



Yield, Quality and Water Use Efficiencies of Silage Maize as Effected by Deficit Irrigation Treatments

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ABSTRACT

The present study was carried out to investigate the effects of different water deficit levels applied through growing season on silage yield, quality and water use efficiency (WUE) of main crop silage maize under semi-arid climate conditions during the years 2014 and 2015. Irrigation treatments were set as 100% (I₁₀₀), 70% (I₇₀) and 35% (I₃₅) supply of depleted water within 0-90 cm effective root zone in 7-day intervals. Applied irrigation water quantities in I₁₀₀(control) treatment of the first and second year (in 8 irrigations) were respectively observed as 693 and 666 mm. Plant water consumptions in control treatment were respectively measured as 770 and 738 mm. Silage yield was 10650 kg da⁻¹ in the first year and 10600 kg da⁻¹ in the second year. The silage yield obtained from I₇₀ treatment with 30% water deficit was statistically placed in group (B) following I₁₀₀ (control) treatment. The water deficits over 30% resulted in significant decreases in silage yield and quality. The correlation coefficient between ETa and dry matter was respectively identified as (r: 0.78), (r: 0.87) in 2014 and 2015 and the correlation coefficient between plant water consumption (ETa) and protein content was respectively identified as (r:0.81), (r:0.80) and the correlations between ETa and quality parameters were found to be positive and highly significant. There were significant linear correlations between ETa and kernel yield (Y). Yield response factor (ky) of experimental years were respectively calculated as 0.74 and 1.06. Irrigation water use efficiency (IWUE) values varied between 3.80-5.10 kg da⁻¹ mm and water use efficiency (WUE) values varied between 3.62 and 4.42 kg da⁻¹ mm.

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ÖZET

Bu araştırma yarı kurak iklim koşullarında, yetiştirme sezonu süresince farklı düzeylerde oluşturulan su kısıntısının ana ürün silajlık mısırın verimine, kalitesine ve su kullanım randımanı üzerine (WUE) etkilerini belirlemek amacıyla, 2014 ve 2015 yıllarında yürütülmüştür. Araştırmada sulama konuları, her 7 günde bir 0-90 cm'lik etkili kök derinliğinde tüketilen suyun %100 (I₁₀₀), %70 (I₇₀), %35 (I₃₅)'inin yeniden uygulanması şeklinde oluşturulmuştur. Çalışmada, bitki kök bölgesindeki eksik nemin tamamının karşılandığı I₁₀₀ (kontrol) konusuna denemenin ilk ve ikinci yılında 8'er kez, sırasıyla toplam 693 ve 666 mm sulama suyu uygulanmıştır. Kontrol konusunun bitki su tüketimi değeri birinci yıl 770 mm, ikinci yıl ise 738 mm olarak bulunmuştur. Anılan sulama konusunda silaj verimi denemenin birinci yılında 10650 kg/da, ikinci yılında 10600 kg/da arasında değişmiştir. % 30 oranında su kısıntısı uygulanan I₇₀ konusundan alınan silaj verimi istatistiksel olarak I₁₀₀ (kontrol) konusuna yakın grupta (B) yer almıştır. %30 oranından daha fazla yapılan su kısıntıları silaj verimi ve kalitesinde önemli oranda azalışlara sebep olmuştur. Ayrıca ET ile kuru madde arasında korelasyon katsayısı (r:0.78**,-r:0.87**) ve ET ile silaj verimi, protein miktarı arasında korelasyon katsayısı sırasıyla (r:0.81**) ve (r:0.80**), olarak belirlenmiş ve ETa ile kuru madde ve protein miktarı arasında istatistiki olarak önemli pozitif yönde yüksek bir ilişki bulunmuştur. Sulama suyu (I) ve su tüketim (ETa) değerleri ile tane verimi (Y) arasında %1 önem düzeyinde doğrusal ilişkiler belirlenmiştir. Deneme yıllarında sırasıyla verim tepki etmeni (ky) 0.74 ve 1.06 olarak bulunmuştur. Konulara göre sulama suyu kullanım randımanı (IWUE), 3.80-5.10 kg da⁻¹ mm; su kullanım randımanı (WUE) ise 3.62 ile 4.42 kg da⁻¹ mm arasında değişmiştir.

Introduction

About 22% of daily calorie consumption of the world is supplied from maize. Since maize is available for machine cultivation and has quite high yield levels, it plays a significant role in both human and animal nutrition. Annual silage corn production of Turkey is around 14 million tons (TUIK, 2014). However, the country need is about 18 million tons. The remaining 4 million tons are supplied through imported raw materials. The best quality and optimum silage is obtained from maize both in Turkey and throughout the world. About 95% silage production of Turkey is obtained from maize. The present research site, Southeastern Anatolia region of Turkey meets about 27.6% of country maize (*Zea mays L.*). The region has also quite intense dairy and goat production activities. Therefore, silage maize production is of great significance for the region. Although quality is a quite significant factor in forage crops, it is most of the time disregarded. Biomass quality or nutritional value is generally assessed with chemical composition or digestibility parameters (Budak and Budak, 2014). Karakozak and Ayasan (2010) indicated maize as the most commonly ensilaged crop in Turkey because of various positive attributes such as high dry matter content, low buffering capacity and available carbohydrate levels for lactic acid fermentation. Carpici et al. (2010) indicated plant density and nitrogen treatments as the significant factors effecting silage maize yield and silage quality.

Insufficient water resources have become a serious concern in some parts of the world (Kang and Zhang 2004). Before deficit irrigation can be accepted as a management strategy, potential effects on yield, quality and net income should be determined based on water-yield relationships and economic evaluation assessments (Kuscu et al., 2014). There are several inputs in maize (*Zea mays L.*) culture and irrigations constitute a significant portion of input costs in regions especially with deficit and expensive water resources. Since climate and soil characteristics vary from one region to another, the most proper irrigation programs should be developed for the region in concern. With a well-designed irrigation program, it is quite possible to provide efficient use of production inputs like water, energy and fertilizer. The present research site is located within semi-arid climate zone and has quite limited water resources. Therefore in maize culture of the region, required irrigation water should be supplied at proper periods in proper amounts with a proper method as to provide water saving and high water use efficiencies. Right at this point, water production functions come into scene especially in semi-arid and arid climates with deficit water resources.

Water production functions aim to irrigate more fields with the each unit of saved water. "Water-production" functions are also used to estimate economic outcomes of the decisions made by planners related to optimal water distribution plans. On the other hand, water production functions provide significant clues in assessment of irrigation system capacities, irrigation programs and water use efficiencies (Sammis, 1981; Gencoglan and Yazar, 1999). Such functions are also employed in assessment of plant water requirements, plant growth models, water use efficiencies and irrigation schedules, in water distribution

operations and design, operation and economic analysis of irrigation systems (Howell and Musick, 1985; Gencoglan, 1999). The basic target in deficit irrigation is to increase WUE values and to get the maximum yield from each drip of water (Kirda, 2002)

In deficit irrigation, water is saved by applying less water than plant requirement and the saved amount is used to irrigate more fields, in other words to open new fields for irrigation. Plant water requirement is reduced to a point over the production function in which reduction in income is equal to production costs. Since less water is applied to plants than their actual water requirement, a certain amount of yield is evident or a certain amount of yield loss is allowed in deficit irrigation.

Recent increases in maize cultivated lands and high water requirement of maize may exert an increasing water deficit pressure over the producers of Southeastern Anatolia region in near future. On the other hand, current climate change and resultant global warming also result in water deficits. Such cases require optimum use of water resources for the sustainability of agricultural activities. However, number of studies about the effects of deficit irrigation treatments on maize silage yield and quality and water use efficiency under semi-arid climate conditions is not sufficient. Therefore, the present study was carried out to investigate the effects of different deficit irrigation treatments on yield and quality of maize silage and water use efficiencies.

Material and Methods

The present research was carried out throughout the growing season of maize in 2014 and 2015 over the experimental fields of Siirt University Agricultural Faculty. Experimental fields are located at 37° 58' N latitude and 41° 50' E longitude and have an altitude of 894 m. P30B74 maize cultivar was used as the plant material of the study.

Long-term and experimental year climate data of the experimental site (throughout the maize growing season) are provided in Table 1. The region has terrestrial climate characterized by precipitated and cold winter months and dry and hot summer months. It was observed that mean temperature in summer was over 26°C and mean temperature in winter was over 2.7°C, maximum long-term annual mean relative humidity (70.2%) was seen in January and minimum (26.9%) in August. Annual mean relative humidity of the region is 50.41%. Long-term mean precipitation is 669.2 mm and monthly precipitations vary between 103.6 - 1.3 mm (DMI, 2016).

Before sowing, disturbed and undisturbed soil sampling was performed from three different soil layers as of 0-30, 30-60 and 60-90 cm to find out physical and chemical properties of experimental soils. Three undisturbed and one disturbed soil sample were taken from each layer. Undisturbed soil samples were taken into 100 cm³ steel tubes. Macro, micro and total porosity of these samples were determined in accordance with Danielson and Sutherland (1986); water holding capacity at field capacity (33 kPa) was determined in accordance with Klute (1986); soil bulk density was determined in

accordance with Blake and Hartge (1986). Disturbed soil samples were subjected to organic matter, texture and permanent wilting point analyses. Organic matter content was determined with Walkey-Black dichromate oxidation method (Nelson and Sommers, 1996), water holding capacity at permanent wilting point (1500 kPa) was determined in accordance with Klute (1986) and texture was analyzed through hydrometer method in accordance with Bouyoucos (1962).

The resultant data on soil characteristics are provided in Table 2. Experimental soils were classified under brown forest soils (Dengiz et al., 2013). Soil texture was clay with low electrical conductivity, medium lime, low phosphorus, high potassium and medium organic matter contents. Field capacity (FC) was found to be 443 mm in depth for 0-90 cm soil profile, permanent wilting point (PWP) was found to be 322 mm, soil bulk density was measured as 1.40 gr cm⁻³ and available water holding capacity was found to be 121 mm. The methods specified in Tuzuner (1990) were used to determine irrigation water quality parameters (EC, pH, anion and cation). Irrigation water quality class was identified as C₂S₁ (with and EC of 0.34 dS m⁻¹ and a pH of 7.21). Irrigation water was not considered to pose any problems to growth of maize plants.

Experiments were conducted in randomized blocks - split plots experimental design with 3 replications. Three different irrigation treatments were set as I₁₀₀, I₇₀ and I₃₅. Irrigation interval was selected as one week. Irrigation treatments were set as full irrigation in which 100% of depleted water in 90 cm soil profile in a week was supplied (I₁₀₀, control treatment), 30% deficit irrigation in which 70% of full irrigation was applied (I₇₀) and 65% deficit irrigation in which 35% of full irrigation was applied (I₃₅). In this way, 3 irrigation treatments were formed as of 1 full and 2 deficit irrigations.

For water conveyance and distribution into plots, PE pipes with 63 mm outer diameter and 10 atm operational pressure were used. In drip irrigation, a lateral line was

installed for each plant row (70 cm). Water distribution within the plots was carried out through soft PE pipe lines with 20 mm outer diameter and 4 atm operational pressure. Experimental soils have heavy texture with an infiltration rate of 7 mm h⁻¹. Dripper spacing was 0.30 m, dripper discharge rate was 4 L h⁻¹. In-line pressure regulated drippers work at 1 atm operational pressure. Since irrigation water was applied at plant requirement, deep percolation or runoff was not encountered. Seed bed was prepared as to have planting over the ridges. Each plot had 4 rows 70 cm apart and on-row plant spacing was 18 cm. Plots were 6 m long and 2.8 m wide (16.8 m²). Sowing was performed with a 4-row pneumatic single seed planter and seeds were dropped at 4-5 cm depth. Buffer zones of 2 m were placed to prevent interactions between the plots and replications.

All of phosphorus fertilizer (9 kg da⁻¹ as pure P₂O₅) and one-third of nitrogenous fertilizer (28 kg da⁻¹ N) were supplied at the time of sowing and the remaining two-third of nitrogen was supplied in two doses at a plant height around 40-50 cm (Hammad et al. 2012).

Following the emergence, thinning was performed among close plants at a plant height of around 15-20 cm, hoeing and earthing up were performed when the plants had 8-9 leaves. Herbicides were not used since an intense weed invasion was not observed; only mechanical weed control was preferred. Since there wasn't any high epidemic to common maize stalk worm and cob worm, pesticides were not also used. Before each irrigation, moisture content at efficient root depth (90 cm) was determined with gravimetric method. The amount of irrigation water to be applied in each irrigation was determined based on full irrigation treatment (I₁₀₀) as to bring the deficit moisture in 90 cm soil profile into the field capacity. Therefore, before each irrigation, soil moisture content in 0-30, 30-60 and 60-90 cm layers was determined in dry-weight base (%). Then the dry-weight-based moisture contents for each layer were converted into depths by using the Equation 1; (Eq. (1)).

Table 1 Climate data of the experimental area for the growing seasons of 2014-2015 and from 1962 to 2014

Years	Months	MMXT (°C)	MT (°C)	MMNT (°C)	MH (%)	MWS (m s ⁻¹)	MDS (h)	TR (mm)	MST (°C)	TE (mm)
Average 1962 - 2014	May	25.2	19.4	9.0	49.3	1.0	9.1	36.9	19.5	67.4
	June	27.2	26.0	17.8	34.9	1.1	11.6	11.5	26.0	162.2
	July	35.1	30.5	23.4	30.3	1.1	12.3	0.6	30.8	217.2
	August	34.5	30.3	27.0	29.5	1.0	11.4	2.7	31.8	231.0
	September	30.0	25.1	14.7	37.4	1.0	10.1	7.0	29.9	48.3
2014	May	27.07	20.88	14.79	41.40	1.1	8.9	18.6	20.1	41.6
	June	32.98	26.95	19.57	24.82	1.0	11.8	15.1	25.6	161.0
	July	38.09	31.48	24.15	19.05	1.2	12.1	0.10	30.4	208.6
	August	38.35	31.38	24.34	17.95	1.1	11.6	5.20	31.2	221.7
	September	31.75	24.63	19.31	34.90	1.0	10.0	32.1	30.3	50.6
2015	May	26.62	21.29	14.52	38.87	1.0	8.7	29.6	20.6	51.9
	June	33.09	28.16	20.0	25.50	1.1	12.0	3.6	27.4	170.7
	July	39.13	31.19	24.35	20.69	1.0	12.4	0.1	31.3	228.3
	August	38.92	31.45	24.23	23.95	1.0	11.8	6.0	32.6	243.1
	September	35.23	27.43	21.5	31.90	1.1	10.0	0.2	30.5	61.4

MMXT: Mean maximum temperature (°C), MT: Mean temperature (°C), MMNT: Mean minimum temperature (°C), MH: Mean humidity (%), MWS: Mean wind speed (m s⁻¹), MDS: Mean daily sunshine (h), TR: Total rain (mm), MST: Mean 50cm soil temperature (°C), TE: Total evaporation (mm)

Table 2 Soil physical and chemical properties of the experimental fields

Properties	Soil layer (cm)		
	0-30	30-60	60-90
Texture	Clay	Clay	Clay
Clay (%)	57.12	55.12	53.12
Silt (%)	22.0	16.0	14.0
Sand (%)	20.88	28.88	24.88
Field capacity (Pw)	33.52	36.04	35.38
Wilting point (Pw)	24.44	26.08	25.57
Bulk density (g cm ⁻³)	1.42	1.39	1.41
pH (1:2.5 s/w)	7.50	7.66	7.91
Electrical conductivity (dS m ⁻¹)	1.55	1.77	1.75
Organic matter (%)	3.09	2.06	1.80
CaCO ₃ (%)	6.4	1.9	1.9

$$d=(FC-Pw)AsxD/100 \quad (1)$$

Where; d: soil moisture content in depth (mm), FC: Field Capacity (%), Pw: dry weight-based moisture content of each layer (%), As: soil bulk density (g cm⁻³) and D: depth of layer (mm). Then, the moisture depths calculated for each layer are summed up to get total moisture content in depth (d_T) for efficient root depth (Eq. (2)):

$$d_T=d_{(0-30)}+d_{(30-60)}+d_{(60-90)} \quad (2)$$

Volume of water to be applied to each plot was calculated with Equation 3 by multiplying plot size, deficit ratio (1.0, 0.70, 0.35) and cover ratio (Eq. (3)):

$$V=d_T \times A \times U_o \times P \quad (3)$$

Where; V: Volume of water to be applied (L), A: plot size (m²), U_o: deficit ratio (%) and P: cover ratio (%).

Cover ratio was calculated through dividing plant canopy width by plant row spacing. Cover ratio (CR) was taken as 0.30 until 30% cover, as the calculated value until 80% cover and fixed at 80% at further values. The principles in Howell (2006) were considered to determine the amount of water to be used in each plot. Water applications were performed in a controlled manner through water meters and continuous dripper discharge checks. Monthly and seasonal evapotranspiration values were calculated with water balance method by using weekly soil moisture measurements (90 cm) throughout the growing season, at the beginning and end of harvest (Zelege and Wade, 2012).

Water use efficiency (WUE) was calculated through dividing dry biomass yield (kg ha⁻¹) by seasonal evapotranspiration (mm) value and irrigation water use efficiency (IWUE) was calculated through dividing dry biomass yield (kg ha⁻¹) by the amount of applied irrigation water (mm) (Scott, 2000). The following water balance equation was used to calculate plant water consumptions (Eq. (4)) (Zelege and Wade, 2012).

$$ETa = P + I - R_f - D_p \pm \Delta S \quad (4)$$

Where; ETa: Evapotranspiration (mm), P: precipitation (mm), I: amount of irrigation water (mm); R_f: runoff (mm); D_p: deep percolation (mm) and $\pm \Delta S$

(mm): change in soil water storage in root zone.

Since the discharge of selected drippers was lower than soil infiltration rate, runoff was not encountered. Since a certain amount of water was applied to bring the current moisture levels into field capacity, deep percolation was not also observed.

The equations provided in Scott (2000) were used to calculate irrigation water use efficiency (IWUE) and water use efficiency (WUE) values (Eq. (5, 6)).

$$IWUE = Y/I \quad (5)$$

$$WUE = Y/Eta \quad (6)$$

ETa: Evapotranspiration (mm)

I: amount of irrigation water (mm)

Where;

IWUE: Total irrigation water use efficiency (kg da⁻¹ mm)

WUE: Total water use efficiency (kg da⁻¹ mm)

Y: Dry matter yields of irrigation treatments

The relationship between relative evapotranspiration reduction (1-Eta⁻¹ Etm) and relative yield reduction (1-Ya⁻¹ Ym) was determined using the method given by Doorenbos and Kassam (1979). The equations are as follows (Eq. (7)).

$$\left(1 - \frac{Y_a}{Y_m}\right) = ky \left(1 - \frac{ET_a}{ET_m}\right) \quad (7)$$

Where; Y_a is actual harvested yield kg da⁻¹, Y_m is maximum harvested yield, ky is yield response factor, ET_a is actual evapotranspiration, ET_m is maximum evapotranspiration.

Following the entire measurements over the experimental plots, harvest was performed at milk-dough stage (Alkhamisi et al., 2011). Side rows were omitted and 0.5 m from top and bottom of the rows were not also considered, thus harvest was made from 5 m sections of inner rows (harvested plot size: 7 m²). Fresh biomass yield was determined at harvest. Then, randomly selected 5 plants from each plot were dried at 65°C until a constant weight to determine dry matter weights.

Dried samples were grinded in a mill with 1 mm screen. Nitrogen (N) contents of samples were determined with Kjeldahl method and crude protein ratios were calculated as (N x 6.25) (Kacar and Inal, 2008). Chemical

analyses were performed to assess feed quality and silage quality of silage maize. Dry matter analyses were performed in accordance with Weende analysis method (Nehring 1960). Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) analyses were carried out in accordance with the principles specified in Van Soest et al. (1991) with an ANKOM Fiber Analyzer device. Digestible dry matter (DDM) ratio was calculated by using ADF values with the following equation (Eq. (8)) (Ayasan and Karakozak, 2012).

$$\%DDM = 88.9 - (0.779 * \%ADF) \quad (8)$$

Where; DDM: Digestible dry matter (%) and ADF: Acid Detergent Fiber (%).

In this study, leaf areas were measured with the following equation (Eq. (9)) proposed by Stewart and Dwyer (1999). Leaf area measurements were made once in flowering period. For measurements, 3 plants from the 2nd and 3th rows of all plots were cut from the soil surface and sampled. Total leaf area of a plant was proportioned to area of a plant in order to calculate the Leaf Area Index (Eq. (10)).

$$LA = Wm \times L \times 0.743 \quad (9)$$

Where; Wm: Maximum leaf width (cm) and L: Leaf size (cm).

Leaf Area Index (LAI) was calculated using the equation below.

$$LAI = YA / PA \quad (10)$$

Where; LAI: Leaf Area Index, YA: Leaf area (cm²), PA: Plant area (cm²)

All the data acquired through these methods have been subjected to an Analysis of Variance (ANOVA) in randomized blocks - split plots design. Based on the results obtained from the analysis of variance, the significant treatments were compared with LSD (Least Significant Difference) test.

Results and Discussion

Water–Yield Relationship

Right after sowing on 19 May 2014 in the first year and on 20 May 2015 in the second year, irrigation water was supplied through drip irrigation to bring the soil moisture in 0-90 cm soil profile to field capacity (59 mm in the first year and 52 mm in the second year), thus to provide a homogenous emergence. Higher irrigation water supply of the first year was because 29.6 mm precipitation was observed in May 2015 in which sowing was performed.

Irrigation treatments were initiated together with earthing up (when the plants had 6-8 leaves) on 04.05.2014 in the first year and on 05.07.2015 in the second year (44 and 45 days after sowing) when 50% of available moisture was depleted (Howell 2001) and treatments were terminated at the beginning of dough stage on 22.08.2014 in the first year and on 23.08.2015 in the second year (93 and 94 days after sowing). A total of

8 irrigations were performed through drip irrigation in both years. Harvest times varied between 105 days (03.09.2015) in deficit irrigations and 115 days (13.09.2015) in full irrigation. Harvest was performed 10 days earlier in deficit irrigations than in full irrigation.

Amount of irrigation water applied to irrigation treatments and plant water consumptions under semi-arid climate conditions of the present study and relevant statistical analysis results (LSD groups) are provided in Table 3.

Weekly amount of irrigation water applied in irrigation treatments varied between 54-68 mm. While daily water requirement varied between 3.5-4.5 mm day⁻¹ in early vegetative period, the value reached to maximum level (9 mm day⁻¹) in pre-blooming, blooming and cob kernel-set periods. In full irrigation treatment (I₁₀₀), the amount of irrigation water applied in the first and second year was respectively measured as 693 and 666 mm. In relevant irrigation treatment, amount of applied irrigation water was more than the other treatment. Such a higher value was because of greater plant cover ratio and thus higher transpiration in I₁₀₀ treatment. In previous studies carried out about water-yield relationships in maize plants, the amount of irrigation water applied in full irrigation treatments in which soil moisture depletion was fully met varied between 263-1206 mm. The values were reported as between 752-823 mm by Gencoglan and Yazar (1999); between 463-477.7 mm by Bouazzama et al. (2012); between 814-1206 mm by Simsek and Gercek (2005); between 562-619 mm by Ucak et al. (2013); between 459-514 mm by Yolcu and Cetin (2015); as 813.9 mm by Isik et al. (2012) and between 263-322 mm by Ariturk and Erdem (2011). Current values were lower than the values reported by Gencoglan and Yazar (1999), Isik et al. (2012) and Simsek and Gercek (2005), higher than the values reported by Bouazzama et al. (2012), Yolcu and Cetin (2015) and Ariturk and Erdem (2011) and relatively coincided with the values reported by Ucak et al. (2013). Such different results were mainly because of different soil, climate and environmental conditions, irrigation programs and cultural practices (Igbadun et al. 2008).

Seasonal plant water consumption (ETa) values of full irrigation (I₁₀₀) and excessive water deficit treatment (I₃₅) were respectively observed as 770 and 411 mm in the first year and 738 and 390 mm in the second year. The plant water consumptions in the other irrigation treatment (I₇₀) were between the values of the other two treatments. In the first year, plant water consumption of I₁₀₀ treatment was 359 mm higher than I₃₅ and 161 mm higher than I₇₀ treatment. In the second year, plant water consumption of I₁₀₀ treatment was 348 mm higher than I₃₅ and 155 mm higher than I₇₀ treatment. The reasons for such higher values were higher leaf area index values (LAI) of I₁₀₀ treatment (4.65) than I₃₅ treatment (3.22) (Table 3). Soil moisture content and seasonal plant water consumption values were lower in deficit irrigation treatments. Norwood and Dumler (2002), Li et al. (2004) and Kuscu (2010) carried out deficit irrigation researches on maize plants and reported similar results with the present study. Seasonal water consumption of maize plants was reported as 562 mm by Kaman (2007) for P31G98 cultivar and 405

mm for Tietar cultivar in the first year; as 580 mm for P31G98 and 421 mm for Rx. 9292 cultivar in the second year. Gencoglan and Yazar (1999) reported values ranging from 1.026 (fully irrigated) to 410 mm (non-irrigated) in Cukurova region, Katerji et al. (1996) reported the values as between 494-644 mm, Pandey et al. (2000) between 641-668 mm, Kiziloglu et al. (2009) between 512.6-688.4 mm, Payero et al. (2006) between

625-366 mm. Greenwood et al. (2008) indicated that amount of rainfall and irrigation for silage maize irrigated by center pivot method was 782 mm in northern Victoria. Present findings were lower than the values reported by Gencoglan and Yazar (1999), higher than the values reported by Katerji et al. (1996), Pandey et al. (2000), Kiziloglu et al. (2009) and Payero et al. (2006) and were quite similar to ones reported by Greenwood et al. (2008).

Table 3 Means and LSD groups for applied irrigation water, ETa and other parameters

IR	MI	MET	DM**	WUE	IWUE	PH**	LAI**	DDM	FB**	PC**	ADF	NDF
2014 (Year)												
I ₁₀₀	693	770	34056 ^a	4.42	4.91	354 ^a	4.66 ^a	70.6 ^a	106499 ^a	8.62 ^{***}		
I ₇₀	527	609	26782 ^b	4.39	5.10	330 ^b	3.91 ^b	70.2 ^b	84417 ^b	8.23 ^b		
I ₃₅	392	411	14971 ^c	3.65	3.82	283 ^c	3.27 ^c	69.5 ^c	63394 ^c	7.17 ^c		
LSD (0.05)			214.1			4.8	0.08	0.073	136.1	0.039	ns	ns
2015 (Year)												
I ₁₀₀	666	738	32360 ^a	4.38	4.86	350 ^a	4.63 ^a	70.0 ^a	106005 ^a	7.53 ^{***}		
I ₇₀	509	583	25500 ^b	4.37	5.00	331 ^b	4.04 ^b	69.3 ^a	84240 ^b	7.26 ^b		
I ₃₅	371	390	14130 ^c	3.62	3.80	274 ^c	3.16 ^c	67.2 ^b	63402 ^c	7.19 ^b		
LSD (0.05)			26.2			10.9	0.45	0.94	34.0	0.10	ns	ns

IR: Irrigation treatments, MI: Mean Irrigation (mm), MET: Mean Eta (mm), DM: Dry matter (kg/ha), WUE: Total water use efficiency (kg/da/mm), IWUE: Total irrigation water use efficiency (kg/da/mm), PH: Plant height (cm), LAI: Leaf area index, DDM: Digestible dry matter (%), FB: Fresh biomass (kg/ha), PC: Protein content (%), ADF: Acid Detergent Fiber (%), NDF: Neutral Detergent Fiber (%), *significant at $P \leq 0.05$, ** significant at $P \leq 0.01$, ns: not significant, *** The plants were given equal watering applications until reaching 40-50 cm. Hence, the reason why the water consumption values of the irrigation subjects I70 and I35 are high is due to this.

Seasonal water consumption of the same cultivar may differ in different climates and regions. It may even be different within the same region. Such differences may be resulted from differences in climate, plant, soil characteristics, irrigation programs and methods and other cultural practices. Abiotic stress factors (temperature, relative humidity, wind) in blooming period may significantly decrease kernel formation in cobs and increase evapotranspiration rates.

Dry Matter (DM)

The results on dry matter yields of irrigation treatments are provided in Table 3. Dry matter yields were low in early and mid-vegetative period, values increased in blooming period and reached to optimum levels in dough stage. Photosynthesis reaction and organic matter production capacity is generally not at maximum level in germination and early-vegetative stages of the plants since number of leaves and sizes are not sufficient in these stages. Since carbon dioxide fixation and thus organic matter production are quite low, dry matter production is also less in these stages. The organic matter synthesized in leaves through photosynthesis to form the kernels is transferred to generative organs, thus quite high amount of organic matter is accumulated in blooming period with full irrigation. Therefore, higher dry matter contents are expected in blooming period. It was also stated in previous studies that 68-72% of carbohydrates accumulated in vegetative parts was transferred to form the kernels (Smith et al., 1999). Thus, high dry matter yields of full irrigation and low dry matter yields of deficit irrigations may be related to above mentioned processes (Yoshida, 1983).

Dry matter (DM) yield of the present study varied with irrigation treatments. In experimental years, the lowest dry matter yield was observed in I₃₅ respectively with 14.970 and 14.130 t ha⁻¹ and the highest value was

observed in I₁₀₀ respectively with 34.050 ve 32.360 t ha⁻¹. The dry matter yields of the other irrigation treatments were observed as between these values (Table 3). The dry matter yield decreased by 22% with 30% deficit (158 mm) and by 56.2% with 65% water deficit (353.5 mm). Such differences in dry matter yields of irrigation treatments were because of water deficits applied throughout the growing season. Increasing dry matter yields were observed with increasing water consumptions (I₁₀₀). This could be explained as such that dry matter (DM) accumulation increased by irrigation (Kiziloglu et al., 2009). Parallel to finding of Yolcu and Cetin (2015), decreasing dry matter contents were observed in this study with decreasing irrigation water quantities. Similarly, Li et al. (2004) reported 49% increase in maize yield with full irrigation (295 mm).

Maize dry matter yields were reported as between 23.2-30.0 t ha⁻¹ by Kiziloglu et al. (2009), between 3.9-16.4 t ha⁻¹ by Bouazzama et al. (2012), as 22 t ha⁻¹ by Greenwood et al. (2008) and as between 14.8-93.3 t ha⁻¹ by Yolcu and Cetin (2015). While the present findings were quite similar to ones reported by Yolcu and Cetin (2015), they were higher than the findings of the other researchers. Such differences between these studies were because of differences in irrigation methods, irrigation programs, local climate, soil and cultural techniques. Considering the photosynthesis metabolism, cells should have optimum moisture levels for plants to have desired photosynthesis rates and for photosystem reactions of chlorophylls to operate at optimum levels. In this case, with the aid of solar energy adsorbed by chlorophyll pigments, photolysis of water molecules takes place. Then with the photolysis of water, electrons and protons effective in organic matter formation through Calvin cycle of photosynthesis take place (Smith and Hamel, 1999). Ultimately, increase in dry matter yields in full irrigation (I₁₀₀) may be resulted from increased dry matter

contents of the plants. As it can be seen from the correlation analyses (Table 4), correlation coefficient was determined as ($r = 0.80$) and a significant positive correlation was observed between ET and dry matter at 1% significance level. Second-order significant linear relationships were observed between plant water consumption and dry matter yields of irrigation treatments (I_{35} , I_{70} , I_{100}) respectively as $Y = 2.072 ETa + 633$ ($r^2 = 0.95$), $Y = 2.371 ETa + 663.1$ ($r^2 = 0.96$), $Y = 2.030 ETa + 1635$ ($r^2 = 0.98$) in the first year and as $Y = 2.072 ETa + 633$ ($r^2 = 0.93$), $Y = 2.371 ETa + 663.1$ ($r^2 = 0.94$), $Y = 2.030 ETa + 1635$ ($r^2 = 0.97$) in the second year (Figure 1). A linear increase was observed in dry matter yields with increasing plant water consumptions (ETa). A linear relationship was also reported in previous studies between corn grain yield and evapotranspiration (Payero et al. 2006, Overman and Martin 2002). Yolcu and Cetin (2015) confirmed the linear relationships between grain and silage yield response to irrigation for corn. On the other hand, Kiziloglu et al. (2009) indicated that the decrease in fresh biomass yield per unit decrease in irrigation water was not constant.

The relationships between plant water consumption (ETa) and kernel yields may also be assessed through the relationships between relative reduction in water consumption and relative reduction in yield (Gencoglan and Yazar, 1999). Water-yield relationships were used to assess the relationships between relative reduction in evapotranspiration and relative reduction in yield and adjusted maximum yield values corresponding to maximum evapotranspiration values were determined. Then, for $(1 - ETa ET^{-1})$ and adjusted yield values, $(1 - Y_a Y_m^{-1})$ ratios were determined. Linear regression analyses were performed in experimental years between $(1 - ETa ET^{-1})$ and $(1 - Y_a Y_m^{-1})$ and equations were developed for the entire growth season. The yield response factor (k_y) was determined as 0.74 for the overall growth season of the first year as 1.06 in the second year (Figure 2).

Average k_y value of two years was calculated as 0.97. When the experimental years were assessed together, it was observed that amount of irrigation water applied to irrigation treatments were different (Table 3). Therefore, plant water consumptions and fresh biomass yields were also different. Then, different k_y values were observed in experimental years. It can be stated that irrigation treatments had a significant effect on k_y values. Yield response factor (k_y) is a quite significant parameter for irrigation planning and used as a measure of the effects of water deficits throughout growing season on crop yield. Gencoglan and Yazar (1999) reported k_y values as between 1.61-1.08; Özgürel and Pamuk (2003) reported the lowest k_y value as 0.90 and the greatest value as 1.07; Kusu (2010) reported the seasonal k_y value as 0.90; Simsek and Gercek (2005) as between 0.70-0.97; Dagdelen et al. (2006) as 1.04; Oktem (2006) as between 0.88-0.93; Kaman (2007) as between 0.75-1.78. Ertek and Kanber (2000) reported k_y value as 0.70 and indicated that a unit water deficit may result in 0.70 unit decrease in yield. The present k_y values were different from some of the above mentioned authors and were similar to some others. Slight differences were because of the differences in climate parameters, plant water consumptions, cultivars, soil characteristics and irrigation programs.

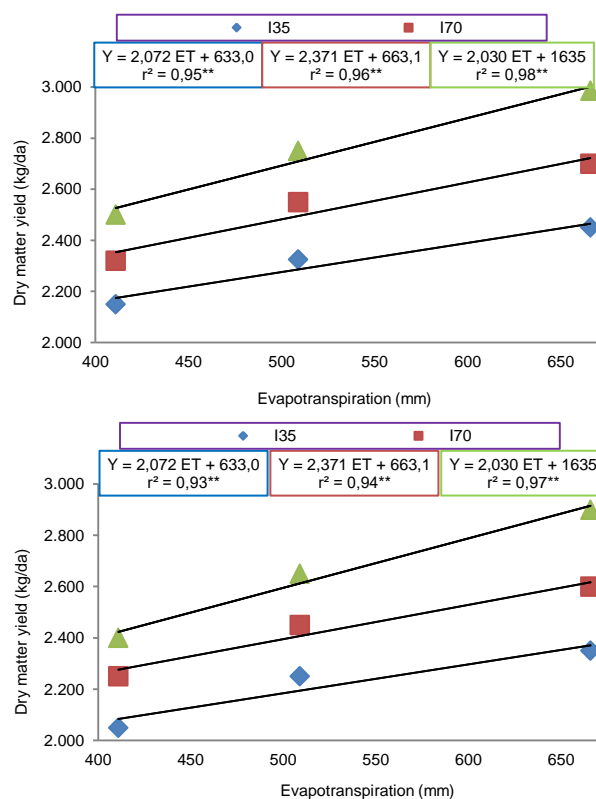


Figure 1 Plant water consumption – dry matter yield relationships of irrigation treatments

Water use efficiency (WUE) values indicating kernel yield in response to seasonal plant water consumption are provided in Table 3 for different irrigation treatments. WUE values varied with irrigation treatments. In experimental years, the lowest WUE value was observed in I_{35} irrigation treatment respectively with 3.65 and 3.62 $kg da^{-1} mm$ and the highest value was observed in I_{100} treatment respectively with 4.42 and 4.38 $kg da^{-1} mm$. WUE values of the other irrigation treatments were between these values. WUE values were quite close to each other. Except for I_{35} irrigation treatment, there are slight differences between WUE values of treatments. Since applied irrigation water quantities, water consumptions and dry matter yields were close to each other, similar WUE values were observed. These slight differences were mainly because of similar water deficits applied throughout the growing season. There was an increasing trend in WUE values with increasing water consumptions (I_{100}). This could be explained that dry matter (DM) accumulation was increased by irrigation (Kiziloglu et al. 2009). Similarly, Dagdelen et al. (2006) reported increasing WUE values with increasing applied irrigation quantities. WUE values were reported as between 1.49 - 2.71 $kg m^{-3}$ by Özgürel and Pamuk (2003), between 8.84-11.0 $kg m^{-3}$ by Mostafa and Derbala (2013), between 19.56-29.52 $kg m^{-3}$ by Ariturk and Erdem (2011), between 2.0-2.9 $kg m^{-3}$ by Trejo et al. (2006) and between 1.74-2.61 kg/m^3 by Kusu (2010). Kiziloglu et al. (2009) reported the greatest water use efficiency as 15.04 $kg m^{-3}$ in full irrigation and the lowest value as 3.16 $kg m^{-3}$ in non-irrigated treatment. While current findings were similar to findings of Kiziloglu et al. (2009), they were higher than the findings of Trejo et al. (2006),

Ozgürel and Pamuk (2003) and Kuscu (2010) and lower than the values reported by Mostafa and Derbala (2013) and Ariturk and Erdem (2011). Such differences were again because of differences in plant species, local climate conditions, plant densities, irrigation programs and cultural practices. However, while dry matter yields were taken into consideration when calculating WUE values in this study, fresh biomass yields were taken into consideration in above mentioned studies. Therefore, the values were not complying one another. Mostafa and Derbala (2013) and Bouazzama et al. (2012) reported decreasing WUE values in maize with decreasing irrigations. Gencoglan and Yazar (1999), Zhang et al. (2004) and Dagdelen et al. (2006) reported the lowest WUE values for corn in non-irrigated conditions. Current WUE values comply with these earlier findings.

The lowest irrigation water use efficiency (IWUE) value of two years was observed in I₃₅ irrigation treatment with 3.81 kg da⁻¹ mm and the highest value was observed in I₇₀ irrigation treatment with 5.05 kg da⁻¹ mm. Decreasing IWUE values were observed with increasing irrigation water quantities. Current findings comply with the results of Gencoglan and Yazar (1999) indicating similar decreasing trends in IWUE values with increasing applied irrigation water.

Fresh Biomass (FB)

Fresh biomass (FB) harvest was performed at dough stage with a black line between kernel and cob (Bouazzama et al. 2012). There were significant differences in fresh biomass yields of irrigation treatments (P<0.01). For the first and second year of the experiments, the lowest FB yield was obtained from I₃₅ irrigation treatment (63.40 t ha⁻¹) and the greatest value was obtained from I₁₀₀ irrigation treatment (106.25 t ha⁻¹). Plant canopy developed more, number of leaves increased and thus fresh biomass yields linearly increased with increasing applied irrigation water quantities. However, genotype is another significant factor effecting fresh biomass yields of the cultivars. Kiziloglu et al. (2009) reported fresh biomass yield under Erzurum conditions as between 50.74-80.70 t ha⁻¹, Erdal et al. (2009) reported the yields under Antalya conditions as between 54.61-76.54 t ha⁻¹ and Yolcu and Cetin (2015) reported the values under semi-arid climate conditions as between 54.8-93.3 t ha⁻¹. Current findings were higher than the values reported by Kiziloglu et al. (2009) and Erdal et al. (2009), but relatively similar with the ones reported by Yolcu and Cetin (2015). Such differences were primarily because of differences in irrigation programs and methods, soil and climate conditions, genetic diversity, ripening durations and cultural practices.

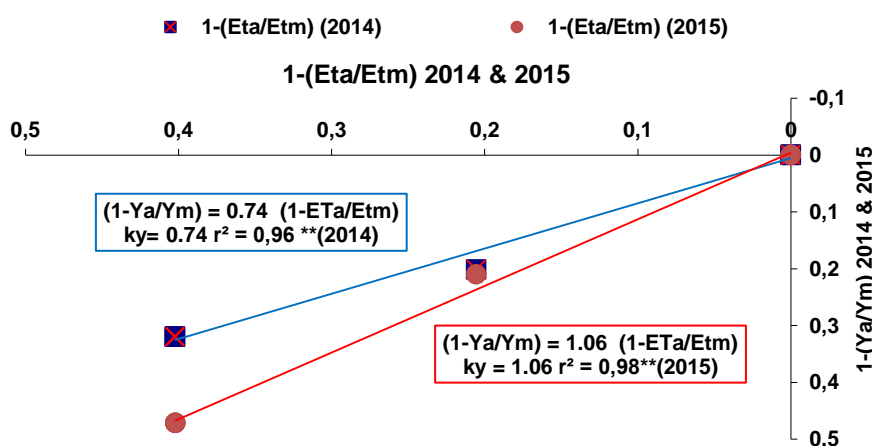


Figure 2 The relationship between evapotranspiration reduction and relative yield reduction

Table 4 Correlation coefficients between fresh biomass quality parameters

Year (2014)	Dry Matter	Protein Content	ADF	NDF	ETa	FB***
Dry Matter	1.0000					
Protein Content	0.6703**	1.0000				
ADF	0.1872ns	-0.2580ns	1.0000			
NDF	-0.0077ns	-0.4207ns	0.9800**	1.0000		
ETa	0.7824**	0.8752**	0.1280ns	-0.0449ns	1.0000	
FB	0.7923**	0.9334**	0.0114ns	-0.1664ns	0.9885**	1.0000
Year (2015)	Dry Matter	Protein Content	ADF	NDF	ETa	FB
Dry Matter	1.0000					
Protein Content	0.6698**	1.0000				
ADF	0.5688**	0.3843*	1.0000			
NDF	0.6603**	0.2844 ^{ns}	0.9024**	1.0000		
ETa	0.8135**	0.8087**	0.2450 ^{ns}	0.2976 ^{ns}	1.0000	
FB	0.4117*	0.3827*	-0.1212 ^{ns}	-0.1003 ^{ns}	0.7392**	1.0000

ADF: Acid Detergent Fiber, NDF: Neutral Detergent Fiber, FB: Fresh biomass, ETa: Plant water consumption, **: significant at P<0.01, ns: Not significant, *** Particularly emphasized parts are taken into consideration. Therefore, the others are not emphasized.

It can be stated that fresh biomass yield in maize was closely related to applied irrigation water quantities. There was an increasing trend in full irrigation and decreasing trend in deficit irrigation treatments. When the irrigation water requirement was supplied fully, plant leaves fully developed and leaf ratio was higher than stalk ratio (Frost et al., 2008). As it was in the other forage crops, differences in fresh biomass yields of irrigation treatments were because of differences in applied irrigation water quantities. Yolcu and Cetin (2015) in a deficit irrigation study on silage maize indicated different FB values and reported the lowest value for excessive water deficit treatment. Similar differences in fresh biomass yields of irrigation treatments were also reported by other researchers (Kiziloglu et al. 2009; Bouazzama et al. 2012).

Quality Analyses Results

In the first year, the greatest crude protein ratio was observed in I₁₀₀ treatment with 8.62% and the lowest crude protein ratio was observed in I₃₅ treatment with 7.17%. During the second year, the greatest crude protein ratio was observed in I₁₀₀ treatment with 7.53% and the lowest crude protein ratio was observed in I₃₅ treatment with 7.19%. Sufficient moisture levels within plant root zone and thus potential transpiration and photosynthesis of leaves yielded optimum crude protein ratios in full irrigation treatment (I₁₀₀) (Leakey et al., 2006). A portion of organic matter produced through photosynthesis, the most basic metabolism of the plants, is used in production of protein-specific precursory materials. These processes take place in chloroplasts. With the aid of DNA, RNA and ribosomes in stroma, chloroplasts both produce the proteins required for their activities and complement itself. Thus, for full activity of chloroplasts, optimum moisture is supplied with full irrigation (I₁₀₀). When the irrigation water requirement was fully supplied, organic matter is synthesized in Calvin cycle initiated with carbon dioxide fixation. A portion of synthesized organic matter is used in structure of glycerol, fatty acids, vitamins, proteins and amino acids. In this sense, optimum photosynthesis reaction takes place when the irrigation water requirement of the plant was fully supplied (I₁₀₀). With the degradation of synthesized organic matters in peroxisomes, protein precursors are formed. Such a case then assumed to increase protein ratios in full irrigation (I₁₀₀) (Lawlor and Tezara, 2009).

Karrasahin and Sade (2011) reported protein ratios in drip irrigation as between 8.31-8.75%, Buyukerdem and Akman (2008) reported protein ratios with zinc-supplemented fertilizers as between 10.7-11.4%, Ariturk and Erdem (2011) reported protein ratios as between 8.13-8.94% and Yolcu and Cetin (2015) reported the values as between 7.40-8.80%. While current findings were relatively similar with the results reported by Karrasahin and Sade (2011) and Yolcu and Cetin (2015), they were lower than the values reported by Buyukerdem and Akman (2008), Ariturk and Erdem (2011). Such differences were mainly because of differences in soil and climate conditions, irrigation program and methods, cultural practices and supplementary micro fertilizer (Zn) treatments.

Variance analyses revealed that there were not significant differences in ADF (Acid Detergent Fiber) and NDF (Neutral Detergent Fiber) values of irrigation treatments. Current findings comply with the results of Isik et al (2012) indicating linear increases in crude protein ratios with increasing irrigation water levels and insignificant differences in ADF and NDF ratios of different irrigation levels.

Several researchers indicated that a quality maize fresh biomass should have a digestible dry matter (DDM) content of 70-75% and animals could convert that much DDM into optimum yields (Karakozak and Ayasan 2010; Guney et al., 2010). Therefore, the digestible dry matter content of 70% in I₁₀₀ irrigation treatment complied with the values specified for quality silage. The DDM content of 68% in I₃₅ irrigation treatment indicated that DDM ratios decreased linearly with increasing water deficits and DDM contents negatively influenced by water deficits. High DDM ratio of full irrigation treatment (I₁₀₀) may also be related to low ADF ratio (25%) of the treatment. In brief, DDM ratios increased with decreasing ADF ratios. Higher ADF ratios of deficit irrigation treatments also decreased DDM ratios in these treatments.

Correlation analyses were performed to elucidate the relationships between plant water consumption and quality parameters of maize. The correlation coefficients (r) for the relationships of plant water consumption (ETa) with protein ratio, ADF, NDF and silage yield are provided in Table 4. There were some significant correlations between investigated traits at 1% level. Highly positive correlation (r: 0.824) was observed between ETa and dry matter content of the first year (P<0.05). The greatest correlation (r: 0.98) was observed between ETa and fresh biomass yield. The correlation coefficient between ETa and protein content was identified as (r: 0.87) and significant positive correlation was observed between ETa and protein content at 1% level.

In the second year, highly positive correlation (r: 0.8135) was observed between ETa and dry matter at 1% significance level. The correlation coefficient between ETa and protein content was observed as (r: 0.87) and the correlation was again significantly positive at 1% level. The correlations of ETa with ADF and NDF were not found to be significant. Therefore, it can be stated based on these findings that dry matter and protein contents linearly increased with increasing plant water consumptions. Then, it can also be stated that deficit irrigations should be avoided for quality silage. However, I₇₀ deficit irrigation can also be recommended under deficit water resources conditions. Previous researchers also reported positive correlations between plant water consumption and dry matter contents (Camoglu et al., 2011; Kiziloglu et al., 2009; Yolcu and Cetin, 2015; Bouazzama, 2012; Karimi et al., 2005; Demirtas and Kirnak, 2009). Karrasahin and Sade (2011) reported similar correlations between plant water consumption and protein contents. Thus, current findings comply with those earlier results.

Conclusion

Current findings revealed that total fresh and dry matter yield of silage maize significantly decreased with water stress. Water use efficiency values decreased with increasing water deficit levels. A positive linear relationship was observed between evapotranspiration and total fresh biomass yield. Digestible dry matter (DDM) and leaf area index values also increased with increasing amount of applied irrigation water.

Correlation analyses revealed significant correlations between plant water consumption (ETa) and quality parameters at 1% significance level. Highly positive correlation was observed between ETa and dry matter ($r: 0.80$) ($P < 0.01$). The correlation coefficient between ETa and protein content was identified as ($r: 0.80$) and the positive correlation was also assessed as highly significant at 1% level. Dry matter and protein contents linearly increased with increasing plant water consumptions. On the other hand, water use efficiency (WUE) values were quite different in different irrigation treatments. The lowest WUE values of the experimental years were observed in I_{35} irrigation treatments respectively with 3.65 and 3.62 kg da⁻¹ mm and the greatest values were observed in I_{100} irrigation treatment respectively with 4.42 and 4.38 kg da⁻¹mm.

Dry matter yields decreased by 22% under 30% deficit (158 mm) and decreased by 56.2% under 65% (353.5 mm) deficits. Statistical analysis revealed that I_{100} irrigation treatment with 33 t ha⁻¹ dry biomass yield was placed in the 1st group and the I_{70} irrigation treatment with 25.5 t ha⁻¹ dry biomass yield was placed in the 2nd group (they were placed in quite close groups). Therefore, it was thought that production with more than 30% water deficit was not profitable and such higher deficit ratios significantly reduce dry biomass yields and quality of the resultant silage. Thus it was concluded that full irrigation (I_{100}) should be applied in maize culture under semi-arid climate conditions when the water resources were sufficient. However, under deficit water resources in semi-arid climates, I_{70} irrigation treatment can be recommended. When the deficit irrigations were distributed evenly over the growing stages, the yield response factor (ky) indicating the effects of water deficits on crop yields can be taken as 0.90.

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