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Full Length Research Paper

The effects of different irrigation regimes on yield and silage quality of corn under semi-arid conditions

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The aim of this study was to evaluate the effects of different quantities of drip irrigation water on the corn yield and silage quality under semi-arid conditions. The seasonal evapotranspiration (ET_c) for the different irrigation regimes varied from 434 to 947 mm in 2004 and from 468 to 1003 mm in 2005 for total irrigation periods of 108 and 113 days, respectively. Combining data from both years, the relative evapotranspiration deficit ($1-ET_a/ET_m$) for different regimes was 19 to 54% in corn compared to the maximum seasonal ET_c when water was not limited in the (I_{100}) regime. During the course of both years, irrigation had an apparent effect on the total fresh silage yield (FSY), with yields increasing steadily from water stress to fully irrigated conditions, while silage yields increased linearly with the total depth of irrigation water applied between planting and harvest. Combining data from both years showed that the FSY was 35.0, 53.6, 83.3 and 88.9 t ha^{-1} for I_{25}, I_{50}, I_{75} and I_{100}, respectively. Moreover, the largest FSY recorded amongst these experiments at maximum seasonal yield in single treatment was 89.1 t ha^{-1} in 2004 and 88.7 t ha^{-1} in 2005. The water content decreased considerably in all but FSY, while the dry matters yield (DMY), organic matter (OM), acid detergent fiber yield (ADFY) and *in vitro* dry matter digestibility (IVDMD) increased. Furthermore, the study substantiated that the highest yield and silage quality were obtained at the full (I_{100}) irrigation regime.

Key words: Silage, deficit irrigation, yield, silage quality.

INTRODUCTION

Corn is a primary source of energy in the Turkish dairy cattle industry, and its nutritive value is good due to its high digestibility. Corn plants generally have a crude protein (CP) content of about 8%, which is below the requirement for most lactating cows (Miller, 1979).

Moreover, the water stress greatly affects the fresh silage yield and quality, whereas the smaller plants with less leaf area, lead to a great loss in the dry matter produced per hectare. Severe droughts, delay tasseling, silking and grain-filling, can lead to substantial reductions in yield (NeSmith and Ricthie, 1992).

Corn kernel contributes immensely to the silage quality. If a plant is stressed, the seed set and grain filling are negatively affected, leading to poor silage quality because grain is a highly digestible source of energy (Cox et al., 1998). The ideal moisture concentration (65 to 70%) for ensiling corn closely coincides with the stage of development ensuring maximum production of total digestible nutrients. Reported values of one-fourth to two-thirds milk-line (650 to 680 g kg^{-1} moisture) are considered the optimum stage of harvest to maximize intake, digestion and milk production (Bal et al., 1997).

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Abbreviations: ET_c, Evapotranspiration; **FSY,** fresh silage yield; **DMY,** dry matter yield; **OM,** organic matter; **ADFY,** acid detergent fiber yield; **IVDMD,** *in vitro* matter digestibility.

Corn has been reported to have high irrigation requirements (Musick and Dusek, 1980; Stone et al., 1996; Karam et al., 2003; Payero et al., 2006; Farre and Faci, 2009). However, the great challenge for the coming decades will be the task of increasing food production with less water, particularly in countries with limited water and land resources as well as inefficient usage of water (FAO, 2002). Therefore, a lot of improvement is needed in order to increase the efficiency and adequate use of the available water.

One approach is the development of new irrigation scheduling techniques, such as deficit irrigation, which is not necessarily based on full crop water requirement but at the same time, maximizes water use efficiency for higher yields per unit of irrigation water applied (Bekele and Tilahun, 2007). Deficit irrigation is also practiced in many arid areas of the world, and increased demand of water supplies worldwide suggests that this practice must continue to increase. It is a water demanding crop, and can achieve high grain yields when water and nutrients are not limited. However, corn is particularly sensitive to water and other environmental stresses around flowering (Pandey et al., 2000; Cakir et al., 2004; Payero et al., 2006). This high sensitivity to water stress makes implementation of irrigation management strategies difficult without causing significant yield losses (NeSmith and Ritchie, 1992; Lamm et al., 1995).

Silk emergence is the most crucial time to avoid drought stress, while early vegetation is the least critical period for drought stress. When irrigation water is limited, irrigation should be refrained until the silking to blister stages of development, if possible. Moreover, the drought stress during the blister to drought stage can also cause yield losses between 20 and 40%. Drought may result in lower starch contents because less grain in the total silage mix occurs (Curran, 2002). Even short-term water stress causes approximately 28 to 32% loss of final dry matter weight of the plants, omitting first irrigation in 1995 and 1996, respectively, while no loss was observed during the rainy third experimental year. As expected, the non-irrigated regime caused the most significant loss in the dry matter, while the most severe effect of water deficits on dry matter loss was observed on the non-irrigated regime (Cakir, 2004). During the entire growing period, the total water requirements of corn changed between 500 and 800 mm (Brouwer and Heibloem, 1986). Water stress also had an important effect on water consumption and yield of corn. Several researchers had showed that there was a positive linear relationship between yield and water use (Cakir, 2004; Payero et al., 2006). Many environmental, cultural and genetic factors affect corn silage yield and quality (Howell et al., 1997). It is also observed that the irrigation frequency and application method did not affect corn yields; however, deficit irrigation did have an impact on crop yields by reducing the seed mass and the seed number.

Corn is a major summer crop in the irrigated areas of the GAP area. In the Harran plain, corn covered 38% of the irrigated agricultural land in 2009. It grows best on fertile, well-drained loamy soils. Moreover, under the semi-arid conditions of Turkey, water is by far the major constraint to crop production. Rainfall is also extremely irregular and concentrated during winter months, reducing thus, the choice of annual summer crops to a minimal. Consequently, the high temperature and evapotranspiration rates, in combination with limited water storage capacity of soils during winter, reduce water availability for crops during summer time. The purposes of this study were: (i) to quantify fresh silage yield response under full and deficit irrigation regimes, and (ii) to delineate the impact of water stress on yield components, water use and water use efficiency of silage corn in semi-arid environments of the GAP Harran plain.

MATERIALS AND METHODS

Site and climate description, and crop agronomy

The field data for this study were collected in the corn growing season of 2004 and 2005 at the Field Research Facility of the Faculty of Agriculture at Harran University, Sanliurfa, Turkey. The soil of the study area, classified as Entisol and Fluvisol according to soil taxonomy, had high clay content (51 to 59%) and organic matter (1.89 to 2.50) (Soil Survey Staff, 1999).

The soil water content (w/w%: dry weight basis) at field capacity (-0.33 bar) was between 29.36 and 31.21% and the permanent wilting point (-15.00 bar) was between 21.07 and 21.97%. Average bulk density in the 0 to 90 cm of soil profile was between 1.38 and 1.46 g cm^{-3}, and the extractable plant water was estimated at 108.6 mm for 90 cm rooting depth.

GAP had a well-defined hot and dry season from June to October and a very cold one for the remainder of the year. Daily values of mean monthly air temperature, relative humidity, pan evaporation, solar radiation and wind speed during the growing season (June to October) varied from 21.7 to 32.8°C, 27.0 to 48.7%, 173 to 431 mm, 13.2 to 26.8 MJ m^{-2} d^{-1} and 5.8 to 10.8 km hr^{-1} in 2004, and from 18.6 to 33.0°C, 32.8 to 52.9%, 161 to 404 mm, 14.4 to 25.3 MJ m^{-2} d^{-1} and from 4.7 to 10.1 km hr^{-1} in 2005, respectively.

The total rainfall during the growing season (June to October) ranged from 3.4 to 50.0 mm in 2004 and 2005, respectively. The open pan evaporation (June to October) is 1605 mm in 2004 and 1516 mm in 2005 during the study period. During the experimental period (June to October), the lowest and highest air temperature were recorded as 18.6 and 21.7°C in October and 32.8 and 33.0°C in July, in both years, respectively. Long-run data indicate an average annual rainfall of 494 mm, with 81% of rain occurring between November and April. Daily mean temperature generally increased from 15 to 22°C in May and 30 to 33°C at the end of July, after which it decreased from 13 to 18°C in October. In both experimental years, in mid-summer, the relative humidity values were higher than it was observed for the 15-year mean. All other parameters except relative humidity were consistent since the beginning of irrigation. The reason for the considerable increment in relative humidity might be due to irrigation in the plain (Tonkaz et al., 2003).

Corn (Cargill 955 F1 cv; high yield and moderate drought-tolerance) was planted manually on June 24, 2004 (DOY: 175) and on June 29, 2005 (DOY: 180) and harvested by hand on October 10 and 20 in the 2004 (DOY: 283) and 2005 (DOY: 293) growing season, respectively. The planting date has been reported to significantly affect the yield and quality of silage (Fairey, 1980; Graybill et al., 1991). However, the plot size spacing was 17 cm in plants and 70 cm between rows. Each plot contained 5 rows and each row is 10.00 m long. The average plant density level is 84,000 plant ha^{-1}. In both years, fields received a basal fertilizer (N, P and K) application. Before sowing, 80 kg ha^{-1} of triple-super-phosphate (0-46-0) and 100 kg ha^{-1} K_2O were applied. Additionally, nitrogen fertilizer (210 kg ha^{-1}) was partitioned into one pre-planting (⅓) application and two post-planting (⅔) during the early whorl applications. Ammonium nitrate and phosphoric acid (35 mg L^{-1} H_3PO_4) was also injected into a fertilizer tank connected to the irrigation systems.

Irrigation application and soil water balance

The field experiment was conducted using a randomized complete block design (RBD) with four irrigation regimes (I_{100}-I_{25}) and three replications. The different irrigation regimes were full irrigation (IW/CPE ratio 100%) as control regimes and three deficit irrigation (IW/CPE ratio 75, 50 and 25%) during the growing season. The use of IW/CPE ratios made the irrigation programming easier. There have been many researches conducted in the past, relating to irrigation programming using IW/CPE ratios (Saudan et al., 2000; Ferreira and Carr, 2002; Simsek et al., 2005). The three regimes tested in this study of deficit irrigation were compared with full irrigation regime. Irrigation amounts varied during the growing season according to the crop water requirements.

The irrigation regimes started, when soil water content at the effective root depth decreased to 50% of the available soil water at 20 DAP (July, 14) and 21 DAP (July, 21), and ended at DOY: 277 (October 03) and DOY: 287 (October 13) in 2004 and 2005, respectively. All plots were pre-irrigated before planting, in order to ensure enough moisture in the soil profile at the planting time.

Evaporation from United States Weather Bureau (USWB) Class A pan is the most common and simple approach for scheduling irrigation for field, vegetable and fruit crops (Yuan et al., 2003; Karam et al., 2003). Three day CPE values were used for irrigation. The irrigation water was checked by a flow water meter in valves. The amount of applied irrigation water and seasonal crop evapotranspiration were calculated by using the following equations:

$V = A \times IW$

$IW = E_{pan} \times$ (CPE ratio: 75, 50 and 25)

$ET_c = IW + P - D - R \pm \Delta S$

IW/CPE: [I_{100}: 1.00 (100%)], [I_{75}: 0.75 (75%)], [I_{50}: 0.50 (50%)] and [I_{25}: 0.25 (25%)]

where, A is the plot area (m^2); V is the volume of irrigation water applied; IW is the total amount of irrigation water applied (mm); E_{pan} is the pan evaporation; CPE is the cumulative pan evaporation; ET_c (and also ET_a) is the seasonal crop evapotranspiration; P is the precipitation; D is the drainage; R is the run-off and $\pm \Delta S$ is the variation in water content of the soil profile. All terms were expressed in mm of water in the corn root zone, although, the effective root depth was taken as 90 cm. In addition, the water content at the depths of 90 to 120 cm were also determined and the total water content in these layers was considered to be deep percolation. Run-off was taken to be zero since it did not occur with the use of drip irrigation system.

The yield response factor, k_y, is defined by the ratio between the relative yield decrease and the relative evapotranspiration deficit as shown in the following equation:

$$1 - \frac{Y_a}{Y_m} = k_y \left(1 - \frac{ET_a}{ET_m}\right)$$

Where, Y_a and ET_a are the actual yield and actual evapotranspiration; Y_m and ET_m represent the maximum yield and maximum evapotranspiration and k_y is the yield response factor. k_y values are experimentally derived using field data considering the linear relationship between relative yield decrease $(1-Y_a/Y_m)$ and relative evapotranspiration deficit $(1-ET_a/ET_m)$ during the entire growing season, or in one of the different growth stages. Doorenbos and Kassam (1979) stated that when $k_y<1$, yield loss is less important than evapotranspiration deficit; when $k_y>1$, yield loss is more important than evapotranspiration deficit (for corn, $k_y = 1.25$ is for the entire growing period); and when $k_y=1$, yield loss is equal to evapotranspiration deficit (line 1:1).

The surface drip (SD) lines with 70 cm spacing were laid on the soil surface beside the plant rows. The irrigation network consisted of a main delivery pipe [∅50 mm diameter polyethylene (PE)] and the secondary pipes (∅32 mm PE). The drip laterals for SD system was used, with dripping wings placed on each row and “on line” droppers, spacing 40 cm, with a 2.5 L hr^{-1} delivery. Lateral lines were plugged at the ends with figure-eight loops. Soil water measurements were made approximately every 2 weeks during the growing season, using the gravimetric soil samples by soil auger. Soil samples were replicated seven times on each plot. Measurements were regularly made at 30 cm increments, to a depth of 90 cm, 24 h before irrigation and in the course of the season. The volumetric water contents (v/v%) were calculated using gravimetric water contents (w/w%) and bulk density (ρ_b) using v/v% = w/w% x ρ_b. Volumetric soil water was then converted into millimeter and it accounted for each incremental soil depth (d) by [(v/v%xd)/10] (Foroud et al., 1993).

Water use efficiency and irrigation water use efficiency

Corn silage yields were corrected from 60 to 70% moisture on a wet basis. Water use efficiency (WUE), also known as water productivity, is usually expressed either in kg ha^{-1} mm^{-1} or in kg m^{-3}. IWUE is obtained from silage corn yield per unit IW. In silage corn crop, WUE decreased with decreasing irrigation and WUE is the ratio of fresh corn silage yield [aboveground biomass (t ha^{-1})] and seasonal crop evapotranspiration (ET_c; mm) (Howell et al., 1998).

$$WUE = \frac{Y_a}{ET_c}$$

$$IWUE = \frac{Y_a}{IW}$$

Ensiling procedure and chemical analyses

Silage materials were packed tightly in 1 L jars with 1 jar per replicate of field experiment. The jars were opened after a fermentation of 60 days. Water extracts of fermented materials were prepared by homogenizing 25 g of wet material with 100 mL water in a blender at full speed for 5 min. The content was filtered through two layers of cheesecloth and the filtrate was used to measure the pH level. The Fleig points of the silages were calculated by the following equation reported by Kilic (1984):

Fleig points = 220+(2×DM%−15)−40×pH

Where, Fleig points denote that values between 85 and 100, have a very good quality; values between 60 and 80, have a good quality; values between 55 and 60, have a moderate quality; values between 25 and 40, have a satisfying quality; and values <20 are worthless. Silage samples were dried at 65°C and ground (1 mm), after which they were analyzed for DM, OM and CP by the procedure of AOAC (1984). NDF and ADF contents were measured according to the procedure of Goering and Van Soest (1970). *In vitro* dry matter digestibility (IVDMD) of silages was determined according to the procedure described by Tilley and Terry (1963).

Statistical analysis

All the data were analyzed using SAS statistical program (SAS Inst, 1991). Analysis of variance (ANOVA) was conducted and significance of differences among regimes was tested using the least significant difference test via the Turkey method. Nonetheless, differences were declared as very significant at P<0.01 and significant at P<0.05.

RESULTS AND DISCUSSION

Soil water content

To avoid water stress, the best management practices commonly recommend that the root zone depletion should be maintained below the available water line. Howell et al. (1997) implied the possibility of irrigation frequency according to soil water levels, in that if the soil water levels were initially low or if the soil had a lower water holding capacity, the irrigation frequency would become more important.

The soil water content at the end of the growing season, was lower than that at the beginning of the regimes (I_{25} and I_{50}), indicating that the crop extracted water from all soil layers down to 90 cm. However, most of the water uptake was from 0 to 60 cm depth. In this study's different irrigation regimes, the corn under mild irrigation deficit (I_{75}) extracted more water than the plants under severe irrigation deficit (I_{25}), suggesting that the less stressed plants developed deeper and more dense rooting systems.

Crop water use

Seasonal crop evapotranspiration (ET_c) of silage corn regimes was determined from the water balance approach. During the experimental period, including the seven irrigated water periods (a total of 288 mm in 2004 and 343 mm in 2005) before the experiment started, the seasonal total amount of applied water was 506, 723, 941 and 1158 mm in 2004 (from June 24 to October 03) and 573, 804, 1034 and 1264 mm in 2005 (from June 29 to October 09, 2004) for I_{25}, I_{50}, I_{75} and I_{100}, respectively (Table 2). The irrigation treatments started at 20 DAP in 2004 and 21 DAP in 2005 and ended at 105 and 106 DAP in 2004 and 2005, respectively.

Table 1 shows that the seasonal ET_c reached the physiological silage maturity or harvest date on October 10, 2004 (DOY 283) and October 20, 2005 (DOY 293). The total number of irrigation periods, and the amount of irrigation water and seasonal ET_c values of silage corn for the experimental years are presented in Table 2. The total irrigation water applied and the seasonal ET_c in 2004 were lower than in 2005. This may be attributed to the differences in climatic conditions and in the total growing period. The mean temperature in July and August, and the total growing seasonal period in 2004 were lower than that in 2005. The seasonal ET_c for the different irrigation regimes was 46 to 79% in 2004 and 47 to 82% in 2005 when compared with the seasonal ET_c, when water was not limited or fully irrigated. Combining data from both years, the yield increased linearly with seasonal irrigation. In 2004, seasonal irrigation depths for irrigation regimes, ranged from 506 to 1158 mm in 2004, and from 573 to 1264 mm in 2005. In both years, the seasonal irrigation depths represent 100% seasonal ET_c silage corn, while the peak rates of water use reached 13 to 15 mm per day.

According to the results of a 2-year study, the total fresh yield of silage corn significantly decreased by water stress. The positive linear relationship was obtained between seasonal ET_c and total FSY. As a result, the I_{100} regime could be used for the silage corn grown in semi-arid regions under no water shortage. On the other hand, according to results of this study, the I_{75} could be used for the silage corn grown in semi-arid regions where irrigation water supplies are limited. Under this condition, 18% of water saving was obtained, even though there was a 6% relative yield decrease for silage corn, based on the averages of 2 years (Table 2).

In both years plant height, biomass and shoot water content increased with increasing total amount of irrigation from the IW/CPE ratio (25%0 to IW/CPE ratio (100%). The cob weight per plant decreased with the increase of the seasonal irrigation water. Some of the significant effects of water stress on corn included the visible symptoms of reduced growth, delayed maturity and reduced crop yield. For instance, water stress has been shown to reduce plant height (Kang et al., 2000, Karam et al., 2003; Payero et al., 2006). This confirmed the linear relation between grain yield and silage response, to irrigation for corn (Overman and Martin, 2002).

Table 1. Cultural parameters and crop phenology for silage corn of 2004 to 2005 trials.

Phenology (stage title)	2004		2005	
	Date	Approximate day from title emergence (DAP)	Date	Approximate day from title emergence (DAP)
Planting date	24.06.2004 (DOY:175)	0	29.06.2005 (DOY:180)	0
Germination and emergence (VE)	29.06.2004 (DOY:180)	5	04.07.2005 (DOY:185)	5
First leaf-nth leaf (V1-Vn)	03.07.2004 18.08.2004 (DOY:184-230)	9-55	08.07.2005 26.08.2005 (DOY:189-238)	58
Tasselling (VT)	21.08.2004 (DOY:233)	58	31.08.2005 (DOY:243)	63
Silking (R1)	28.08.2004 (DOY:240)	65	05.09.2005 (DOY:248)	68
Blister (R2)	02.09.2004 (DOY:233)	70	11.09.2005 (DOY:254)	74
Milk (R3)	07.09.2004 (DOY:250)	75	15.09.2005 (DOY:258)	78
Dough (R4)	17.09.2004 (DOY:243)	85	21.09.2005 (DOY:264)	84
Harvest	10.10.2004 (DOY:283)	88	20.10.2005 (DOY:293)	92

†DOY, Day of year ‡DAP, days after planting.

Table 2. Effects of different irrigation regimes on corn relative yield decrease, yield response factor, water use efficiency and water saving.

Treatment	IW			ET_a			FSY	$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	ky	IWUE	WUE
	2004	2005	Average	2004	2005	Average						
I_{25}	506	573	540	434	468	451	35..0	0.54	0.61	1.13	6.49	7.76
I_{50}	723	804	764	625	678	652	53.6	0.33	0.40	1.20	7.02	8.23
I_{75}	941	1034	988	745	825	785	83.3	0.19	0.06	0.32	8.44	10.61
$I_{100\text{-control}}$	1158	1264	1211	947	1003	975	88.9	0.00	0.00	0.00	7.34	9.12

I_{25}, I_{50}, I_{75} and I_{100} represent the four irrigation regimes: IW/CPE=0.25, IW/CPE=0.50, IW/CPE=0.75 and IW/CPE=1.00, respectively.
IW: Water consumption (mm); ET_a: actual seasonal evapotranspiration (mm); ET_m: maximum seasonal evapotranspiration (mm); Y_a=FSY: actual fresh silage yield (t ha^{-1}); Y_m=FSY: maximum fresh silage yield (t ha^{-1}); ky: yield response factor; IWUE: irrigation water use efficiency (kg m^{-3}); WUE: water use efficiency (kg m^{-3}); IW_a: actual water consumption (mm); IW_c: maximum water consumption (mm); $1-(IW_a/IW_c)$: water saving.

A good linear relationship between corn yield and seasonal ET_c was reported by Stone et al. (1996), Karam et al. (2003) and Cakir (2004). Similarly, a positive linear relationship was also obtained between seasonal ET_c and total FSY in this study (Figure 1).

Saving water by 55, 37 and 18% increased the relative silage yield decrease by 61, 40, and 6% for I_{25}, I_{50} and I_{75} irrigation regimes, respectively, when compared to the full irrigation regime (I_{100}). Saving water by 1% during growth stages of total fresh yield decreased by 1.1, 1.0 and 0.3%, respectively. Water deficit in IW/CPE: 0.75 ratio, which had little effect on silage yield, and in IW/CPE: 0.50 and 0.25 ratio effects, were significant. This study's results with the findings of Howell et al. (1997) and Kiziloglu et al. (2009) also concluded that there was a good linear relationship between yield and irrigation water applied to

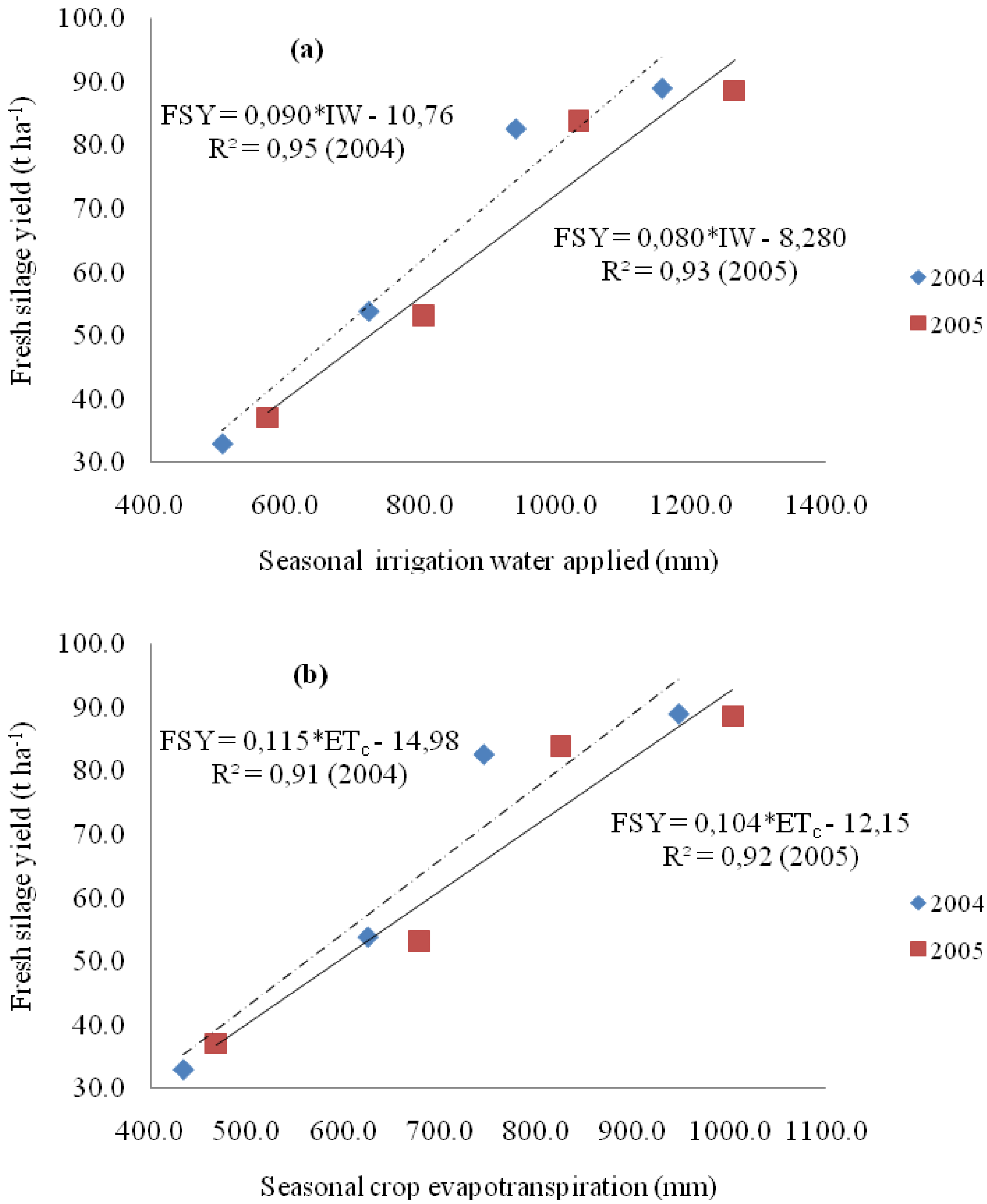

Figure 1. (a) Linear relationships between silage yield and seasonal total water applied and (b) seasonal ET_c, for all irrigation regimes (I_{25}-I_{100}) of corn obtained at Harran Plain as a function of 2004 (dotted circles) and of 2005 (solid circles).

corn.

Yield-irrigation relationship

In both years, silage yield in irrigation regime I_{75} was lower than in regime I_{100}. Combining both data, the maximum yield was 88.9 t ha^{-1} in the control treatment for both years. When the data for 2004 and 2005 were combined, irrigation had the better relationship to silage yield. In combining both years, seasonal ET_c had the best correlation to silage yield and the irrigation levels.

The relationships between fresh silage yields and IW, as well as fresh silage yields and seasonal ET_c for the average year are in a linear model, presented in Figure 1. Data of both years demonstrated that the FSY was

Table 3. Effects of different irrigation regimes on silage corn yield and quality components.

Treatment	FSY	PH	DM	DMY	OM	ADF	ADFY	NDF	NDFY	CP	CPY	% IVDMD	IVDMDY	pH	FP
I_{25}	35.0d	179.5c	23.0c	8.1d	92.8a	41.4b	3.5d	60.0c	5.0c	8.2a	0.7d	62.6b	5.1d	3.6b	77.4b
I_{50}	53.6c	237.5b	25.2b	13.5c	92.1ab	41.8ab	5.7c	60.2c	8.1b	8.2a	1.1c	64.0ab	8.6c	3.7ab	85.6a
I_{75}	83.3b	273.8a	25.6ab	21.4b	91.5b	41.8ab	8.9b	61.6b	14.0a	8.3a	1.8b	65.2a	14.0b	3.7ab	86.8a
$I_{100\text{-control}}$	88.9a	278.3a	26.5a	23.6a	90.3c	42.52a	9.8a	65.6a	14.1a	8.4a	2.0a	66.1a	15.6a	3.8a	87.1a

FSY, Fresh silage yield (t ha^{-1}); PH, plant height (cm); DM (%),dry matter (%); DMY, dry matter yield (t ha^{-1}); OM, organic matter (t ha^{-1}); ADF%, acid detergent fiber %; ADFY, acid detergent fiber yield (t ha^{-1}); NDF%, neutral detergent fiber %; NDFY, neutral detergent fiber yield (t ha^{-1}); CP%, crude protein %; CPY, crude protein yield (t ha^{-1}); IVDMD%, *in vitro* dry matter digestibility %; IVDMDY, *in vitro* dry matter digestibility yield (t ha^{-1}); FP, fleig point.

significantly decreased in deficit irrigation treatments I_{25} and I_{50}. As can be seen in Figure 1a, the linear relationship with a coefficient of determination (R^2) of 0.95 and 0.93 were observed between total water applied and FSY in 2004 and 2005, respectively. In addition, the coefficient of determination of 0.91 and 0.92 were obtained from Figure 1b for the relationship between seasonal ET_c and FSY in 2004 and 2005, respectively.

According to Figure 1, 125 mm of seasonal ET_c was derived from the equation of the line ($FSY=0.1104*ET_c-13.8$) obtained using the 2004 and 2005 data given in Table 2 with the assumption of a silage yield of 0 t ha^{-1}. The slope of the line indicated that silage yield increased with seasonal ET_c at a rate of 0.1104 t ha^{-1} mm^{-1}.

The corn grew rapidly, tasseled on August 21, 2004 (DOY 233) and silken on August 28, 2004 (DOY 240). Tasseling occurred on August 31, 2005 (DOY 243) and silking occurred on September 5, 2005 (DOY 248). Air temperatures were similar to historical patterns in both years. The yield and yield data components of the regimes are presented in Table 2. The growing seasons lasted for 108 and 113 days in 2004 and 2005, respectively. In both growing seasons, the deficit irrigation level of IW/CPE: 0.75 produced good yields (94% of I_{100}), while reducing the irrigation amount by 25%.

In combining data, the highest IW and ET_c were observed in the full irrigated regimes. In I_{100} regime, the amount of total irrigation water and ET_c values were 1158 and 947 mm in 2004 and 1264 and 1003 mm in 2005, respectively. The lowest IW and ET_c were observed in the water deficit regimes. In I_{25} regime, the amount of irrigation water applied and ET_c values were 573 and 468 mm by the increasing water deficit in the 2005 growing period and was higher than that in 2004. Plant density significantly affected the silage DM yield and all measured silage quality parameters. The response of the silage DM yield to plant density was linear, with the maximum DM yield observed at the highest plant density level of 88,900 plants ha^{-1} (Widdicombe and Thelen, 2002). Thus, plant density can affect forage yield and quality (Cusicanqui and Lauer, 1999).

Total fresh silage yield, plant height, DM, NDF and IVDMD increased with increasing amount of irrigation. The highest yield and yield components were obtained at I_{100} regime. The maximum yield obtained in both years, averaged across irrigation regimes when deficit irrigation was applied (I_{25}), was about 35.0 t ha^{-1} and increasing to about 88.9 t ha^{-1} in the full irrigated regimes (I_{100}). Carmi et al. (2006) reported that excess irrigation decreased DM content, DM ratio of leaves/stems and IVDMD of sorghum. In this study, deficit irrigation regime had a similar effect on DM and IVDMD of corn silage.

Yield components

FSY, DMY, ADFY, CPY and IVDMDY were linearly related to the amount of water applied (from I_{25} to I_{100}) in the plant corn. When irrigated, using an IW/CPE ratio of 100%, it was concluded that silage corn on entisol and fluvisol should be irrigated using an IW/CPE ratio of 0.75 or more.

The use of a lower IW/CPE ratio may reduce silage yield significantly and affect silage quality (Tables 2 and 3). Table 3 shows that in all treatments, the ADF, NDF, IVDMD, pH and FP significantly differ for I_{25} and I_{100} silages. Water stress decreased silage yield components during both growing seasons in 2004 and 2005. Yield components of corn are significantly different between I_{100} and I_{25}-I_{75} and are shown in Table 3. Conversely, there are poor significant differences among deficit irrigation regimes, except ADF, CP, IVDMD, pH and FP. In general, the ADF, CP, IVDMD, pH and FP are from 41.40 to 42.52%; 8.2 to 8.4%; 62.6 to 66.1%; 3.6 to 3.8% and from 77.4 to 87.1%, respectively. The maximum yield components (PH, DM, DMY, OM, ADFY, NDF, NDFY, CPY and IVDMDY) were recorded with I_{100}, while the greatest reduction was recorded with I_{25}. DMY, OM, ADFY, CPY and IVDMDY were relatively decreased by 65.6, 42.7 and 9.3%; 67.7, 43.8 and 10.0%; 64.2, 41.8 and 9.1%; 65.0, 45.0 and 10.0%; and 67.3, 44.8 and 10.2% in I_{25}, I_{50} and I_{75}, respectively, when compared with I_{100}. The data obtained from this study showed that yield and some yield components significantly (P<0.001) affected soil water deficits (Tables 2 and 3).

CPY and IVDMDY were relatively decreased by 65.6, 42.7 and 9.3%; 67.7, 43.8 and 10.0%; 64.2, 41.8 and 9.1%; 65.0, 45.0 and 10.0%; and 67.3, 44.8 and 10.2% in I_{25}, I_{50} and I_{75}, respectively, when compared with I_{100}. The data obtained from this study showed that yield and some yield components significantly (P<0.001) affected soil water deficits (Tables 2 and 3).

Yield response factor, *ky* and water use efficiency

The evapotranspiration and yield facts acquired from the experiment were also evaluated and described by Stewart et al. (1977). The k_y values, from 0.32 to 1.13, were higher than the 0.70 value reported by Doorenbos and Kassam (1979) for stress, during the total growing season. k_y values ≥1.0 are considered to represent an actual sensitivity to drought. Within a given season, further IW/CPE ratio application from I_{100} to I_{25} increased the variation of *ky* values significantly, and the good linear relationships between relative yield decrease and relative evapotranspiration deficit were observed (Table 2).

In this study, WUE was calculated for FSY and per seasonal ET_c, in kg m^{-3}. Silage yields, used to determine IWUE and WUE, were calculated in a wet-mass basis (65 to 70% water content). A summary of the total irrigation water (IW), actually seasonal evapotranspiration, water use efficiency and irrigation water use efficiency data for the different irrigation regimes are shown in Table 2.

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In this study, WUE was calculated for FSY and per seasonal ET_c, in kg m^{-3}. Silage yields, used to determine IWUE and WUE, were calculated in a wet-mass basis (65 to 70% water content). A summary of the total irrigation water (IW), actually seasonal evapotranspiration, water use efficiency and irrigation water use efficiency data for the different irrigation regimes are shown in Table 2.Water use efficiency (WUE) related to the production of total fresh silage yields were 7.76, 8.23, 10.61 and 9.12 kg m^{-3} for the I_{25}, I_{50}, I_{75} and I_{100} irrigation regime, respectively, whereas the highest value was the I_{75} regime. The highest IWUE was obtained in the irrigated IW/CPE ratio 75% (8.44 kg m^{-3}), while the lowest IWUE was obtained in the partially irrigated IW/CPE ratio (6.49 kg m^{-3}) with the drip method. Thus, IWUE and WUE increased with the increasing amount of irrigation from I_{25} to I_{75}.

In both years, the yields increased linearly with the total depth of water applied between planting and harvest (Table 2). The WUE related to the production of fresh silage yields were 7.76, 8.23, 10.61 and 9.12 kg m^{-3} for I_{25}, I_{50}, I_{75} and I_{100} regimes, respectively with the highest value being I_{75} regime. WUE was higher in I_{75} treatment than in I_{100}. In both years, the highest IWUE and WUE values were in the water stressed (I_{75}) treatment, reaching 8.44 and 10.61 kg m^{-3}, respectively, while the lowest IWUE and WUE values were in the strongly water stressed (I_{25}) treatment, reaching 6.49 and 7.76 kg m^{-3}, respectively.

Conclusion

Combining the data of both years, seasonal ET_c of silage corn regimes varied during the growing period from 451 mm in the deficit irrigation regime of I_{25} to 975 mm in I_{100}. Moreover, it is also concluded that flowering is the most critical time to avoid drought stress. Thus, usage of water must be limited, from silking to blister stage development, if possible. Meanwhile, the relationships between silage fresh yield and seasonal ET_c were reported to be linear (Howell et al., 1997; Payero et al., 2006; Kiziloglu et al., 2009). Combining the data from both years, the total seasonal ET_c values for the entire growing season of corn for all treatments were 451, 652, 785 and 975 mm for I_{25}, I_{50}, I_{75} and I_{100}, respectively. The effect of water stress on reducing corn silage yield might be related to the decreasing yield components, dry matter yield, organic matter, acid detergent fiber yield, crude protein yield, or the *in vitro* true digestibility.

The relationships between yield and several seasonal water variables obtained during 2004 and 2005 are shown in Figure 1. It took approximately 130 mm ($FSY = 0.115*ET_c-14.98$) in 2004 and 117 mm ($FSY=0.104*ET_c-12.5$) in 2005 for the crop of the seasonal ET_c to start producing silage yield. Irrigation regime I_{75} also resulted in the highest IWUE and WUE values. Applying a specific amount of the irrigation water, as IW/CPE ratio 75%, on the full irrigation regime throughout the entire growing season, improved the irrigation water use and water use efficiency.

Fundamentally, water use varied from 434 mm for I_{25} to 947 mm for I_{100} in 2004 and from 468 mm for I_{25} to 1003 mm for I_{100} in 2005 for the total growing season periods of 108 and 113 DAPS, respectively, from planting to harvest. I_{75} irrigation regime could be suggested in semi-arid conditions under deficit irrigation treatment, thereby providing 18% water saving and 94% relative yield.

However, if the water is not limited, the water stress should not be applied in semi arid conditions, because water stress contributes to the silage quality negatively.

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