Pak. J. Agri. Sci., Vol. 52(3), 595-607; 2015
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

YIELD, QUALITY AND IRRIGATION WATER USE OF DRIP-IRRIGATED SILAGE MAIZE WITH DIFFERENT IRRIGATION TECHNIQUES

Selda Ors, Ustun Sahin* and Fatih Mehmet Kiziloglu

Ataturk University, Faculty of Agriculture, Department of Agricultural Structures and Irrigation, 25240 Erzurum, Turkey
***Corresponding author's e-mail: ussahin@atauni.edu.tr**

In this two-year field experiment the effects of partial root-zone drying (PRD) irrigation technique on yield, growth, yield quality and irrigation water use efficiency (IWUE) of drip-irrigated silage maize were investigated by comparing them with the full root-zone wetting (FI) irrigation technique, under three different irrigation levels (W1: 115, W2: 100 and W3: 85% of Class-A pan evaporation) at two different irrigation intervals (I1: 4-day and I2: 8-day). Averaging data from both years, irrigation quantities were 209.5 mm in PRD treatments and 372.5 mm in FI treatments. Among FI treatments, total fresh and dry matter yields were the highest in FI-I2W1 treatment, 48.6 Mg ha^{-1} and 11.4 Mg ha^{-1}, respectively. In PRD treatments, the highest total fresh yield (40.5 Mg ha^{-1}) was obtained in the PRD-I2W1 treatment, while the highest dry matter yield (11.8 Mg ha^{-1}) was obtained in the PRD-I1W2 treatment. The PRD-I1W2 treatment had the highest IWUE values. The treatments had no significant effect on plant mineral content, acid detergent fiber, neutral detergent fiber and crude protein. According to the results of this study, the PRD treatment with 100% of Class-A pan evaporation at the 4-day irrigation interval is the most appropriate treatment in regions with water scarcity due to its higher IWUE.
Keywords: Forage, water management, water use efficiency, root-zone drying irrigation

INTRODUCTION

Irrigation is an important practice for agricultural production in arid and semiarid regions. However, water resources for irrigation aren't sufficient in all regions of the world. More than two billion people live in water deficient regions (Oki and Kanae, 2006). About 70% of developed water worldwide is used for agricultural irrigation (FAO, 2002; Gerbens-Leenes and Nonhebel, 2004). Thus rising global food demand can result from increasing competition over water resources in the coming decades (Lotze-Campen *et al.,* 2008; Abubakar *et al*., 2014; Amin *et al*., 2014).

Nowadays the importance of effective water use is continuously increasing because of the lack of fresh water resources. Effective water use can be changed by factors such as soil characteristics, meteorological conditions, water management practices and agronomic practices (Molden *et al.,* 2003; Huang *et al.,* 2006). Deficit irrigation (DI) and partial root-zone irrigation (PRD) are irrigation practices developed to increase water use efficiency of field and fruit crops (Kang and Zhang, 2004; Sadras, 2009; Sepaskhah and Ahmadi, 2010). The DI technique is a sustainable production strategy used in water scarce regions. Although some yield reduction was observed in DI practices, water productivity is high (Geerts and Raes, 2009). Also, high water productivity values are achieved through PRD practices. In recent years, the PRD technique has been extensively considered water saving irrigation strategy for agronomic and horticultural crops in especially water deficient arid and semi-arid regions (Sepaskhah and Ahmadi, 2010). Sadras (2009) found that DI and PRD practices increased water productivity by an average of 76% and 82%, respectively, in horticultural crops grown under field conditions. Kang and Zhang (2004) indicated that the water used on field crops and fruit trees can be significantly reduced by using PRD practices compared to normal irrigation practices.

Silage maize is one of the most important field crops for animal feeding. Maize is quite sensitive to water stress and it shows different responses to water deficiency in different developmental stages. Generally, there is a linear relationship between maize yield and evapotranspiration or irrigation (Çakir, 2004; Farre and Faci, 2006; Payero *et al.,* 2006; Kiziloglu *et al.,* 2009; Yenesew and Tilahun, 2009; Simsek *et al.,* 2011). But, Payero *et al.* (2008) showed that while yield was linearly related to the evapotranspiration of corn, the relationship was polynomial with irrigation depth. Similarly, Salemi *et al.* (2011) obtained a polynomial relationship between irrigation depth and silage yield.

Some experiment results showed that irrigation water use efficiency (IWUE) decreased with water deficiency in maize (Farre and Faci, 2006; Simsek *et al.,* 2011). In contrast, Payero *et al.* (2008) and Yenesew and Tilahun (2009) determined that IWUE decreased with increasing irrigation quantity.

Crop yields obtained from PRD treatments were better than those from DI treatments that used the same amount of water (Sepaskhah and Ahmadi, 2010). Kang *et al.* (2000) determined that high grain yield in maize using alternately furrow irrigation saved up to 50% of water. Significant increases in the WUE for pot-grown maize were obtained with the alternate watering method compared to bottom watering and surface watering methods (Kang *et al.,* 2002). Yazar *et al.* (2009) evaluated the effects of PRD and DI treatments on yield and IWUE of the drip-irrigated corn and obtained the highest IWUE from the PRD treatment. But, they also found that corn grain yield in the PRD treatment was not statistically higher than the yield from the DI treatment. Kirda *et al.* (2005) determined that yield and IWUE values in maize were statistically similar for PRD and DI treatments. But, IWUE for the PRD treatment was significantly higher than the full irrigation treatment in spite of lower yield.

Crop quality is also important in silage maize production. Crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF) and minerals are considered important quality parameters of silage maize. ADF and NDF percentages are inversely related to the digestibility of silage and dry matter intake (Javanmard *et al.,* 2009; Subramani and Loper, 2011; Eskandari, 2012). Thus, low ADF and NDF percentages are desirable. Also, high protein levels mean high forage quality (Montgomery, 2009).

The objective of this study was to examine the effects of full root-zone wetting (FI) and partial root-zone drying (PRD) techniques with different irrigation intervals and levels on yield, growth and yield quality parameters, water-yield relations and the efficiency of using irrigation water on drip-irrigated silage maize in a semiarid agricultural region.

MATERIAL AND METHODS

The field experiment was conducted for two years (2010 and 2011) at the Agricultural Research Station of Ataturk University, Erzurum in East of Turkey (lat. 39º 56' N, long. 41º 14' E, alt. 1793 m above sea level). The average rainfall from 1970 to 2011 in Erzurum and in Turkey was 407.5 mm and 642.8 mm, respectively. Some weather data including temperature, humidity, wind speed and sunshine during the growing seasons (May-September) of 2010 and 2011 are given in Table 1. These data were collected at the Erzurum weather station located within 5 km from the study site. Precipitation and evaporation data were also collected manually from a standard pluviometer and a Class-A pan, respectively that were installed at the experimental site.

The top soil layer of 30 cm at the experimental site is clay loam. The texture of the soil layer from 30 cm to 90 cm was loam. From measurements obtained using methods provided by Klute (1986) and Page *et al.* (1982), water holding capacity, soil pH, soil EC, soil carbonate content and organic C content were measured at 127.4 mm, 7.49, 1.48 dS m^{-1}, 2.17% and 1.02 g kg^{-1} in upper 0.90 m of the soil profile in experimental plots.

Each experimental plot consisted of 5 plant rows 3.50 m × 10.0 m by in size. Spaces between plots were 1.0 m and spaces between blocks were 2.0 m. OSSK-596 maize (*Zea mays* L.) seeds were planted on May 16, 2010 and May 20, 2011 with a spacing of 15 cm by 70 cm between the plants and the rows, respectively. During soil preparation in trial years, experimental plots received 75 kg N ha^{-1} and 80 kg P_2O_5 ha^{-1} as a basal fertilizer. This was followed by 75 kg N ha^{-1} 6 weeks after planting. Pesticides weren't applied. Hoeing was done by hand three times during both years.

Irrigation water was applied using a surface drip irrigation system. Water for the system was pumped from groundwater stored in a pool. Electrical conductivity, sodium adsorption ratio and pH of the water were 0.295 dS m^{-1}, 0.42 and 7.4, respectively. The drip irrigation system consisted of a control unit and distribution lines. There was a screen filter, a flow meter, a pressure gauge and valves in the control unit. PE manifolds of 50 mm in diameter were placed along the edge of each plot. PE driplines of 16 mm in diameter had in-line type round emitters spaced every 33 cm. The flow rate of emitters was 3.8 L h^{-1} at a pressure of 0.1 MPa. Driplines

Table 1. Some weather data of the experimental region in the growing periods of 2010 and 2011 as mean monthly.

Years	Months	Weather parameters					
		Maximum temp. (°C)	Minimum temp. (°C)	Mean temp. (°C)	Relative humidity (%)	Wind speed (m s^{-1})	Sunshine (h)
2010	May[#]	18.9	3.4	11.2	65.4	3.0	8.6
	June	24.5	7.2	15.9	60.1	2.8	9.1
	July	28.2	10.8	19.5	56.0	3.3	9.9
	August	29.1	10.4	20.3	44.8	3.7	10.1
	September[&]	30.4	10.2	20.3	37.8	3.6	9.2
2011	May[£]	17.4	5.6	11.2	70.1	2.9	9.2
	June	22.3	6.1	14.6	63.4	2.7	10.9
	July	28.7	10.8	19.6	53.3	4.0	8.1
	August	28.6	10.2	19.4	48.2	3.8	6.4
	September[$]	24.2	7.2	15.6	57.6	3.1	5.5

[#] Calculated from the data between 16-31 May; [&] Calculated from the data between 1-8 September.
[£] Calculated from the data between 20-31 May; [$] Calculated from the data between 1-6 September.

were placed between the crop rows in the experimental plots. There were 6 driplines in each plot. Irrigation was controlled manually using valves on manifolds and plots were irrigated for calculated irrigation times. Irrigation quantity applied to each plot was recorded and used for the calculation of monthly and seasonal irrigation amounts.

The experimental site was a randomized complete block design with two irrigation techniques [full root-zone wetting (FI) and partial root-zone drying (PRD)], two different irrigation intervals (I1: 4-day and I2: 8-day), three levels of irrigation amount (W1, W2 and W3) adjusted using three different plant-pan coefficients (1.15, 1.00 and 0.85) from Class-A pan evaporation and three replicates. There were a total of 36 plots with 12 different treatments (FI-I1W1, FI-I1W2, FI-I1W3, FI-I2W1, FI-I2W2, FI-I2W3, PRD-I1W1, PRD-I1W2, PRD-I1W3, PRD-I2W1, PRD-I2W2 and PRD-I2W3) in this study.

To calculate irrigation quantity, the pan evapotranspiration equation provided below was used as suggested by Ertek (2011).

$$W = E_{pan} \times K_{cp} \times P$$

where W is the amount of applied irrigation water (mm), E_{pan} is the evaporation amount for considering irrigation intervals (mm), K_{cp} is the plant-pan coefficient, and P is the wetting factor. Evaporation values were measured from a Class-A pan installed in the experimental area. Plant-pan coefficients were selected according to results of a study conducted by Kiziloglu *et al.* (2009). The wetting factor was calculated using following equation (Ertek, 2011).

$$P = (W_p / W_b)$$

where W_p is the plant cover width (m), and W_b is the plant row spacing (m).

The irrigation treatments were started on July 2, 2010 (48 days after planting) and July 7, 2011 (49 days after planting). Fixed water depths (42 mm in 2010 and 51 mm in 2011) were applied to all plots during the first irrigation of the trial years. Subsequent irrigations were provided periodically with 4-day and 8-day intervals till the end of irrigation period. Irrigation treatments were completed on September 4, 2010 and September 1, 2011. In all irrigations except for the first irrigation of both years, 50% of the irrigation water treated to the FI plots was alternately applied to the PRD plots. Thus, only half of the rooting zone was wetted in each irrigation of the PRD plots. No runoff was observed during the irrigations. Also, there was no capillary rise from the water table to the plant rooting depth because of the deep water table level (> 20 m) at the experimental site.

Twenty plants were randomly chosen from 6 m sections of three center rows in each plot and were hand-harvested on September 8, 2010 and September 6, 2011. The heights of plants, which were cut at ground level, were measured. Stem diameters were measured at the base of stem above the soil surface. Leaves and cobs were separated from the stems and weighed separately. Sub-samples collected from harvested crops to determine dry matter amounts were weighed after drying at 68°C in an oven for 48 h. Dry matter percentages were used for the calculation of above ground dry matter yields.

Also, samples oven-dried at 68°C were ground to pass through a 1 mm screen to determine acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP) and minerals. ADF and NDF contents were measured by ANKOM fiber analyzer (ANKOM Technology, Fairport, NY) using the procedure suggested by Van Soest *et al.* (1991). The Nitrogen concentration was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982). Thus, CP content was obtained by multiplying total nitrogen (%) by 6.25. Plant mineral contents (Al, B, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S and Zn) were analyzed after wet digestion using a HNO_3-H_2O_2 acid mixture (2:3 v/v) with three different steps (1st step: 145°C, 75% RF, 5 min; 2nd step: 180°C, 90% RF, 10 min and 3rd step: 100°C, 40% RF, 10 min) in a microwave unit (Speedwave MWS-2 Berghof products + Instruments Harresstr.1. 72800 Enien Gernmany) (Mertens, 2005a). Mineral contents were measured by ICP OES spectrophotometer (Inductively Couple Plasma spectrophotometer, Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) (Mertens, 2005b).

The IWUE was calculated by dividing economic yield (kg ha^{-1}) by the amount of seasonal irrigation water (mm) (Howell, 2001). Total fresh yields and dry matter yields of silage maize instead of economic yield were used to determine $IWUE_{fresh}$ and $IWUE_{dry}$ in this study.

The analysis of variance (ANOVA) using MINITAB software was conducted to evaluate the effects of treatments on observed parameters. Significant means were compared and ranked at $P < 0.05$ level with Duncan's multiple range test using MSTATC software. Regression analysis was performed to determine relationships between some parameters and water quantity.

RESULTS AND DISCUSSION

***Evaporation, precipitation and irrigation water amount*:** Figure 1 shows monthly total evaporation and precipitation values measured at the experimental site throughout the growing periods of 2010 (16 May-8 September) and 2011 (20 May-6 September). Seasonal evaporation values in the growing period of 2010 and 2011 were 781.7 mm and 741.5 mm, respectively. The total evaporation value obtained from Class-A pan was 486.8 mm in the irrigation period of 2010 (2 July-4 September in 2010) and 450.0 mm in the irrigation period of 2011 (7 July-1 September in 2011). The August evaporation value was the highest for both years. Precipitation values were very low compared to evaporation values in trial years (Fig. 1). Seasonal precipitation values measured in growing periods of 2010 and 2011 were 144.3 mm and 163.2 mm, respectively. Total precipitation during the irrigation period was 71.8 mm in 2010 and 31 mm in 2011. Thus, net evaporation (total evaporation minus precipitation) from Class-A pan was 415 mm and 419 mm in irrigation period of 2010 and 2011, respectively.

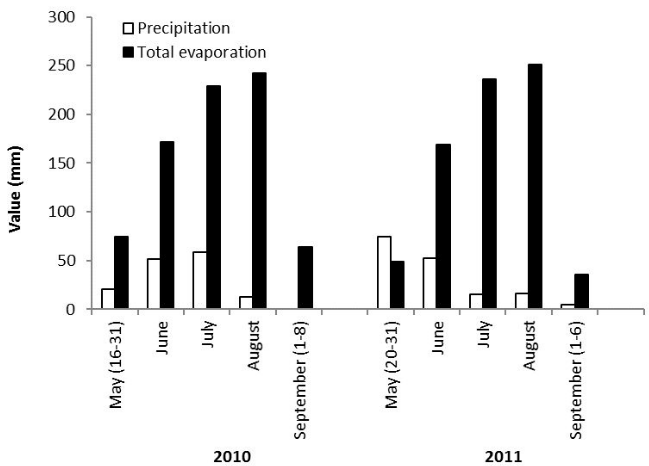


Figure 1. Monthly total evaporation and precipitation values in 2010 and 2011 growing periods of silage maize.

Irrigation water requirement of silage maize was high due to high evaporation and low precipitation values during irrigation periods of 2010 and 2011. In the first irrigation, soil water contents in 0-90 cm soil depth of all plots were increased up to field capacity by applying water amounts of 42 mm in 2010 and of 51 mm in 2011 and then scheduled irrigations with 4 and 8-day intervals were continued. Monthly and seasonal irrigation amounts applied to treatments are given in Table 2. Plots were irrigated 17 times in 2010 and 15 times in 2011 at irrigation interval of 4-days. The irrigation number for the irrigation interval of 8-days was 9 and 8 in 2010 and 2011, respectively. Although the irrigation number in 2010 was higher than in 2011, applied water amounts were close to each other in trial years due to similar net evaporation values. The seasonally applied water amount was 209.5 mm for PRD treatments and 372.5 mm for FI treatments according to average data over two years. The amount of irrigation water applied for PRD plots was 43.8% lower than of FI plots. Total irrigation water amounts applied to plots at 4 and 8 day irrigation intervals were 289.0 mm and 293.0 mm, respectively. Among irrigation levels, the highest amount of irrigation water was treated as 327.7 mm at the W1 irrigation level, adjusted according to the highest plant-pan coefficient (1.15Kcp). The water amounts treated at the W2 and W3 irrigation levels were 11.2% and 22.4% lower than at the W1 irrigation level.

Considering all treatments, the PRD-I1W3 treatment was irrigated with the lowest water amount of 183.9 mm, while the FI-I2W1 treatment was irrigated with the highest water amount of 424.5 mm on an average over trial years (Table 2). The ratio of seasonal applied irrigation water to net evaporation measured in Class-A pan during irrigation period was 44.1% at the PRD-I1W3 and 101.8% at the FI-

Table 2. Monthly and seasonal irrigation water amounts (mm) applied to treatments in 2010 and 2011 irrigation periods of silage maize.

Treatments	2010				2011			
	July	August	September	Total	July	August	September	Total
FI-I1W1	144.8	242.3	33.4	420.5	146.1	226.3	43.7	416.1
FI-I1W2	131.3	210.7	29.0	371.0	133.7	196.8	38.0	368.5
FI-I1W3	118.0	179.1	24.7	321.8	121.3	167.3	32.3	320.9
Irrigation number	8	8	1	17	6	8	1	15
FI-I2W1	116.5	243.5	64.4	424.4	126.9	220.6	77.1	424.6
FI-I2W2	106.8	211.7	56.0	374.5	117.0	191.8	67.0	375.8
FI-I2W3	97.1	179.9	47.6	324.6	107.1	163.0	57.0	327.1
Irrigation number	4	4	1	9	3	4	1	8
Mean	119.1	211.2	42.5	372.8	125.4	194.3	52.5	372.2
PRD-I1W1	93.3	121.2	16.7	231.2	98.6	113.2	21.9	233.7
PRD-I1W2	86.7	105.4	14.5	206.6	92.4	98.4	19.0	209.8
PRD-I1W3	80.0	89.5	12.3	181.8	86.1	83.6	16.2	185.9
Irrigation number	8	8	1	17	6	8	1	15
PRD-I2W1	79.3	121.7	32.2	233.2	89.0	110.3	38.5	237.8
PRD-I2W2	74.4	105.9	28.0	208.3	84.0	95.9	33.5	213.4
PRD-I2W3	69.5	90.0	23.8	183.3	79.1	81.5	28.5	189.1
Irrigation number	4	4	1	9	3	4	1	8
Mean	80.5	105.6	21.3	207.4	88.2	97.2	26.3	211.6

FI: Full root-zone wetting; PRD: Partial root-zone drying; I1: 4-day; I2: 8-day; W1: 115% of Class-A pan evaporation; W2: 100% of Class-A pan evaporation; W3: 85% of Class-A pan evaporation

I2W1 treatment.

Total irrigation water amounts treated in this study were lower than results of studies conducted by other researchers under semiarid conditions. For example, Kiziloglu *et al.* (2009) applied mean irrigation water of 468 mm for full-irrigated silage maize by hose-drawn traveler with a line of sprinklers. Çakir (2004) reported that the seasonal irrigation water amount for full-irrigated corn by furrow method varied by year from 390 mm to 575 mm. Yazar *et al.* (2002) reported total irrigation water amount of 581 mm for full-irrigated corn by drip method. Simsek *et al.* (2011) treated irrigation water of 1211 mm for full-irrigated silage corn by drip method. Similar results were observed also under Mediterranean climatic conditions where summers are hot and dry, and winters are mild and rainy. Yazar *et al.* (2009) provided seasonal irrigation water of 644 mm in full irrigation and 396 mm in partial root-zone irrigation for drip-irrigated corn under Mediterranean climatic conditions. Dagdelen *et al.* (2009) reported mean irrigation water of 617 mm for full-irrigated silage maize by drip method. Bozkurt *et al.* (2006) applied irrigation water of 550-756 mm for full-irrigated maize by drip method under the Mediterranean climatic conditions. On the contrary, Bozkurt *et al.* (2011) applied the least irrigation water, 316 mm, for corn irrigated with 100% of total Class-A pan evaporation by drip method. At same time, irrigation water of 316 mm was lower than irrigation water applied to the FI treatments in this study. Different climatic conditions of the regions studied is one of the main reason of variations in water applications.

***Yield and growth parameters*:** Plant height, stem diameter and leaf number as growth parameters and leaf, cob, stem, total fresh and dry matter yields as yield parameters were observed and recorded. Table 3 shows data for yield and growth parameters in trial years. Generally, values from 2010 for all yield and growth parameters, except for leaf number, were higher than values from 2011. Although there was a higher leaf number in 2011, leaf yields in 2011 were lower than of 2010 due to smaller leaves. Kenter *et al.* (2006) reported that weather is one of the factors affecting growth of agricultural crops. So, higher values in 2010 could be attributed to weather conditions since the mean temperature and daily sunshine values in the irrigation period of 2010 were higher than values in the irrigation period of 2011 (Table 1).

Mean values for all growth and yield parameters in the FI treatments were higher than the values in the PRD treatments (Table 3). However, stem diameter, leaf number and dry matter yield values in the FI treatments were statistically similar to the values from the PRD treatments for both years. Insignificant differences between the FI and

Table 3. Plant heights, stem diameters, leaf number and yields of silage maize for different irrigation treatments in 2010 and 2011.

Irrigation techniques	Irrigation intervals	Irrigation levels	Plant height (cm)		Stem dia. (mm)		Leaf number (per plant)		Yields ($Mg\ ha^{-1}$) leaf		Cob		Stem		Total fresh		Dry matter	
			2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
FI	I1	W1	203.2	185.0	19.6	17.3	13.0	13.4	16.1	7.71	18.1	12.6	19.1	15.2	53.3	35.5	13.0	9.60a*
	I1	W2	201.2	185.0	18.1	19.1	12.7	13.3	11.7	7.42	15.5	16.7	16.4	15.6	43.6	39.7	9.77	10.2a
	I1	W3	185.5	161.5	18.2	15.6	12.1	12.6	12.0	5.78	14.0	9.06	16.4	10.8	42.4	25.6	7.33	5.97b
		P value	0.199	0.353	0.489	0.062	0.067	0.262	0.058	0.181	0.095	0.075	0.403	0.198	0.051	0.104	0.093	0.010
	I2	W1	199.3	190.6	19.6	17.7	13.1	13.7a	15.9	8.92	17.6	21.0a	19.0	14.8	52.5a	44.7	11.1	11.6
	I2	W2	187.5	178.5	18.8	17.6	12.8	12.4b	13.9	7.27	16.7	15.2b	17.3	14.7	47.9b	37.1	10.3	10.0
	I2	W3	182.5	166.4	17.4	16.6	12.6	12.9b	12.9	6.59	14.6	10.4c	14.9	11.8	42.5c	28.8	10.2	8.00
		P value	0.167	0.098	0.264	0.765	0.521	0.043	0.291	0.301	0.107	0.014	0.281	0.491	0.043	0.107	0.955	0.225
PRD	I1	W1	194.7	175.0	18.6	16.5	13.5	13.2	12.4	7.88	14.5a	12.4b	17.1a	12.0	44.0a	32.3b	11.2a	8.87
	I1	W2	178.9	172.8	17.3	16.8	12.2	12.7	10.6	8.24	13.1a	20.1a	14.0b	12.7	37.7b	41.0a	11.8a	11.7
	I1	W3	162.9	150.3	15.0	15.4	12.6	12.7	7.66	5.28	9.48b	7.95b	11.3c	9.01	28.4c	22.2c	5.30b	6.83
		P value	0.111	0.279	0.091	0.461	0.053	0.431	0.111	0.097	0.025	0.005	0.034	0.149	0.017	0.019	0.026	0.073
	I2	W1	195.9a	177.6a	18.3	18.4	12.9	13.4a	11.9	7.62	17.4a	12.7	17.2	14.1a	46.5a	34.4	10.9a	9.60
	I2	W2	189.8a	166.3a	16.6	17.3	12.6	13.1a	11.3	6.27	12.6b	11.8	16.0	12.0b	39.9b	30.0	9.40a	10.6
	I2	W3	163.4b	144.1b	18.2	16.5	12.3	12.3b	7.33	5.64	9.53c	8.71	12.3	9.45c	29.2c	23.8	6.57b	8.47
		P value	0.048	0.041	0.738	0.185	0.673	0.047	0.090	0.294	0.000	0.738	0.303	0.036	0.000	0.362	0.029	0.746
Average for irrigation techniques		FI	193.2	177.9	18.6	17.3	12.7	13.0	13.8	7.28	16.1	14.2	17.2	13.8	47.0	35.2	10.3	9.24
		PRD	180.9	164.4	17.3	16.8	12.7	12.9	10.2	6.82	12.8	12.3	14.7	11.5	37.6	30.6	9.19	9.34
		P value	0.005	0.010	0.052	0.312	0.879	0.420	0.000	0.337	0.000	0.228	0.007	0.008	0.000	0.065	0.233	0.888
Average for irrigation intervals		I1	187.7	171.6	17.8	16.8	12.7	13.0	11.7	7.05	14.1	13.1	15.7	12.5	41.6	32.7	9.72	8.87
		I2	186.4	170.6	18.2	17.4	12.7	13.0	12.2	7.05	14.7	13.3	16.1	12.8	43.1	33.1	9.76	9.72
	P value		0.746	0.839	0.554	0.252	0.879	0.852	0.505	1.000	0.257	0.927	0.646	0.737	0.261	0.865	0.971	0.262
Average for irrigation levels		W1	198.3a	182.1a	19.0	17.5a	13.1a	13.4a	14.1a	8.03a	16.9a	14.7a	18.1a	14.0a	49.1a	36.7a	11.6a	9.93a
		W2	189.3a	175.7a	17.7	17.7a	12.6b	12.9b	11.9b	7.30a	14.5b	15.9a	15.9b	13.7a	42.3b	37.0a	10.3a	10.6a
		W3	173.6b	155.6b	17.2	16.0b	12.4b	12.6b	9.98c	5.82b	11.9c	9.03b	13.7c	10.3b	35.6c	25.1b	7.36b	7.32b
		P value	0.000	0.000	0.065	0.017	0.009	0.002	0.000	0.002	0.000	0.002	0.001	0.001	0.000	0.000	0.002	0.002

* There is no statistically significant difference between values marked with same small letter. Different letters indicate important differences at P = 0.01 or 0.05 level.

FI: Full root-zone wetting; PRD: Partial root-zone drying; I1: 4-day; I2: 8-day; W1: 115% of Class-A pan evaporation; W2: 100% of Class-A pan evaporation; W3: 85% of Class-A pan evaporation

PRD treatments were also observed for leaf yield, cob yield and total fresh yield values in 2011 only. However, the significant increase or decrease for cob yield in 2011 compared to 2010 were observed under FI and PRD irrigation treatments (Table 3). It could be said that significant changes in cob yield is due to number of cobs. From looking at the averaged data over two seasons, while leaf number in the PRD treatments was 0.4% lower than in the FI treatments, leaf yield in the PRD treatments was 19.3% lower than in the FI treatments. It could be said that the PRD treatments produced smaller leaves compared to the FI treatments. Schachtman and Goodger (2008) reported that leaf growth decreases due to certain chemical signals that are transported from roots to leaves under drought-like conditions. Also, Bahrun *et al.* (2002) observed a reduction in leaf growth in field-grown maize due to this chemical signaling in soil-drying conditions. Lower stem yields in the PRD treatments were obtained due to both short plant heights and small stem diameters compared to the FI treatments (Table 3). Also mean cob yield (12.6 Mg ha^{-1}) in the PRD treatments was 17.2% lower than in the FI treatments. Thus, shorter plant heights, smaller leaves, smaller stem diameters and less cob yields provided lower fresh and dry matter yields in the PRD treatments compared to the FI treatments. Similarly, Yazar *et al.* (2009) determined that grain yield and above ground dry matter yield of corn in the full irrigation treatments was significantly higher than in the PRD treatments. Montgomery (2009) reported that plants with smaller leaf area result in a loss of dry matter yield.

Dry matter yield as a percentage of total fresh yield in the FI treatments was lower than in the PRD treatments due to plants in FI treatments having higher water content compared to PRD treatments. Comparing the mean values of trial years indicated that dry matter yield made up 23.8% of total fresh yield in the FI treatments while dry matter yield made up 27.2% of total fresh yield in the PRD treatments. So, it could be said that PRD treatments provided a higher quality yield due to the high percentage of dry matter.

There was non-significant effect of irrigation intervals on yield and growth parameters (Table 3). However, higher values for all yield and growth parameters, except for plant height and leaf number, were obtained from the 8-day irrigation interval.

Irrigation levels had a statistically significant effect on the yield and growth parameters of silage maize. The treatments with the highest amount of water applied had the highest yield and growth parameters (Table 3). Among growth parameters, plant height increased more with increasing irrigation quantity compared to stem diameters and leaf number. According to the averaged data over the two years, plant height, stem diameter and leaf number in the W1 treatment was 15.6%, 9.9% and 6.0% higher than the same respective values in the W3 treatment. However, the increases in ratios of yield parameters coinciding with increasing irrigation quantity were greater than growth parameters. From the averaged values of the trial years, total fresh yield (42.9 Mg ha^{-1}) and dry matter yield (10.8 Mg ha^{-1}) values in the W1 treatment were 41.1% and 47.1% higher than those in the W3 treatment, respectively. According to results of previous studies, yield and growth of maize is directly related to the available water in soil. Simsek *et al.* (2011) reported that total fresh yield and dry matter yield of silage maize significantly decreased with water stress. Hirich *et al.* (2012) reported that fully irrigated treatments provided the highest sweet corn height and that there was a good correlation between plant height and stem diameter. Gheysari *et al.* (2009) indicated that plant height and total above ground biomass of silage maize decreased with water deficiency. Yet, there was no significant effect of irrigation level on stem diameter. Çakir (2004) found that the highest yields for corn were observed in the fully irrigated treatment and that water stress reduced plant height. Bozkurt *et al.* (2011) determined that irrigation levels had significant effect on fresh and dry above ground biomass yield, stem diameter and plant height of corn. Higher values were obtained from fully or excessively-irrigated plots. Celebi *et al.* (2010) indicated that the effect of different irrigation regimes on plant height, fresh and dry matter yield was significant and that the highest values were measured at the highest irrigation level.

Among all treatments, the FI-I2W1 treatment and among only the PRD treatments, the PRD-I2W1 treatment had the highest total fresh yield according to the averaged values from the trial years (Table 3). Dry matter yield was the highest in the PRD-I1W2 treatment. Total fresh and dry matter yields in the PRD-I2W1 treatment were 16.7 and 9.7% lower than the yields from the FI-I2W1 treatment, respectively. The highest percentage of total fresh yield was cob yield at 39.7% in the FI-I2W1 treatment, while the highest percentage of total fresh yield was stem yield at 38.7% in the PRD-I2W1 treatment. The lowest percentage of total fresh yield was leaf yield and it was 25.5% in the FI-I2W1 treatment and 24.1% in the PRD-I2W1 treatment. Celebi *et al.* (2010) found that the leaf percentage of total fresh yield in the best irrigated silage maize by flood method was the lowest (15.6%) compared to stem (46.9%) and cob (37.5%) percentages. The leaf, stem and cob percentages of total fresh yield in silage maize that was fully-irrigated by the hose-drawn traveler with a line of sprinklers under Erzurum, Turkey conditions were 14.6%, 60.0%, and 25.4%, respectively (Kiziloglu *et al.,* 2009).

Statistically important second degree polynomial (quadratic) relationships were obtained between seasonal irrigation water amounts and total fresh yields or dry matter yields of silage maize for both the FI and PRD treatments (Fig. 2).

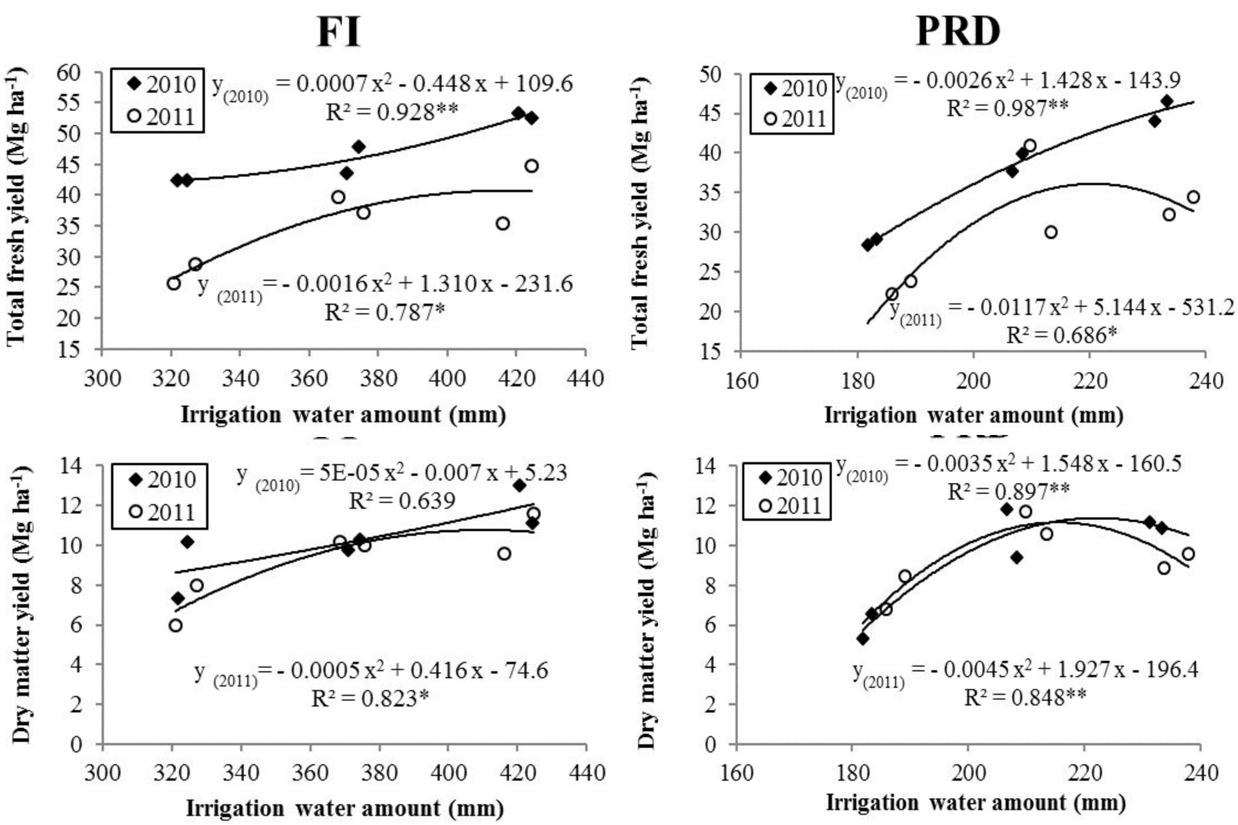


Figure 2. Relationships between seasonal irrigation water amount and total fresh or dry matter yield of silage maize in 2010 and 2011 (FI: Full root-zone wetting; PRD: Partial root-zone drying).

The strong correlation between amount of irrigation water and yield indicated that irrigation quantities are needed for maximizing production. However, more water applications will decrease benefits of irrigation on production. There were also significant second degree polynomial relationships between seasonal irrigation water amounts and plant growth parameters (Fig. 3). Linear or second degree polynomial relationships between yield and water use on the maize plant were also reported in other studies. Salemi *et al.* (2011) presented a second degree polynomial crop water production function for silage maize. Bozkurt *et al.* (2006), Gençoglan and Yazar (1999) and Payero *et al.* (2008) determined a significant second degree polynomial relationship between grain yield and irrigation water amount. Ko *et al.* (2009) reported that grain yield of maize in response to water input showed a threshold-like curve. On the contrary, linear relationships were found between grain yield and irrigation water amount by Farré and Faci (2006), Payero *et al*. (2006), Yazar *et al.* (2009) and Yenesew and Tilahun (2009). Similarly, Simsek *et al.* (2011) obtained a positive linear relationship between fresh silage yield and seasonal irrigation water amount.

***Yield quality parameters*:** Acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP) and mineral contents of plants were considered quality parameters in silage maize.

ADF, NDF and CP were not affected by irrigation techniques, levels and intervals. Although we did not observe substantial differences for ADF, NDF and CP at different irrigation levels, some researchers obtained significant results for these parameters. Results of a study conducted by Shahrabian and Soleymani (2011) showed that CP, NDF and ADF of silage maize were significantly increased by water stress. Montgomery (2009) determined that irrigation levels did not affect the percentage of CP in corn forage samples while ADF and NDF values during drought stress (50% of evapotranspiration) were statistically higher than during full irrigation (100% of evapotranspiration). On the contrary, Simsek *et al.* (2011) determined that CP, ADF and NDF values in silage maize decreased with water deficiency and the decrease in ADF and NDF values was significant.

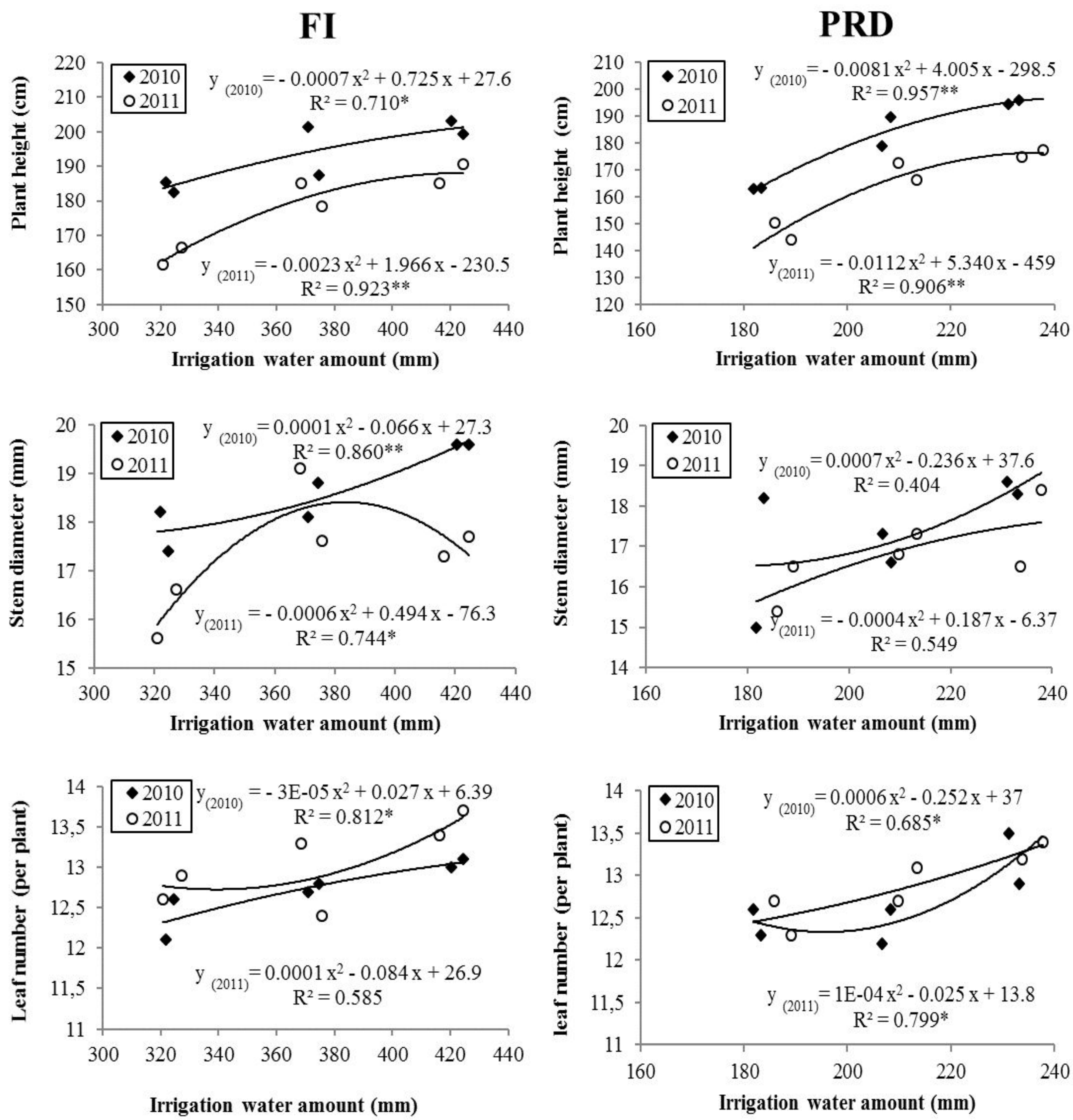
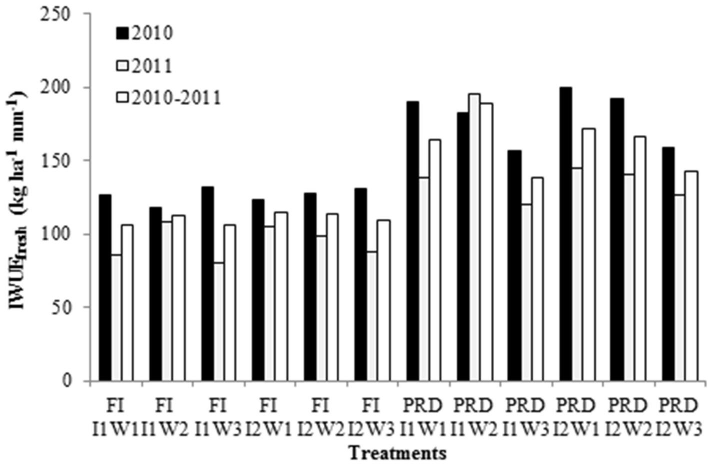


Figure 3. Relationships between seasonal irrigation water amount and plant growth parameters of silage maize in 2010 and 2011 (FI: Full root-zone wetting; PRD: Partial root-zone drying).

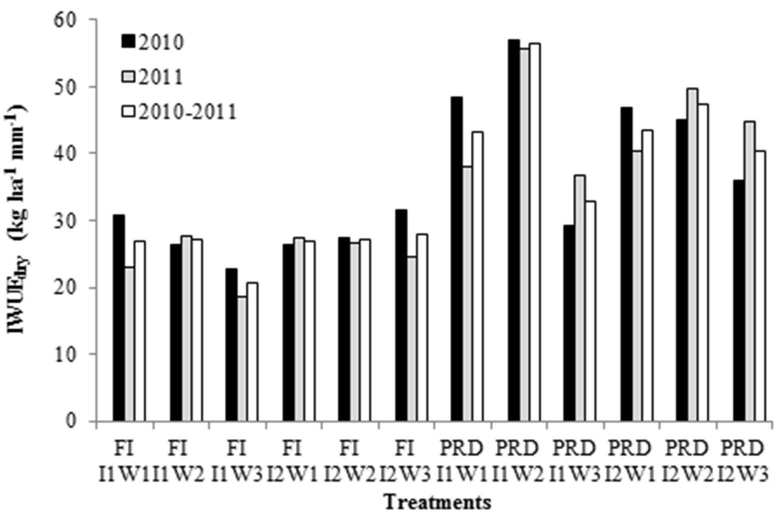
Plant mineral (Al, B, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S and Zn) contents were measured only in 2011 and most values did not vary significantly with different irrigation techniques, irrigation intervals or irrigation levels. But, Oktem (2008) determined that Fe, Zn and Cu concentrations in sweet corn kernel decreased significantly with increasing water shortage. Similarly, Bahrun *et al.* (2002) reported that in drought conditions, limited nutrient availability may be observed in plants and nutrient uptake into the roots may decrease.

***Irrigation water use efficiency (IWUE)*:** As shown in Figure 4 and 5, $IWUE_{fresh}$ values in 2010 were higher than values in 2011 due to fresh yields being higher in 2010 (Table 3). All the PRD treatments had higher $IWUE_{fresh}$ and $IWUE_{dry}$ values compared to all the FI treatments for both years (Fig. 4 & 5). From the averaged values over two years, $IWUE_{fresh}$ (162.0 kg ha^{-1} mm^{-1}) and $IWUE_{dry}$ (43.96 kg ha^{-1}



	2010	2011
FI	126.4	94.12
PRD	179.9	144.1
P value	*0.000*	*0.000*
I1	150.9	121.0
I2	155.4	117.2
P value	*0.419*	*0.684*
W1	160.0	118.3ab
W2	154.9	135.7a
W3	144.5	103.3b
P value	*0.085*	*0.027*

Figure 4. $IWUE_{fresh}$ values of irrigation treatments in 2010 and 2011 (FI: Full root-zone wetting; PRD: Partial root-zone drying; I1: 4-day; I2: 8-day; W1: 115% of Class-A pan evaporation; W2: 100% of Class-A pan evaporation; W3: 85% of Class-A pan evaporation).



	2010	2011
FI	27.54	24.65
PRD	43.71	44.21
P value	*0.000*	*0.000*
I1	35.75	33.32
I2	35.49	35.55
P value	*0.937*	*0.495*
W1	38.06	32.20
W2	38.98	39.96
W3	29.82	31.15
P value	*0.055*	*0.067*

Figure 5. $IWUE_{dry}$ values of irrigation treatments in 2010 and 2011 (FI: Full root-zone wetting; PRD: Partial root-zone drying; I1: 4-day; I2: 8-day; W1: 115% of Class-A pan evaporation; W2: 100% of Class-A pan evaporation; W3: 85% of Class-A pan evaporation).

mm^{-1}) values in the PRD treatments were 46.9% and 68.4% higher than in the FI treatments, respectively. Dry matter yield values in the PRD and FI treatments were similar to each other (Table 3). Therefore, the PRD treatments that applied less water compared to the FI treatments resulted in a higher percentage increase in IWUEdry values. Practical results showed that higher IWUE values were obtained with the PRD treatments. Kang *et al.* (1998) observed higher WUE values in a controlled alternate irrigation treatment for pot-grown maize when compared to the well irrigated treatment. Kang *et al.* (2000) determined that IWUE of maize in alternately furrow irrigation was higher than in fixed and conventional furrow irrigation for different irrigation amounts. The alternate watering method was compared to bottom watering and surface watering methods in pot grown maize by Kang *et al.* (2002) and they obtained significant increases in the WUE. Wang *et al*. (2008) obtained the highest IWUE value in pot grown maize using alternate partial root-zone irrigation treatment compared to conventional irrigation and fixed partial root-zone irrigation treatments at three irrigation levels (well-watered, mild and severe water deficit). Also, Yazar *et al.* (2009) determined that the IWUE value in the PRD treatment which had 50% of cumulative evaporation from the Class-A pan was higher than value of full irrigation treatment for drip-irrigated corn.

$IWUE_{fresh}$ and $IWUE_{dry}$ values of silage maize were similar for different irrigation intervals (Fig. 4 and 5). According to the averaged values over two years, $IWUE_{fresh}$ and $IWUE_{dry}$ values in the 4-day irrigation interval were 136.0 kg ha^{-1} mm^{-1} and 34.54 kg ha^{-1} mm^{-1}, respectively. These values were 136.3 kg ha^{-1} mm^{-1} and 35.52 kg ha^{-1} mm^{-1} in the 8-day irrigation interval, respectively. Instead, irrigation levels had more effect on $IWUE_{fresh}$ and $IWUE_{dry}$. The highest $IWUE_{fresh}$ and $IWUE_{dry}$ values were obtained at the W2 irrigation level. The W3 irrigation level provided the lowest values. Simsek *et al.* (2011) obtained lower IWUE values for silage maize under lower irrigation conditions. Farre and Faci (2006) reported that IWUE in maize decreased markedly with decreasing water amount. Yet, some studies showed that higher IWUE values in maize were obtained with lower water treatment conditions. Dagdelen *et al.* (2009) reported that the IWUE value for silage maize was the highest under the lowest irrigation conditions. Similarly, Bozkurt *et al.* (2011), Gençoglan and Yazar (1999), Kang *et al.* (2000), Payero *et al.* (2008), Yazar *et al.* (2002) all obtained higher IWUE values for corn under lower water treatment conditions.

The averaged data of 2010 and 2011 indicated that the PRD-I1W2 treatment had the highest $IWUE_{fresh}$ and $IWUE_{dry}$ values (Fig. 4 & 5). Among the FI treatments only, the highest $IWUE_{fresh}$ and $IWUE_{dry}$ values were obtained with the FI-I2W1 treatment and the FI-I2W3 treatment. From comparing the best PRD and FI treatments to each other in terms of $IWUE_{fresh}$ and $IWUE_{dry}$, values in the PRD treatments were 65.2% and 101.4% higher than in the FI treatments, respectively. So, it could be said that the PRD technique provided higher fresh and dry yields using the same amount of water compared to the FI technique.

In general, the $IWUE_{fresh}$ and $IWUE_{dry}$ values increased with increasing irrigation water amount up to the W2 irrigation level, and thereafter any additional amount of irrigation water did not provide an increase in $IWUE_{fresh}$ or $IWUE_{dry}$. Thus, second degree polynomial relationships between $IWUE_{fresh}$ with irrigation water amount and $IWUE_{dry}$ with irrigation water amount were found both years (Fig. 6). These relationships were more pronounced in the PRD applications. At the same time, there was a similar polynomial relationship between irrigation water amount and fresh or dry matter yields (Fig. 2). Ko and Piccinni

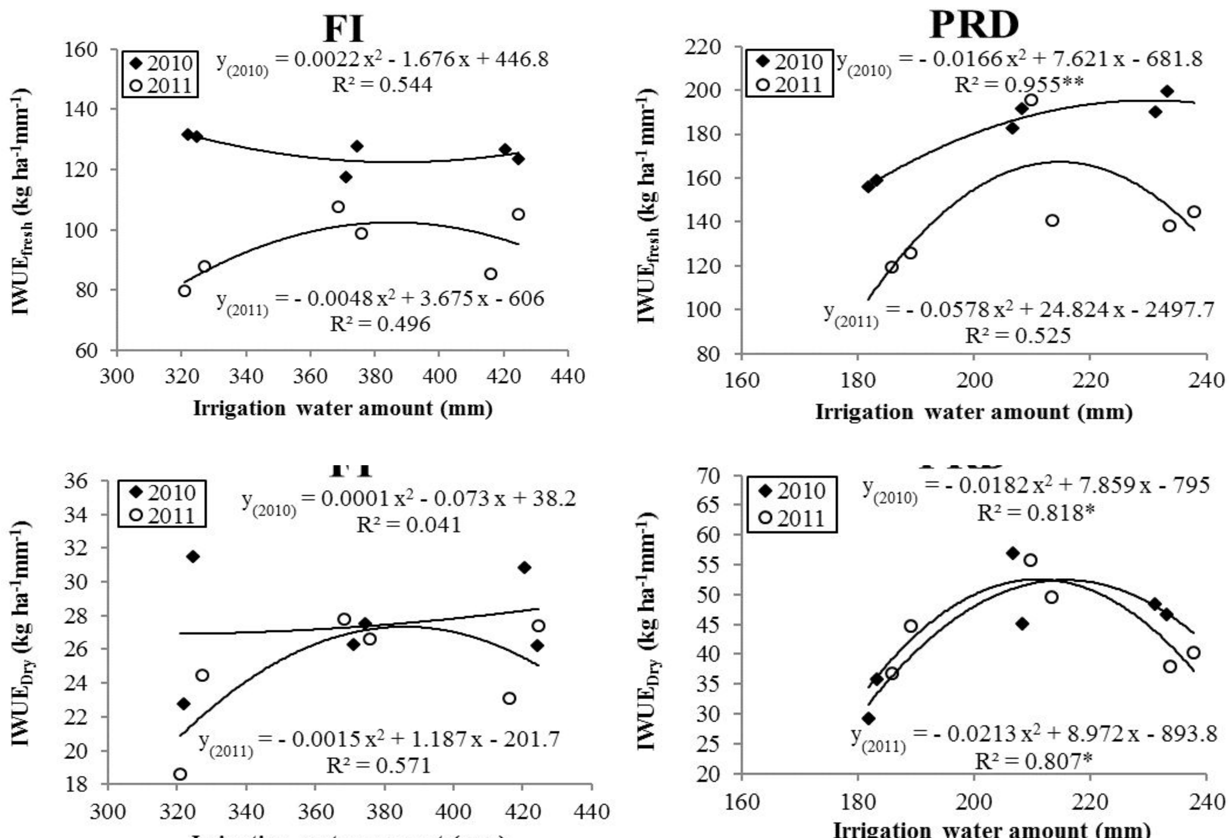


Figure 6. Relationships between seasonal irrigation water amount and $IWUE_{fresh}$ or $IWUE_{dry}$ in 2010 and 2011 (FI: Full root-zone wetting; PRD: Partial root-zone drying).

(2009) showed WUE related to water input through a parabolic curve; WUE increased to a point and then decreased thereafter. Payero *et al*. (2008) determined a second degree polynomial relationship between IWUE and irrigation water amount for corn but, they reported that IWUE remarkably decreased with increasing irrigation water.

***Conclusion*:** In this study, silage maize plants were irrigated by partial root-zone drying (PRD) and full (FI) irrigation techniques by applying different irrigation amounts (115%, 100% and 85% of Class-A pan evaporation) at two irrigation intervals (4-day and 8-day). The findings of two years of research indicated that yield and vegetative growth of silage maize were significantly affected by the PRD treatments. Shorter plants, smaller leaves, thinner stems and lower cob yields in the PRD treatments provided lower fresh yields compared to the FI treatments. Although there was no significant effects of irrigation intervals on yield and growth parameters, irrigation levels had a statistically significant effect on these parameters. Generally, the highest yield and growth parameters were obtained from the highest water applied treatments. Irrigation techniques, intervals and levels had no significant effect on plant mineral (Al, B, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S and Zn) contents, acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude protein (CP) contents.

The management of water resources with is vital to reach optimal crop production. If water is insufficient for maximum crop production, higher water productivity will be prefer. Otherwise higher yield will be desirable. Therefore, it could be concluded that the PRD treatment with 100% of Class-A pan evaporation at the 4-day irrigation interval is the more desirable treatment due to higher maize dry matter yield and higher water productivity under water shortage conditions. If water is sufficient for irrigation during the growing period of silage maize, the FI treatment with 115% of Class-A pan evaporation at the 8-day irrigation interval is the more desirable treatment due to higher maize fresh yield.

REFERENCES

Abubaker, B.M.A., Y.S. En, S.G. Cheng, S.N. Panda and M. Alhadi. 2014. Impact of different water harvesting techniques on soil moisture content and yield components of sorghum. Pak. J. Agri. Sci. 51:779-88.

Amin, M., R. Ahmad, S.M.A. Basra and G. Murtaza. 2014. Silicon induced improvement in morpho-physiological traits of maize (*Zea mays* L.) under water deficit. Pak. J. Agri. Sci. 51:187-196.

Bahrun, A., C.R. Jensen, F. Asch and V.O. Mogensen. 2002. Drought-induced changes in xylem pH ionic composition and ABA concentration act as early signals in field-grown maize (*Zea mays* L.). J. Exp. Bot. 53: 251-263.

Bozkurt, S., A. Yazar and G.S. Mansuroglu. 2011. Effects of different drip irrigation levels on yield and some agronomic characteristics of raised bed planted corn. Afr. J. Agric. Res. 6: 5291-5300.

Bozkurt, Y., A. Yazar, B. Gencel and M.S. Sezen. 2006. Optimum lateral spacing for drip-irrigated corn in the Mediterranean Region of Turkey. Agr. Water Manage. 85:113–12.

Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen-total. pp. 595-622. In: A.L. Page, R.H. Miller and D.R. Keeney (eds.), Methods of Soil Analysis: Chemical and Microbiological Properties, Part II 2nd Ed. ASA- SSSA Agronomy No: 9 Madison, WI.

Cakir, R. 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crop. Res. 89: 1-16.

Celebi, S.Z., S. Demir, R. Celebi, E.D. Durak and I.H. Yilmaz. 2010. The effect of arbuscular mycorrhizal fungi (AMF) applications on the silage maize (*Zea mays* L.) yield in different irrigation regimes. Eur. J. Soil. Biol. 46: 302-305.

Dagdelen, N., H. Akçay, F. Sezgin, A. Unay and T. Gurbuz. 2009. Determination of water production functions of silage maize under different irrigation regimes. J. Adnan Menderes Univ. Agr. Fac. 7: 55-64.

Ertek, A. 2011. Importance of pan evaporation for irrigation scheduling and proper use of crop-pan coefficient (*K*cp) crop coefficient (*K*c) and pan coefficient (*K*p). Afr. J. Agric. Res. 6: 6706-6718.

Eskandari, H. 2012. Yield and quality of forage produced in intercropping of maize (*Zea mays*) with cowpea (*Vigna sinensis*) and *mungbean* (*Vigna radiata*) as double cropped. J. Basic Appl. Sci. Res. 2: 93-97.

FAO. 2002. World Agriculture: Towards 2015/2030. Summary Report, FAO, Rome.

Farre, I. and J.M. Faci. 2006. Comparative response of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L Moench) to deficit irrigation in a Mediterranean environment. Agr. Water Manage. 83: 135-143.

Geerts, S. and D. Raes. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agr. Water Manage. 96: 1275–1284.

Gençoglan, C. and A. Yazar. 1999. The effects of deficit irrigations on corn yield and water use efficiency. Turk. J. Agric. For. 23: 233–241.

Gerbens-Leenes, P.W. and S. Nonhebel. 2004. Critical water requirements for food methodology and policy consequences for food security. Food Pol. 29: 547–564.

Gheysari, M., S.M. Mirlatifi, M. Bannayan., M. Homaee and G. Hoogenboom. 2009. Interaction of water and nitrogen on maize grown for silage. Agr. Water Manage. 96: 809-821.

Hirich, A., A. Rami, K. Laajaj, R. Choukr-Allah, S.E. Jacobsen, L. El youssfi and H. El Omari. 2012. Sweet corn water productivity under several deficit irrigation regimes applied during vegetative growth stage using treated wastewater as water irrigation source. World Acad. Sci. Eng. Tech. 61: 840-847.

Howell, T.A. 2001. Enhancing water use efficiency in irrigated agriculture. Agron. J. 93: 281–289.

Huang, R., C.J. Birch and D.L. George. 2006. Water use efficiency in maize production – the challenge and improvement strategies, pp. 1-7. In: Water to gold - Proc. 6th Triennial Conf. Maize Assoc. Australia; Griffith NSW, 21-23 February 2006.

Javanmard, A., A.D. Mohammadi Nasab, A. Javanshir, M. Moghaddam and H. Janmohammadi. 2009. Forage yield and quality in intercropping of maize with different legumes as double cropped. J. Food Agr. Environ. 7: 163-166.

Kang, S., Z. Liang, Y. Pan, P. Shi and J. Zhang. 2000. Alternate furrow irrigation for maize production in an arid area. Agr. Water Manage. 45: 267-274.

Kang, S., Z. Liang, W. Hu and J. Zhang. 1998. Water use efficiency of controlled alternate irrigation on root-divided maize plants. Agr. Water Manage. 38: 69-76.

Kang, S., W. Shi, H. Coa and J. Zhang. 2002. Alternate watering in soil vertical profile improved water use efficiency of maize (*Zea mays*). Field Crop Res. 77: 31–41.

Kang, S. and J. Zhang. 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. J. Exp. Bot. 55: 2437-2446.

Kenter, C., C.M. Hoffmann and B. Marlander. 2006. Effects of weather variables on sugar beet yield development (*Beta vulgaris* L). Eur. J. Agron. 24: 62-69.

Kirda, C., S. Topcu, H. Kaman, A.C. Ulger, A. Yazici, M. Cetin and M.R. Derici. 2005. Grain yield response and N-fertiliser recovery of maize under deficit irrigation. Field Crop. Res. 93: 132–141.

Kiziloglu, F.M., U. Sahin, Y. Kuslu and T. Tunc. 2009. Determining water–yield relationship water use efficiency crop and pan coefficients for silage maize in a semiarid region. Irrig. Sci. 27: 129-137.

Klute, A. 1986. Methods of Soil Analysis: Physical and mineralogical properties, Part I, 2nd Ed. ASA- SSSA Agronomy No: 9 Madison, WI.

Ko, J., G. Piccinni and E. Steglich. 2009. Using EPIC model to manage irrigated cotton and maize. Agr. Water Manage. 96: 1323–1331.

Ko, J. and G. Piccinni. 2009. Corn yield responses under crop evapotranspiration-based irrigation management. Agr. Water Manage. 96: 799-808.

Lotze-Campen, H., C. Müller, A. Bondeau, S. Rost, A. Popp and W. Lucht. 2008. Global food demand productivity growth and the scarcity of land and water resources: A spatially explicit mathematical programming approach. Agr. Econ. 39: 325–338.

Mertens, D. 2005a. AOAC Official Method 92202, Plants preparation of laboratory sample; pp.1-2. In: W. Horwitz and G.W. Latimer (eds.), Official Methods of Analysis. Chap. 3, 18th Ed. AOAC-International Suite 500 481 North Frederick Avenue, Gaitherburg Maryland, 20877-2417 USA.

Mertens, D. 2005b. AOAC Official Method 97503, Metal in plants and pet foods; pp.3-4. In: W. Horwitz and G.W. Latimer (eds.), Official Methods of Analysis. Chap. 3, 18th Ed. AOAC-International Suite 500 481 North Frederick Avenue, Gaitherburg Maryland, 20877-2417 USA.

Molden, D., H. Murray-Rust, R. Sakthivadivel and I. Makin. 2003. A water-productivity framework for understanding and action, pp.1–18. In: J.W. Kijne, R. Barker and D. Molden (eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI Publishing Wallingford, UK.

Montgomery, R. 2009. Influence of corn hybrids and water stress on yield and nutritive value. MS Thesis, Texas Tech University.

Oki, T. and S. Kanae. 2006. Global hydrological cycles and world water resources. Sci. 313: 1068-1072.

Oktem, A. 2008. Effect of water shortage on yield and protein and mineral compositions of drip-irrigated sweet corn in sustainable agricultural systems. Agr. Water Manage. 95: 1003-1010.

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of Soil Analysis: Chemical and microbiological properties, Part II, 2nd Ed. ASA-SSSA Agronomy No: 9, Madison, WI.

Payero, J.O., S.R. Melvin, S. Irmak and D. Tarkalson. 2006. Yield response of corn to deficit irrigation in a semiarid climate. Agr. Water Manage. 84: 101–112.

Payero, J.O., D.D. Tarkalson, S. Irmak, D. Davison and J.L. Petersen. 2008. Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration yield water use efficiency and dry matter production in a semiarid climate. Agr. Water Manage. 95: 895-908.

Sadras, V.O. 2009. Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. Irrig. Sci. 27: 183–190.

Salemi, H., M.A.M. Soom, S.F. Mousavi, A. Ganji, T.S. Lee, M.K. Yusoff and V.R. Verdinejad. 2011. Irrigated silage maize yield and water productivity response to deficit irrigation in an arid region. Pol. J. Environ. Stud. 20: 1295-1303.

Schachtman, D.P. and J.Q.D. Goodger. 2008. Chemical root to shoot signaling under drought. Trends Plant Sci. 13: 281-287.

Sepaskhah, A.R. and S.H. Ahmadi. 2010. A review on partial root-zone drying irrigation. Int. J. Plant Prod. 4: 241-258.

Shahrabian, E. and A. Soleymani. 2011. Influence of silage maize (*Zea mays* L) cultivars and different water level on nutritive value. J. Food Agr. Environ. 9: 336-339.

Simsek, M., A. Can, N. Denek and T. Tonkaz. 2011. The effects of different irrigation regimes on yield and silage quality of corn under semi-arid conditions. Afr. J. Biotechnol. 10: 5869-5877.

Subramani, J. and S. Loper. 2011. Silage corn variety trial in Central Arizona. 2011 Forage & Grain Report. College of Agriculture and Life Sciences, University of Arizona, pp.51-57.

Van Soest, P.J., J.B. Robertson and B.A. Lewis. 1991. Methods for dietary fiber neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583-3597.

Wang, J., S. Kang, F. Li, F. Zhang, Z. Li and J. Zhang. 2008. Effects of alternate partial root-zone irrigation on soil microorganism and maize growth. Plant Soil 302: 45–52.

Yazar, A., S.M. Sezen and B. Gencel. 2002. Drip irrigation of corn in the Southeast Anatolia Project (GAP) area in Turkey. Irrg. Drain. 51: 293-300.

Yazar, A., F. Gokçel and M.S. Sezen. 2009. Corn yield response to partial rootzone drying and deficit irrigation strategies applied with drip system. Plant Soil Environ. 55: 494-503.

Yenesew, M. and K. Tilahun. 2009. Yield and water use efficiency of deficit-irrigated maize in a semi-arid region of Ethiopia. Afr. J. Food Agr. Nutr. Develop. 9: 1635-1651.