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Irrigation and fertigation scheduling under drip irrigation for maize crop in sandy soil

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A b s t r a c t. Field experiments was conducted to determine the best irrigation scheduling and the proper period for injecting fertilizers through drip irrigation water in a sandy soil to optimize maize yield and water productivity. Four irrigation levels (0.6, 0.8, 1.0 and 1.2) of the crop evapotranspiration and two fertigation periods (applying the recommended fertilizer dose in 60 and 80% of the irrigation time) were applied in a split-plot design, in addition to a control treatment which represented conventional irrigation and fertilization of maize in the studied area. The results showed that increasing the irrigation water amount and the fertilizer application period increased vegetative growth and yield. The highest grain yield and the lowest one were obtained under the treatment at 1.2 and of 0.6 crop evapotranspiration, respectively. The treatment at 0.8 crop evapotranspiration with fertilizer application in 80% of the irrigation time gave the highest water productivity (1.631 kg m^{-3}) and saved 27% of the irrigation water compared to the control treatment. Therefore, this treatment is recommended to irrigate maize crops because of the water scarcity conditions of the studied area.

K e y w o r d s: fertigation, sandy soil, drip irrigation, water productivity, maize yield

INTRODUCTION

Fertigation is the addition of fertilizers through irrigation water. It is particularly important for irrigated agriculture in sandy soils where large quantities of fertilizers should be applied to meet crop requirements and to prevent loss by leaching. Fertigation has been found as one of the best ways for applying water and nutrients through the drip irrigation system. It has been reported by several researchers (Deshmukh and Hardaha, 2014; El-Hendawy *et al.*, 2008; Feleafel and Mirdad, 2013; and Vijayakumar *et al.*, 2010) that the drip irrigation system has many advantages. It saves water, machinery and labour, application of fertilizers is more accurate and uniform, and nutrient uptake by roots is improved. Drip irrigation proves its superiority over other methods of irrigation due to the direct application of water and nutrients in the vicinity of the root zone. Abd El-Wahed and Ali (2013) showed that the drip irrigation system maximized maize grain yield and water use efficiency compared to the sprinkler irrigation system. The highest values of grain yield and water use efficiency were recorded for plants irrigated with 100% of the crop evapotranspiration (*Etc*). El-Meseery (2003) found that drip irrigation for maize in sandy soil saved about 20 to 25% of the water used by applying 80 and 75% of the *Etc*, respectively, and no significant difference in crop yield was observed in comparison to crop yield at application of 100% of *Etc*. Additionally, there was an increase in the water use efficiency by 6%. AbdEl-Hafez *et al*. (2001) revealed that the drip irrigation method increased field and crop water use efficiency of maize crops in clay soil by 35 and 9.52%, respectively, as compared to furrow irrigation. The mean values of water application efficiency and the percentage of percolation losses for the drip irrigation system were 93.25 and 6.75%, respectively. In turn, the mean values for the furrow irrigation method were 76.4 and 23.6%, respectively.

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Maize (*Zea mays*) is one of the most important cereals for both human and animal consumption. It is planted for grain and forage. In terms of global production, maize is the third most important food crop after rice and wheat (USDA, 2011). The demand for maize is increased as both fresh and processed food. The greatest challenge for the agricultural sector is to produce more yields from less water *ie* maximizing water productivity (WP). This could be achieved by proper irrigation scheduling and application of fertilizers through the irrigation water (fertigation) using the drip irrigation system. Extensive research has been undertaken in order to investigate WP. Zwart and Bastiaansen (2004), for example, reported values of 1.1-2.7 kg m^{-3} for the WP of maize. The varying range they reported was attributed to factors such as climate, irrigation practices, and the application of fertilizers. Their findings suggest that decreasing irrigation application is the key for improving WP. Moayeri *et al.* (2011) reported a low value of 1.01 kg m^{-3} for maize WP in Iran. They indicated that the most important cause of the low WP was farmers inadequate knowledge about irrigation, plant nutrient deficiencies, and improper crop management practices.

On other hand, water is a vital source for crop production and its resources are limited in Egypt. The per capita share of fresh water resources is now below 800 m^3 per person and it is expected to decrease to 350 m^3 per person by 2025 when the number of population increases to 100 million. About 84% of water resources are consumed by the agricultural sector (El-Beltagy and Abo-Hadeed, 2008). One way to maximize the use of this limited resource is to improve water management techniques and use proper and more efficient irrigation systems such as the drip irrigation system, particularly in newly reclaimed sandy soils (Abu-Zeid, 1999).

Therefore, the first aim of this study is to determine the best irrigation scheduling and the proper period for injecting fertilizers through the irrigation water, which can optimize the maize crop yield. The second aim is to enhance the water productivity of maize in the sandy soils under the drip irrigation in Egypt.

MATERIALS AND METHODS

Two field experiments were conducted at AlyMobarak experimental farm in the South Tahrir Research station, Egypt, during the growing seasons of 2009 and 2010. The experimental site was a newly reclaimed sandy soil of the El-Bustan area in the west of the Nile delta. It is situated at an altitude of 6.7 m above the mean sea level and is intersected by 31° 02' N latitude and 30° 28' E longitude. The weather is hot with no rain from May to October, and with a mean air temperature exceeding 27°C and mean relative humidity of about 70% during daytime in these months. In winter, the weather is usually cold with a mean air temperature of about 16°C. The scarce amounts of water coming from rainfall do not contribute to water requirements of winter crops. The weather data for the experimental site during the growing seasons of 2009 and 2010 are presented in Table 1.

The soil of the experimental area is sandy in texture (90.5% sand, 3.85% silt, and 5.65% clay) with an average bulk density of 1.67 Mg m^3 for 0-60 cm depth and is alkaline in reaction with pH values ranging from 9.13 to 9.38. Average soil salinity expressed as soil electrical conductivity (EC) in the saturated soil paste extract and organic matter content over 60 cm depth were about 0.33 dS m^1 and 0.12%, respectively. Field capacity, wilting point, and available water values were 10.3, 5.02, and 5.28%, respectively. The available macronutrient values N, P, and K were 15.10, 4.85, and 60.75 mg kg^{-1}. Chemical and physical soil analyses were conducted by the standard methods as

Table 1. Monthly mean: minimum (Tmin) and maximum (Tmax) temperature, relative humidity (RH), and pan evaporation (Ep) at the experimental site in the 2009 and 2010 growing seasons

Month	Ep (mm day^{-1})	Sunshine duration (h)	RH (%)	Tmin (°C)	Tmax (°C)	Ep (mm day^{-1})	Sunshine duration (h)	RH (%)	Tmin (°C)	Tmax (°C)
	Season 2009					Season 2010				
May	3.95	13.6	68	18.6	31.8	5.4	13.6	60	17.6	30.7
June	5.87	14.0	65	17.7	31.6	6.5	14.0	61	17.9	32.5
July	6.36	13.8	73	22.0	37.1	5.9	13.8	74	21	36.7
August	7.25	13.2	68	18.2	32.5	8.2	13.2	77	19.8	34.7
September	6.43	12.2	69	19.4	34.2	6.5	12.2	71	18.5	33.6
October	5.97	11.3	64	21.0	29.3	6.3	11.3	71	19.9	29.2

described by Tan (1996). Chemical analysis of the irrigation water indicated that electrical conductivity was 0.50 dS m^{-1} at 25ºC and the pH value was 7.55.

The experiments were laid out in a split-plot design with four replicates. Each plot area was 140 m^2 (20 x 7 m). The main plots were designed for the irrigation treatments and the sub-plots were assigned to the fertigation treatments. The irrigation treatments (I) comprised four irrigation water amounts *ie* 0.6 (I_1), 0.8 (I_2), 1.0 (I_3), and 1.2 (I_4) of the crop evapotranspiration (Etc). In addition, in the control treatment (conventional irrigation) represented the traditional irrigation in the studied area, in which maize is irrigated every 3 days by the drip irrigation method for an irrigation time of about 5 h ha^{-1}, depending on the growers experience, with fertilizer application manually side-dressed on the field. This method results in a total amount of applied water of 7 230 and 8 410 m^{-3} h^{-1} in 2009 and 2010, respectively.

The fertigation treatments consisted in two periods of fertilizer application through the irrigation water, namely the application of the recommended fertilizer dose for periods equal to 80 and 60% of the irrigation time. Fertilizers should not be added to irrigation water at the very beginning of irrigation to ensure the stability of water pressure and discharges. This maintains high efficiency and equality in water and fertilizer distribution for each plant. Similarly, at the end of irrigation, some short time should be also left without injecting any fertilizers to leach any remaining deposits from the dippers to evade any possible closures.

The maize crop (hybrid SC10) was planted on the 30th of May 2009 and 2010, and was harvested on the 3rd of October 2009 and 2010. Plant density was seven plants per square meter, which is appropriate to sandy soil. Irrigation water was applied every three days by using surface drip lateral lines connected to the sub-main line. Each lateral line is 20.0 m long and spaced at 0.7 m on the sub-main and is equipped with build-in emitters of a 2 l h^{-1} discharge rate spaced at 0.3 m on the lateral lines. A differential pressure tank was connected to the drip irrigation system to inject all fertilizer *via* irrigation. Nitrogen fertilizer was added in the form of ammonium nitrate at the rate of 318 kg N ha^{-1}. Potassium sulphate was added at the rate of 120 kg K ha^{-1}. Phosphorous fertilizer was added at the rate of 55 kg P ha^{-1}. Micronutrients *ie* Fe, Zn, and Mn were also added at the rate of 238:238:238 g ha^{-1}.

The amount of the irrigation water applied (Wa) through drip irrigation per treatment was calculated by the following formula:

$$Wa = \frac{I\,Etc}{Ea} + LR, \tag{1}$$

where: I – empirical irrigation level (0.6, 0.8, 1.0, and 1.2 of Etc, respectively, for treatments I_1, I_2, I_3, and I_4), Etc – crop evapotranspiration, Ea – irrigation efficiency of the drip system, determined at the beginning of each season as 0.80 and LR – leaching requirements (20% of the calculated irrigation water was additionally applied per irrigation during the growing seasons for leaching purposes).

Crop evapotranspiration (Etc) was calculated according to Allen *et al*. (1998), using the equation:

$$Etc = ETo\ Kc, \tag{2}$$

where: ETo – reference crop evapotranspiration and Kc – crop coefficient. The recommended values of Kc for maize crops were used according to Allen *et al*. (1998).

The reference crop evapotranspiration (ETo) was calculated by the following formula:

$$ETo = Ep\ Kp, \tag{3}$$

where: Ep – the cumulative evaporation amount for considering the irrigation interval, Kp – evaporation pan coefficient (the Kp value used for the experimental site is 0.75). Evaporation data were collected daily from a standard class A pan evaporation tank located near the experimental field.

Irrigation time was calculated according to the equation:

$$t = \frac{Wa\ A}{q}, \tag{4}$$

where: t – irrigation time (h), Wa – depth of applied irrigation water (mm), A – wetted area by emitters (m^2), q – emitter discharge (l h^{-1}).

Irrigation water productivity (WP) was determined to evaluate the benefit of the applied water through economic crop production. It can be defined as the amount of grain yield a cubic meter of water may produce. The values of WP (kg m^{-3}) were determined by dividing grain yield (kg ha^{-1}) by total applied irrigation water (m^3 ha^{-1}) according to Ali *et al*. (2007).

Samples of four plants were taken after 105 days from the planting date for each subplot randomly in all replicates and the following measurements were made:
– plant height (cm) from the soil surface,
– the maximum leaf area was measured and the leaf area index (LAI) was calculated by the following equation:

$$LAI = \frac{leaf\ area\ per\ plant}{plant\ ground}, \tag{5}$$

where: plant ground area is the area of land occupied by the plant (equal distance between the plant × distance between the ridges).

Four plants were selected randomly from each plot to estimate the yield components. The straw yield and the grain yield (t ha^{-1}) were calculated from the yield of the whole plot. The data recorded at harvest were as follows: (a) ear length (cm), (b) number of grain ear^{-1}, (c) 100 grain weight (d), and grain yield (t ha^{-1}) adjusted at 15.50% moisture content.

Data were analyzed using analysis of variance (ANOVA). Comparisons between average values from the different treatments were made by LSD test at a 0.05 probability significance level (Steel and Torrie, 1984).

RESULTS AND DISCUSSION

The studied vegetative growth, plant height, and leaf area index was significantly affected by the irrigation application rates ($p<0.05$) (Table 2). The highest values over the two seasons were recorded when plants were irrigated at 1.2 *Etc*, while the lowest ones were obtained when plants received irrigation at 0.6 *Etc*. The average values of the plant height and leaf area index over the two seasons were higher by about 25% under the treatment at 1.2 *Etc* than that at 0.6 *Etc*. This could be attributed to the increase in the activity as a result of good absorption of nutrients with a high level of available moisture (El-Kalla *et al*., 1985). The data also showed that the plant height and leaf area index had significantly higher values ($p<0.05$) under the conventional irrigation than that under the irrigation scheduling treatments at 0.6, 0.8, and 1.0 *Etc*. However, the difference between conventional irrigation and irrigation scheduling at 1.2 *Etc* was not significant ($p<0.05$). These results may be due to the higher amount of the water applied under the conventional irrigation and the 1.2 *Etc* treatments than that applied under the other treatments, which leads to improved availability and absorption of the nutrient elements. It has been observed that even when higher amounts of nutrients are present in the soil, crops cannot absorb or utilize nutrients properly and optimally if water supply becomes inadequate (Majumder, 2002). The grown plants may also be stressed under the treatments at 0.6, 0.8, and 1.0 *Etc* due to insufficient water supply. Maize crop is sensitive to both moisture stress and excessive moisture

Table 2. Vegetation growth traits affected by fertigation and irrigation treatments

Irrigation treatment (*I*)	Fertigation treatment (F)							
	Season 2009				Season 2010			
	F test	Mean	60%	80%	F test	Mean	60%	80%
				Plant height				
Conventional irrigation		230	Side dressed			226	Side dressed	
0.6 *Etc*		172.5	170.0	175.0		175.0	173.0	178.0
0.8 *Etc*		184.0	178.0	190.0		189.5	182.0	197.0
1.0 *Etc*	LSD=10.55	188.5	186.0	191.0	LSD=11.52	195.0	190.0	200.0
1.2 *Etc*		217.5	210.0	225.0		217.0	214.0	220.0
Mean			186.0	195.2			189.7	198.7
LSD			8.504				6.562	
*I**F			NS				NS	
				Leaf area index				
Conventional irrigation		5.0	Side dressed			5.1	Side dressed	
0.6 *Etc*		3.85	3.79	3.90		3.98	3.80	4.15
0.8 *Etc*		3.99	3.86	4.11		4.73	4.25	5.20
1.0 *Etc*	LSD=0.41	4.40	4.11	4.70	LSD=0.407	4.80	4.30	4.90
1.2 *Etc*		4.77	4.72	4.81		5.03	4.75	5.30
Mean			4.12	4.38			4.25	4.99
LSD			0.406				0.405	
*I**F			NS				NS	

NS – not significant.

(Doorenbos and Kassam, 1979). Excess moisture is harmful to crops, and the water stress at flowering and seed formation stages reduces the crop yield. Otegui *et al*. (1995), Pandey *et al*. (2000) and El Nady and Borham (2009) found that maize is particularly sensitive to water and other environmental stresses around flowering.

The vegetative growth traits were also significantly affected by the fertigation application rates ($p<0.05$). The results in Table 2 indicate that the increasing fertigation period increased the plant height and leaf area index significantly. The average values of the plant height and leaf area index over the two seasons were increased significantly by about 5 and 16%, respectively, with application of the recommended fertilizer dose in 80% of the irrigation time, compared to that in 60% of the irrigation time. This may be caused by the fact that the application of the fertilizer dose in 80% of the irrigation time reduced nutrient leaching from the root zone and increased its absorption by the growing plants, compared to the application of the recommended fertilizer dose in 60% of the irrigation time. These results are in harmony with those obtained by Lamm *et al*. (2001) and by Papadopoulos (1995), who stated that under the drip fertigation system an uptake of the N fertilizer exceeding 80% was obtained with the same amount of water compared to conventional soil N fertilization, where the N utilization efficiency rarely exceeds 50% even under good irrigation scheduling. The interaction effect of irrigation and fertigation treatments did not show any significant effect on the studied vegetative growth traits in the two years of study. However, the values of the studied vegetative growth parameters were slightly higher in 2010 than those in 2009 as a result of better weather conditions prevailing in 2010.

The average values over the two seasons of the yield components, namely ear length, number of grains ear^{-1}, and 100 grain weight were significantly increased with the increasing irrigation amount from 0.6 to 1.2 *Etc* (Table 3). The treatment at 1.2 *Etc* increased ear length by 25.7%, number of grain/ear by 27.6%, and 100 grain weight by 31.1%, compared to treatment at 0.6 *Etc*. The different yield components were also significantly affected by the fertigation period treatments (Table 3). These trends were similar in the two growing seasons. When the fertilizer application period was reduced from 80 to 60% of the irrigation time, a reduction in all yield components was noticed. The reduction percentages over the two seasons were about 14.6, 11.1, and 8.6% for ear length, number of grain ear^{-1}, and 100 grain weight, respectively.

The maize grain yield increased significantly with the increasing irrigation water amount from 0.6 to 1.2 *Etc* (Table 3). Irrigation of maize plants at 1.2 *Etc* increased grain yield by about 18.7, 23.0, and 97.0%, as an average for the two seasons, compared to irrigation at 1.0, 0.8, and 0.6 *Etc*, respectively. The highest grain yield over the two seasons (7.98 t ha^{-1}) was produced at irrigation at 1.2 *Etc*, while the lowest one (4.05 t ha^{-1}) was obtained at 0.6 *Etc*. Grain yield was also influenced positively and significantly by the fertilizer application period. Fertigation in 80% of the irrigation time increased the average grain yield by 5.7%, compared to that in 60% of irrigation time. Grain yield and yield component differed significantly under the different irrigation scheduling, compared to the control treatment. The highest grain yield under the treatment at 1.2 *Etc* exceeded that of the conventional irrigation (the control treatment) by about 6.7%. This may be due to the leaching of nutrients away from the root zone as a result of the increasing amount of the irrigation water applied under the conventional irrigation, which produced low yield, as shown in Table 4. Meanwhile, the treatment at 0.6 *Etc* resulted in the lowest grain yield and exhibited a 46.4% decrement in the grain yield, compared to the control treatment. This means that the grown plants may be stressed under the treatment at 0.6 *Etc* due to insufficient water supply.

The interaction between the irrigation and fertigation treatments was significant in the two seasons, except for ear length and 100 grain weight, and for the grain yield in the first season only. The highest values of the grain yield and yield components were obtained when maize was irrigated at 1.2 of *Etc* and at fertigation application in 80% of the irrigation time. This may be related to the fact that application of the fertilizer dose in 80% of the irrigation time provides excellent uniformity of fertilizer application, reduces nutrient leaching, and supplies the growing plants with the necessary nutrients. In addition, the high amount of the irrigation water applied under the treatment at 1.2 *Etc* resulted in more available soil moisture in the root zone, which induced greater accessibility of nutrients to be absorbed by plant roots; this was positively reflected in the yield and yield components. The ideal conditions for maize growth require high and nearly constant soil water potential, particularly during flowering and pollination stages (Ne Smith and Ritchie, 1992; Stone *et al*., 2001). The results obtained were in agreement with those of El-Gindy *et al.* (2003), who indicated that the highest average grain yield and yield components were achieved from the highest irrigation level, and with those of El-Hendawy (2008), who reported that drip irrigation frequency once every 2 or 3 days with nitrogen fertigation was recommended to maximize the maize yield grown in sandy soil under the Egyptian conditions.

The highest irrigation water amount applied (7 820 m^3 ha^{-1}), averaged over the two seasons, was obtained under the conventional treatment, compared with other irrigation treatments in both growing seasons (Table 4). Meanwhile, the applied water under the irrigation scheduling treatments at 0.6, 0.8, 1.0, and 1.2 *Etc* varied between 3 430 and 5 655 m^3 ha^{-1}, an average of 2 seasons, respectively. This was expected since the irrigation scheduling procedure was planned with regard to the crop and weather conditions, whereas the conventional irrigation depends on visual inaccurate indicators. The seasonal amount of water applied

T a b l e 3. Yield and yield components of maize with different irrigation levels under drip irrigation and fertigation treatments in a sandy soil

Irrigation treatment (*I*)	Fertigation treatment (F)							
	Season 2009				Season 2010			
	F test	Mean	60%	80%	F test	Mean	60%	80%
				Ear length (cm)				
Conventional irrigation		19.5	Side dressed			19.0	Side dressed	
0.6 *Etc*		17.0	16.5	17.5		17.2	16.5	17.8
0.8 *Etc*		18.3	18.3	18.2		18.1	17.5	18.6
1.0 *Etc*	LSD=1.75	18.4	16.8	20.0	LSD=1.31	18.9	18.4	19.4
1.2 *Etc*		21.0	20.0	22.0		22.0	21.0	23.0
Mean			17.9	19.4			18.4	23.0
LSD			1.35				1.20	
*I**F			NS				NS	
				Number of grain ear^{-1}				
Conventional irrigation		528	Side dressed			516	Side dressed	
0.6 *Etc*		426	400	451		466	440	492
0.8 *Etc*		530	528	533		589	628	650
1.0 *Etc*	LSD=24.48	540	446	533	LSD=39.68	540	533	546
1.2 *Etc*		581	504	658		557	516	598
Mean			491	547			504	572
LSD			33.36				27.72	
*I**F			LSD at 5% = 66.73				LSD at 5% = 55.45	
				100 grain weight (g)				
Conventional irrigation		46.6	Side dressed			43.8	Side dressed	
0.6 *Etc*		33.7	32.2	35.2		37.0	35.3	38.7
0.8 *Etc*		37.7	36.8	38.7		42.2	39.1	45.2
1.0 *Etc*	LSD=3.385	39.00	36.7	41.5	LSD=2.868	43.2	40.5	45.9
1.2 *Etc*		47.7	43.5	51.9		47.2	46.9	47.5
Mean			37.3	41.8			40.5	44.3
LSD			2.02				1.411	
*I**F			NS				LSD at 5% = 2.822	

NS – not significant.

T a b l e 3. Continuation

Irrigation treatment (*I*)	Fertigation treatment (F)							
	Season 2009				Season 2010			
	F test	Mean	60%	80%	F test	Mean	60%	80%
				Grain yield (t ha^{-1})				
Conventional irrigation		7.88	Side dressed			7.09	Side dressed	
0.6 *Etc*		3.86	3.85	3.88		4.25	4.23	4.26
0.8 *Etc*		6.44	3.36	6.52		6.54	5.93	7.16
1.0 *Etc*	LSD=1.443	6.55	6.49	6.61	LSD=0.644	6.89	6.52	7.26
1.2 *Etc*		8.57	8.42	8.56		7.39	7.33	7.46
Mean			6.20	6.40			6.00	6.50
LSD			0.194				0.511	
*I**F			NS				LSD at 5% = 2.019	

NS – not significant.

T a b l e 4. Applied water and water productivity for maize crops in 2009 and 2010 seasons

Irrigation treatment (*I*)	Water productivity (kg m^{-3})			Applied water (m^{3} ha^{-1})		
	Fertigation treatment (F)					
	Mean	60%	80%	Mean	60%	80%
			Season 2009			
Conventional irrigation	1.089	Side dressed			Side dressed	
0.6 *Etc*	1.196	1.195	1.197	3230	3220	3240
0.8 *Etc*	1.640	1.638	1.642	3950	3930	3970
1.0 *Etc*	1.423	1.420	1.427	4600	4570	4630
1.2 *Etc*	1.620	1.619	1.622	5240	5200	5280
Mean		1.468	1.467		4230	4280
			Season 2010			
Conventional irrigation	0.843	Side dressed		8410	Side dressed	
0.6 *Etc*	1.169	1.168	1.170	3630	3620	3640
0.8 *Etc*	1.493	1.366	1.620	4380	4340	4420
1.0 *Etc*	1.342	1.286	1.399	5130	5070	5190
1.2 *Etc*	1.218	1.213	1.222	6070	6040	6100
Mean		1.258	1.353		4767	4837

NS – not significant.

for each irrigation treatment during season 2010 was relatively higher than that during season 2009. This could be attributed to the stressful weather conditions prevailing in season 2010 (higher evaporation demand in season 2010 than that in 2009) as shown in Table 1. Keeping in mind the average amount of water of the two seasons that had been supplied in treatment at 1.2 *Etc* (5 655 m^3 ha^{-1}) and the application of the fertilizer in 80% of irrigation time, which gave the best yield, it can be concluded that irrigation scheduling at 1.2 *Etc* with application of the fertilizer in 80% of irrigation time could save water by 27.2% and increase the grain yield by 6.7%, compared to the conventional treatment.

The conventional irrigation treatment had the lowest water productivity (WP) (0.966 kg m^{-3}), an average of the two seasons, compared with other irrigation scheduling and fertigation treatments in both growing seasons (Table 4). This is mainly due to the higher water amounts applied under the conventional irrigation than under the other treatments. The WP values under the irrigation and fertigation treatments ranged between 1.195 and 1.642 kg m^{-3} in the 1st season and from 1.168 to 1.620 kg m^{-3} in the 2nd season. The highest value of WP (1.631 kg m^{-3}) over the two seasons was recorded under the treatment at 0.8 *Etc* with fertigation application in 80% of the irrigation time. In turn, the lowest one (1.181 kg m^{-3}) was recorded for the treatment at 0.6 *Etc* with the fertilizer applied in 60% of the irrigation time. These results indicate that the irrigation at an amount of 0.8 *Etc* and fertigation application in 80% of the application time is the best treatment under the condition of the studied area because it increased the WP of the maize crops by about 68.8%, compared to the conventional method, and it allowed the application of less irrigation water for maize grain production. Similar results were obtained by Zwart and Bastiaansen (2004), who reported values of 1.1-2.7 kg m^{-3} for the WP of maize. These finding indicate that it is essential to employ appropriate methods for determining the amount of irrigation water and the period of applying the fertilizer through the irrigation water under the drip irrigation system.

CONCLUSIONS

1. Fertigation scheduling under the drip irrigation is more efficient than the conventional method for the maize crops in the sandy soil because it had higher water productivity than the conventional method.

2. In order to maximize maize yields and the productivity of the irrigation water under the drip irrigation system in the sandy soil, it is recommended to irrigate maize crops using a water amount at 1.2 of crop evapotranspiration every 3 days and applying the recommended fertilizer dose in 80% of the irrigation time.

3. Under water scarcity conditions, irrigation at 0.8 of crop evapotranspiration and application of fertigation in 80% of the irrigation time is recommended, since this treatment had the highest productivity of irrigation water 1.631 kg m^{-3} over the two seasons.

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