculated by the following functions (Ali and Talukder 2008):

$$WUE_{fresh\ ear} = \frac{crop\ economical\ yield\ (kg\,ha^{-1})}{water\ volume\ used\ to\ product\ the\ yield\ (m^3)}$$

$$WUE_{biomass} = \frac{crop\ biomass\ (kg\,ha^{-1})}{water\ volume\ used\ to\ product\ the\ biomass\ (m^3)}$$

Plant sampling

Days from sowing to 50% silking, tasseling and anthesis were recorded in two years. Anthesis-silking interval was determined by subtracting these two traits. Three plants were randomly sampled from each plot to determine RWC of leaves at tasseling. The RWC was calculated as given by Barrs and Weatherley (1962):

$$RWC\% = \frac{leaf\ fresh\ weight - leaf\ dry\ weight}{leaf\ saturated\ weight - leaf\ dry\ weight} \times 100$$

When ears kernel went to dough stage, number of plants in two crucial rows of each plot and also their ears were counted. These data were used to correct the raw data, which were obtained from field measurements, such as ear weight or biomass. Ten ears were chosen from each plot randomly to measure yield components. The traits were ear length, ear diameter, kernels number per row, kernel rows per ear, and dry kernel weight.

Thousand kernels were separated from the ten sample ears. Kernels were then weighed and dried in a 75°C oven for 48 hours and the thousand kernel weights was recorded for each sample. The kernel weights were adjusted to a dry matter basis and corrected by 70% moisture content calculated as follow, represented the dry kernel weight:

$$\text{Humid}\ \% = \frac{wet\ 1000\ kernel\ weight - dried\ 1000\ kernel\ weight}{wet\ 1000\ kernel\ weight} \times 100$$

Fresh ear yield, biomass and harvest index were measured in a 17 m^2 for each treatment.

Statistical analysis

The data obtained from two years of experiment, combined and analyzed by standard two-way ANOVA using the SAS statistical package (Ver.8) and significance of differences between means was conducted using Duncan's multiple range test at P=0.05.

Results

Kernel yield and its components

There were significant differences among genotypes with respect to yield and yield components. Dry kernel weight, kernel rows per ear and kernel number per row were significantly affected by irrigation level (Table 1). Anthesis-silking interval (ASI) was significantly longer in the limited irrigation conditions (Table 1), which decreased kernel number per row by limiting pollination (Edmeades *et al*. 1990). Decrease of the kernels per row results in total kernel limitation and kernel yield loss. Calculation of correlations, after combining the data for the two years, showed that kernel yield was strongly correlated with ear length (r^2 = 0.75, P < 0.01), kernels per row (r^2 = 0.72, P < 0.01) and ASI (r^2 = -0.66, P < 0.01). Ear length and kernels per row were correlated too (r^2 = 0.82, P < 0.01). There were no significant differences between two planting methods with respect to measured traits (Table 1).

Table1. Effects of irrigation level, variety and their interaction on measured traits in sweet corn

Treatment	Measured traits											
Varieties	Ear length (mm)	Ear diameter (mm)	Kernel rows per ear	Kernel number per row	Dry kernel weight (gr)	Anthesis silking interval (day)	Kernel yield (ton/ha)	Fresh ear yield (ton/ha)	Biomass (ton/ha)	Harvest index	Fresh ear WUE	Biomass WUE
I1	188 a	46.1 a	17 a	39.2 a	327 a	1.88 c	10.51 a	15.4 a	23.1 a	46.3 a	3.06 a	3.62 a
I2	159 b	41.6 b	15.9 b	34.3 b	292 b	3.63 b	6.82 b	10.6 b	19.11 b	45.31 a	2.86 a	3.35 a
I3	136 c	38.9 b	15.3 b	30 c	271 c	6.19 a	5.7 c	8.2 c	16.69 c	44.88 a	1.61 b	2.72 b
Merit	177 a	45.6 a	17 a	38.5 a	306 a	3.71 b	8.96 a	14.3 a	22.71 a	57.2 a	2.82 a	3.42 a
Obsession	162 b	39.7 b	15.8 b	33.6 b	285 b	3.82 ab	7.62 b	10.5 b	16.68 c	41.6 b	2.49 b	3.04 c
KSC 403	145 c	41.3 ab	15.4 b	31.4 c	299 ab	4.1 a	6.49 c	9.5 c	19.41 b	37.6 c	2.21 c	3.22 b
I1×Merit	211 a	50.5 a	18.4 a	44.2 a	350 a	1.62 c	12.1 a	19.7 a	27.7 a	58.3 a	3.47 a	3.87 a
I2×Merit	170 bc	44.2 b	16.8 b	38.3 b	297 cd	3.31 b	8.34 c	13.2 bc	21.8 b	56.8 a	3.1 b	3.59 b
I3×Merit	150 d	42 bc	15.9 bcd	33.2 d	27 de	6.31 a	6.4 d	9.8 d	18.7 c	56.6 a	1.91 e	2.8 e
I1×Obsession	178 b	42.8 bc	16.4 bc	37.8 b	307 bc	1.80 c	10.23 b	12.3 c	18.8 c	42.5 b	3.02 bc	3.44 bc
I2×Obsession	159 cd	41 bc	15.8 bcd	32.8 d	282 cde	3.71 b	6.2 d	8.7 de	16.4 d	41.2 bc	2.87 c	3.14 d
I3×Obsession	149 d	35.4 d	15.3 bcd	30.2 e	267 e	6.10 a	6.39 d	7.4 e	14.7 d	41.1 bc	1.57 f	2.53 f
I1×KSC403	175 b	44.9 b	16.4 bc	35.7 c	325 ab	2.21 c	8.99 a	14.2 b	22.8 b	38 c	2.68 d	3.52 bc
I2×KSC403	149 d	39.7 c	15 cd	31.9 de	297 cd	3.80 b	6.02 d	9.9 d	18.9 c	37.8 c	2.6 d	3.31 bc
I3×KSC403	111 e	39.3 c	14.8 d	26.7 f	276 de	6.21 a	4.5 e	7.4 e	16.4 d	36.9 c	1.36 g	2.84 e

For each section, means within a column followed by same letters are not significantly different at P = 0.05

Results show that limited irrigation had no significant effect on harvest index. Fresh ear was significantly correlated with above ground biomass (r^2 = 0.71, P < 0.01). It seems that reduction in both fresh ear and biomass, results in HI stability (Sinclair *et al.* 1990; Ghadiri and Majidian 2003). Merit showed the highest HI of 57 percent (Table 1).

The highest fresh ear yield (19.7 ton/ha) was found for Merit at I_1 irrigation level and the lowest belonged to Obsession and KSC403 at I_3 (7.4 ton/ha). Deficit irrigation decreased the fresh ear yield in all varieties (Table 1). Merit produced the highest fresh ear yield in all irrigation levels. Even though kernel and fresh ear yield decreased by water decrease, RWC and WUE did not decrease significantly in 100% and 80% ETc water treatments.

Relative water content

RWC decreased significantly in 60% water treatment (Figure 1). There were no significant differences between 100% and 80% ETc with respect to RWC. RWC was significantly correlated by fresh ear yield (r^2 = 0.59, P < 0.01). A reduction in RWC decreased fresh ear and kernel yield. Furthermore, different varieties showed similar RWC at each irrigation level and there were no significant differences between two planting methods with respect to RWC.

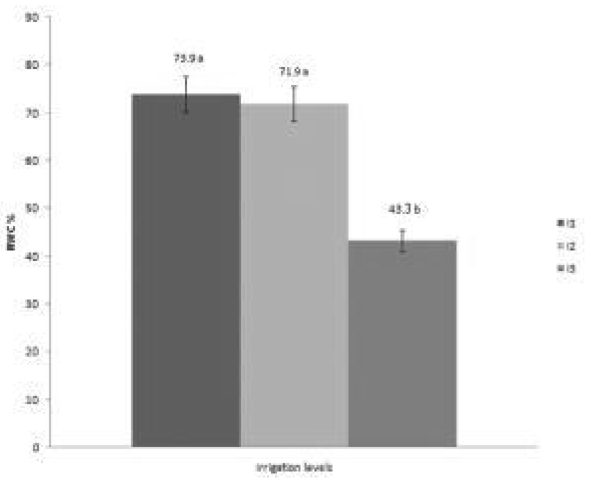

Figure 1. Effect of different irrigation levels on RWC, averaged over three sweet corn varieties and planting methods

Water use efficiency

Fresh ear and biomass water use efficiency was significantly affected by irrigation regimes (Table 1).The lowest fresh ear and biomass WUE belonged to 60% ETc treatment (1.61 kg/m^3 and 2.72 kg/m^3, respectively. There was no significant difference between fresh ear production rate per cubic meter of water, in 100% and 80% ETc, but decrease in water resulted in yield loss (Table 1). WUE increased by biomass and fresh ear yield increase. Fresh ear and biomass WUE were significantly correlated with fresh ear yield (r^2 = 0.66, P < 0.01) and biomass (r^2 = 0.70, P < 0.01), respectively. Therefore, the decrease in WUE by reducing the water amount was due to fresh ear yield loss. Differences among varieties were significant for fresh ear and biomass WUE (Table 1). The highest biomass and fresh ear WUE belonged to Merit (3.4 and 2.8 kg fresh ear, respectively, by using one m^3 of water. Results showed no significant differences between two planting methods with respect to WUE.

Unexpectedly, no significant interaction was observed between water level and planting method for fresh ear and biomass WUE. This means that furrow planting did not decrease the amount of water requirement or enhance the maize yield at the water deficit condition.

Discussion

ASI of 1.6 days is considered optimal for sweet corn at the Mashhad condition. Increasing ASI to 6 days and more, decreased kernel number per row by limiting pollination (Edmeades *et al*. 1990). Pollination was hampered by the pollen death or silk desiccation (Bassetti and Westgate 1993). Consequently, the decrease in kernels per row resulted in yield reduction. The reduction of RWC at the water limited condition in corn was reported by many researchers (Lawlor 2002; Ko and Piccinni 2009; Shamsi 2010). The decrease in the leaf RWC progressively decreased stomatal conductance and slowed CO2 assimilation which eventually reduced photosynthetic metabolites (Lawlor 2002). Metabolite deficiency during grain development results in lightweight kernels which finally results in yield limitation. The results showed no significant differences between RWC of I_1 and I_2 while fresh ear and kernel yield decreased significantly in I_2, thus yield decrease in I_2 was more related to the reduction in kernel number and was controlled by ASI duration rather than kernel weight.

Fresh ear production per unit of water was not affected by I_2 but yield decreased significantly in 80% ETc. Thus, even 20% decrease in water availability in Mashhad causes yield loss. Peak pollination period occurs in late July to early August which is the warmest month of Mashhad with no precipitation (Figure 2). Heat, combined with lack of water, has devastating effect on pollination and seed set (Bassetti and Westgate 1993) that results in kernel loss. The decrease in RWC results in the assimilate reduction which reduces kernel weight. Results showed that both kernel number and weight were reduced by water limitation (Table 1). Kernel number and weight are two important yield components and yield reduction is expected when they are affected by water deficiency (Edmeades *et al*. 1990). Water deficit in I_2 and I_3 treatments results in the reduction of kernel number per row and dry kernel weight which finally decreased fresh ear and kernel yield. Ibrahim *et al*. (1995), Karimi *et al*. (2001) and Al-Kaisi and Xinhua (2003) reported that water limitation decreased WUE in pearl millet and maize. However, other researches showed that WUE decreased by increasing water supplement (Ansari *et al*. 2006; 2006; Yi *et al*. 2010). Jin *et al.* (1999) found that the increase in irrigation level when soil moisture content exceed a certain threshold may induce small yield increase, and too much irrigation may merely enhance non-physiologically active soil surface evaporation (Olesen *et al*. 2000), which may contribute to the reduction of WUE. In this experiment high yielding varieties showed higher WUE and yield reduction by limiting irrigation.. Raised bed and furrow planting are both conventional production methods in Iran (Khavari Khorasani 2009). There is little information about their advantages upon each other. In this experiment furrow planting did not improve WUE. It seems that in the Mashhad environment furrow planting could not conserve water more than the raised bed method.

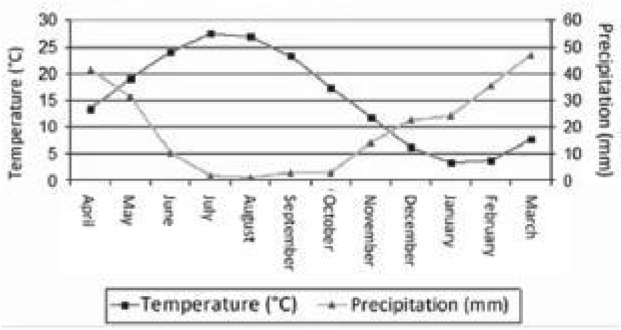

Figure 2. Ombrothermic diagram of Mashhad station (1989-2011)

Conclusion

This study showed that the WUE depends more on fresh ear and biomass yield rather than water availability. The conservative strategy adopted by farmers in the region is the furrow planting, however, it had no significant effect on yield or water consumption in this study. RWC decreased by water limitation and resulted in kernel weight loss, whereas ASI elongation by drought resulted in the reduction in kernel number. These two factors decreased fresh ear and kernel yield significantly. This experiment suggests that Merit was the best variety for the Mashhad condition and water limitation prevents sweet corn to produce the high yield in Mashhad.

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