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Effect of soil water management and different sowing dates on maize yield and water use efficiency under drip irrigation system

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A 2-year field experiment (2012–2013) was conducted to evaluate the yield and water use efficiency (WUE) response of maize (*Zea mays L.*) to different soil water managements at different sowing dates. The experiment included three sowing dates (22 June, 6 July and 21 July) and four irrigation regimes based on maximum allowable depletion (MAD) of the total available soil water (TAW). The irrigation treatments were marked by I_1 to I_3 as 40%, 60% and 80% MAD of TAW, respectively, and with no irrigation. The results showed that grain yield reduced when planting was delayed in both years, ranging from 6105 to 4577 kg ha^{-1} in 2012 and from 7079 to 5380 kg ha^{-1} in 2013. However, WUE increased when planting was delayed from 22 June until 21 July. Also the highest grain yield was observed in the first irrigation treatment (MAD = 40%) in both years, and the highest WUE was obtained in the second irrigation treatment (MAD = 60%) with 1.64 and 1.61 (kg m^{-3}) in 2012 and 2013, respectively. These findings suggest that delay in planting date and the use of MAD = 60% treatment in Mediterranean-type region such as Golestan, Iran, can be useful in saving water that is highly important in such regions.

Keywords: maize; deficit irrigation; sowing date; water use efficiency; Gorgan

Introduction

According to FAO in 2013, agriculture currently uses about 70% of the total water withdrawal, mainly for irrigation. With the increasing demand for food, competition for water is rising (WWAP 2014). Turner (2004) declared that one of the greatest challenges in agriculture is developing technologies or agronomic options to improve water use efficiency (WUE). Martin et al. (1990) classified irrigation programs as full or deficit irrigation, based on plant, soil, and climate conditions. Deficit irrigation is a strategy to increase WUE and yields per unit of water applied (Kamkar et al. 2011). Before implementing a deficit irrigation program, it is necessary to determine the crop yield response to water stress, either during defined growth stages or throughout the whole season (Kirda & Kanber 1999). In many crops, including maize, drought stress is one of the most important factors in decreasing yield. Under deficit irrigation practices, it may be necessary to make a few modifications to agronomic practices, such as adopting flexible

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sowing dates (FAO 2002). Maize crops can be exposed to a certain level of water stress either during a particular period or throughout the whole growing season without experiencing a significant decrease in the yield (Sepaskhah & Ghahraman 2004).

Sowing date is probably the most subject to variation because of the very great difference in weather at planting time between season and within the range of climates (Otegui et al. 1995; Mokhtarpour 2011). Wrong sowing dates can cause critical stages of plant growth and development to coincide with environmental stress that can potentially damage, limit, or terminate plant growth and development (Sindelar et al. 2010; Mokhtarpour et al. 2011).

Huang et al. (2006) noted that selection of planting dates must ensure that the thermal environment is favorable to crop establishment and completion of its life cycle without a reduction in yield. Norwood (2001a) found that grain yield increased by 31.9% when sowing date was changed from mid-April to mid-May in Kansas, USA. Also he reported that WUE increased when sowing date was delayed from 16 April until 8 May (Norwood 2001b). Many researchers have observed yield reduction when planting was delayed (Nielsen et al. 2002; Sindelar 2006; Feyzbakhsh et al. 2011; Mokhtarpour 2011).

The effect of drought stress on the growth and yield of maize has been investigated by many researchers (Yazar et al. 2002; Panda et al. 2004; Igbadun et al. 2006; Alizadeh et al. 2008; Payero et al. 2009; Shirkhani & Chukan 2010; Nakhjavani et al. 2011). But most of the previous studies were done under sprinkler irrigation or furrow irrigation. Drip irrigation is more efficient than other irrigation systems. A typical drip irrigation efficiency is 90%, while the maximum efficiency of typical sprinkler irrigation is 75% (Hanson et al. 1995). The number of experiments that explain the effect of deficit irrigation under different sowing dates under drip irrigation system is rare (Yazar et al. 2002; Bozkurt et al. 2006). So far, few studies have investigated the interaction effects between soil water management and sowing date on maize yield and WUE. Therefore, in the current study, we investigated some agro-physiological characteristics, yield, and WUE of maize in a Mediterranean-type region under drip irrigation system.

Materials and methods

The current study was conducted at the agricultural research station of Gorgan, Golestan province, Iran (36° 53′ N, 54° 21′ E) during 2012 and 2013. The soil type in the experimental station is silty clay loam. The weather data during cropping season and physical and chemical properties of soil at the experimental field are shown in Tables 1 and 2, respectively.

The experiment included three sowing dates (22 June, 6 July, and 21 July) and four irrigation regimes based on maximum allowable depletion (MAD) of the total available soil water (TAW). The irrigation treatments were marked by I_1, I_2, and I_3, that is, 40%, 60%, and 80% MAD of TAW, respectively, and with no irrigation. Irrigation regimes were done after the third leaf appearance. Amount of irrigation applied plus rainfall (I + R) during the growing season is shown in Table 3. The lowest amount of water was applied in the first year (2012) because of the low rainfall and low evaporation (Table 3).

Hybrid SC.704 (MO17 B73) was used in the present study. Each plot consisted of four rows that were 10 m long. Plots were spaced 2 m apart to prevent water movement between plots. The rows were planted 75 cm apart and 20.5 cm spaced in the rows.

Soil samples were taken from each plot at 0–15, 15–30, 30–60, and 60–90 cm soil depth profile before each irrigation by means of Auger and were used to determine water content by a standard gravimetric method.

Table 1. Soil properties in different soil depth.

Depth (cm)	Soil parameters								
	pH	Ec (dS m^{-1})	Organic carbon (%)	Bulk density (mg cm^{-3})	Clay (%)	Silt (%)	Sand (%)	Field capacity (%) (θ_m)	Permanent wilting point (%) (θ_m)
0–15	7.5	1.35	1.5	1.44	28	54	18	39.8	18.9
15–30	7.3	1.27	1.1	1.41	30	52	18	38.0	17.3
30–60	7.3	1.42	0.6	1.40	34	52	14	38.6	13.7
60–90	7.3	1.41	0.4	1.40	33	52	15	38.7	13.7

Note: Soil texture was also silty clay loam.

Table 2. Monthly weather condition (average of 2012 and 2013) at the agricultural research station of Gorgan during the cropping season.

Year	Month	Minimum temperature (°C)	Maximum temperature (°C)	Average temperature (°C)	Sunshine hours (h)	Evaporation class A pan (mm)
2012	June	20.1	32.5	26.3	8.0	226
	July	22.3	32.7	27.5	7.6	263
	August	22.3	33.8	28.0	7.5	199
	September	21.0	32.2	26.6	7.4	174
	October	13.4	24.6	19.0	6.5	158
2013	June	21.3	33.2	27.2	9.5	346
	July	22.9	30.6	26.7	6.4	162
	August	24.8	36.0	30.4	6.5	237
	September	20.5	30.7	25.6	7.7	156
	October	15.9	28.1	22.0	6.7	117

Table 3. Amount of applied water (mm) during 2012 and 2013.

Year	2012		2013	
Treatment	Amount of applied water (mm)	Rainfall (mm)	Amount of applied water (mm)	Rainfall (mm)
$P_1 \times I_1$	593	174.0	863	25.3
$P_1 \times I_2$	493	174.0	750	25.3
$P_1 \times I_3$	373	174.0	444	25.3
$P_1 \times I_4$	88	174.0	73	25.3
$P_2 \times I_1$	517	179.0	683	79.2
$P_2 \times I_2$	423	179.0	489	79.2
$P_2 \times I_3$	315	179.0	331	79.2
$P_2 \times I_4$	76	179.0	81	79.2
$P_3 \times I_1$	430	136.5	549	97.0
$P_3 \times I_2$	335	136.5	373	97.0
$P_3 \times I_3$	223	136.5	272	97.0
$P_3 \times I_4$	71	136.5	75	97.0

Applied water was measured by means of contour in each plot with an accuracy of 0.1 l. Drip pipes were made of polyethylene (diameter 20 mm), with 20-cm nozzle distances, and were placed at the plants rows before sowing.

The volume of irrigation water for each irrigation time was calculated using the following equation (Sohrabi & Ghorbani 2002):

$$V = (((\theta_{\mathrm{FC}} - \theta) \times D \times \mathrm{Bd}))/(\mathrm{Ea}) \times A \tag{1}$$

where V = the volume of water to be applied (l), θ_{FC} = the gravimetric soil moisture content at field capacity (%), θ = the gravimetric soil moisture content before irrigation (%), D = rooting depth (cm), Bd = soil bulk density (g cm^{-3}), Ea = irrigation efficiency and is equal to 90% for drip irrigation system (Hanson et al. 1995), and A = plot area.

The dry matter and leaf area were measured at four important growth stages (5-leaf stage (V5), 8-leaf stage (V8), tasselling (Ta), and effective filling period (EFP).

Leaf area was measured using leaf area meter (Delta-T Devices Ltd, Cambridge, UK). After separating the different parts of the plants, samples were dried to a constant weight at 65°C for approximately 3 days. In both years, ten plants were tagged randomly in each plot to record different developmental dates, such as days to anthesis, and days to maturity.

Both experiments were conducted without nutrient limitations. Fertilizers were applied based on the soil test results. Soil properties were determined prior to planting, and the fertilizers (N–P–K) were applied before planting at the rate of 60–45–100 kg ha^{-1}, respectively. The sources of N, P, and K were urea (46% N), triple super phosphate (46% P_2O_5), and potassium sulfate (50% K_2O), respectively. Additional 100 kg N ha^{-1} was also applied as side dressing at 5- and 8-leaf stages (50 kg ha^{-1} in each stage). Weed control was carried out manually when necessary. The plants were protected against insect pests (mainly European corn borer (*Ostrinia nubilalis*)) using a combination of two pesticides: Larvin® (Thiodicarb) and Nuvacron® (Monocrotophos) at the rate of 1 kg ha^{-1} and 1.5 l ha^{-1}, respectively, once at 12-leaf stage (V12).

After physiological maturity, two central rows of 6 m, considering the border effect, were harvested. After harvest, plant height, ear length, number of seeds per ear, grain yield, 1000 seed weight (W1000), and harvest index (HI) were recorded.

Finally, WUE was calculated based on Equation (2).

$$\mathrm{WUE} = \frac{\text{Seed yield } (\text{kg ha}^{-1})}{\text{Amount of applaied water } (\text{m}^{-3}\text{ ha}^{-1})} \tag{2}$$

HI was calculated using the following equation:

$$\mathrm{HI} = \frac{\text{Seed yield } (\text{kg ha}^{-1})}{\text{total biomass } (\text{kg ha}^{-1})} \tag{3}$$

Grain yield (kg ha^{-1}) was calculated based on 14% moisture.

To describe the changes in leaf area index (LAI) during the growth period, the following model was used (Rahemi-Karizaki 2005):

$$y = \frac{ae^{-a(x-b(c))}}{(1+e^{-a(x-b)})^2} \tag{4}$$

where y is value of the variable under study, a, b, and c are coefficients of the model, and x is days after sowing. The coefficients a and c are related to the rate of LAI increase and decrease, respectively, and b is the time when LAI reaches its maximum amount.

All obtained data from two factorial experiments based on a randomized complete block design with three replications were analyzed by the analysis of variance (ANOVA).

The least significant differences test (LSD) was used to compare the mean values in each trait.

Correlations were calculated to determine relationships between the measured parameters and applied water. Also path analysis was carried out by applying standard statistical techniques. Data analysis was done using SAS software (SAS Institute Inc., 1996).

Results and discussion

Growth and yield effects

Figure 1 showed that all treatments showed the same growth pattern. Growth started slowly and then accelerated until LAI reached the maximum value at tasselling stage; then, LAI decreased until physiological maturity. As the finding indicated, LAI and total dry matter (TDM) decreased with a delay in planting from 22 June to 21 July in both years. The highest averages of LAI (4.55) and TDM (19,408 kg ha^{-1}) were obtained on the first sowing date and decreased with delays in planting date. Table 1 shows that mean temperatures were suitable for maize crop on the first sowing date, which allowed high photosynthetic efficiency and, consequently, higher leaf area. In all irrigation treatments, a decrease in the volume of irrigation had a negative effect on LAI and TDM indices for both years (Figure 1). Treatment I_1 had a higher maximum LAI than the other treatments. So, in this treatment, assimilation, production, transportation, and dry matter increased. The increases in LAI and TDM at higher levels of irrigation and at the first planting date resulted in better crop growth. It produced higher plant height, higher LAI, and ultimately higher TDM (Figure 1 and Table 5). In the current study, it was observed that when planting date was delayed, the maximum, minimum, and average daily temperatures begin to decrease (Table 2), which resulted in the reduction of LAI and TDM. The LAI trend on all sowing dates revealed that the time needed to reach the maximum LAI (tasselling stage) was ultimately the same (4.55 to 3.15), while the maximum decrease in LAI was observed when dates were delayed and MAD increased. The importance of leaf area as a determinant of radiation interception has been long appreciated and well recognized (Lindquist et al. 2005). Yazar et al. (2002) showed that photosynthetic and, in general, dry matter production by plant is integrally associated with the amount of available water. When the amount of available water increases, the dry matter also increases integrally.

Based on this finding, planting date and irrigation regimes had a significant effect on days to anthesis, anthesis-silking interval (ASI), days to physiological maturity, seeds per ear, ear length, W1000, yield, and HI during 2012 and 2013. The interaction between planting date and irrigation also had a significant effect on W1000, grain yield, and HI in both years (Table 3).

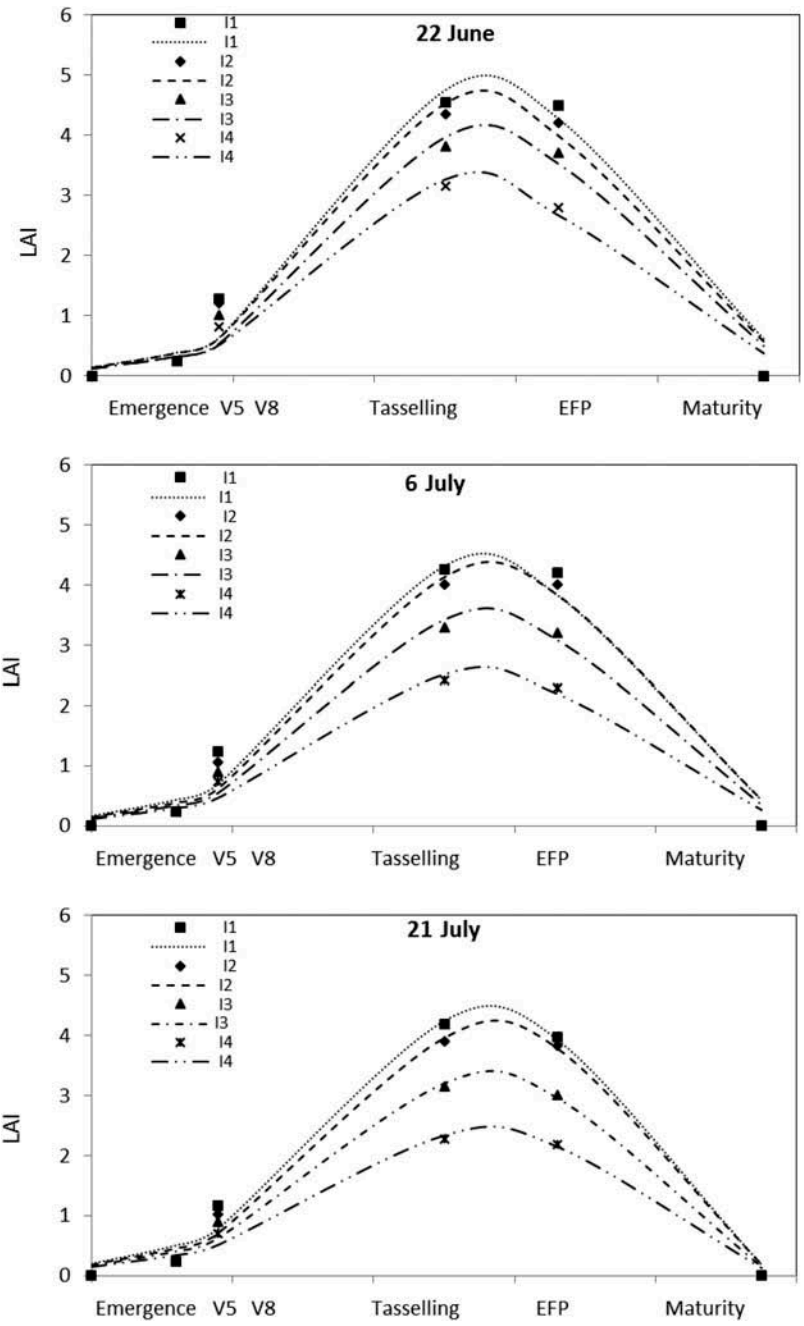

Figure 1. Leaf area index of maize as influenced by sowing date, averaged across 2 years. Symbols are observed data, while dashed lines show predicted values by Equation (4).

Similar trends were observed for days to anthesis, ASI, and days to physiological maturity in both years. With a delayed sowing date in 2013, days to anthesis and days to physiological maturity increased from 52 to 55 and from 91 to 109.7, respectively.

In both years, seeds per ear, ear length, grain yield, and HI were decreased by delayed planting dates. Conversely, W1000 increased (Table 5).

Based on the results of this study, lower mean daily temperature during late planting (21 July) reduced TDM and resulted in decreased seeds per ear and ear length values. Many researchers have reported that when planting dates were delayed, the number of seeds per ear and ear length decreased (Sindelar et al. 2010; Feyzbakhsh et al. 2011). The result also showed that the highest 1000 seed weights (256 and 259 g during 2012 and 2013, respectively) were obtained at the last planting date in both years (Table 5). The lower mean daily temperature after anthesis at the last planting date (Table 2) prolonged the period between anthesis and physiological maturity, and consequently, W1000 increased. These results was in line with Alizadeh et al. (2008).

Delayed sowing date caused the grain yield to decrease in both years, ranging from 6105 to 4577 kg ha^{-1} in 2012 and from 7079 to 5380 kg ha^{-1} in 2013 (Table 5).

The highest grain yield was obtained when maize was sown on the 22 June in both years. Grain yield was higher in 2013 than in 2012 (Table 5). This is related to the better conditions (temperature and sunshine hours) during 2013 and the first planting dates of both years. Lower temperatures on the last planting date (21 July) resulted in lower number of seeds per ear and shorter ear length, so yield decreased. The results of the current study is in agreement with those of other researchers who reported a reduction in grain yield when planting date occurred either before or after the optimum period (Nielsen et al. 2002; Sindelar et al. 2010). HI declined when planting was delayed; the highest HI value was obtained from the planting date 22 June. Similar results have been reported by Mokhtarpour (2011).

To study the effects of drought stress, we measured soil moisture contents in different depths.

Figure 2 and Table 3 shows the soil moisture content during the plant growth stages in 2013 for the first sowing date (patterns of soil moisture content at other sowing dates in 2012 and 2013 were the same as the first sowing date in 2013; therefore, data are not shown here). A variation has been observed in water content with depth and time. Sudden increase in moisture contents was due to rainfall event. The lower applied water in 2012 compared with that of 2013 was the result of lower rainfall in 2013 during the growth stages as shown in Table 3.

Changes in soil water content at different MAD indicated that all studied traits were sensitive to drought stress. With increasing water stress severity, days to anthesis and ASI increased, but days to maturity, seeds per ear, ear length, W1000, grain yield, and HI decreased (Table 5).

The highest values of days to anthesis and ASI were recorded in the I_4 treatment with 55 and 8.4 during 2012, respectively. Similar trends of days to anthesis and ASI were obtained during 2013 (Table 5). A significant negative correlation coefficient was found between days to anthesis and applied water (−0.51, $P \leq 0.001$), demonstrating that stress on the crop delayed the onset of reproductive growth and accelerated maturity. This result is in agreement with that of Boote (1996).

Irrigation regimes had similar effects on seeds per ear and ear length in both years. The lowest seeds per ear and ear length were observed in the no-irrigation treatment. The significantly correlation coefficient was observed between seeds per ear and applied water (0.91, $P \leq 0.001$), showing that seeds per ear variable is sensitive to drought stress. Reduction in seeds per ear may occur due to failure of fertilization (due to large ASI) or increased rate of kernel abortion due to water stress. This result is consistent with that of Nakhjavani et al. (2011).

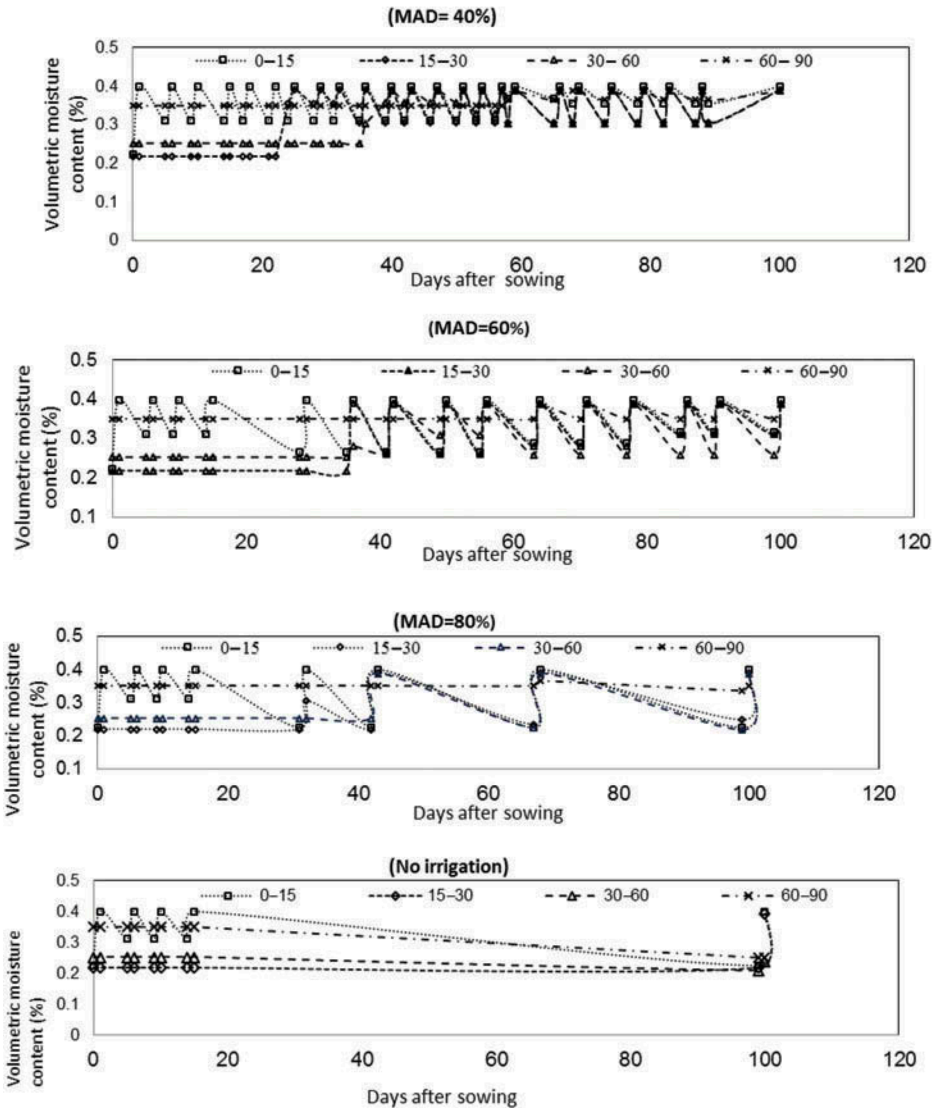

Figure 2. Temporal variation of soil moisture in root zone of maize at different available soil water at the first sowing date during 2013.

The highest grain yield reductions were observed in treatment I_4 followed by I_3, I_2, and I_1, respectively (Table 5). Grain yield was significantly higher in the I_1 treatment compared with the other irrigation regimes during 2012 and 2013, due to the better soil condition in all soil layers (Figure 2). A significant correlation coefficient was also found between grain yield and applied water (0.96, $P \leq 0.001$). Once irrigation was reduced or stopped, less water was available in the soil profile to meet crop demand, so the grain yield decreased. Lack of moisture in the layers of soil in the no-irrigation treatment reduced grain yield, but in treatments I_2 and I_3, different MAD and the variation in water content over time were the main factors of reduced grain yield.

In the current study, higher LAI on early sowing dates and MAD = 40% irrigation probably increased the interception of solar radiation and thus a greater CO_2-fixing ability of the plants resulted in the accumulation of more assimilates (Figure 3), leading to higher seed yield. This result agrees with that of Faraji et al. (2009) who studied canola. The result of path analysis indicated that the number of seeds per ear influenced yield more than W1000 (data not shown). This result is consistent with that of Mokhtarpour (2011), who reported that the reduction in grain yield was not attributed to W1000, but to a reduction in the number of seeds per ear.

The highest HI value was obtained from treatment I_1 and was decreased in treatments I_2, I_3, and I_4 successively, because the rate of reduction was higher in grain yield than in TDM. The higher the efficiency of converting dry matter into economic yield, the higher

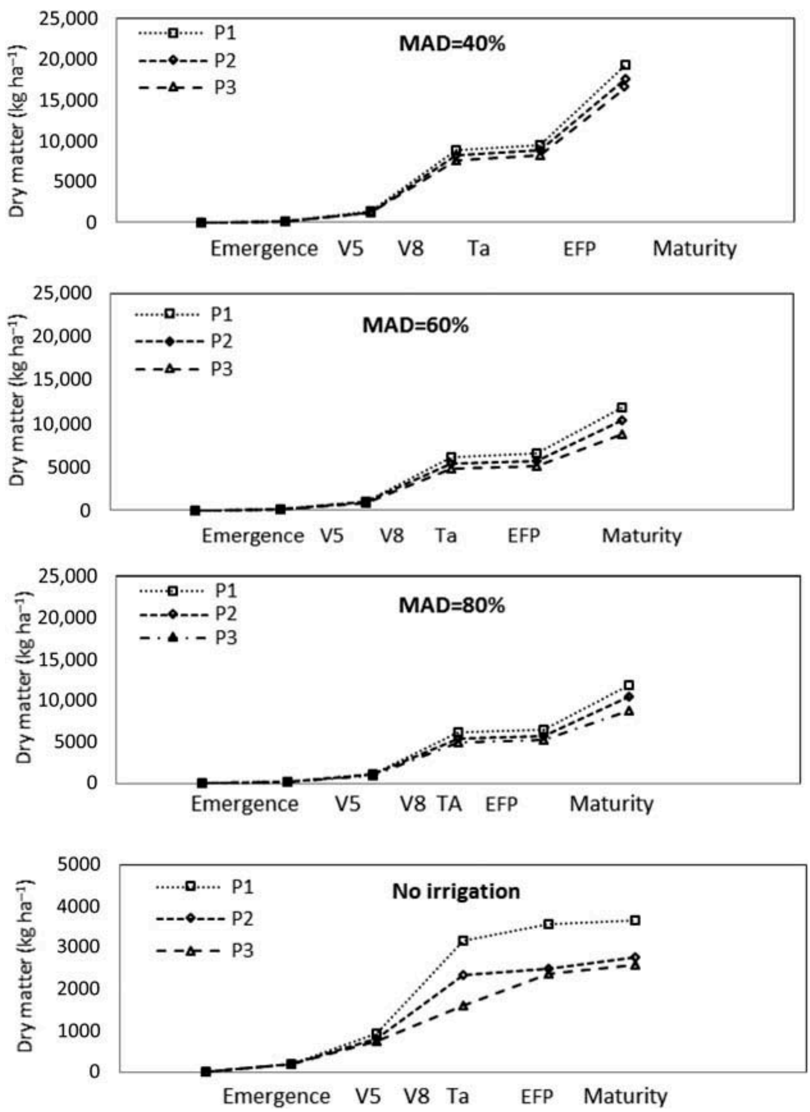

Figure 3. Dry matter of maize as influenced by irrigation, averaged across 2 years.

the value of HI at treatment I_1. This means that reproductive organs are more susceptible to high drought stress than vegetative organs.

Water use efficiency

Results showed that sowing date, irrigation regimes, and their interaction had significant effects on WUE, which increased with a delay in sowing date (Tables 4 and 5). The highest WUE was obtained on the planting date 21 July in both years. Cooler temperatures on 21 July decreased evaporation, causing WUE to increase (Table 5). Norwood (2001b) also found that WUE increased when planting was delayed from 16 April to 8 May. This suggests that delay in planting may be a viable option. Experimental results indicated that irrigation treatments significantly affected WUE. The highest WUE values were obtained at MAD = 60% with 1.64 and 1.61 (kg m^{-3}) in 2012 and 2013,

Table 4. Analysis variance for some agronomic traits.

Source of variation	Df	Days to silking	Days to maturity	Anthesis-silking interval	Number of seed	Ear length	W1000	Grain yield	WUE	HI
Year (Y)	1	NS	NS	*	**	**	NS	**	**	**
Planting date (P)	2	**	**	*	**	**	**	**	**	**
Irrigation (I)	3	**	**	**	**	**	**	**	**	**
P × I	6	NS	NS	NS	NS	NS	**	**	**	**
P × Y	2	NS	**	NS	NS	NS	NS	**	**	NS
I × Y	3	NS	NS	*	**	**	NS	NS	**	**
P × I × Y	6	NS	NS	NS	NS	NS	NS	**	**	NS

Notes: NS, nonsignificant; * and **, significant at the 0.05 and 0.01 levels of probability, respectively.

Table 5. Means of some traits of maize (SC.704) under different sowing dates and irrigation management.

	Days to silking	Days to maturity	Anthesis-silking interval	Number of seed per ear	Ear length (cm)	W1000	Grain yield (kg ha^{-1})	WUE (kg m^{-3})	HI (%)
2012									
P_1	52b	88.3b	5.1a	509a	15.8a	242.5b	6105a	1.56c	45.8a
P_2	52b	95.1b	5.8a	482b	15.8a	241.6b	5307b	1.59b	45.0a
P_3	55a	105.7a	6.0a	474c	14.9b	256.0a	4577c	1.69a	44.3a
I_1	51c	98.1a	4.0b	598a	18.8a	261.5a	8371a	1.64b	51.0a
I_2	51c	97.6a	5.0b	548b	16.7b	255.1b	6987b	1.68a	49.0b
I_3	53b	96.8a	5.3b	494c	14.6c	252.7c	4757c	1.60c	48.0b
I_4	55a	93.0b	8.4a	315d	11.4d	216.4d	1203d	1.50d	31.0c
2013									
P_1	52b	91.3b	5.1a	545a	17.1a	240.0c	7079a	1.08b	43.0a
P_2	53b	94.0b	6.2ab	516b	16.0b	242.3b	6351b	1.34a	42.0b
P_3	55a	109.7a	6.6a	490c	15.7c	259.0a	5380c	1.35a	39.0c
I_1	52c	100.4a	4.0c	679a	20.5a	265.2a	10,814a	1.61b	56.0a
I_2	52c	100.4a	4.7bc	624b	18.3b	256.0b	9079b	1.75a	54.0b
I_3	53b	98.6ab	5.8b	548c	16.3c	248.0c	5016c	1.45c	45.0c
I_4	56a	94.0b	9.4a	217d	10.0d	218.0d	172d	0.22d	11.0d

Note: Means with same letter in each columns are not significantly different at a 5% probability level.

respectively. The lower WUE associated with higher amount of irrigation water could be due to a greater loss of water by evapotranspiration (ET) than the corresponding increase in seed yield (Kamkar et al. 2011). WUE was significantly decreased with a decrease in the amount of irrigation water from I_2 to I_4, possibly due to the decrease in seed yield with increased drought stress.

Conclusion

Before sowing, it is necessary to know crop yield responses to sowing dates and water stress. Results of the current study showed that the yield and yield components were limited by soil moisture content and low temperature stress in the delayed sowing date. Sowing on a warm date (22 June) reduced WUE; the highest WUE value and the lowest grain yield were obtained on the delayed sowing date (21 July) during 2012 and 2013. These are opposite. So it is recommended that maize should be planted for grain production in the first sowing date and the forage production in late sowing dates, respectively.

The results presented here are encouraging, because they provide agronomists with an opportunity to increase WUE. Attention to WUE in planting patterns is emphasized, because WUE increases by delayed sowing dates.

Based on these results, to save water and to obtain the highest WUE, MAD should be considered; when the MAD is higher than 60%, irrigation should not be performed. It is suggested that the volume of water be adjusted according to the depth of maize root during plant growth. Drip irrigation systems can be designed for and operated in maize fields; they are promising options for improving both WUE and yield.

Disclosure statement

No potential conflict of interest was reported by the authors.

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