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Water-Yield Relations of Drip Irrigated Maize in Arid and Semi-Arid Regions

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ABSTRACT: *This study was conducted to determine water-yield relations of drip-irrigated maize that was grown in Central Anatolia Region of Turkey with a dominant arid and semi-arid climate. Four different irrigation treatments were applied to experimental plots in 7-day intervals. Irrigation treatments were laid out based on 7-day cumulative evaporation from class-A pan (I_{120} – 120%, I_{100} – 100%, I_{80} – 80% and I_{60} – 60% of pan evaporation). Applied irrigation water quantities varied between 431-676 mm in 2009 and between 453-726 mm in 2010. The greatest seasonal water consumption (821 mm) was observed in I_{120} treatment of 2010 and the lowest (590.1 mm) in I_{60} treatment of 2009. The greatest kernel yield per hectare (15773 kg ha^{-1}) was obtained from I_{120} treatment of 2010 and the lowest (8986 kg ha^{-1}) from I_{60} treatment of 2009. Water use efficiency (WUE) values varied between 1.45-1.99 kg m^{-3} and irrigation water use efficiency (IWUE) values varied between 1.84-2.39 kg m^{-3}. Yield-response factor (ky) of maize was calculated as 1.47 in 2009 and 1.36, in 2010. While I_{100} was recommended as the ideal irrigation program, I_{80} treatments could also be used to improve water use efficiencies in places where full irrigation is not possible.*

Keywords: *Corn,* ***Zea mays*** L., *seed yield, class-A pan, drip irrigation, water use efficiencies.*

Kurak ve Yarı Kurak Bölgelerde Damla Sulama ile Sulanan Mısır Bitkisinin Su-Verim İlişkileri

ÖZ: *Bu araştırma, Türkiye'nin kurak ve yarı kurak iklim özelliği gösteren İç Anadolu Bölgesi'nde yer alan Konya ilinde damla sulama yöntemi ile sulanan mısır bitkisinin su-verim ilişkilerini belirlemek amacıyla yürütülmüştür. Araştırmada, parsellere 7 gün sulama aralığında dört farklı sulama miktarı uygulanmıştır. Sulama suyu miktarları, A sınıfı buharlaşma kabından oluşan yığışımlı buharlaşma değerinin; % 120'si (I_{120}), % 100'ü (I_{100}), % 80'i (I_{80}) ve % 60'ı (I_{60}) alınarak oluşturulmuştur. Araştırmada konulara 2009 yılında 431-676 mm, 2010 yılında ise 453-726 mm arasında değişen miktarlarda su uygulanmıştır. Araştırma sonuçlarına göre, mısır bitkisinin mevsimlik su tüketimi en yüksek 821 mm ile 2010 yılında I_{120} konusunda, en düşük 590.1 mm ile 2009 yılında I_{60} konusunda gerçekleşmiştir. Birim alan tane verimi, en yüksek 15773 kg ha^{-1} ile 2010 yılında I_{120} konusunda; en düşük ise 8986 kg ha^{-1} ile 2009 yılında I_{60} konusundan elde edilmiştir. Su kullanım randımanı (WUE) ve sulama suyu kullanım randımanı (IWUE) konulara bağlı olarak, sırasıyla 1.45-1.99 kg m^{-3} ve 1.84-2.39 kg m^{-3} arasında değişmiştir. Mısır verim tepki etmeni (ky) 2009-2010 yıllarında sırası ile 1.47 ve 1.36 olarak hesaplanmıştır. Araştırma sonucunda I_{100} konusu ideal sulama programı olarak önerilirken, tam sulamanın mümkün olmadığı koşullarda mevcut su potansiyeline bağlı olarak I_{80} konusu da benzer ekolojik bölgelerde su kullanım verimliliğini artırmak için önerilebilir.*

Anahtar Kelimeler: *Mısır,* ***Zea mays*** L., *verim, A sınıfı buharlaşma kabı, damla sulama, su kullanım etkinliği.*

INTRODUCTION

Among cereal crops, maize is perfectly rich in nutrients, thus playing a significant role in human nutrition and animal feed. With a rich starch and oil content, maize is also used as a raw material in the starch-based sugar and oil industries. Cereals compensate for the nutritional needs of the ever-increasing world and Turkish population. The USA (36%) is the leading maize producer of the world and China (21%) is the second greatest maize producer. Kernel maize production is performed over 189 million ha worldwide and annual grain-kernel production is around 1.088 million tons (Anonymous, 2017). In 2018, in Turkey, kernel maize production was practiced over 591.900 ha and annual production was 5.7 million tons. In Konya province, maize is cultivated on over 107.462 ha and annual production was 110.453 tons (Anonymous, 2018). In this region, maize was cultivated on only 13.138 ha in 2009; thus, by 2018, this value increased by 718%. The primary reason for such a great increase in cultivated area is the greater income-generating potential of maize for farmers compared to other cereals. Widespread use of drip irrigation in the region also accelerated the rate of increase in land used for maize cultivation.

Konya province has a dominant terrestrial climate with hot-dry summers and quite limited water resources. Annual precipitation levels are below 350 mm. Both limited water resources and quite low precipitation levels obligate efficient water use for irrigation. Irrigation is a vital component of agricultural practices especially in Konya province. As compared to other cereal crops, maize has a relatively greater irrigation water requirement (Van Donk *et al.*, 2013). Despite the limited water resources of the region, the rapidly increasing area of land under maize cultivation entailed the development of new irrigation techniques and programs. In the near future, the primary challenge will be more productions with less water. Therefore, in such regions, pressurized irrigation methods should be widespread to improve water use efficiencies. Optimum plant growth could be achieved by applying sufficient quantities of water at proper times in a suitable agroecological zone. Previous studies revealed that kernel yield per hectare could be significantly increased with accurate irrigation schedules (Çakır, 2004; Kızıloğlu *et al.*, 2008; Kara and Biber, 2008). Field irrigation losses constitute the greatest losses in agricultural irrigation. Such losses are reduced by selection of appropriate programs and management practices pursuant to soil-plant-water relations. Drip irrigation with a high water application efficiency should be preferred in regions with deficit water resources. The drip irrigation method has various advantages over the other pressurized irrigation methods in terms of plant and nutrient management, saline water management, yield and quality, disease and pests control, weed control and deep percolation (Doğan and Kırnak, 2010). Maize culture has been practiced under drip irrigation in Konya region and the method is also supported by the Turkish Government.

Deficit irrigation is a strategy for efficient water use in irrigation. It improves water and irrigation water use efficiencies of irrigation. In deficit irrigation, plants are exposed to specified water stress levels at certain growth stages of varying times up to harvest. In this way, water saving is provided without significant yield losses (Kırda, 2002). Water-yield relations should be well comprehended while generating deficit irrigation programs and deficits should then be shaped accordingly. Some previous researchers reported linear decreases in yields with decreasing crop water consumption and indicated such a relation as a yield response factor (ky) (Stewart *et al.*, 1976; Doorenbos and Kassam, 1979; Yazar *et al.*, 2002).

Crop evapotranspiration is mostly estimated from correlations between evaporation measured from class-A pans and reference crop evapotranspiration. Since the climate factors effective on pan evaporations are also effective on crop water consumption, quite accurate results are achieved with this method. This method of estimation is commonly used worldwide (Irmak *et al.*, 2002; Kızıloğlu *et al.*, 2008).

The present research was carried out to assess water consumption, yield response factor (ky) and water use efficiency of drip-irrigated maize cultivated in Konya province located in the Central Anatolia Region of Turkey with dominant terrestrial climate.

MATERIALS and METHODS

"Market" hybrid grain corn cultivar was used as an experimental material. Market is a medium maturity hybrid maize in FAO 600 group, resistant to common smut (*Ustilago maydis)* and *Fusarium graminearum.* The experiment was conducted on experimental fields of Konya Sugar Company in 2009 and 2010 growing seasons. The experimental fields are located between 36° 42′ - 39° 16′ N latitudes and 31° 14′ - 34° 26′ E longitudes. The altitude of the experimental site is 1020 m. A portable climate station was installed to measure climate parameters (Table 1) in the years of the experimental period.

Experimental soils had clay-loamy texture with an available water capacity of 132.3 mm in 90 cm soil profile (Table 2). Soil pH values varied between 7.7 - 7.8 and salinity values varied between 0.67 - 0.74 dS m^{-1}. Irrigation water quality class was C_2S_1 and suitable for use in maize culture without any problems.

Plants were irrigated with drip irrigation established with 16 mm lateral lines spaced 70 cm in rows with 4 L ha^{-1} drippers spaced 33 cm apart in the rows. Double-ring infiltrometer was used to measure soil infiltration rate. The infiltration rate value for the experimental site was measured as 25 mm ha^{-1}.

Table 1. Climate parameters throughout the growing seasons.
Çizelge 1. Büyüme mevsimleri boyunca iklim parametreleri.

Year Yıl	Climate parameters İklim parametreleri	May Mayıs	June Haziran	July Temmuz	August Ağustos	September Eylül	October Ekim
2009	Mean temperature (°C) Ortalama sıcaklık (°C)	14.6	20.4	22.6	21.2	16.8	14.8
	Mean relative humidity (%) Ortalama bağıl nem (%)	59.5	46.9	49.1	41.6	55.9	61.1
	Monthly precipitation (mm) Aylık yağış (mm)	47.2	11.8	17.4	0.0	25.6	24.2
	Wind speed (m s^{-1}) Rüzgar hızı (m s^{-1})	0.9	1.1	1.2	0.9	0.6	0.7
2010	Mean temperature (°C) Ortalama sıcaklık (°C)	16.7	20.1	25.0	26.1	20.6	12.8
	Mean relative humidity (%) Ortalama bağıl nem (%)	51.2	58.7	45.8	38.4	45.8	68.9
	Monthly precipitation (mm) Aylık yağış (mm)	35.6	95.2	7.4	0.5	0.8	77.8
	Wind speed (m s^{-1}) Rüzgar hızı (m s^{-1})	1.0	1.3	1.1	0.9	1.0	0.8

Table 2. Some physical characteristics of soil in experimental field.
Çizelge 2. Deneme alanı topraklarının bazı fiziksel özellikleri.

Depth Derinlik (cm)	Texture Tekstür	Bulk density Hacim ağırlığı (g cm^{-3})	Field capacity Tarla kapasitesi (cm^3 cm^{-3})	Permanent wilting point Solma noktası (cm^3 cm^{-3})	Available water capacity Faydalı su kapasitesi (mm/30 cm)
0 - 30	CL	1.26	30.6	15.4	45.6
30 - 60	CL	1.31	34.2	20.0	42.6
60 - 90	CL	1.32	36.0	21.3	44.1
90-120	CL	1.35	39.4	25.2	42.6

Four different irrigation treatments were calculated with the use of 7-day evaporation from Class-A pan multiplied with different pan coefficients (I_{60} =60% of pan evaporation, I_{80} = 80% of pan evaporation, I_{100} = 100% of pan evaporation and I_{120} = 120% of pan evaporation). Experimental design was Randomized Block Design (RCBD) with three replicates. Sowing was performed at 70 x 18 cm apart on plant density. Each plot (4.2 x 6 m) had 6 rows. Randomized blocks were laid out 2 m apart and plots 3.5 m apart to prevent interactions.

Sowing and harvest dates were 15 May - 30 October in 2009 and 14 May - 02 November in 2010. Initial emergence was observed in the last week of May and homogeneous emergence was observed in the second week of June.

Fertilizations were performed based on soil analysis results. The plots were fertilized before planting with a compound fertilizer NPK (15% N, 15% P_2O_5, 15% K_2O) at the rate of 0.50 ton ha^{-1} in the first year, and at the rate of 0.45 ton h^{-1} in the second year. After planting, when the plant reached 30 - 40 cm in height, ammonium sulfate (21% N) was applied at the rate of 0.40 ton ha^{-1} in the first year, and 0.38 ton ha^{-1} in the second year. Pests and disease controls were practiced when needed. The ears were harvested manually. The central four rows were harvested and outer rows were omitted. One meter was also omitted from the beginning and end of each row. Therefore, harvest was performed from 11.2 m^2 (4 x 2.8 m) in order to exclude boundary effects.

An initial irrigation was performed for germination and homogeneous emergence. Irrigation treatments were initiated when 30% of available water capacity was depleted (Kırda *et al.*, 2005). Equation 1 was used to determine the amount of water to be applied as specified by Kanber (1984):

I=A x Epan x Kpc (Eq.1)

where;

I: Applied water (liters),

Epan:7-days evaporation from class-A pan (mm),

Kpc: Crop-Pan coefficient.

ΔT Profile-Probe device was used to monitor soil moisture.

Gravimetric moisture contents were used in calibration of ΔT Profile-Probe. Equation 2 was used to determine crop water consumptions (ET) as recommended by James (1988):

$$ET = I + R - D_P + C_P - R_f \pm \Delta S \quad \text{(Eq.2)}$$

where;

ET: Crop water consumption (mm),

I: Applied water (mm),

R: Efficient precipitation (mm),

Dp: Deep percolation (mm),

Cp: Capillary rise (mm),

Rf: Surface runoff (mm),

ΔS: change in soil moisture (mm) (calculated as the difference in moisture contents before sowing and at harvest).

Dp values were measured gravimetrically from soil samples taken from 90 and 120 cm depths with a soil auger before and after irrigation following the controls made with ΔT Profile-Probe. Since the experimental site was composed of deep and unsaline soils without any drainage problems, there was no capillary rise, thus Cp was not taken into consideration in calculations. Since the drip irrigation system was designed and operated properly, Rf was also not taken into consideration.

Equations 3 and 4 were used to determine water use efficiency (WUE) and irrigation water use efficiency (IWUE) (Tanner and Sinclair, 1983).

$$WUE = \frac{E_y}{ET} \quad \text{(Eq.3)}$$

where;

WUE: Water use efficiency (kg m^{-3}),

Ey: Grain yield per hectare (kg ha^{-1}),

ET: Seasonal crop water consumption (mm).

$$IWUE = \frac{E_y}{I} \qquad \text{(Eq.4)}$$

where;

IWUE: Irrigation water sue efficiency (kg m^{-3}),

I: Seasonal irrigation water quantity (mm).

Several models have been developed for water-yield relations. Equation 5 was used to model water-yield relations (Stewart *et al.*, 1976).

(1-Ya/Ym) = ky(1-ETa/ETm) (Eq.5)

where;

Ya: Actual grain yield per hectare under water deficit (kg ha^{-1}),

Ym: Maximum grain yield per hectare under full irrigation (kg ha^{-1}),

ETa: Actual crop water consumption under water deficit (mm),

ETm: Maximum crop water consumption under full irrigation (mm),

ky: yield-response factor.

Yield and yield components

The cobs harvested from 11.2 m^2 (4 x 2.8 m) were shucked and weighed. Grain moisture was measured with a grain moisture meter. Grain yield was expressed on a 15% moisture basis. To determine yield components, ten cobs from each plot were randomly selected. A hundred kernels extracted from selected cobs was randomly selected, weighed and multiplied by ten. This procedure was repeated four times and mean thousand seed weight was calculated and expressed on a 15% moisture basis. Cob diameter and length of the ten cobs were measured using a vernier caliper with an accuracy of ±0.01. To determine the numbers and weight of the kernels, the kernels from the selected cobs were counted and weighed, average values were recorded.

Statistical analysis

The data were analyzed with SPSS software version 16.0 (Anonymous, 2019). The results were analyzed using analysis of variance. Differences among treatments were determined using Duncan's multiple range tests (Yurtsever, 1984; Steel and Torrie, 1980).

RESULTS and DISCUSSION

Irrigation water quantity and crop water consumption

For uniform germination and emergence, 105 and 95 mm irrigation water was administered in 2009 and 2010 respectively, through irrigation sprinkler. Irrigation treatments were commenced on 1st of July and terminated on 9th of September in 2009 and initiated on 2nd of July and terminated on 14th of September in 2010. Applied irrigation water quantities and water consumption are given in Table 3.

In I_{120}, total deep percolation was calculated as 21 mm in 2009 and 30 mm in 2010. Deep percolation was not observed in I_{60}, I_{80} and I_{100} treatments. Net applied irrigation water quantity varied between 431 - 676 mm in 2009 and 453 - 726 mm in 2010. Seasonal water consumption varied between 590.1 - 781.0 mm in 2009 and between 617.4 - 821.0 mm in 2010. The greatest water consumptions were observed in I_{120} treatments and the lowest in I_{60} treatments of both years. The present study's seasonal water consumptions at full irrigation (781 – 821 mm) were lower than the values of previous studies; 937 mm (Howell *et al.*, 1995) and 1078 mm (Kuşcu *et al.*, 2013). Such greater values were mostly obtained from the cultivation of dent corn varieties (Emeklier *et al.*, 2018) with longer vegetative periods used in those studies. Kızıloğlu *et al.* (2008) reported less water consumption (688.4 mm) than the present study for maize plants with shorter vegetative period in Erzurum compared to Konya province.

Table 3. Applied irrigation water quantities and seasonal crop water consumptions.
Çizelge 3. Uygulanan sulama suyu miktarları ve mevsimsel bitki su tüketim değerleri.

Year Yıl	Irrigation treatments Sulama konuları	Net irrigation water Net sulama suyu miktarı (mm)	Effective rainfall Etkili yağış (mm)	Soil moisture at sowing Ekimde toprak nemi (mm/90cm)	Soil moisture at harvest Hasatta toprak nemi (mm/90cm)	Seasonal plant water consumption Mevsimlik bitki su tüketimi (mm)
2009	I_{120}	676	111.2	238.1	244.3	781.0
	I_{100}	608	111.2	238.1	229.6	727.7
	I_{80}	519	111.2	238.1	205.8	662.5
	I_{60}	431	111.2	238.1	190.2	590.1
2010	I_{120}	726	139.5	250.5	295.0	821.0
	I_{100}	635	139.5	250.5	265.0	760.0
	I_{80}	544	139.5	250.5	236.9	697.1
	I_{60}	453	139.5	250.5	225.6	617.4

Yield and yield components

Kernel yields per hectare for 2009 and 2010 are provided in Table 4. Greater kernel yields obtained in 2010 than 2009 could be explained by differences in climate conditions and longer vegetative durations. There were significant differences in kernel yields per hectare of the experimental treatments ($p<0.01$).

The greatest mean kernel yield per hectare was observed in I_{100} irrigation in 2009 and I_{120} irrigation in 2010 and the least in I_{60} irrigations of both years. According to Duncan's test results for kernel yields, the differences between I_{120} and I_{100} irrigations were not significant. The water quantity used in I_{120} irrigation was 11% greater than the quantity in I_{100} irrigation in 2009 and 14% greater in 2010. Such findings revealed about 11 - 14% water savings with deficit irrigations. Previous studies also reported increased kernel yields per hectare with increased quantities of water (Kara and Biber, 2008; Payero *et al.*, 2008; Farré and Faci, 2009). Present mean kernel yield per hectare of full irrigation treatments (14480 kg ha^{-1}) was greater than the values of earlier reports (11340 kg ha^{-1}, Dağdelen *et al.*, 2006; 10370 kg ha^{-1}, Bozkurt *et al.*, 2011).

The relationships among yield, irrigation water and plant water consumptions are presented in Figure 1. The linear relationships among kernel yield per hectare, net irrigation water and plant water consumptions of the present study are in accordance with the results of previous research (Kırnak *et al.*, 2003; Payero *et al.*, 2006; Djaman *et al.*, 2013).

Table 4. Kernel yields per hectare of experimental treatments (kg ha^{-1}).
Çizelge 4. Konulara ait birim alan tane verimleri (kg ha^{-1}).

Treatments (I) Konular (I)	Year (Y) / Yıl (Y) 2009	2010	Mean Ortalama
I_{120}	13187 a	15773 a	14480 a
I_{100}	13188 a	15160 a	14174 a
I_{80}	9575 b	11920 b	10748 b
I_{60}	8986 b	10527 c	9757 b
I	**	**	**
I×Y			ns
CV(%)	6.67	2.93	4.86

**p<0,01, *p<0,05, ns: not significant (önemli değil). Same letters in a column are not significantly different at the 0.01 probability levels [Aynı harfle gösterilen ortalamalar arasında önemli fark (P ≤ 0,01) yoktur].

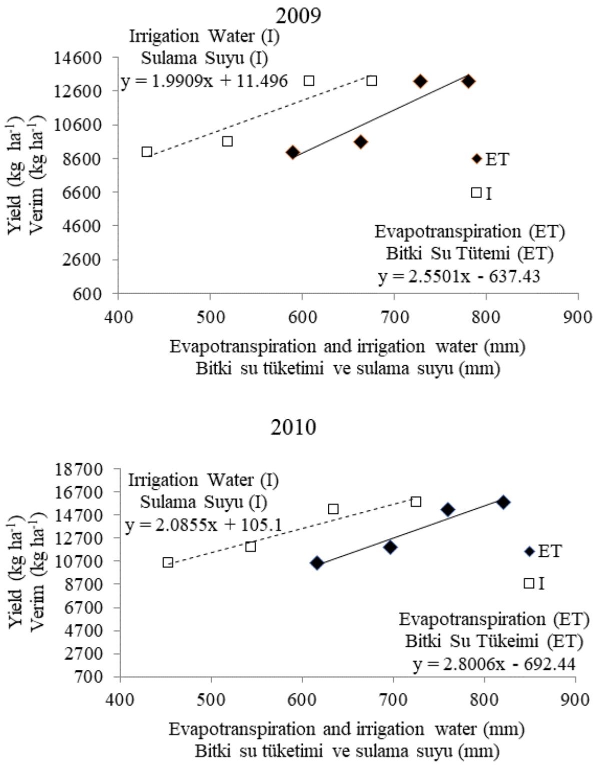

Figure 1. Relationships among yield, irrigation water and plant water consumptions.
Şekil 1. Verim, sulama suyu ve bitki su tüketimi arasındaki ilişkiler.

The maize yield components of the present experimental treatments (different irrigation regimes) are provided in Table 5. Differences in thousand-kernel weight, cob length and diameter, number of kernels per cob and kernel weight per cob of the experimental treatments were found to be significant. Only the differences in number of kernels per cob were not significant in 2009.

Yield components were positively affected by irrigation treatments and increasing values were observed with increasing amount of water. According to Duncan's test results for yield components, I_{120} and I_{100} treatments were generally found in the same group in both years. It can be concluded that the irrigation amount difference between the I_{120} and I_{100} treatment did not significantly affect yield components. Özgürel and Pamuk (2003) reported the least thousand-kernel weights (265 - 271 g) in deficit irrigations and the greatest values (332 - 353 g) in full irrigations indicating significant decreases in thousand-kernel weights with water deficits. Vural and Dağdelen (2008) reported significant effects of irrigations on thousand-kernel weight of maize. Gençel (2002) reported thousand-kernel weights under different irrigation regimes as between 328.7 - 353.2 g with the greatest value from full irrigation.

Vural and Dağdelen (2008) reported significant effects of irrigation treatments on cob diameters. İstanbulluoğlu and Kocaman (1996) indicated that water deficits at the tasseling formation stage prevented pollination and thus reduced number of kernels. In present study, number of kernels per cob also decreased with water deficits. Çakır (2004) indicated that water deficits at full mature stage reduced kernel weights; İstanbulluoğlu and Kocaman (1996) reported average cob lengths as between 16.7 - 20.4 cm and Özgürel and Pamuk (2003) as between 13.7 - 20.0 cm. Present cob lengths are in accordance with those earlier studies.

Water use efficiencies

The ratio of biomass or kernel yield to water used to produce this biomass is defined as water use efficiency while the ratio of yield to irrigation water supplied is defined as irrigation water use efficiency. WUE indicates the amount of production per unit of water. Apart from applied water, plants also benefit from soil moisture and precipitation. Plants also may not be able to fully benefit from irrigation water since there may be runoff and deep percolation. Water and irrigation water use efficiencies both generally affected by yield potential, method of irrigation, environmental and climatic parameters (Kuşcu *et al.*, 2013). In the present study, soil, climate and agronomic practices had different effects on WUE and IWUE values, therefore differences were observed in both values (Table 6).

Table 5. Yield components of experimental treatments.
Çizelge 5. Deneme konularına ait verim parametreleri.

Treatments I Konular I	Thousand-kernel weight Bin tane ağırlığı (g)			Cob diameter Koçan çapı (mm)			Cob length Koçan boyu (cm)			Number of kernels per cob Koçandaki tane sayısı			Kernel weight per cob Koçan başı tane ağırlığı (g)		
	Yıllar Y Years Y		Mean Ort.	Yıllar Y Years Y		Mean Ort.	Yıllar Y Years Y		Mean Ort.	Yıllar Y Years Y		Mean Ort.	Yıllar Y Years Y		Mean Ort.
	2009	2010		2009	2010		2009	2010		2009	2010		2009	2010	
I_{120}	339.1 a	338.5 a	338.8 a	48.9a	50.6a	49.8 a	18.9a	23.1a	21.0 a	740.6	835.7a	788.2 a	243.9 a	276.1 a	260.0 a
I_{100}	328.8 ab	332.8 a	330.8 ab	47.1ab	49.8ab	48.5 a	17.6ab	20.5ab	19.1 ab	694.7	806.0a	750.3 ab	216.9 ab	265.3 a	241.1 a
I_{80}	294.3 b	319.2 b	306.7 b	45.9b	47.9bc	46.9 b	17.4ab	18.1bc	17.7 bc	671.3	672.7b	672.0 bc	199.3 bc	208.9 b	204.1 b
I_{60}	289.8 b	263.4 c	276.6 c	45.5b	47.0c	46.2 b	15.6b	16.8c	16.2 c	637.0	634.3b	635.7 c	172.7 c	184.2 c	178.5 c
I	*	**	**	**	**	**	**	*	**	ns	*	**	**	**	**
IxY			*			ns			ns			ns			*
CV (%)	6.03	1.28	4.35	1.65	1.57	1.61	4.21	8.13	6.71	6.25	8.16	7.34	6.52	2.97	4.88

**p<0,01, *p<0,05, ns:not significant; Same letters in a column are not significantly different at the 0.01 probability levels [Aynı harfle gösterilen ortalamalar arasında önemli fark ($P \leq 0{,}01$) yoktur].

Table 6. Water use efficiencies of experimental treatments (kg m^{-3}).
Çizelge 6. Deneme konularına ait su kullanım randımanları (kg m^{-3}).

Treatments Konular	Water use efficiency Su kullanım randımanı		Irrigation water use efficiency Sulama suyu kullanım randımanı	
	2009	2010	2009	2010
I_{120}	1.69	1.92	1.95	2.17
I_{100}	1.81	1.99	2.17	2.39
I_{80}	1.45	1.71	1.84	2.19
I_{60}	1.52	1.71	2.08	2.32

Water use efficiency (WUE) of I_{120}, I_{100}, I_{80} and I_{60} irrigation were determined to be 1.69, 1.81, 1.45 and 1.52 kg m^{-3} in 2009 and as 1.92, 1.99, 1.71 and 1.71 kg m^{-3} in 2010, respectively. Irrigation water use efficiency (IWUE) of I_{120}, I_{100}, I_{80} and I_{60} irrigations were determined to be 1.95, 2.17, 1.84 and 2.08 kg m^{-3} in 2009 and as 2.17, 2.39, 2.19 and 2.32 kg m^{-3} in 2010, respectively. The greatest WUE and IWUE were obtained from I_{100} treatments and the least from I_{80} treatments in both years. When the water and irrigation water use efficiencies of I_{120} and I_{100} irrigations with the greatest yields were compared, it was observed that in both years, I_{100} treatments had greater WUE (1.81-1.99) and IWUE (2.17- 2.39) values than the I_{120} treatments WUE (1.69-1.92) and IWUE (1.95- 2.17). These findings suggest that that greatest yields per unit of water were achieved in I_{100} treatments, thus full irrigation was recommended for maize irrigation in Konya province.

WUE values were lower than IWUE values in both years since plants benefited from already available stored water within the soil profile before the growing season and plant water consumptions varied based on available water capacity of the soils. Present WUE (1.81-1.92) and IWUE (2.17- 2.17) values of the treatments with the largest yields were greater than the values of Kuşcu *et al.* (2013) (WUE: 1.52-1.58; IWUE: 1.24-1.02); Abd El- Wahed and Ali (2013) (WUE: 1.21-1.22). In those studies, it was observed that less water was consumed per kg maize production in Konya Plain with shorter vegetative durations. Yazar *et al.* (2002) conducted a study in Harran Plain on second crop maize with shorter vegetative duration and reported WUE values of the treatment with the greatest yields as 2.01 and 2.11 and IWUE values as 1.95 and 2.05.

Yield-response factor (ky)

The ky designates the relative effects of deficit irrigations on yields. A ky value greater than 1 indicates plant sensitivity to deficit irrigations and a ky value less than 1 indicates plant tolerance to water deficit (Steduto *et al.*, 2012).

The relative decreases in yield corresponding to the relative decreases in water consumption for 2009 are provided in Table 7. As can be inferred from the Table, in 2009, the highest yield was not observed in treatments with the greatest seasonal water consumption. The method specified by Köksal *et al.* (2001) was used while calculating yield-response in 2009. While calculating ky values, the relationships between actual water consumptions and yields were investigated through regression analysis and a linear relationship was determined between water consumptions and yields. With the use of the equation of this linear relationship, a new yield value was calculated for the treatment with the largest water consumption. The ky graphs and relevant regression equations are presented in Figure 2. A linear relationship was observed between water consumption and yields, and yields increased with increasing water consumption.

Relative decreases in yield corresponding to relative decrease in water consumption for 2010 are provided in Table 8. The resultant regression equations and ky graphs are shown in Figure 2.

Table 7. Relative decrease in yield corresponding to relative decrease in water consumption in 2009.
Çizelge 7. 2009 yılına ait oransal su tüketimi açığına karşılık oransal verim azalması değerleri.

Treatments Konular	ETm (mm)	ETa (mm)	1-ETa/ETm	Ym (kg ha^{-1})	Ya (kg ha^{-1})	1-Ya/Ym
I_{120}	781	-	0.00	13542*	13187	0.00
I_{100}	-	728	0.07	13188	-	0.03
I_{80}	-	663	0.15	-	9576	0.29
I_{60}	-	590	0.24	-	8986	0.34

*Ym is adjusted maximum yield with the equation of 2.5501ET-637.43 (Köksal *et al.*, 2001).
* Ym: 2,5501ET-637,43 denklemiyle hesaplanan düzeltilmiş en yüksek verim değeri. (Köksal ve ark., 2001).
ETm: Maximum crop water consumption under full irrigation (mm) / ETm: Tam sulama şartlarında en yüksek bitki su tüketimi (mm).
ETa: Actual crop water consumption under water deficit (mm) / ETa: Kısıtlı sulama şartları altında gerçekleşen bitki su tüketimi (mm).
Ym: Maximum grain yield per hectare under full irrigation (kg ha^{-1}) / Ym: Tam sulama şartlarında en yüksek verim (kg ha^{-1}).
Ya: Actual grain yield per hectare under water deficit (kg ha^{-1}) / Ya: Kısıtlı sulama şartlarında gerçekleşen verim (kg ha^{-1}).

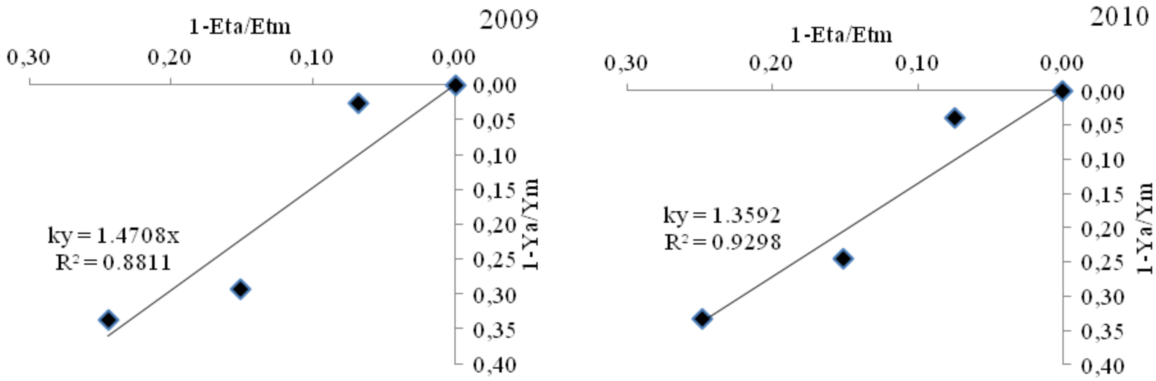

Figure 2. Relationships between relative decrease in water consumptions and relative decrease in yields in 2009 and 2010.
Şekil 2. 2009-2010 yılları mısır bitkisi oransal su tüketim açığı ile oransal verim azalışı ilişkisi.
ETm: Maximum crop water consumption under full irrigation (mm) / ETm: Tam sulama şartlarında en yüksek bitki su tüketimi (mm).
ETa: Actual crop water consumption under water deficit (mm) / ETa: Kısıtlı sulama şartları altında gerçekleşen bitki su tüketimi.
Ym: Maximum grain yield per hectare under full irrigation (kg ha^{-1}) / Ym: Tam sulama şartlarında en yüksek verim (kg ha^{-1}).
Ya: Actual grain yield per hectare under water deficit (kg ha^{-1}) / Ya: Kısıtlı sulama şartlarında gerçekleşen verim (kg ha^{-1}).

Table 8. Relative decrease in yield corresponding to relative decrease in water consumption in 2010.
Çizelge 8. 2010 yılına ait oransal su tüketimi açığına karşılık oransal verim azalması değerleri.

Treatments Konular	ETm (mm)	ETa (mm)	1-ETa/ETm	Ym (kg ha^{-1})	Ya (kg ha^{1})	1-Ya/Ym
I_{120}	821	-	0.00	15773	-	0.00
I_{100}	-	760	0.07	-	15160	0.04
I_{80}	-	697	0.15	-	11920	0.24
I_{60}	-	617	0.25	-	10527	0.33

ETm: Maximum crop water consumption under full irrigation (mm) / ETm: Tam sulama şartlarında en yüksek bitki su tüketimi (mm).
ETa: Actual crop water consumption under water deficit (mm) / ETa: Kısıtlı sulama şartları altında gerçekleşen bitki su tüketimi.
Ym: Maximum grain yield per hectare under full irrigation (kg ha^{-1}) / Ym: Tam sulama şartlarında en yüksek verim (kg ha^{-1}).
Ya: Actual grain yield per hectare under water deficit (kg ha^{-1}) / Ya: Kısıtlı sulama şartlarında gerçekleşen verim (kg ha^{-1}).

Again, a linear relationship was obtained between water consumption and yield. The ky of maize was calculated as 1.47 in 2009 and 1.36 in 2010. Doorenbos and Kassam (1979) indicated that seasonal ky of maize could be taken as 1.25. The present study's yield response factors were similar with the values reported by Kızıloğlu *et al.* (2008) (1.51) and Payero *et al.* (2009) (1.50), but greater than the values of several other researchers (Karam *et al.*, 2003; Öktem, 2008; Kuşcu *et al.*, 2013).

CONCLUSION

Water-yield relations of maize were investigated in this study. Kernel yields per hectare decreased with water stress. There were linear relationships among yield, net irrigation water and plant water consumption. In both years, WUE values varied between 1.45-1.99 kg m^{-3} and IWUE values varied between 1.84-2.39 kg m^{-3}. In both years, the greatest water and irrigation water use efficiencies were observed in I_{100} and the least in I_{80} treatments. The ky of maize was calculated as 1.47 in 2009 and 1.36 in 2010. These values could be used in maize culture of arid and semi-arid regions. Full irrigation (I_{100}) was identified as the ideal irrigation program. Despite the greatest yield of I_{100} irrigation, I_{80} also had a yield quite close to average yields of Turkey and Konya province. Therefore, it was concluded that I_{80} treatments could be used in Konya Plain and similar ecosystems.

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