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Responses of Maize to Full and Limited Irrigation at Different Plant Growth Stages[a]

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Abstract: This study was carried out to investigate the relationships between yield and irrigation water applied at different growth stages and to determine the most critical stage(s) for maize (*Zea mays* L.) in a sub–humid environment. A rainfed (non–irrigated) treatment as the control, full irrigation (VFG) and 15 different irrigation treatments (V, F, G, VF, VG, FG, V_{75}FG, V_{50}FG, V_{25}FG, $VF_{75}G$, $VF_{50}G$, $VF_{25}G$, VFG_{75}, VFG_{50} and VFG_{25}) with full or limited (25, 50 and 75%) irrigation water, were applied to the hybrid Pioneer 31P41 (Pioneer Seed Company) planted on clay-loam soil, at three critical development stages: vegetative (V), flowering (F), and grain-filling (G) in the years of 2008 and 2009. The highest seasonal evapotranspiration (an average of 1133 mm) was measured in the VFG treatment. Limited irrigation applied at different growing stages had different effects on the yield–related characters examined. According to average of two years, the highest grain yield (20.52 t ha^{-1}) and dry matter yield (33.78 t ha^{-1}) were obtained from the VFG and VFG_{75} treatments, respectively. Therefore, we confirm that VFG and VFG_{75} irrigations are the best choice for maximum yield under the local conditions. The flowering and vegetative were also determined as the most sensitive stages to water deficit of maize.

Key Words: Maize, irrigation, water deficit, evapotranspiration, growth stages, yield.

Farklı Bitki Büyüme Dönemlerinde Uygulanan Tam ve Kısıntılı Sulama Uygulamalarına Mısır Bitkisinin Tepkisi

Özet: Bu çalışma, yarı nemli bir iklim bölgesinde, mısır bitkisinin farklı bitki büyüme dönemlerinde uygulanan sulama suyu ile verim arasındaki ilişkileri araştırmak ve bitkinin sulamaya karşı en kritik büyüme dönemlerini belirlemek amacıyla yürütülmüştür. Tarla denemeleri, hibrit Pioneer 31P41 çeşidiyle killi tınlı bir toprak üzerinde 2008 ve 2009 yıllarında yürütülmüştür. Bitkinin bilinen üç kritik gelişme dönemi; vejetatif (V), çiçeklenme (F) ile tane oluşum ve olgunlaşma (T) göz önüne alınmış ve susuz (kontrol), tüm fenolojik gelişme dönemlerinde sulama yapılması (VFG) ile 15 farklı

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kısıntılı sulama uygulaması (V, F, G, VF, VG, FG, $V_{75}FG$, $V_{50}FG$, $V_{25}FG$, $VF_{75}G$, $VF_{50}G$, $VF_{25}G$, VFG_{75}, VFG_{50} and VFG_{25}) olmak üzere toplam 17 deneme konusu oluşturulmuştur. En yüksek mevsimlik bitki su tüketimi (ortalama 1133 mm), VFG konusundan belirlenmiştir. Farklı büyüme dönemlerinde uygulanan kısıntılı sulama uygulamaları, verim ve değerlendirmeye alınan verim bileşenleri üzerinde farklı etkiye sahip olmuştur. En yüksek tane ve kuru madde verimleri VFG ve VFG_{75} konularından elde edildiğinden yerel koşullar altında, bu sulama uygulamalarının en iyi seçim olacağı sonucuna varılmıştır. Ayrıca, mısır bitkisinin su kısıntısına en duyarlı dönemlerinin sırasıyla çiçeklenme ve vejetatif büyüme olduğu saptanmıştır.

Anahtar Kelimeler: Mısır, sulama, su kısıntısı, bitki su tüketimi, büyüme dönemi, verim.

Introduction

In Turkey, maize is grown on around 594,000 ha per year with average grain yield of 7.2 t ha^{-1} (http://faostat.fao.org, 2010; http://www.tuik.gov.tr, 2010). It is grown almost all over Turkey under varied soil and climatic conditions. In the Marmara region, the third most important maize production region in Turkey, maize, vegetables, fruits and sugar beet are largely grown under irrigation.

Many environmental, cultural and genetic factors influence maize yield and quality (Çarpıcı et al., 2010). Maize producers require more information on how different water supply regimes affect grain yield, dry matter yield and yield components like plant height, ear weight and 1000 kernel weight.

The fact that water stress effects on growth and yield are species– and variety–dependent is well known. Moreover, sensitivity to drought varies by development stage (Doorenbos and Kassam, 1979). Even limited irrigation–water applied at different growth stages of maize, can significantly increase grain yields. However, Lamm et al. (1995) stated that it is difficult to plan deficit irrigation for maize without causing yield reduction. Igbadun et al. (2008) reported that deficit irrigation at any crop growth stage of the maize crop led to decrease in dry matter and grain yields, seasonal evapotranspiration, deep percolation. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were strongly influenced by the number of growth stages in which deficit irrigations were applied and how critical the growth stages were to moisture stress rather than the amount of irrigation water applied. Many researchers have evaluated the effect of stress timing on maize yield and yield components (NeSmith and Ritchie, 1992; Jama and Ottman, 1993; Kang et al., 2000; Karam et al., 2003; Payero et al., 2006; Igbadun et al., 2008). In Turkey, however a few studies have been made to assess to full and limited irrigation at different plant growth stages of maize. Anaç et al. (1992) determined the maize yield response to water deficits, water-yield functions and evaluated the potential for limited irrigation in Aegean region of Turkey. They reported that the WUE decreased considerably when the water deficit was imposed at both the vegetative and the flowering stages. In Central Anatolia region, Yıldırım et al. (1996) determined the effects of both adequate and limited soil water supplies on grain yields of maize during total and individual growth stages. They stated that the greatest sensitivity to soil water deficit was at the flowering stage, and relative grain yield reductions were found to be 27.9%, 25.2%, 21.2%, 57%, 27.9%, 50.8%, and 68% when irrigation water was not applied during the vegetative, flowering, yield formation, vegetative and flowering, vegetative and yield formation, flowering and yield formation, and total growing stages, respectively. Istanbulluoglu et al. (2002) found that the highest maize yield (9.92 t ha^{-1}) and seasonal evapotranspiration (586 mm) were obtained after irrigations at vegetative, tasseling, and cob with no water-stress under Tekirdag climatic conditions. They also stated that tasseling stage was the most sensitive to water stress. In a study carried out under the arid Southeast Anatolia Project (GAP) area conditions by Yazar et al. (2002), they reported that highest average grain yield (11.92 t ha^{-1}) was obtained from the full irrigation treatment with six-day interval. In the Thrace region, Çakir (2004) observed that the highest grain yields were obtained in the fully irrigated and the treatment which allowed water stress during the vegetative growth stage.

The climate of the location, which dictates the evaporative demand on the crop, and the soil type, which dictates the available water for plant uptake, play vital roles in dictating the influence of deficit irrigation (Igbadun et al., 2008). Therefore, yield response of maize to water under different climate, soil and irrigation scheduling conditions should be investigated.

The aim of this research was to study the effects of full and limited irrigation applied at different growth stages of maize on yield and certain yield-components and to determine the most critical growth stage(s) of maize for water usage under southern Marmara conditions. The results utilized by the Turkish irrigation agencies and the regional growers can promote the introduction of new cost–effective management techniques in maize production in the region.

Material and Methods

The study was conducted in Mustafakemalpasa, Bursa, Turkey (40°02′ N, 28°23′ E; altitude 22 m) in 2008 and 2009 years. It is located in the southern Marmara region, with average annual rainfall of 679 mm and 14.2ºC mean monthly temperature. The local climate is temperate, summers are hot and dry, and winters are mild and rainy. Total monthly precipitation and mean air temperature data during the maize growing stage are given in Table 1.

Table 1. Annual (2008 and 2009) and long-term (1975-2007) mean air temperature and total monthly precipitation data of the study area

Months	Temperature (C°)			Precipitation (mm)		
	2008	2009	1975–2007	2008	2009	1975–2007
May	18	18	17	25	38	43
June	23	23	22	11	6	23
July	24	25	24	0	0	14
August	24	23	23	0	0	15
September	20	20	20	87	67	31
October	16	17	15	49	80	70
Total				172	192	196

Total rainfall from May to September was 123 and 112 mm in 2008 and 2009, respectively. These correspond to 15–23% of the total annual precipitations. It is insufficient for maize production as expected. The experimental field soil was clay–loam (CL) (23.6% sand, 43.6% silt and 32.8% clay) and its pH level varied between 7.8 and 8.0. Some chemical and physical properties of the soil are given in Table 2. Waterlogging was not observed in the area and the water table was deeper than 100 cm in early spring. In the research area, Mustafakemalpasa aquifer was used as the water source. Irrigation water applied during the experimental years was also analysed (electrical conductivity: 1.4 dS m^{-1} and Na adsorption ratio: 0.7) and classified as C_3S_1 (high salinity with low sodium) according to the classification based on the United States Salinity Laboratory diagram (US Salinity Laboratory 1954). Maas and Hoffman (1977) classified maize as a moderately salt sensitive crop, and they reported that initial yield decline started at a threshold EC of 1.7 dS m^{-1}.

Table 2. Some of chemical and physical properties of experimental field soil

Soil depth (cm)	Soil type	Bulk density (g cm^{-3})	Field capacity (%)	Wilting point (%)	Water holding capacity (%)	pH	Total salt (%)	$CaCO_3$ (%)	Total organic matter (%)
0 – 30	CL	1.44	37.47	22.77	14.70	7.8	0.018	11.2	1.8
30 – 60	CL	1.36	39.82	25.34	14.48	7.8	0.021	11.8	2.5
60 – 90	CL	1.44	39.90	25.55	14.34	8.0	0.026	13.5	1.9
90 – 120	CL	1.49	36.02	21.84	14.19	-	-	-	-

The hybrid cultivar PR31P41 obtained from Pioneer Seed Company was used as plant material. In the experiments, plot size was 21.0 m^2 (5.0 m × 4.2 m); row spacing was 0.70 m; plant–plant spacing was 0.20 m. A buffer zone spacing of 2.0 m was provided between the plots. Planting was done on 14 May 2008 and 8 May 2009. Standard cultural practices were adopted during the crop–growing season. Fertilizer applications were based on soil test results. Maize plots were fertilized with 70 kg ha^{-1} P_2O_5 as triple super phosphate (%43–44 P_2O_5) and 100 kg ha^{-1} N in the form of ammonium sulphate each year before sowing. Since the soil analysis results indicated that there was a sufficient level of the potassium in the soil, no additional fertiliser was applied on the experimental site. After planting, acetochlor (Cengaver™) herbicide was sprayed on each plot at the manufacturer's recommended rate of 2 L ha^{-1} for weed control. The treatment variation was based on deficit or full irrigation in the critical crop growth stages. Three growth stages of maize which were suggested by Doorenbos and Kassam (1979), Anaç et al. (1992) and Igbadun et al. (2007): vegetative (V), flowering (F), and grain-filling (G), sensitive to water stress, were considered. Irrigation was applied at each of these stages as full and deficit according to the treatments listed in Table 3.

All the experimental treatments were harvested at the same time as the VFG treatment (full irrigated), i.e. on 7 October 2008 and 4 October 2009. Ten plants were selected randomly from rows 2 to 5 of each plot at harvest and plant height, leaf per plant, stem diameter, ear weight, ear height, ear diameter, and first ear height were measured. The sampled plants were divided into stover and ear fractions, and then weighed. The fresh samples from each plot were dried at 70 °C for 48 h for dry matter percentage. Then, dry matter yield of the plots was calculated (Turgut et al. 2005). The ears of four middle rows in each plot constituting an area of 2.8 m by 3.8 m were harvested by hand harvesting. The samples were shelled by a maize shelling machine. After, the grain samples were weighed to obtain the grain weight. The grain moisture content at the shelling was determined to be 15–23%. The grain yields were converted to standard grain moisture of 15%. Hectoliter weight and harvest index were also determined according to the methods of Şehirali (2002) and Beadle (1985).

All data were subjected to analysis of variance for each character using MSTAT-C (version 2.1–Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The experiments were designed in a randomized complete block with three replications. The significance of irrigation treatment, main effects and treatment × year interactions were determined at the 0.05 and 0.01 probability levels, by the F test. The F–protected least significant difference (LSD) was calculated at the 0.05 probability level according to Steel and Torrie (1980).

Table 3. Irrigation treatments included in the study

Treatments	Growth stages			
	Establishment	Vegetative (V)	Flowering (F)	Grain–filling (G)
Control	+	–	–	–
V	+	+	–	–
F	+	–	+	–
G	+	–	–	+
VF	+	+	+	–
VG	+	+	–	+
FG	+	–	+	+
VFG	+	+	+	+
$V_{75}FG$	+	+ 25% water deficit	+	+
$V_{50}FG$	+	+ 50% water deficit	+	+
$V_{25}FG$	+	+ 75% water deficit	+	+
$VF_{75}G$	+	+	+ 25% water deficit	+
$VF_{50}G$	+	+	+ 50% water deficit	+
$VF_{25}G$	+	+	+ 75% water deficit	+
VFG_{75}	+	+	+	+ 25% water deficit
VFG_{50}	+	+	+	+ 50% water deficit
VFG_{25}	+	+	+	+ 75% water deficit

+, irrigated at a given stage; –, no irrigation.

Soil water contents were monitored in 0.3 m depth increments to 1.2 m prior to and after irrigation weekly using the gravimetric method (Black, 1965) from the plots of the second replication (block) throughout the growing season, and then these values were converted to volumetric water contents using bulk density. According to the soil water contents measured, the plots of the treatments were irrigated from deficit moisture content of 0–0.9 m soil layer to field capacity (FC) at each growth stage. Irrigation management in the full irrigation treatment was based on the common practice in the area, which consists of irrigation at 7 days intervals. All irrigation treatments were applied on the same day. Water was allowed into the plot for the calculated time and volume. Drip irrigation system was installed before planting in both seasons. First irrigation water was applied to all treatments using the system during the experiments in 2008 and 2009 to bring the soil water content in 0–0.9 m soil depth up to level of FC. Irrigation treatments were started when the water content of soil decreased to 50% of available soil water.

Evapotranspiration (ET) at each irrigation treatment (V, F, G, VF, etc.) was estimated using the following water balance equation (Garrity et al., 1982):

$$\mathrm{ET} = I + P \pm \Delta S - D$$

where I is the irrigation water (mm), P is the rainfall (mm), ΔS is the moisture variation in the soil profile (mm), and D is deep percolation (mm). In the equation, I was measured by a water meter, P was observed at the meteorological station nearby the experimental area, ΔS was obtained from moisture measurements in the soil. In this study, runoff was assumed to be negligible because the amount of irrigation water was controlled through the drip irrigation. Whenever available water in the root zone (0–0.9 m) and the total amount of water applied by irrigation were above the field capacity, it was assumed that excess water leaked into the deeper soil zones and was called deep percolation (D = amount of available total water at 0–0.9 m soil depth before irrigation (mm) + irrigation water applied (mm) – soil water hold in field capacity (mm)) (El–Hendawy and Schmidhalter, 2010).

Water use efficiency was determined to evaluate the productivity of irrigation in the treatments. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) are two terms used to promote the efficient use of irrigation water at the crop production level (Bos, 1980). WUE was calculated as the ratio of grain yield (Y_i) to seasonal crop evapotranspiration (ET), given as WUE = Y_i / ET (kg m^{-3}). IWUE (kg m^{-3}) was estimated by following equation (Zhang et al. 1999):

$$\mathrm{IWUE} = \frac{Y_i - Y_0}{I_i}$$

where Y_i is the grain yield for irrigation treatment i (kg ha^{-1}), Y_0 is yield for equivalent dry land (nonirrigated control) and I_i is amount of irrigation water applied for treatment i (mm).

Results and Discussion

Analysis of Variance

The analysis of variance indicated that years significantly affected all the characters measured except hectoliter weight. According to the data combined over 2 years and both individual year, irrigation treatments significantly affected all characters.

On the other hand, “year × treatment” interactions were significant at 1% level of probability for number of leaves per plant, ear weight, grain yield, dry matter yield and harvest index and at 5% for plant height and 1000 kernel weight (Table 4). These interactions, statistically significant for plant height, number of leaves per plant, ear weight, 1000 kernel weight, grain yield, dry matter yield and harvest index, indicated that treatments responded variously to different years.

Grain Yield, Dry Matter Yield and Harvest Index

The mean values of grain yield, dry matter yield and harvest index determined in different treatments are summarized in Table 5. The full and limited irrigation at three growth stages (VFG, $V_{75}FG$, $V_{50}FG$, $V_{25}FG$, $VF_{75}G$, $VF_{50}G$, $VF_{25}G$, VFG_{75}, VFG_{50}, and VFG_{25}) produced more grain yield and dry matter yield. The highest grain yields were achieved from VFG treatment and 25% deficit irrigation at grain-filling (VFG_{75}). The mean of two years data showed that grain yields of VFG and VFG_{75} treatments were 20.52 and 20.45 t ha^{-1}, respectively. Grain yield significantly reduced as the amount and the number of irrigations decreased. The lowest grain yield was obtained from the non-irrigated treatment (control) with 7.88 t ha^{-1} (Table 5). Relatively higher yields were observed for treatments with deficit irrigation and irrigation omission in grain filling (VF, VFG_{75}, VFG_{50} and VFG_{25}), showing relative tolerance of maize to water deficit in the soil profile during this stage. Water stress and limited irrigation in the flowering stage significantly reduced grain yield in both years. For that reason, in the case of water deficit, withdrawal of irrigation water during the flowering stage should be avoided. In addition, difference between the years was statistically significant for grain yields. In general, grain yields increased at all treatments except V in 2009 while these treatments produced lower grain yields in 2008 (Table 5).

Table 4. Results of variance analysis of grain yield, dry matter yield, harvest index and other agronomic traits of maize under different irrigation treatments in 2008, 2009 and combined years

Source	d.f.[a]		Significations of *F*-ratios												
			Plant height (cm)			Number of leaves per plant			Stem diameter (mm)			Ear weight (g)		
	1	2	2008	2009	2-year	2008	2009	2-year	2008	2009	2-year	2008	2009	2-year
Years (Y)	–	1			**			**			ns			**
Blocks	2	4	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatments (T)	16	16	**	**	**	**	**	**	ns	*	*	**	**	**
Y × T	–	16			*			**			ns			**
Error	32	64												

Source	d.f.*		Significations of *F*-ratios											
			Ear height (cm)			Ear diameter (cm)			First ear height (cm)			1000 kernel weight (g)		
	1	2	2008	2009	2-year	2008	2009	2-year	2008	2009	2-year	2008	2009	2-year
Years (Y)	–	1			**			**			**			**
Blocks	2	4	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatments (T)	16	16	**	**	**	**	**	**	**	**	**	**	**	**
Y × T	–	16			ns			ns			ns			*
Error	32	64												

Source	d.f.*		Significations of *F*-ratios											
			Hectoliter weight (kg hl^{-1})			Grain yield (t ha^{-1})			Dry matter yield (t ha^{-1})			Harvest index		
	1	2	2008	2009	2-year	2008	2009	2-year	2008	2009	2-year	2008	2009	2-year
Years (Y)	–	1			ns			**			**			**
Blocks	2	4	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatments (T)	16	16	*	**	**	**	**	**	**	**	**	**	**	**
Y × T	–	16			ns			**			**			**
Error	32	64												

[a], Degrees of freedom for (1) individual year and (2) combined over 2 years; ns, non-significant; *, significant at the 5% of probability level ($P < 0.05$); **, significant at the 1% of probability level ($P < 0.01$).

Table 5. The effects of irrigation treatments on yield and yield components (2-years average)

Treatments	Plant height (cm)	Number of leaves per plant	Stem diameter (mm)	Ear weight (g)	Ear height (cm)	Ear diameter (cm)	First ear height (cm)	1000 kernel weight (g)	Hectoliter weight (kg hl^{-1})	Grain yield (t ha^{-1})	Dry matter yield (t ha^{-1})	Harvest index
Control	265 f	13.2 e	24.4 bc	141.6 l	16.4i	4.46 f	113.9 g	443.4 h	71.8 f	7.88 l	17.82 l	0.45 h
V	338a-c	14.4 a-d	25.7 ab	217.8 k	18.8 gh	4.68 e	164.5 b-d	451.5 gh	74.0 e	12.34 j	26.60 i	0.47 g
F	281 e	13.2 e	24.3 bc	237.6 j	19.4 fg	4.99 cd	123.3 f	453.3 g	74.8 de	12.99 i	25.08 j	0.53 e
G	267 ef	14.1 cd	23.2 c	209.4 k	18.5 h	4.90 d	118.7 fg	443.3 h	71.7 f	10.54 k	21.11 k	0.45 h
VF	346 ab	14.7 a-c	25.7 ab	339.3 d	21.4 ab	5.06 b-d	159.7 cd	513.6 d-f	77.2 ab	19.53 c	29.10 g	0.68 a
VG	325 cd	13.8 de	25.4 ab	259.1 i	19.7 ef	5.04 b-d	160.5 b-d	509.8 ef	74.1 e	14.32 h	29.18 g	0.49 f
FG	279 ef	13.8 de	25.0 ab	312.8 f	19.7 ef	4.99 cd	124.3 f	508.0 f	76.9 a-c	18.06 e	28.90 gh	0.63 b
VFG	341 ab	14.7 a-c	26.1 a	370.8 a	21.8 a	5.30 a	172.4 a	530.7 a	77.7 a	20.52 a	32.72 b	0.63 b
$V_{75}FG$	337a-c	14.8 ab	25.1 ab	354.9 b	21.3 ab	5.17 a-c	162.2 b-d	523.2 a-c	76.8 a-c	19.97 b	31.92 bc	0.63 b
$V_{50}FG$	333 bc	15.0 a	25.2 ab	339.6 cd	21.5 ab	5.20 ab	160.5 b-d	518.9 cd	76.5 a-c	18.91 d	30.94d-f	0.61 c
$V_{25}FG$	316 d	14.5 a-c	24.4 bc	302.9 g	20.4c-e	5.02 b-d	145.4 e	520.3 b-d	76.3 a-d	17.63 f	28.25 h	0.63 b
$VF_{75}G$	349 a	14.8 ab	25.2 ab	349.3 bc	21.1a-c	5.15 a-c	161.5 b-d	523.2 a-c	76.8 a-c	19.43 c	32.03 bc	0.61 c
$VF_{50}G$	351 a	14.7 a-c	25.6 ab	308.3 fg	20.8b-d	5.15 a-c	164.9 bc	517.7 c-e	76.0 b-d	17.88 ef	31.37c-e	0.57 d
$VF_{25}G$	343 ab	14.3 b-d	26.4 a	282.5 h	20.2 d-f	5.06 b-d	158.8 d	516.2 c-f	75.4 c-e	16.35 g	30.85 ef	0.57 d
VFG_{75}	340a-c	14.5 a-c	26.5 a	348.2b-d	21.9 a	5.31 a	172.2 a	528.2 ab	77.7 ab	20.45 a	33.78 a	0.61 c
VFG_{50}	345 ab	14.6 a-c	25.4 ab	329.2 e	21.2a-c	5.20 ab	165.7 b	524.1 a-c	76.7 a-c	19.57 c	31.71 cd	0.62 bc
VFG_{25}	345 ab	14.5 a-c	25.2 ab	323.7 e	20.7b-d	5.08 b-d	164.4 b-d	519.1 cd	76.6 a-c	19.05 d	30.50 f	0.63 b
Mean	324	14.3	25.2	295.7	20.3	5.04	152.5	502.6	75.7	16.79	28.93	0.58
LSD(0.05)	15.60	0.60	1.60	9.78	0.80	0.20	5.80	8.34	1.56	35.40	83.78	0.02

It is known that the amount and distribution of precipitation and variation in temperature and soil conditions are the major factors affecting grain yield and some yield components of maize in arid and semi-arid regions. Grain yields of the treatments as a percentage of the control were also determined. VFG produced 62% higher grain yield than the control. However, $V_{75}FG$, $V_{50}FG$, $V_{25}FG$, $VF_{75}G$, $VF_{50}G$, $VF_{25}G$, VFG_{75}, VFG_{50} and VFG_{25} produced 52–61% more grain yield than the control. The other treatments (V, F, G or VF, VG, FG) also produced 25–60% more grain yield, with maximum from VF treatment (Table 5). Çakir (2004) reported that highest grain yield was obtained in the fully irrigated treatment and the treatment which allowed water stress during the vegetative growth stage. The researcher stated that even a single irrigation omission during one of the sensitive growth stages, caused up to 40% grain yield losses during dry years. Igbadun et al (2008) reported that deficit irrigation at any crop growth stage of the maize crop led to decrease in grain yields and dry matter yields.

Dry matter yield was also significantly affected by the soil water deficit (Table 5). The highest dry matter yield (33.78 t ha^{-1}) were obtained in the VFG_{75} treatment, which was fully irrigated at stages of vegetative and flowering but had 25% water deficit at grain–filling stage, while control treatment (C) recorded the least dry matter yield (17.82 t ha^{-1}). These results indicate a close relationship between dry matter yield and irrigation water amount. Moisture stress resulting from the limited water supply at vegetative and flowering stages affected crop canopy development which led to low dry matter yield. On the other hand, deficit irrigation at any crop growth stage resulted in yield decrease in dry matter, and this agrees with the findings of Naescu (2000), Karam et al. (2003), Panda et al. (2004), Mengü and Ozgurel (2008) and Oktem (2008), who reported that deficit irrigation definitely reduces yield of maize crop, and maize dry matter increases significantly with irrigation. Results also agree with the reports of Çakir (2004) and Igbadun et al. (2008) that the effect of the deficit irrigation on dry matter of the maize crop depends on the crop growth stage and the frequency of the deficit, irrespective of whether it was at one or more growth stages.

The results related to harvest index (ratio of grain yield to dry matter yield) indicated that the effect of stress timing on harvest index was significant. The highest harvest index (0.68) was obtained from VF treatment (weekly irrigation in the vegetative and flowering stages). On the other hand, the lowest values of harvest index were determined from control and G treatments. Bryant et al. (1992) indicated that water stress reduces yield by reducing accumulated biomass and the harvest index. However, Traore et al. (2000) found that the harvest index was affected by water deficit only when stress was imposed during anthesis. Our results indicate that in the case of deficit irrigation, water stress should be scheduled on grain filling stage. On the other hand, withdrawal of irrigation water during the vegetative and flowering stage should be avoided.

Yield Components

Irrigation at three growth stages (VFG treatment) and limited irrigation (VFG_{75}, VFG_{50}, VFG_{25}, etc.) produced the tallest plants (316–351 cm). Weekly irrigations applied at two growth stages (vegetative and flowering) affected plant height growth significantly. However, deficit irrigations during the grain-filling stage did not reduce plant height significantly. The shortest plants (265 cm) were obtained from the non-irrigated treatment (Table 5). Our findings were in agreement with the results reported by El Neomani et al. (1990), Istanbulluoglu et al. (2002), Çakir (2004) and Karasu et al. (2009).

Irrigation treatments also significantly affected number of leaves per plant and their average values varied from 13.2 to 15.0 per plant in all treatments (Table 5).

Irrigations applied at the vegetative stage (V), two growth stages (VF, VG and FG), as well as full and deficit irrigations at three growth stages (VFG, $V_{75}FG$, $V_{50}FG$, $VF_{75}G$, $VF_{50}G$, $VF_{25}G$, VFG_{75}, VFG_{50} and VFG_{25}) increased stem diameter more than the other treatments. Average of stem diameter was obtained as 25.2 mm for all the treatments.

Irrigation treatments also resulted in differences in ear characteristics as shown in Table 5. The highest values of ear weight, ear height, ear diameter and first ear height were obtained from VFG and VFG_{75} treatments while the lowest by the control. The characteristics related to ear parameters significantly increased with increments in irrigation water amount.

In this study, the highest 1000 kernel weight (530.7 g) was obtained from VFG treatment, followed by the 25% deficit-irrigation treatment in the grain-filling stage (VFG_{75}). In a similar study, Pandey et al. (2000) reported that yield reduction (22.6–26.4%) caused by deficit irrigation was associated with a decrease in kernel number and weight. As shown in Table 5, the hectoliter weight values are significantly ($P < 0.01$) affected by water deficits in the soil profile. The highest average hectoliter weight (77.7 kg hl^{-1}) was recorded from VFG treatment.

Evapotranspiration (ET) and Yield–ET Relations

Table 6 presents the seasonal ET, seasonal applied water, grain yield, WUE and IWUE for the 17 treatments.

Table 6. Maize response to irrigation treatments (2–years average)

Treatments	Seasonal total evapotranspiration (mm)	Seasonal applied water (mm)	Grain yield (t ha^{-1})	WUE (kg m^3)	IWUE (kg m^3)
Control	305	71*	7.88	2.61	–
V	613	415	12.34	2.02	1.31
F	692	514	12.99	1.88	1.15
G	535	422	10.54	1.98	0.75
VF	972	793	19.53	2.01	1.62
VG	825	709	14.32	1.74	1.01
FG	883	745	18.06	2.05	1.51
VFG	1133	1007	20.52	1.82	1.35
$V_{75}FG$	1082	955	19.97	1.84	1.29
$V_{50}FG$	1016	889	18.91	1.86	1.35
$V_{25}FG$	957	831	17.63	1.84	1.29
$VF_{75}G$	1054	921	19.43	1.84	1.36
$VF_{50}G$	977	848	17.88	1.83	1.29
$VF_{25}G$	924	794	16.35	1.77	1.17
VFG_{75}	1087	950	20.45	1.88	1.43
VFG_{50}	1055	908	19.57	1.86	1.40
VFG_{25}	1024	857	19.05	1.87	1.43

*Water amount applied at the establishment stage.

ET increased markedly when irrigation water increased. The highest seasonal ET was obtained from the FVG treatment with no water stress (1133 mm). The lowest value was observed in non-irrigated treatment with water stress (305 mm). The other treatments gave ET values between these extremes. As a result, grain yields significantly increased as seasonal ET increased from 305 mm for the non-irrigated treatment to 1133 mm for VFG treatment. Similar results were also observed by Yıldırım et al. (1996), Istanbulluoglu et al. (2002), Oktem et al. (2003), Çakir (2004) and Igbadun et al. (2008). Seasonal ET when soil water is sufficient ranges from 500 to 1300 mm in maize depending upon the differences in climate, soil conditions and plant species (Doorenbos and Kassam, 1979; Sepaskhah and Khajehabdollahi, 2005).

Seasonal applied water varied from 415 mm for V treatment to 1007 mm for VFG treatment. Grain yield increased significantly as irrigation amount increased (Table 6).

WUE did not significantly change when irrigation amount increased. However, WUE values ranged from 1.77 kg m^{-3} for $VF_{25}G$ treatment to 2.61 kg m^{-3} rainfed (control) treatment. Little higher WUE values were obtained from FG, V, VF and G treatments as 2.05, 2.02, 20.1 and 1.98 kg m^{-3}, respectively. Previous studies indicated that WUE ranged from 0.41 to 2.71 kg m^{-3} (Howell et al., 1995; Pandey et al., 2000; Yazar et al., 2002; Karam et al., 2003; Oktem et al., 2003; Kar and Verma, 2005; Dagdelen et al., 2006 and Mengü and Özgürel, 2008). Our results are in agreement with Gençoğlan and Yazar (1999) who reported that WUE values decreased with increasing water use.

The highest IWUE value was obtained from the VF treatment and the lowest value from the G treatment (Table 6). Results indicate that when seasonal irrigation water was limited, weekly irrigations in the growth stages of vegetative and flowering is profitable for higher levels of IWUE. Our results support the previous work Igbadun et al. (2008) who reported that if water is limited and deficit irrigation is to be spread over different growth stages of the maize crop, WUE and IWUE may be improved if the flowering growth stage is exempted from the deficit irrigation schedule.

Conclusion

Maize is commonly grown almost all over Turkey under varied soil and climatic conditions and it responds significantly to irrigation. Our results, from 2–year period (2008 and 2009), indicated that full and limited irrigation treatments at three growth stages (vegetative, flowering, and grain–filling) increased grain yield, dry matter yield and other traits observed, more than the non–irrigated (control) and weekly irrigation applications in only one growth stage. The highest grain yields (20.52 and 20.45 t ha^{-1}) and dry matter yields (32.72 and 33.78 t ha^{-1}) were obtained from the VFG treatment with no water stress and VFG_{75} treatment, which full irrigation at stages of vegetative and flowering but 25% water deficit at grain–filling stage, respectively. Limited irrigations applied at the three growth stages produced higher grain and dry matter yields as well as VFG treatment. The lowest grain and dry matter yields (7.88 and 17.82 t ha^{-1}, respectively) were found in non-irrigated treatment. The VFG irrigation program increased grain yield about 62%, and dry matter yield about 38% compared with the control. The average grain yields of full and limited irrigations applied at three growth stages were about 57% higher than that of the non–irrigated treatment. Withdrawal of irrigation water during flowering and vegetative resulted in greater yield losses than during other stages, indicating that this is a critical growth stage. Relatively high yields were observed for treatment with irrigation omission in grain filling (VF), showing in relative tolerance of maize to water shortage in the soil profile during this stage. Our results indicate that maize should be irrigated as weekly with full or limited irrigation water at vegetative, flowering and grain–filling stages for high grain yield. In the case of deficit irrigation, reduced irrigation water during the flowering stage should be avoided. When seasonal irrigation water was limited, weekly irrigations especially during the stages of vegetative and flowering should be applied for the irrigation efficiency.

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