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EFFECT OF IRRIGATION AMOUNTS APPLIED WITH DRIP IRRIGATION ON MAIZE EVAPOTRANSPIRATION, YIELD, WATER USE EFFICIENCY, AND NET RETURN IN A SUB–HUMID CLIMATE

Hayrettin KUSCU[1], Abdullah KARASU[1], Mehmet OZ[1], Ali Osman DEMIR[2], İlhan TURGUT[3]*

[1]Uludag University, Mustafakemalpasa Vocational School, Department of Crop and Animal Production, Mustafakemalpasa, Bursa, TURKEY.
[2]Uludag University, Faculty of Agriculture, Department of Biosystems Engineering, Gorukle, Bursa, TURKEY.
[3]Uludag University, Faculty of Agriculture, Department of Field Crops, Gorukle, Bursa, TURKEY.
**Corresponding author: kuscu@uludag.edu.tr*

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ABSTRACT

The purpose of this study was to determine the effect of irrigation amount applied with drip irrigation on field maize (*Zea mays* L.) evapotranspiration (ET), yield, water use efficiency, yield response factor (ky) and net return in a sub–humid environment of Turkey. Irrigation management treatments were created as 125%, 100%, 75%, 50%, 25% and 0% replenishment of water depleted in the 90 cm root zone from 100% replenishment treatment in every seven days. Irrigation amounts ranged from 76 to 1120 mm in 2007 and from 91 to 997 mm in 2008. The treatments resulted in seasonal ET of 311–1078 mm and 298–1061 mm in 2007 and 2008, respectively. The average grain yields varied from 5570 to 16535 kg ha^{-1}. In both seasons, irrigation significantly affected yields, which increased with irrigation up to a level (1100 mm of irrigation water amount), but additional amounts of irrigation did not increase it any further. Yields increased linearly with seasonal ET. The yield response factor (ky) averaged 0.89 over the two seasons. Maximum water use efficiency (WUE) and irrigation water use efficiency (IWUE) values were obtained for the treatment of 25% deficit irrigation. A further increase in water amount from reference irrigation (T–100) increased grain yield but reduced both the WUE and IWUE. The reference irrigation treatment gave the highest net return of $3212 ha^{-1}. The results revealed that the full irrigation is the best choice for higher yield and net income. The results also suggest that 25% deficit irrigation approach may be a good strategy for increase water use efficiencies when full irrigation is not possible.

Keywords: Maize, net return, water–yield relationships, water use efficiency, yield response factor

INTRODUCTION

Maize is one of the most important cereal crops in Turkey (İlker, 2011) and the cultivated area is about 0.60 million hectares (FAO stat, 2009). Maize production in Turkey is about 4.25 million tons and it covers about 95% of corn consumption in the country (FAO stat, 2009). Today, the government of Turkey through its financial assistance programme is trying to encourage farmers to grow maize. It is grown almost all over the country under varied soil and climatic conditions. Most of the maize in Turkey is irrigated and is grown under low rainfall and heat stress conditions. In these conditions, irrigation is the major factor determining yield. It is consequently essential to determine the water regimes leading to highest yield. Maize has been reported in the literature to have high irrigation requirements (Stone et al., 1996; Karam et al., 2003). Maize grain yield increased significantly by irrigation water amount and irrigation frequency (Yazar et al., 1999; Kara and Biber, 2008; Farré and Faci, 2009). However, water availability is usually the most important natural factor limiting expansion and development of agriculture in Marmara region of Turkey. Competition for water from other sectors such as industry and domestic use will force irrigation to operate under water scarcity.

When water supplies are limiting, the farmer's goal should be to maximize net income per unit water used rather than per land unit. Deficit irrigation, by reducing irrigation water use, can aid in coping with situations where water supply is restricted. In field crops, a well-designed deficit irrigation regime can optimize water productivity over an area when full irrigation is not possible (Fereres and Soriano, 2007). The correct application of deficit irrigation requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest (English, 1990). However, maize has been reported to be very sensitive to drought (Otegui et al., 1995). Lamm et al. (1995) stated that it is difficult to plan deficit irrigation for maize without causing yield reduction. Payero et al. (2006a) reported that trying to increase crop water productivity by imposing deficit irrigation for maize might not be a beneficial strategy in a semiarid climate. Karam et al. (2003) found that grain and dry matter yield, and leaf area index was reduced by severity of water stress. Pandey et al. (2000) stated that yield reduction (22.6–26.4%) caused by deficit irrigation was associated with a decrease in kernel number and weight. The effects of deficit irrigation for the same crop may vary with location. Climate and soil type of the location are perhaps the most important factors dictating the influence of deficit irrigation (Igbadun et al., 2008).

Shortage in irrigation water supplies in the Marmara region has motivated farmers to find ways to produce crops, especially maize, with less irrigation water, such as using more efficient irrigation systems and changing from fully–irrigated to deficit irrigated cropping systems. Furrow irrigation is the most common method used for irrigating row crops such as maize in the Marmara region of Turkey. However, the drip irrigation method is becoming more popular because of numerous advantages over other methods (Hanson et al., 1997). Some advantages of drip irrigation over other irrigation methods include improved water and nutrient management, improved saline water management, potential for improved yields and crop quality, reducing the incidence of diseases and weeds in dry row middles, greater control on applied water resulting in less water and nutrient loss through deep percolation, and reduced total water requirements (Ayars et al., 1999; Dogan and Kirnak., 2010). During the past decade, Turkish government has been financially supporting the farmers who are willing to set up drip irrigation system. Therefore, the use of drip irrigation is increasing substantially each year in the region. However, local information from the Marmara region of Turkey on the response of maize yield with drip irrigation is very limited, especially dealing with the effect of limited water allocations. In Marmara climatic region, little attempt has been made to assess the water–yield relationships and optimum water management programs of maize for recently developed hybrids.

The main aim of this study is to examine the effect of different irrigation amounts applied with drip irrigation on evapotranspiration, grain yield, water use efficiency, total production cost and net return of maize grown in a sub-humid climate of Turkey.

MATERIALS AND METHODS

Field experiments were conducted at the experimental station of the Mustafakemalpasa Vocational School, Uludag University located in Bursa, Turkey (40° 02′ N, 28° 23′ E, 25 m above sea level) for two consecutive summer seasons (2007 and 2008). The climate in this part of the country is classified as sub–humid according to Thornthwaite climate classification system (Feddema, 2005). The climatic parameters during the crop growing seasons are summarized in Table 1. The soil in the experimental field was clay loam. The soil moisture content at field capacity (–33 kPa) and permanent wilting point (–1500 kPa) was 36% and 21% on an oven dry weight loss basis, (moisture content on dry weight basis) respectively. The average bulk density of the soil was 1.41 g cm^{-3}. The plant available soil moisture was 186.1 mm m^{-1}.

Table 1. Some climatic parameters in 2007, 2008 and between 1975 and 2007 at Mustafakemalpasa in Bursa, Turkey.

Months	Climatic Parameters								
	Temperature (°C)			Humidity (%)			Precipitation (mm)		
	2007	2008	Average[a]	2007	2008	Average	2007	2008	Average
May	19.9	18.1	17.2	61	66.7	66.3	12.1	24.8	42.9
June	24.6	23.1	21.6	55	63.2	61.2	47.2	10.8	23.4
July	26.2	24.3	23.6	51	60.9	61.1	13.4	0	13.9
August	26.4	24.1	23.3	53	62.0	61.7	1.0	0	14.9
September	21.4	20.2	19.6	57	76.1	64.8	3.4	87.2	31.2

[a] Average values between 1975 and 2007.

The experiments were conducted using a randomized complete block design with three replications. The area of each plot was 22.75 m^2 (long: 5.00 m, wide: 4.55 m). A buffer zone spacing of 2 m was provided between the plots. Experimental plots received 180 kg ha^{-1} nitrogen and 120 kg ha^{-1} P_2O_5. The maize hybrid Ada–523 was planted at a spacing of 0.20 m × 0.65 m at a plant population of 76920 plants per hectare (Çarpıcı et al., 2010). In 2007, maize was planted on May 10, and harvested on October 10. In 2008, maize was planted on May 17 and harvested October 18. Grain yields were determined by hand harvesting the 3.8 m sections of the five adjacent center rows in each plot. The harvest area in each plot was 12.35 m^2. Grain yields were adjusted to a constant moisture basis of 150 g kg^{-1} water.

Each experiment consisted of six irrigation levels, i.e. the amount of water in different treatments was 0 (T–0), 25 (T–25), 50 (T–50), 75 (T–75), 100 (T–100) and 125% (T–125) of water depleted in the 90 cm root zone in every seven days (Panda et al., 2004). Gravimetric method was used in determining the amount of water need to bring the soil in the crop root zone to field capacity. All irrigation treatments were applied on the same day. Crops were irrigated by drip irrigation. Irrigation water was pumped directly from a well to the drip irrigation system. The lateral lines were laid adjacent to each crop row. The laterals had an outer diameter of 16 mm and pressure-compensating emitters spaced every 0.3 m. Each emitter had a nominal flow rate of 1.6 L h^{-1} at a pressure of 100 kPa. The sub-main line was connected to a water meter and a control valve. During the first 2 weeks all the treatments received a daily amount of 5–7 mm irrigation water in order to establish plants.

Soil moisture contents were monitored in 0.3 m depth increments to 1.5 m prior to and after irrigation weekly from the plots of the second replication (block) throughout the growing season. Soil samples were taken at positions immediately under the drippers. Soil moisture was determined by the gravimetric method (oven dry basis).

Actual crop evapotranspiration under the different irrigation treatments was estimated using the following from of the water balance equation (Garrity et al., 1982):

$$ET = I + P \pm \Delta S - R - D \quad (1)$$

where ET is evapotranspiration (mm), I is the irrigation water (mm), P is the precipitation (mm), ΔS is the change in soil water storage (mm), R is the runoff, and D is the drainage below the root zone. In the equation, I was measured by water meters, P was observed at the meteorological station nearby the experimental area, ΔS was obtained from gravimetric moisture observations in the soil profile to a depth of 90 cm. In this study, surface runoff was assumed to be negligible because the amount of irrigation water was controlled through the drip irrigation.

The water use–yield relationship was determined using the Stewart's model (Stewart et al., 1977). Water use efficiency (WUE, kg m^{-3}) was calculated as grain yield divided by seasonal ET. Irrigation water use efficiency (IWUE, kg m^{-3}) was also determined according to Howell (2001).

Estimates of net return were calculated as

$$R_{net} = R_{gross} \times Y_{grain} - C_{water} - C_{production}$$

where, R_{net} is net return (\$ ha^{-1}), R_{gross} is commodity price (\$ t^{-1}), Y_{grain} is grain yield (t ha^{-1}), C_{water} is cost of water (\$ ha^{-1}) and $C_{production}$ is cost of production (\$ ha^{-1}). Gross return was calculated by assuming a unit of the commodity price \$320.63 t, the average price in Bursa province of Turkey during the period 2003–2008 (Turk stat, 2010). The cost of water for each irrigation treatment was calculated by multiplying the cost of unit volume of water and the total quantum of irrigation water required for the maize crop (Panda et al., 2004). The main source of the irrigation water was the groundwater. All other production costs including labor (installation, irrigation, planting, weeding, cultivation, fertilizer application, spraying, and harvesting), land preparation, seeds, fertilizers, chemicals (insecticides and pesticides) were assumed constant across all water treatments except I_0. The irrigation cost was eliminated from the production cost for I_0 treatment. Data required for the production cost were collected from 20 sample farms by field survey, and it was determined as \$1550.85 ha^{-1}. The production cost was not included in land rental cost.

Data were subjected to analysis of variance for grain yield using MINITAB (University of Texas at Austin) software. The F–protected least significant difference (LSD) was calculated at the 0.05 probability level according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

Water applied and evapotranspiration (ET)

Seasonal water applied and seasonal ET values for the different treatments are shown in Table 2. The amount of irrigation water applied varied from 76 to 1120 mm in 2007 and from 91 to 997 mm in 2008. Active root depth for maize assumed to be 90 cm, and therefore, deep percolation measurements were made 90–120 cm soil depth. Result indicated that percolation occurred only with T–125 treatment of about 9% calculated from 2 years average. Regression analysis indicated a linear relationship between seasonal ET and seasonal water applied (Fig. 1). In a similar study, Payero et al. (2008) reported the strong quadratic relationships between

Table 2. Seasonal water applied, seasonal maize evapotranspiration (ET), grain yield, water use efficiency (WUE) and irrigation water use efficiency (IWUE) for each irrigation treatment obtained in 2007 and 2008 at Mustafakemalpasa in Bursa, Turkey.

Year	Treatment	Seasonal water applied (mm)	Seasonal ET (mm)	Grain yield (kg ha^{-1})	WUE (kg m^{-3})	IWUE (kg m^{-3})
2007	T–0	76	311	5650 e	1.82	–
	T–25	285	452	6690 d	1.48	0.50
	T–50	494	621	11680 c	1.88	1.44
	T–75	702	809	15610 b	1.93	1.59
	T–100	911	992	15920 b	1.60	1.23
	T–125	1120	1078	16340 a	1.52	1.02
	$LSD_{(P=0.05)}$	–	–	346.1	–	–
2008	T–0	91	298	5490 f	1.84	–
	T–25	272	447	6240 e	1.40	0.41
	T–50	454	652	12110 d	1.86	1.82
	T–75	635	824	15240 c	1.85	1.79
	T–100	816	957	16480 b	1.72	1.52
	T–125	997	1061	16730 a	1.58	1.24
	$LSD_{(P=0.05)}$	–	–	75.0	–	–

seasonal ET and seasonal water applied for maize under sprinkler irrigation. On the other hand, Mengu and Ozgürel (2008) determined a linear relationship for these two variations.

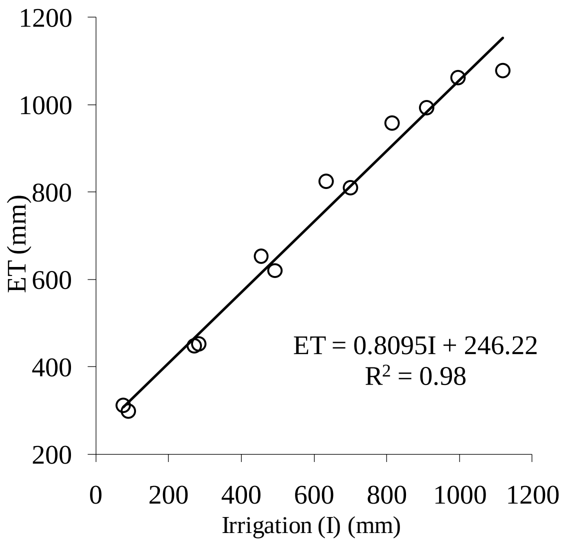

Figure 1. Relationship between irrigation and seasonal evapotranspiration (ET) for maize obtained at Bursa, Turkey, for combined years (2007 and 2008)

The seasonal values of ET per treatment ranged from 311 to 1078 mm in 2007 and from 298 to 1061 mm in 2008. As expected, the highest seasonal ET occurred in the T–125 treatment and the lowest ET occurred in the non–irrigated treatment (T–0). Yildirim and Kodal (1998) reported that seasonal ET in maize varied between 300 and 1024 mm in Ankara, Turkey. Under furrow irrigation applications, seasonal ET of maize obtained by Gencoglan and Yazar (1999) was 1026 mm for full irrigation treatment and 410 mm for non–irrigated treatment in the Cukurova region of Turkey. Oktem et al. (2003) found that seasonal ET for maize by using drip irrigation method in Sanliurfa conditions of Turkey varied between 1040–701 mm depending on irrigation scheduling. The values of seasonal ET obtained in this study are in agreement to those values reported in the previous literature for maize.

Grain yield and water–yield relationships

Irrigation treatments also resulted in differences in grain yield as shown in Table 2. This ranged from 5650 to 16340 kg ha^{-1} in 2007 and from 5490 to 16730 kg ha^{-1} in 2008 for the different irrigation regimes. Increased water amounts resulted in a relatively higher yield, since water deficit was the main yield–limiting factor in both years. The maximum yield was obtained at T–125 and the minimum yield at T–0 in both 2007 and 2008. However, in 2007, there was no significant difference between the treatments T–100 and T–75 i.e. irrigated with a 25 percent deficit. The results in this study are in agreement with previous studies. For instance, Bozkurt et al. (2011) reported that the highest grain yield was found in 120% of evaporation from a Class A Pan under the Eastern Mediterranean climatic conditions in Turkey. Yazar et al. (2002) reported also that the highest average maize grain yield obtained from full irrigation treatment using drip irrigation method. However, Yildirim and Kodal (1998) stated that applications of excessive irrigation water did not increase grain yields at the important level.

The relation between applied water and grain yield was evaluated for each experimental year (Fig. 2). The relationship between applied water and grain yield was quadratic. Small irrigation amounts increased yield, more or less linearly up to a level where the relationship was curvilinear because part of the water applied is not used in ET. At a point of 1100 mm of irrigation water amount, yield reached its maximum value (16730 kg ha^{-1}). Moreover, the regression equation shows that additional amounts of irrigation did not increase it any further (Fig. 2). Nonlinear relationships have also been reported by Gencoglan and Yazar (1999), Kipkorir et al. (2002), Bozkurt et al. (2006), and Farré and Faci (2009). However, Payero et al. (2006b) reported that there was linear relationship between grain yield and seasonal irrigation water amount.

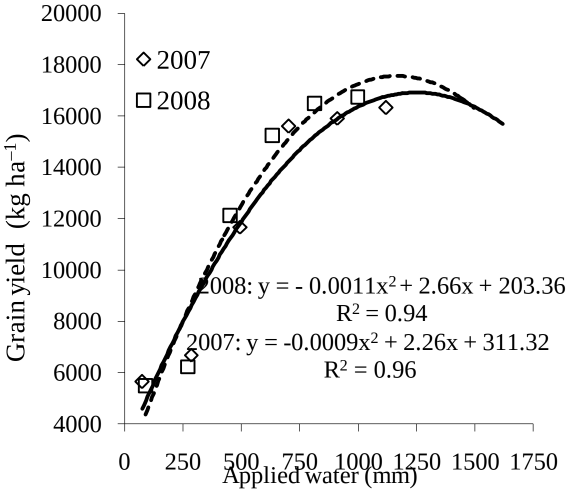

Figure 2. Relationship between applied water and grain yield for maize

A linear relationship was found between seasonal ET and grain yield in both years (Fig. 3). Grain yield responded linearly to crop water consumption. The linearity between grain yield and ET has also been reported by Cakir (2004), Oktem (2006) and Igbadun et al. (2007).

A good linear relationship between relative evapotranspiration deficit and relative yield decrease was observed from combining data over the two years (Fig. 4). The slope of the line in Fig. 4 represents that the yield response factor (ky) is 0.89 (R^2=0.89). This value implies that the rate of yield decrease is proportionally slightly lower (ky<1) than the relative evapotranspiration deficits. The ky value obtained in this study is similar to the literature data (Yildirim et al., 1996; Yazar et al., 2002; Karam et al., 2003; Mengu and Ozgurel, 2008). On the other hand, our result was lower than the values of ky obtained by Kipkorir et al. (2002) as 1.21, by Cakir (2004) as 1.29, by Dagdelen et al. (2006) as 1.04, and by Oktem (2008) as 1.23.

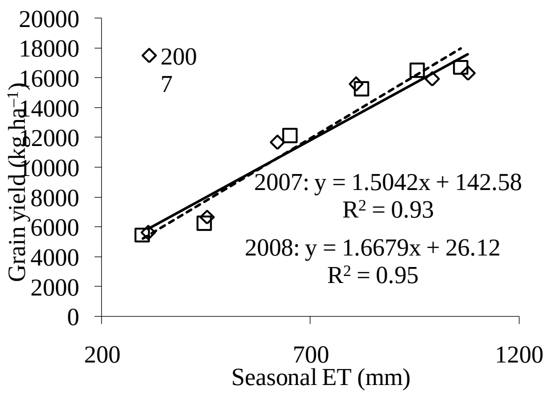

Figure 3. Relationship between seasonal ET and grain yield for maize

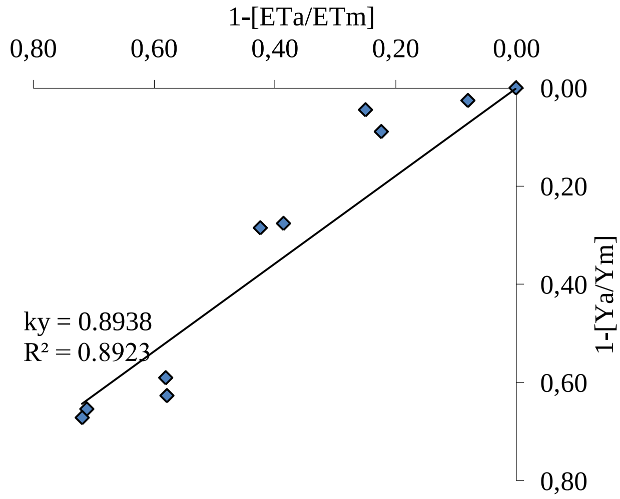

Figure 4. Relationship between relative grain yield decrease and relative ET deficit for maize throughout the total growing season during 2 years (2007–2008)

WUE and IWUE were different based on the treatments and years (Table 2). WUE values ranged between 1.40 and 1.93 kg m^{-3} for the both years. In the first year, the maximum values of both WUE and IWUE were obtained from the T–75 treatment as 1.93 and 1.59 kg m^{-3}, respectively. In the second year, higher water use efficiencies were found for the T–75 and T–50 treatments. However, the efficiencies decreased in the other deficit irrigation treatments (T–25 and T–0) and excessive irrigation treatment (T–125). On the contrary, Oktem (2006) stated that WUE increased as the amount of irrigation water increased. The ranges of WUE and IWUE obtained in this study were close to those reported in the previous literature for maize. Howell et al. (1995) reported WUE range of 0.89–1.45 kg m^{-3}, Yazar et al. (1999) reported WUE ranges of 0.87–1.42 kg m^{-3}, Oktem et al. (2003) reported WUE range of 1.04–1.36 kg m^{-3} and Oktem (2006) reported IWUE range of 1.07-1.43 kg m^{-3}. However, the range of WUE and IWUE obtained in this study were higher than those reported by Igbadun et al. (2008) and Pandey et al. (2000). Generally, WUE and IWUE are influenced by crop yield potential, irrigation method, estimation and measurement of ET, crop environment, and climatic characteristics of the region. The results related to the efficiencies shows that when irrigation water is limited, 25% deficit irrigation can be applied for increase the water use efficiencies. Mansouri–Far et al. (2010) reported that irrigation water can be conserved and yields maintained in maize plant (as sensitive crop to drought stress) under water limited conditions through improved fertilizer managements and selecting more tolerant hybrids. On the other hand, the feasibility of increasing either the WUE or IWUE is a decision that needs to be based not only on the biophysical response of the crop but also on economic factors. Often the objective of producers is not to increase yields but to increase profits (Payero et al., 2008). Determining the level of irrigation needed to optimize profits can be complex and depends on both biophysical and economic factors (Norton et al., 2000; English et al., 2002; Payero et al., 2008).

Net return

Total cost, gross return and net return of maize at different irrigation levels are presented in Table 3. The total cost of production increased with increase in irrigation levels. The net return increased sharply from T–25 to T–75 treatment due to the sharp increase in grain yield. The net return from T–75 to T–125 did not increase considerably because of the insignificant improvement in grain yield.

Table 3. Economic analysis of drip-irrigated maize under different irrigation schedules (average data of 2 years)

Treatment	Seasonal water applied (mm)	Total production cost ($ ha^{-1})	Gross return ($ ha^{-1})	Net return ($ ha^{-1})
T-0	76	1596	1785	189
T-25	285	1700	2167	467
T-50	494	1805	3813	2008
T-75	702	1910	4945	3035
T-100	911	2015	5227	3212
T-125	1120	2119	5301	3182

The reference irrigation treatment (T–100) gave the highest net return of $3212 ha^{-1}. The results revealed that the full irrigation is the best choice for higher yield and net income under drip irrigation. In a similar study, Panda et al. (2004) reported that the highest net return was obtained when irrigation was scheduled at 45% depletion of available soil water. But, net return values (170–206 $ ha^{-1}) determined in their study, were also considerably lower than the values (189–3212 $ ha^{-1}) determined in this study. The reasons for this difference may be lower local production cost, higher local commodity price and higher grain yield at the study area.

CONCLUSION

This study evaluated the effect of different seasonal irrigation amounts on maize evapotranspiration, grain yield, water use efficiency, and net return in a subhumid climate during 2007 and 2008. Increased water amounts resulted in a relatively higher yield, since water deficit was the main yield-limiting factor. This finding supported the hypothesis that less water stress would produce higher yield. In both years, seasonal water applied and grain yield of maize exhibited strong quadratic relationships. The average yield response factor (ky), which indicates the effect of water stress on reducing crop yield, averaged 1.07 over the 2 years. The value of ky obtained for this study could be used for the purposes of irrigation management and water allocation scheduling over irrigation schemes under limited irrigation water supply. In this study, higher values of both WUE and IWUE were obtained when irrigation was scheduled at 75 percent available soil moisture depletion (T–75). On the other hand, full irrigation (T–100) gave the highest net return. Finally, the overall results clearly revealed that in order to obtain higher yield and net income of maize in a sub-humid climate under drip irrigation, crops during the summer season should be irrigated at 100% soil water depletion every week. The results also suggest that 25% deficit irrigation approach may be a good strategy for increase water use efficiencies when full irrigation is not possible.

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