SUNFLOWER WATER RELATIONS AT VARIOUS IRRIGATION REGIMES WITH MODERN IRRIGATION SYSTEMS UNDER CLIMATIC CONDITIONS OF ASSIUT GOVERNORATE, UPPER EGYPT

A.S.A. Abdel-Mawgoud [1], M.A. Gameh[2], S.H. Abd-Elaziz[2] and M.M. El-Sayed[1]

[1] Soil Sci. Dept., Faculty of Agriculture, Al-Azhar University, Assiut, Egypt
[2] Soil Sci. Dept., Faculty of Agriculture, Assiut University, Assiut, Egypt

ABSTRACT

A field experiment was conducted in Assuit City during the growing seasons of 2005 and 2006 to assess the effect of irrigation regimes under different irrigation methods on consumptive water use (ETa) of sunflower. Potential evapotranspiration (ETo) was estimated by some ET formulas to compare them with the actual evapotranspiration (ETa). The crop factor (K_c), plant characteristics and the water application efficiency (WAE) were measured. Flooding and drip irrigation methods and 13, 50 and 75% soil moisture depletion were used.

The highest seasonal ETa value was recorded under flooding irrigation at 13% soil moisture depletion (SMD) treatment, while the lowest one was recorded under drip irrigation at 75% SMD treatment. The seasonal ET_a values were 474.20, 452.97 and 409.19 mm for SMD of 13, 50 and 75 %, respectively in the 1st season and they were 479.13, 458.66 and 414.93 mm at the corresponding irrigation regime in the 2nd season. The seasonal ET_a values decreased as the percentage of SMD increased. The Hargreaves and Turc equations calculated ET_o closer to ETa.

The amount of applied irrigation water was 2649.72 and 2098.56 m^3/fed under flooding and drip irrigation method, respectively at no water stress. Irrigation at 13% SMD under drip irrigation method achieved the highest value of WAE (95%) in both seasons. The lowest WAE was at SMD of 75% under flooding irrigation method in both seasons.

The morphological characteristics of sunflower were significantly affected by irrigation methods and regimes. The best treatment was that irrigated at 13 % SMD under drip irrigation method. The highest seed yield/ plant of 70.24 and 71.70 g were obtained under drip irrigation at 13% SMD in 1st and 2nd season, respectively. The lowest values of 40.62 and 41.30 g were obtained under flooding irrigation at 75% SMD in the respective seasons. The average yield in the first season was 5.97 and 7.22 ton/fed under flooding and drip irrigation methods, respectively. It was 6.16 and 7.83 ton/fed for the corresponding irrigation methods in the second season.

Keywords: Water consumptive use, sunflower crop, Irrigation regimes, Irrigation methods.

INTRODUCTION

In arid and semi-arid regions, water scarcity is the main yield limiting factor where it is difficult to apply full crop water requirements to sustain maximal growth and yield. Therefore it is very important to determine how to maintain optimum crop yields under water deficit conditions. The application of regulated deficit irrigation strategies is one of the most promising methods to improve irrigation efficiency. Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximize net returns. Accurate water application prevents over-or under irrigation. Over-irrigation wastes water, energy and labor, leaches nutrients below the root zone and leads to waterlogging which reduces crop yields. Under-irrigation stresses the plant, resulting in yield reductions and decreased returns. To benefit from irrigation scheduling you must have an efficient irrigation system (Phene, 1999).

Sunflower is one of the most important oil crops throughout most countries all over the world, and provides a major source of oil in human diet. However, it is considered as a relatively new crop in Egypt, in terms of production. Therefore, the response of sunflower crop to soil, water and crop management practices under Egyptian conditions must taken into account, in addition to, a great emphasis should be given towards it for oil production due to the crop advantages and adaptability to various environmental conditions (Berglund, 2003). Nahla (2003) found that the amount of applied water to sunflower plants was 2548.6 and 2506.0 m^3/fed. at New Valley and Agriculture Research Center soils, respectively. Those values were very close to that estimated by the Blaney-Criddle equation (2515.88). The ratio of the seasonal crop ET (891 mm) to the seasonal reference ET (685.38) was around 1.3 for sunflower (Steduto and Albrizio, 2005). In Pakistan, Ashraf and Abdul-Majeed (2006) found that the total ETo value for sunflower crop varied from 651 to 964 mm according to the region.

The water consumptive use of sunflower increased with increasing available soil moisture content (Ahmed and Shouk, 2000). El-Sabbagh et al. (2005) found that the values of seasonal water consumptive use by sunflower plants were 30.92, 35.8, 43.23 and 50.61 cm for irrigation at 0.6, 0.8, 1.0 and 1.2 accumulative pan evaporation, respectively and most the consumed water was removed from the upper soil layer (0-15 cm). Sunflower plants grown under the conditions of irrigation at 40% available soil moisture depletion (ASMD) were significantly higher in total seed yield and followed by that of 55 and 70% ASMD (Esmail, 2000). El-Sabbagh et al. (2005) found that irrigation at 1.2 accumulation pan evaporation (APE) reflected the highest amounts of water applied (64.13 cm) while irrigation at 0.6 APE required the lowest one (42.39 cm). Also, they found that the highest value of water consumptive use was 50.61 cm obtained with irrigation at 1.2 APE, while irrigation at 0.6 APE consumed the lowest one (30.92 cm). The crop coefficient values (Kc) of the grown sunflower reflected the crop characters during its growing season. These values were found to be low as 0.66 and 0.63 for 2001 and 2002 seasons, respectively at the initial period during June. The Kc values increased during July and reached the maximum values at mid-July (mid-season stage), when the sunflower plants consumed the maximum water requirements (Mohamed, 2003). The calculated Kc using water depletion for the grown sunflower crop was 0.993. However, the measured soil water depletions were 2173.06 m^3/fed. While the calculated Kc using Blaney-Criddle equation for the grown sunflower crop was 0.791 and it was 0.62 by using class A-pan data (Nahla, 2003).

Irrigation of crops generally aims to provide sufficient water to fully satisfy the evaporative demand of that crop. For a crop that is fully irrigated, it is expected that ET will be greater if the soil surface and the crop canopy are frequently wetted. Thus the method of applying water (e.g. sprinkler or drip irrigation) will influence on ET. For a crop that is less than fully irrigated, it is expected that ET will decline below a potential, fully watered rate, especially as the crop experiences drying soil conditions and it undergoes the adaptive changes associated with water deficit stress. If a crop is "over-irrigated", it is likely that the excess water will be lost through run-off and additional soil evaporation or drainage below the root zone (Dodds, 2005). The seed index, head diameter, total yield and seed yield increased of sunflower crop under drip irrigation compared to sprinkler and surface irrigation (Abdel-Hamid, 2000). Gameh et al. (2000) stated that although the drip irrigation is more expensive than most other irrigation methods, drip irrigation in terms of water use efficiency is desirable irrigation method in area like the New Valley, where the only source of water is the under ground water. The yield parameters plant height, stem diameter, seed index, head diameter, total yield and seed yield and seed oil content increased with increasing available soil moisture of sunflower crop under drip irrigation compared to sprinkler and surface irrigation (Osman, 2001). The obtained yield was 1354 and 1401 kg/fed. when irrigated with 2570.4 and 2912 m^3/fed. during summer of 1999 and 2000, respectively (Nahla, 2003).

This study was initiated to assess the effect of irrigation regimes under two irrigation methods on consumptive water use, water application efficiency, water use efficiency and yield of sunflower. Also, estimate the potential evapotranspiration by some ET formula then compare it with the actual ET to define the suitable one for Assiut area and the crop factor (K_c).

MATERIALS AND METHODS

A field experiment was conducted at The Experimental Farm, Faculty of Agriculture, Al-Azahar University, Assiut, during the summer seasons of 2005 and 2006. The soil is clay loam, free of salts and non alkali (some physical and chemical properties, according to Klute (1986) and Page et al. (1982) are given in table 1. The experiment was laid out in split plots design with four replicates. Two irrigation methods (flooding and drip) were assigned to the main plots and three irrigation regimes (13, 50 and 75% soil moisture depletion) were assigned to the subplots. The plot was 8x5 m (almost 1/100 fed.) and bounded with buffer zone to avoid the horizontal seepage. In the summer seasons of year 2005 and 2006, sunflower seeds (*Sakha 53, variety*) were planted on June 9, in hills 20 cm apart from each other and 60 cm distance between rows and the plants were harvested 92 days after planting for each season. All the agronomic practices were applied as commonly used. The recommended NPK fertilizers were added at a rate of 45 kg N- 45 kg P_2O_5 and 50 kg K_2O/ Feddan.

To obtain the actual water consumptive use (ETa), the soil moisture percentage was determined gravimetrically on dry basis just before and 24 hours after irrigation. At each sampling date, samples were taken from layers each of 10.0 cm depth down to 60.0 cm from soil surface. The amount of water consumed from the root zone (60 cm) between two successive irrigations as a water depth in cm, was calculated according to Israelson and Hansen (1962). The seasonal ETa values were determined as the summation of irrigation water from planting till harvesting. The reference evapotranspiration (ET_o) values were computed from the meteorological data of Assuit area (Table 2), by using 7 methods (Penman-Monteith and Hargreaves equation according to Allen et al., 1998; Corrected Penman, Ture Method and Priestley-Taylor according to Jensen et al.1990; Modified Blaney-Criddle as presented by Allen and Pruitt, 1986; and Class A pan evaporation method using Kc as described by FAO, 1998). Irrigation application efficiency was calculated using the formula of James (1988). The crop coefficient (Kc) values of sunflower were estimated during the growing season according to Doorenbon and Kassam (1986) using none stress irrigation treatments. At harvest time, ten plants were chosen randomly from each treatment to determine some morphological characteristics (plant height, stem & head diameter, head weight/ plant, seed head weight, seed index, seed yield, total yield and seed oil content). The statistical analysis was carried out according to the procedures outlined by Barbara and Brain (1994).

Table (1). Some physical and chemical properties of the field experiment

A- Physical properties

Soil depth (cm)	Particles distribution (%)			Texture class	OM (%)	$CaCO_3$ (%)	AW (%)	BD (g/cm^3)
	Sand	Silt	Clay					
0-20	25.00	39.65	35.35	Clay loam	1.20	3.50	23.00	1.29
20-40	24.65	39.00	36.35	Clay loam	1.10	3.20	22.80	1.30
40-60	25.90	38.80	35.30	Clay loam	0.95	2.70	22.50	1.33

OM = organic matter AW= available water BD= bulk density

B- Chemical properties

Soil depth (cm)	SP	pH	EC_e (dS/m)	Soluble ions (meq./L)							SAR
				HCO_3	Cl	SO_4	Ca	Mg	Na	K	
0-20	80	7.89	0.99	2.50	1.25	6.15	2.70	1.35	5.74	0.11	4.03
20-40	84	7.95	1.25	3.40	3.00	6.10	3.20	1.30	7.75	0.25	5.16
40-60	83	8.00	1.60	3.30	3.50	9.20	5.80	4.30	5.67	0.23	2.52

SP= saturation percent SAR= sodium adsorption ratio

Table (2). Monthly agrometeorological data of Assiut station during sunflower growing seasons

Month	E pan (mm)	Max. temp. (°C)	Min. temp. (°C)	Wind speed (m/sec)	Relative humidity (%)	Rain fall (mm)	Sun shine (hours)	Solar radiation ($MJ/m^2.d$)
	Growing season of 2005							
Jun.	9.50	36.00	22.30	3.88	47.40	0.00	12.30	639
Jul.	7.20	39.40	22.48	2.00	49.90	0.00	12.20	631
Aug	6.38	38.10	21.62	3.05	51.10	0.00	11.90	608
Sep.	5.96	36.20	19.85	3.50	47.20	0.00	10.80	538
Growing season of 2006								
Jun.	8.70	39.50	22.20	8.33	32.80	0.00	12.30	639
Jul.	8.40	41.00	23.00	4.29	43.40	0.00	12.20	631
Aug	8.80	40.00	20.00	3.78	48.60	0.00	11.90	608
Sep.	8.50	37.20	19.90	3.67	50.10	0.00	10.80	538
Source: Meteorology station of Assiut, Egypt								

RESULTS AND DISCUSSION

Actual evapotranspiration (ETa)

The ETa values as affected by moisture regime under different irrigation methods through the growth stages of sunflower plants in summer season of 2005 and 2006 is presented in Table (3). In general, the results indicated that the highest values of ET_a were recorded in the mid growth stage (24 Jul. to 22 Aug.) followed by development (24 Jun. to 23 Jul.) and end stages (23 Aug. to 8 Sep.); the lowest values were recorded in the initial stage (9 Jun. to 23 Jun.). Monthly consumptive use reached its maximum value during August due to continuous development of plant green canopy. Also, the results of both seasons indicated that the highest seasonal ET_a value was recorded under flooding irrigation at 13% SMD treatment, while the lowest one was recorded under drip irrigation for 75% SMD treatment.

Table (3). Actual evapotranspiration (mm) as affected by soil moisture regime and irrigation methods at different sunflower growth stages during summer season of 2005 and 2006

Treatment		Growth stage								Gross season, 9 Jun. to 8 Sep. (92 day)	
Irrigation method	Irrigation regime	Initial, 9 Jun. to 23 Jun. (15 day)		Development, 24 Jun. to 23 Jul. (30 day)		Mid, 24 Jul. to 22 Aug. (30 day)		End, 23 Aug. to 8 Sep. (17 day)			
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Flooding	SMD 0.13	55.35	56.75	163.15	164.50	181.90	183.25	78.72	80.00	479.12	484.50
	SMD 0.50	53.90	55.09	155.21	156.65	174.48	176.00	73.54	75.16	457.13	462.90
	SMD 0.75	47.95	48.50	140.42	143.13	158.24	158.90	67.85	69.05	414.46	419.58
Drip	SMD 0.13	53.54	54.90	160.87	162.00	180.40	180.95	74.47	75.90	469.28	473.75
	SMD 0.50	51.20	52.00	153.85	155.30	172.53	174.00	71.22	73.12	448.80	454.42
	SMD 0.75	46.07	47.15	138.46	139.85	155.27	157.20	64.12	66.07	403.92	410.27

However, under both irrigation methods, the data revealed that seasonal ET_a values were 474.20, 452.97 and 409.19 mm for soil moisture depletion (SMD) of 13, 50 and 75 %, respectively in the first season and they were 479.13, 458.66 and 414.93 mm at the corresponding irrigation regime in the second season. The seasonal ET_a values decreased as the percentage of soil moisture depletion increased (more available water extracted). The reduction percent was 4.48 and 13.71% for SMD of 50 and 75%, respectively compared to SMD of 13% in the first season and it was 4.27 and 13.40% for 50 and 75% SMD, respectively compared to 13% SMD in the second season. It is clear that increasing the available soil moisture in the root zone of sunflower crop caused a significant increase in the seasonal water consumption by sunflower plants. These results may be attributed to the high availability of water at low moisture depletion which in turn increases transpiration from vigor vegetative growth of existed plants and evaporation from the soil surface by more water capillary movement. Similar results were obtained by El-Sabbagh et al. (2005).

In the two seasons, results clearly showed that daily consumptive water use started with low value during June (Table 4). Thereafter, the daily ET_a rate increased to maximum value at August when plants aged 45-65 days from sowing. During late August the daily ET_a rate decreased and reached its minimum values at September. These results were found to be true in both seasons. The obtained results can be ascribed as that at June, the vegetation has not been established yet and most of the water loss was due to evaporation from the bare soil. Thereafter, as the vegetation growth increased during late June and July the rate of ET_a increased and reached its maximum rate during flowering and early seed filling. During late August the ET_a rate decreased when the lower leaves of the plants dried and the rate reached its minimum values on September (harvesting time). The obtained results are in accordance with those reported by Ashri (2003).

Table (4). Daily consumptive water use (mm) as affected by soil moisture regime and irrigation methods at different sunflower growth stages during summer season of 2005 and 2006.

Treatment		Growth stage								Gross season (92 day)	
Irrigation method	Irrigation regime	Initial (15 day)		Development (30 day)		Mid (30 day)		End (17 day)			
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Flooding	SMD 0.13	3.69	3.78	5.44	5.48	6.06	6.11	4.63	4.71	5.21	5.27
	SMD 0.50	3.59	3.67	5.17	5.22	5.82	5.87	4.33	4.42	4.97	5.03
	SMD 0.75	3.20	3.23	4.68	4.77	5.27	5.30	3.99	4.06	4.51	4.56
Drip	SMD 0.13	3.57	3.66	5.36	5.40	6.01	6.03	4.38	4.46	5.10	5.15
	SMD 0.50	3.41	3.47	5.13	5.18	5.75	5.80	4.19	4.30	4.88	4.94
	SMD 0.75	3.07	3.14	4.62	4.66	5.18	5.24	3.77	3.89	4.39	4.46

Reference evapotranspiration (ET_o)

The estimated seasonal ET_o values in both growing seasons followed the descending order of Corrected-Penman> Priestley-Taylor> evaporation pan> Hargreaves> Turc> Penman-Montithe> Blaney-Criddle (Table 5). The results indicated that the ET_o value estimated by Corrected Penman, Priestley-Taylor, evaporation pan equation, Hargreaves equations over estimated the ET_a value. While the ET_o value estimated by Blaney-Criddle and Penman-Montithe equations under estimated the ET_a value. The estimated ET_o value by Turc equation was less than that of ET_a by 5.87% in the 1st season and exceeded it by 1.66% in the 2nd season. Data of ET_o values estimated by different empirical equations in both seasons revealed that the ET_o values started small according to the small plant cover in the early stage. They increased to reach their maximum values in mid season (August) due to the maximum temperature and plant canopy, and then tended to decline again until the crop maturity due to crop canopy changes.

To evaluate the used empirical equations and their efficiency in calculating ET_o, a comparison between ET_o values and actual evapotranspiration (ET_a) values is shown in Table (6). The obtained results indicated that the ratio between seasonal ET_o of Hargreaves and seasonal ET_a was 1.19 and 1.14 in 1st and 2nd season, respectively. The ratio between seasonal ET_o of Turc and seasonal ET_a was 0.94 and 1.02 in 1st and 2nd season, respectively. It is clear that the Hargreaves and Turc equations calculated ET_o efficiently but Turc equation was the most efficient in calculating ETo of sunflower crop in Assiut region due to its closed under estimation that was only 2.07% as an average value of both seasons compared to that overestimated by Hargreaves that was 14.31% as an average value of both seasons.

Table (5). Calculated reference evapotranspiration (mm) during sunflower growth stages using different empirical equations through the growing season of 2005 and 2006

Method	Equation	Growth stage: Initial (20 day)		Development (50 day)		Mid (50 day)		End (25 day)		Gross season (145 day)	
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Combination	Penman-Montithe	3.18	4.25	3.34	4.17	3.32	3.83	3.23	3.60	302.39	364.94
	Corrected Penman	7.56	9.28	7.67	10.17	7.95	8.84	8.08	7.88	719.65	843.80
Temperature	Blaney-Criddle	2.00	1.66	2.69	3.02	3.89	3.57	3.25	3.16	282.77	276.43
	Hargreaves	5.47	6.38	6.94	6.09	6.10	5.81	5.47	4.47	566.58	545.92
Radiation	Turc	5.08	6.23	4.97	5.59	4.75	4.94	4.61	4.56	446.38	487.20
	Priestley-Taylor	5.96	6.43	6.45	8.48	6.79	9.02	6.38	8.75	595.22	770.15
Evaporation	Evaporation pan	3.80	3.48	5.37	6.07	6.23	8.31	5.53	7.31	499.07	608.20
ETa without water stress (SMD 13%)		3.63	3.72	5.40	5.44	6.04	6.07	4.41	4.58	474.20	479.13

Table (6). Comparison between reference evapotranspiration (ET_o) estimated by different empirical equations and actual evapotranspiration (Et_a) during sunflower growth stages in the growing season of 2005 and 2006

Method	Equation	Growth stage								Gross season (145 day)	
		Initial (20 day)		Development (50 day)		Mid (50 day)		End (25 day)			
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Combination	Penman-Montithe	0.88	1.14	0.62	0.77	0.55	0.63	0.73	0.79	0.64	0.76
	Corrected Penman	2.08	2.49	1.42	1.87	1.32	1.46	1.83	1.72	1.52	1.76
Temperature	Blaney-Criddle	0.55	0.45	0.50	0.56	0.64	0.59	0.74	0.69	0.60	0.58
	Hargreaves	1.51	1.72	1.29	1.12	1.01	0.96	1.24	0.98	1.19	1.14
Radiation	Turc	1.40	1.67	0.92	1.03	0.79	0.81	1.05	1.00	0.94	1.02
	Priestley-Taylor	1.64	1.73	1.19	1.56	1.12	1.49	1.45	1.91	1.26	1.61
Evaporation	Evaporation pan	1.05	0.94	0.99	1.12	1.03	1.37	1.25	1.60	1.05	1.27
ETa without water stress (SMD 13%)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Water application efficiency (WAE)

In general, the applied amount of irrigation water decreased as the percentage of soil moisture depletion increased in both seasons (Table 7). The applied amount of irrigation water by flooding was higher than that applied by drip irrigation method. The amount of applied irrigation water (as an average value of both seasons) was 2649.72 and 2098.56 m^3/fed under flooding and drip irrigation method, respectively at no water stress. The percentage of water application efficiency decreased as the percentage of soil moisture depletion increased in both seasons. The obtained results showed that WAE ranged between 75 and 77% under flooding irrigation and it ranged between 92 and 95% under drip irrigation. The obtained results revealed that irrigation at 13% depletion of available soil moisture under drip irrigation method achieved the highest value of water application efficiency (95%) in both seasons. The lowest value (75%) was at SMD of 75% under flooding irrigation method in both seasons.

Field water use efficiency (FWUE)

Data in Table (7) showed that the irrigation methods and irrigation regimes were significantly affected the field water use efficiency. The obtained results indicated that the FWUE was higher under drip than that under flooding irrigation in both seasons. However, it was noticed that the highest value of FWUE was attained under drip irrigation at 13% SMD in both seasons (1.02 and 1.10 kg/m^3 in 1st and 2nd season, respectively). While the lowest one was recorded under flooding irrigation at 75% SMD in both seasons (0.53 and 0.57 kg/m^3 in 1st and 2nd season, respectively). It is worthwhile to mention that the low value of FWUE under drip irrigation method that recorded at 75% SMD was higher than any value that attained under flooding irrigation method at any soil moisture depletion. The interaction effect between irrigation methods and irrigation regimes was significant for filed water use efficiency in both seasons.

Crop water use efficiency (CWUE)

The data showed that CWUE values were significantly affected by irrigation methods and irrigation regimes based on different water deficit at different growth stages Table (7). The obtained results indicated that the CWUE under drip was higher than that under flooding irrigation in both seasons. It was noticed that the highest value of CWUE was attained under drip irrigation at 13% SMD in both seasons (1.06 and 1.17 kg/m^3 in 1st and 2nd season, respectively). While the lowest one was recorded under flooding irrigation at 75% SMD in both seasons (0.70 and 0.76 kg/m^3 in 1st and 2nd season). The increase in crop water use efficiency was mainly due to the increase of available water resulted in an increase in total grain yield more than the increase of actual water consumptive use. It might be stated that decreasing the water consumptive use by increasing water stress caused a reduction in the attain grain yield that consequently decreased the value of CWUE.

Table (7). Water application efficiency, field water use efficiency and crop water use efficiency with different irrigation methods under various irrigation regimes fro sunflower growth in 2005 and 2006 season

Treatment: Irrigation method	Treatment: Irrigation regime	Irrigation water applied (m^3/fed.)		Water consumptive use (m^3/fed.)		Seed yield (kg/fed)		Water Application efficiency %		Field water use efficiency (kg/m^3)		Crop water use efficiency (kg/m^3)	
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Flooding	SMD 0.13	2620.17	2679.26	2012.30	2034.90	1630.00	1760.00	76.80	75.95	0.62	0.66	0.81	0.86
	SMD 0.50	2526.22	2562.84	1919.94	1944.18	1400.00	1600.00	76.00	75.86	0.55	0.62	0.73	0.82
	SMD 0.75	2320.96	2349.65	1740.73	1762.24	1220.00	1350.00	75.00	75.00	0.53	0.57	0.70	0.77
	Mean	2489.12	2530.58	1890.99	1913.77	1416.66	1570.00	75.93	75.60	0.57	0.62	0.75	0.82
Drip	SMD 0.13	2074.72	2122.39	1970.97	1989.75	2110.00	2340.00	95.00	93.75	1.02	1.10	1.07	1.18
	SMD 0.50	2026.84	2053.30	1884.96	1908.56	1650.00	1730.00	93.00	92.95	0.81	0.84	0.88	0.91
	SMD 0.75	1843.97	1874.38	1696.46	1723.13	1380.00	1530.00	92.00	91.93	0.75	0.82	0.81	0.89
	Mean	1981.84	1983.35	1850.79	1873.81	1713.33	1866.66	93.33	92.87	0.86	0.92	0.92	0.99
L.S.D. 5%	Irri. Sys. Irri. Regi. Interaction	----	----	-----	-----	----	-----	----	----	0.062 0.063 0.089	0.033 0.038 0.054	0.073 0.071 n.s	0.043 0.047 0.066

Crop coefficient (Kc)

In general, the calculated Kc values at different sunflower growth stages by various equations were not always identical in both seasons (Table 8). They were less in the second season than those in the first one except that of Blaney-Criddle where the opposite was true. The obtained results of Kc values for both seasons indicated that the Turc equation was the best one to calculate ETo for the two growing seasons. This may be due to that the differences of the hypothetical reference crop that calculated by Turc equation relative to the crop canopy and aerodynamic resistance were more constant in both growing seasons than hypothetical reference crop that calculated by other equation.

Coefficient of water stress (Ks)

Stresses at different growth stages affected the obtained Kc values (estimated from ETa at 50 & 75% SMD and ETo data) that greatly lowered with the prolonged stress (Tables 9 and 10). Seasonal averages of sunflower Ks values were almost similar under both irrigation methods. The obtained results indicated that the Ks values followed the same trend of Kc value either through the growth stages or under various irrigation methods. The obtained results of Ks values for both seasons indicated that the Turc equation was the best one to calculate ETo for the two growing seasons.

Sunflower yield and yield traits

The averages of yield and sunflower yield components in the two growing seasons under different irrigation methods and irrigation regimes are given in Table 11. The obtained results showed that plant height was significantly affected by irrigation methods in both seasons. The highest values of 235.00 and 247.50 cm were obtained under drip irrigation at 13% SMD in 1st and 2nd season, respectively. The lowest values of 177.25 and 181.25 cm were obtained under flooding irrigation at 75% SMD in the respective seasons. The irrigation regimes significantly affected the plant height in both seasons. The plant height decreased as the SMD increased. In both seasons, results revealed that the interaction between irrigation methods and irrigation regimes was significant. The results showed that the highest value of stem diameter was 2.82 and 2.89 cm under drip irrigation at 13% SMD in the 1st and 2nd season, respectively. The lowest value was 1.85 and 1.83 cm under flooding irrigation at 75% SMD in the 1st season, and 2nd season, respectively. The results showed that the average of stem diameter was significantly affected by irrigation regime in both seasons. The superiority of this character was for sunflower plants that exposed to 13% SMD. It could be noticed that increasing available soil moisture caused an increase in stem diameter.

Table (8). Sunflower crop coefficient for different ETo equations during growth stages without water stress under various irrigation methods through two seasons

Equation	Growing seeson	Flooding irrigation method					Drip irrigation method				
		Growth stage				Seasonal	Growth stage				Seasonal
		Initial	Development	Mid	End		Initial	Development	Mid	End	
Penman-Montithe	2005	1.16	1.63	1.83	1.43	1.58	1.12	1.61	1.81	1.36	1.55
	2006	0.89	1.31	1.59	1.31	1.33	0.86	1.29	1.57	1.24	1.30
Corrected Penman	2005	0.49	0.71	0.76	0.57	0.67	0.47	0.70	0.76	0.54	0.65
	2006	0.41	0.54	0.69	0.60	0.57	0.39	0.53	0.68	0.57	0.56
Blaney-Criddle	2005	1.85	2.02	1.56	1.42	1.76	1.78	1.99	1.55	1.35	1.72
	2006	2.28	1.82	1.71	1.49	1.85	2.20	1.79	1.69	1.41	1.81
Hargreaves	2005	0.67	0.78	0.99	0.85	0.87	0.65	0.77	0.99	0.80	0.85
	2006	0.59	0.90	1.05	0.86	0.89	0.57	0.89	1.04	0.82	0.87
Turc	2005	0.73	1.09	1.28	1.00	1.07	0.70	1.08	1.27	0.95	1.05
	2006	0.61	0.98	1.24	1.03	0.99	0.59	0.97	1.22	0.98	0.97
Priestley-Taylor	2005	0.62	0.84	0.89	0.73	0.81	0.60	0.83	0.89	0.69	0.80
	2006	0.59	0.65	0.68	0.54	0.64	0.57	0.64	0.67	0.51	0.63
Evaporation pan	2005	0.97	1.01	0.97	0.84	1.00	0.94	1.00	0.97	0.79	0.97
	2006	1.09	0.90	0.74	0.64	0.84	1.05	0.89	0.73	0.61	0.82

Table (9). Sunflower crop coefficient for different ETo equations during growth stages at 50% SMD under various irrigation methods through two seasons

Equation	Growing seeson	Flooding irrigation method					Drip irrigation method				
		Growth stage				Seasonal	Growth stage				Seasonal
		Initial	Development	Mid	End		Initial	Development	Mid	End	
Penman-Montithe	2005	1.13	1.55	1.75	1.34	1.51	1.07	1.54	1.73	1.30	1.48
	2006	0.86	1.25	1.53	1.23	1.27	0.82	1.24	1.51	1.19	1.25
Corrected Penman	2005	0.48	0.67	0.73	0.54	0.64	0.45	0.67	0.72	0.52	0.62
	2006	0.40	0.51	0.66	0.56	0.55	0.37	0.51	0.66	0.55	0.54
Blaney-Criddle	2005	1.80	1.92	1.50	1.33	1.68	1.71	1.91	1.48	1.29	1.65
	2006	2.21	1.73	1.64	1.40	1.76	2.09	1.71	1.62	1.36	1.73
Hargreaves	2005	0.66	0.75	0.95	0.79	0.83	0.62	0.74	0.94	0.77	0.81
	2006	0.58	0.86	1.01	0.81	0.85	0.54	0.85	1.00	0.79	0.83
Turc	2005	0.71	1.04	1.22	0.94	1.02	0.67	1.03	1.21	0.91	1.01
	2006	0.59	0.93	1.19	0.97	0.94	0.56	0.93	1.17	0.94	0.93
Priestley-Taylor	2005	0.60	0.80	0.86	0.68	0.78	0.57	0.80	0.85	0.66	0.76
	2006	0.57	0.62	0.65	0.51	0.62	0.54	0.61	0.64	0.49	0.60
Evaporation pan	2005	0.95	0.96	0.93	0.78	0.95	0.90	0.95	0.92	0.76	0.93
	2006	1.06	0.86	0.71	0.60	0.80	1.00	0.85	0.70	0.59	0.78

Table (10). Sunflower crop coefficient for different ETo equations during growth stages at 75% SMD under various irrigation methods through two seasons

Equation	Growing seeson	Flooding irrigation method					Drip irrigation method				
		Growth stage				Seasonal	Growth stage				Seasonal
		Initial	Development	Mid	End		Initial	Development	Mid	End	
Penman-Montithe	2004/05	1.01	1.40	1.59	1.24	1.37	0.97	1.38	1.56	1.17	1.34
	2005/06	0.76	1.14	1.38	1.13	1.15	0.74	1.12	1.37	1.08	1.12
Corrected Penman	2004/05	0.42	0.61	0.66	0.49	0.58	0.41	0.60	0.65	0.47	0.56
	2005/06	0.35	0.47	0.60	0.52	0.50	0.34	0.46	0.59	0.49	0.49
Blaney-Criddle	2004/05	1.60	1.74	1.36	1.23	1.52	1.54	1.72	1.33	1.16	1.48
	2005/06	1.95	1.58	1.48	1.29	1.60	1.89	1.54	1.47	1.23	1.56
Hargreaves	2004/05	0.58	0.67	0.86	0.73	0.75	0.56	0.67	0.85	0.69	0.73
	2005/06	0.51	0.78	0.91	0.74	0.77	0.49	0.77	0.90	0.71	0.75
Turc	2004/05	0.63	0.94	1.11	0.87	0.93	0.60	0.93	1.09	0.82	0.90
	2005/06	0.52	0.85	1.07	0.89	0.86	0.50	0.83	1.06	0.85	0.84
Priestley-Taylor	2004/05	0.54	0.73	0.78	0.63	0.70	0.52	0.72	0.76	0.59	0.69
	2005/06	0.50	0.56	0.59	0.46	0.56	0.49	0.55	0.58	0.44	0.55
Evaporation pan	2004/05	0.84	0.87	0.85	0.72	0.86	0.81	0.86	0.83	0.68	0.84
	2005/06	0.93	0.79	0.64	0.56	0.72	0.90	0.77	0.63	0.53	0.71

Table (11a). Effect of irrigation systems and irrigation regimes on the yield quantity of sunflower crop season of 2005

Characters / Treatments		Plant height (cm)	Stem diam. (cm)	Head diam. (cm)	Head weight /plant (g)	Seed yield/ plant (g)	Seed index (g)	Seed yield (ton/ fed)	Total yield (ton/ fed)	Oil	
										Seed (%)	Yield (ton/fed)
Flooding	SMD 0.13	217.75	2.77	23.75	88.16	54.33	58.65	1.63	7.29	40.58	0.661
	SMD 0.50	195.50	2.42	20.50	77.83	46.75	55.63	1.40	6.04	40.49	0.548
	SMD 0.75	177.25	1.85	18.50	67.20	40.62	50.30	1.22	4.58	39.12	0.494
	Mean	196.83	2.34	20.91	77.73	47.23	54.86	1.41	5.97	40.06	0.567
Drip	SMD 0.13	235.00	2.82	25.75	107.34	70.24	62.55	2.11	9.83	43.14	0.910
	SMD 0.50	209.12	2.55	22.00	87.37	54.99	58.62	1.65	7.18	40.91	0.675
	SMD 0.75	188.75	1.95	19.75	70.49	46.24	51.68	1.38	4.66	40.54	0.473
	Mean	210.95	2.44	22.50	88.40	57.15	57.61	1.71	7.22	41.53	0.686
MEAN	SMS 0.13	226.37	2.79	24.75	97.75	62.28	57.14	1.87	8.56	41.86	0.785
	SMD 0.50	202.31	2.48	21.25	82.60	50.87	57.12	1.52	6.61	40.01	0.611
	SMD 0.75	183.00	1.90	19.12	68.84	43.43	50.99	1.30	4.62	40.51	0.483
L.S.D 5%	Irri. Sys.	10.44	n.s	n.s	8.50	4.80	1.29	0.143	0.685	1.093	0.114
	Irri. Regi	7.35	0.155	1.53	4.93	4.43	1.69	0.133	0.520	1.207	0.086
	Interaction	10.39	0.219	2.16	6.97	n.s	n.s	n.s	0.736	n.s	0.122

Table (11b). Effect of irrigation systems and irrigation regimes on the yield quantity of sunflower crop season of 2006

Treatments \ Characters		Plant height (cm)	Stem diam. (cm)	Head diam. (cm)	Head weight/ plant (g)	Seed yield/plant (g)	Seed index (g)	Seed yield (ton/ fed)	Total yield (ton/ fed)	Oil	
										Seed (%)	Yield (ton/fed)
Flooding	SMD 0.13	225.25	2.80	25.12	91.10	56.77	59.57	1.76	7.54	40.66	0.716
	SMD 0.50	204.75	2.45	21.75	79.22	47.95	56.00	1.60	6.29	40.58	0.650
	SMD 0.75	181.25	1.83	18.60	67.12	41.30	51.15	1.35	4.65	39.66	0.537
	Mean	203.75	2.36	21.82	79.14	48.67	55.57	1.57	6.16	40.30	0.634
Drip	SMD 0.13	247.50	2.89	26.75	111.66	71.70	63.40	2.34	10.75	43.57	1.020
	SMD 0.50	220.00	2.57	24.00	82.52	56.50	58.22	1.73	7.68	42.47	0.736
	SMD 0.75	198.00	1.99	20.37	74.22	46.12	53.20	1.53	5.07	41.93	0.613
	Mean	221.83	2.48	23.70	89.46	58.10	58.27	1.86	7.83	42.65	0.789
MEAN	SMS 0.13	236.37	2.84	25.93	101.38	64.23	61.48	2.05	9.14	42.11	0.868
	SMD 0.50	212.37	2.51	22.87	80.87	52.22	57.11	1.66	6.98	41.52	0.693
	SMD 0.75	189.62	1.91	19.48	70.67	43.71	52.17	1.44	4.86	40.79	0.575
L.S.D 5%	Irri. Sys.	8.78	0.017	0.837	6.032	5.667	1.01	0.078	0.222	0.678	0.030
	Irri. Regi	8.03	0.132	1.641	4.891	1.913	1.01	0.088	0.384	0.653	0.049
	Interaction	11.35	0.187	2.321	6.917	2.281	n.s	0.124	0.543	n.s	0.069

It could be noticed that the head diameter under drip was higher than that under flooding irrigation in both seasons. The highest head diameter was obtained at 13% SMD under drip irrigation while the lowest one was obtained at 75% SMD under flooding irrigation in both seasons. The results indicated that head diameter was significantly affected by irrigation regimes. It could be noticed that increasing available soil moisture caused an increase in the head diameter. The results showed that head weight/ plant were significantly affected by irrigation regime in both seasons. The superiority of this character was for sunflower plants that exposed to 13% SMD by drip irrigation method. It could be noticed that increasing available soil moisture caused an increase in the head weight/ plant. In both seasons, results revealed that the interaction between irrigation methods and irrigation regimes for head weight/ plant was significant.

The highest seed yield/ plant of 70.24 and 71.70 g were obtained under drip irrigation at 13% SMD in 1st and 2nd season, respectively. The lowest values of 40.62 and 41.30 g were obtained under flooding irrigation at 75% SMD in the respective seasons. The results showed that seed yield/ plant were significantly affected by irrigation regime in both seasons. The seed yield/ plant increased with increasing available soil moisture level. The irrigation methods realized a significant effect on the seed index. It was noticed that the seed index value was higher under drip irrigation than that under flooding irrigation. The highest value of 62.55 and 63.40 g was attained under drip irrigation at 13% SMD in the 1st and 2nd season, respectively. The lowest one of 50.30 and 51.15 g was recorded under flooding irrigation at 75% SMD in the 1st and 2nd season, respectively.

The obtained results showed that seed index was significantly affected by irrigation regimes, in both seasons. Also, the data revealed that increasing the percentage of SMD relatively decreased the seed index in both seasons. The sunflower seed yield was significantly affected by irrigation methods in both seasons. In general, the seed yield in the 2nd season was relatively higher than that in the 1st season. The average sunflower seed yield in the first season was 1.41 and 1.71 ton/fed under flooding and drip irrigation, respectively. It was 1.57 and 1.86 ton/fed for the corresponding irrigation methods in the second season. The obtained results showed that sunflower seed yield was significantly affected by irrigation regimes in both season. Also, the data revealed that increasing the percentage of SMD decreased sunflower seed yield.

The tested irrigation methods and irrigation regimes significantly influenced the total yield of sunflower in both seasons. In general, the yield in the 2nd season was relatively higher than that in the 1st season under both irrigation methods. However, it was noticed that the obtained yield was higher under drip irrigation than that under flooding irrigation in both season. The average yield in the first season was 5.97 and 7.22 ton/fed under flooding and drip irrigation methods, respectively. It was 6.16 and 7.83 ton/fed for the corresponding irrigation methods in the second season. The obtained results showed that total yield of sunflower were significantly affected by irrigation regimes in both seasons. Also, the data revealed that increasing the percentage of SMD decreased the total yield of sunflower.

The average value of oil% in seeds was 40.06 and 41.53 under flooding and drip irrigation method, respectively in the 1st season. It was 40.30 and 42.65 under the respective irrigation methods in the 2nd season. The oil% in the 2nd season was relatively higher than that of 1st season. Also, oil% was relatively higher under drip irrigation than that under flooding irrigation. The obtained results showed that oil% in seeds were significantly affected by irrigation regime in both seasons. However, it could be noticed that oil percentage was relatively increased as the available soil moisture increased.

The data revealed that oil yield was significantly affected by irrigation methods in both seasons. The average value of oil yield was 0.567 and 0.686 ton/fed under flooding and drip irrigation method, respectively in the 1st season. It was 0.634 and 0.789 ton/fed under the respective irrigation methods in the 2nd season. The obtained results showed that oil yield was significantly affected by irrigation regime in both seasons. In general, oil yield decreased as the SMD percentage increased.

It can be concluded that increasing the available soil moisture in the root zone of sunflower by irrigation at 13% SMD resulted in significant increase in seed yield/fed and yield components as well as oil content of seeds. This can be attributed to the high growth parameters and the high metric potential and more availability of water in the root zone and these enhanced roots to absorb more water and increased the photosynthesis activity, which consequently increased the dry matter accumulation in plant organs. However, plants that suffered from water deficit in the root zone have small root system and weak shoot growth and this in turn reduce both the vegetative growth and the yield. On the other hand, the observed increase in seed oil content under wet level (13% SMD) may be referred to the accumulation of fat during the development of storage organs (seeds) which resulted from transformation of high sugar contents to the fatty acids (Ashir, 2003). These findings cope with Kramer (1977) who reported that water stress caused a considerable decrease in organic compounds translocation in the plants. On contrary, water stress may cause a reduction in the accumulation of carbohydrate compounds in seeds and this enhanced nitrogen compounds to increase as the relation between C and N compounds which resulted in more protein content than under wet level.

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