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Sunflower Yield, Water Use Efficiency and Soil Moisture Content as Affected by Irrigation Systems and Regimes in Old Land of Egypt

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ABSTRACT

Two field experiments were carried out for the two successive growing seasons of 2012 and 2013 in a clay soil at the Experimental Farm of the Faculty of Agriculture, Benha University, Qalubia Governorate, Egypt. The aim of this study was to select the appropriate irrigation system; i.e. surface drip irrigation (SDI), gated pipes (GP) with long furrow and traditional furrow irrigation (TFI) systems for irrigating sunflower (*Helianthus annuus* L.) plants under old lands conditions in Egypt, and to study the effect of irrigation water regimes (100%, 75% and 50% ETc) on yield and its related parameters, water use efficiency (WUE) and soil moisture distribution. Results showed that drip irrigation and gated pipes furrow irrigation systems exhibited the highest values of WUE for both seed yield and oil yield meanwhile traditional furrow irrigation (TFI) recorded the lowest values in the same concern. The highest values of seed yield/fed. (1280 kg/fed.) and oil yield/fed. (478 kg/fed.) were achieved by 75% ETc treatment. However, 50% ETc surpassed 100% and 75% ETc in WUE for seed yield (0.62 kg/m^3) and oil yield (0.232 kg/m^3). Minimum water stress before and after irrigation occurred under GP then surface drip and then traditional furrow irrigation. Reduction in average depth of contour line of field capacity after irrigation and reduction in average depth of contour line of permanent wilting point before irrigation indicates a decline in the influence of water stress on the cultivated plants. There is a big increase in water stress under 50% of ETc compared with 75% and 100% of ETc. There is a small increase in water stress under 75% of ETc compared with 100% of ETc. It could be concluded that under the conditions of the experiment or any other similar conditions, irrigation at 75% ETc, using drip or gated pipes with long furrow irrigation systems are recommended due to their superiority in seed yield/ fed. with higher water use efficiency (WUE) and consequently higher net profits/ fed.

Keywords: Helianthus annuus L.; seasonal consumptive use; water requirements; oil yield; crop evapotranspiration (ETc).

INTRODUCTION

Currently, water is a primary limiting factor in Egyptian agriculture and it is important to address our efforts to the fundamental issue of increasing crop production while reducing their water consumption especially in the reclaimed sandy lands. This can be achieved through an effective use of modern irrigation techniques.

Abou Kheira [3] mentioned that irrigation is typically practiced in short furrows surrounded by small basins. This method is inefficient in the following respects: (1) Water is used excessively because flow rates are not uniform; (2) Labor is wasted in construction of furrows and water manipulation; (3) 10 - 20% of land is wasted in borders, furrow ends and small canals; and (4) Poor uniformity and distribution of irrigation water results in drainage, water logging, and consequently increasing the salinity of the soil. The questions often arise, “What is the minimum irrigation amount for irrigated sunflower? And what is the suitable irrigation system for irrigating sunflower?” These are very difficult questions to answer because they greatly depend on the weather, yield goal, soil type, area conditions and the economic conditions necessary for profitability.

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English *et al*. [18] defined deficit irrigation as "an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction." They also reported that deficit irrigation strategies aim to increase water use efficiency, either by reducing irrigation adequacy or by eliminating the least productive irrigations. Increasing profits and maximizing or stabilizing regional crop production can be achieved by using a deficit irrigation strategy.

Melvin and Payero [29] reported that at the research level deficit irrigation strategies proved to be valuable water conserving practices and it should be applied as effective strategy at the large scale level in farmer's fields.

Sunflower (*Helianthus annuus* L.) is one of the four most important oil crops in the world [33,14]. Its acreage has increased in both developed and developing countries because of its moderate cultivation requirements and high oil quality [34].

Sunflower oil is highly demanded not only for human consumption, but also for chemical and cosmetic industries. In respect of total yield produced, water requirements of sunflower are relatively high compared to most crops. In Egypt great attention must be given towards this crop to decrease the gab in oil production. Although sunflower is a temperate zone crop, it can perform well under wide spectrum of climatic and soil conditions. The crop is grown both as a summer and winter crop under irrigated system and as a summer crop under rainfed system.

Ghani *et al*. [20] found that irrigation is an important factor which directly influences the yield of sunflower, and practically all the farmers realize its importance. Judicious and timely application of irrigation at critical growth stages of sunflower increase yield considerably.

In general, the optimum use of irrigation water, particulary in seasons where there is insufficient water for crop demand, is an essential for water resource management. Optimum use implies not only an efficient irrigation system capable of providing good uniformity, but also a proper timing of irrigation so as to conform to critical stages of growth of the crop concerned. When water supply does not meet crop water requirements, actual evapotranspiration (ETa) will fall below maximum evapotranspiration (ETm). Under this condition, water stress will develop in the plant, which adversely affects crop growth and ultimately crop yield.

Kassem [24] compared the effect of applying subsurface drip irrigation, surface drip irrigation and furrow irrigation systems on growth and yield of sunflower crop. He indicated that maximum plant height, stem diameter, head diameter, seed yield (1230 kg/fed.) and water use efficiency (0.531 kg/m^3) were obtained by applying subsurface drip irrigation system (30 cm depth). Mehana [27] reported that significant differences due to variation of irrigation systems were obtained regarding the yield and its related seed yield values. It could be concluded that subsurface drip irrigation system was very appropriate for achieving significantly higher seed yield and biological yield of sunflower in both seasons of his experiment as well as oil yield and shelling percentage in the 1st season, in addition to the weight of 1000 seeds and dry matter of straw and heads in the second season. Furthermore, he found that irrigating sunflower plots with different irrigation amounts of water indicated that the higher water use efficiency was obtained by irrigation water 125% ETo (2962 m^3 /fed).

Rady [31] found that using gated pipes to irrigate long furrow (100 m long) resulted in saving water by 20%, 38% and18% and increasing the water use efficiency by 58%, 26% and 17% for beans, corn and peas respectively, compared with conventional surface irrigation method using short furrows (6-10 m long) in sandy soil. Jibin and Foroud [22] compared two methods of irrigation, gated pipes and traditional irrigation in Hebei Lowland Plain of China. The gated pipes system designed for basin irrigation was compared with conventional ditch basin irrigation in wheat grown for three seasons. The gated pipe system saved water by 25-28% and increases water use efficiency by 19- 29% in compared to conventional basin irrigation.

Osman [30] indicated that water use efficiencies for improved surface irrigated cotton and wheat were higher than the traditional system, by 85.71 and 171.4%, respectively.

Hassan [21] reported that using a gated pipes system (in Egyptian old valley, clay soil) having 12 gates, 0.5 m spacing between two gates (6 m length of pipeline under zero slope) and gate discharge 1.0 l/s increased wheat grain yield by 6.5%, giving application efficiency 76.5%, water use efficiency 1.47 kg/m^3 and saving 37.3% of irrigation water applied comparing with traditional method.

Ardakani *et al*. [9] reported that water stress treatments, no irrigation at any stage reduced seed yield and decreased yield components such as seed number and seed weight. Head Diameter, harvest index, oil percent, oil yield and growth indices also were reduced by water stress.

Aiken and Lamm [5] exhibited that supplemental irrigation scheduled by the water balance method resulted in higher yields. Yield reductions depend on the degree of plant water stress at critical stages of growth. Irrigated sunflower yield ranged from 2200 to 2900 kg/ha.

As the water sources in Egypt are limited and the main source is the Nile River (55.5 billion m^3). Since agriculture is the main consumer of water resources in Egypt, the main source of the Nile River. As a result of the increase in population, the annual quota of water per capita is decreasing, and this in turn will lead to water poverty. On the other hand, Egypt is suffering a severe shortage of oil crop production which led to a widening gap between production and consumption. Therefore, it is imperative to use modern irrigation systems not only in the new land, but also in the old lands. Accordingly, development of irrigation and rationalize water use in Egypt's policies should be based on proper management of irrigation water by following the strategies of irrigation management which increase the water use efficiency and crop productivity.

From the above mentioned criteria, the present work aimed to study and identify the following:

1. Select the appropriate irrigation system (surface drip irrigation, gated pipes and traditional furrow irrigation systems) for irrigating sunflower plants under old lands conditions.
2. Study the effect of irrigation water regimes on yield and water use efficiency.

Materials and Methods

Experimental Site and Crop:

The field experiments were conducted during 2012 and 2013 summer seasons at the Experimental Farm of Faculty of Agriculture, Benha University, Qalubia Governorate, Egypt. The studied crop was sunflower (*Helianthus annuus* L.).

Soil properties and irrigation water analysis:

Physical and chemical analysis of the soil were determined according to the methods described by Abuzaid [4]. Physical and hydro-physical properties of the soil are shown in Table 1.

Table 1: Physical and hydro-physical properties of soil, at Moshtohor, Qalubia, Egypt.

Physical properties					
Depth (cm)	Sand (%)		Silt (%)	Clay (%)	Textural class
	Fine	Coarse			
0 - 40	20.95	1.28	27.92	49.85	Clay
40 - 70	21.23	1.96	28.19	48.62	Clay
hydro-physical properties					
Depth (cm)	F.C. (%)	W.P. (%)	A.W. (%)	H.C. (cm/h)	B.D (g/cm^3)
0 - 40	33.50	16.00	17.50	1.19	1.10
40 - 70	38.50	18.50	20.00	0.42	1.15
F.C.: Field capacity P.W.P: Permanent wilting point AW: Available water HC: Hydraulic conductivity B.D.: Bulk density					

Chemical properties of the soil are shown in Table 2.

Table 2: Chemical analysis of the soil at Moshtohor, Qalubia, Egypt.

Chemical properties											
Depth (cm)	pH	EC (dSm^{-1})	Soluble cations (mmol$_C$L^{-1})				Soluble anions (mmol$_C$L^{-1})				
			Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	$CO_3^=$	HCO_3^-	$SO_4^=$
0 - 40	7.72	0.57	2.10	2.40	3.22	0.80	1.50	0.00	2.60	4.42
40 - 70	7.88	0.74	1.50	1.30	3.90	1.35	2.30	0.00	1.90	3.85

Irrigation water analysis in the experimental site is shown in Table 3.

Table 3: Water Chemical analysis in the experimental site at Moshtohor, Qalubia, Egypt.

Water analysis		
Electrical conductivity	dS/m	1.5
pH		7.3
Total Nitrogen	%	0.001
Na+	mg/L	219
Cl-	mg/L	418
Mg++	mg/L	0.48
No_3--	mg/L	0.16

Plant Management:

Seeds of the sunflower variety (Sakha 53) were sown on 29 June 2012 and 26 June 2013 in single rows with 60 cm spacing and hills of 25 cm apart along the rows. Thinning was done before first irrigation (Mohaya) to secure one plant / hill. Fertilizer requirements of sunflower crop for the studied area were added according to recommendations of Agronomy Research Institute, ARC, Ministry of Agriculture and Land Reclamation. The used doses of fertilizers were 100 kg / fed. of calcium super phosphate were added during the seed bed preparation.100kg / fed. of calcium super phosphate (15.5% P2O5), 150 kg / fed. of ammonium sulphate (20.5% N) and 50 kg /fed. of potassium sulphate (48% K2O) added at the first irrigation (Mohaya), two weeks after sowing. Sunflower plants were harvested at (100) days from sowing in both seasons.

Irrigation Systems:

Three irrigation systems were selected to irrigate sunflower plants. The first was surface drip irrigation system (SDI), consisting of G.R, 4L/h emitters at 30 cm spacing, polyethylene laterals 60 cm apart with diameter of 18 mm. The second was gated pipes (GP), P.V.C gates fixed on polyethylene pipes of 160 mm in diameter (gate discharge is 4 m^3/ h and distance between gates was 60 cm, at 0.15 bar pressure). The third was the traditional furrow irrigation (FI), 60 cm apart.

Water Application:

Three water application rates were applied for irrigating sunflower crop; i.e. irrigation at 100%, 75%, and 50% of crop evapotranspiration (ETc) calculated from meteorological data. Crop evapotranspiration (ETc) was calculated according to the climate data recorded at the Experimental Farm of Faculty of Agriculture, Benha University, Qalubia Governorate, using the Penman Montith method described by Allen *et al*., [6]. Irrigation treatments were practiced after the first irrigation (Mohaya), two weeks from sowing and irrigation was withheld 10 days before harvest. The other agricultural practices, except the studied ones, were carried out as usually done in the district. The seasonal and daily consumptive use as well as water requirements of sunflower plants of the different irrigation treatments under the different irrigation systems in the two experimental seasons is presented in Table (4).

Table 4: Seasonal, daily water consumptive use (W.C.U.) and water requirements as affected by irrigation systems and treatments during 2012 and 2013 seasons.

Variables Treatments		irrigation period (days)		No. of irrigations/ season		Water Consumption m^3/fed./season		Water Consumption m^3/fed./day		* Water Requirements m^3/fed./season	
Irrig. Systems	ETc	S 1	S 2	S 1	S 2	S 1	S 2	S 1	S 2	S 1	S 2
SDI	100 %	58	60	14	15	1911	2093	12.85	14.58	2211	2393
	75 %	58	60	14	15	1533	1669	10.98	12.30	1833	1969
	50 %	58	60	14	15	1155	1246	9.11	10.02	1455	1546
M.S.I (GP)	100 %	52	56	5	5	2462	2616	18.56	19.01	2762	2916
	75 %	52	56	5	5	1946	2062	15.56	15.85	2246	2362
	50 %	52	56	5	5	1431	1508	12.53	12.68	1731	1808
FI	100 %	52	56	5	5	3287	3503	24.60	25.34	3587	3803
	75 %	52	56	5	5	2565	2727	20.38	20.90	2865	3027
	50 %	52	56	5	5	1843	1951	16.16	16.48	2143	2251

S 1 = 1st Season S 2 = 2nd Season * = including sowing irrigation SDI = Surface Drip Irrigation
M.S.I (GP) = Modified Surface Irrigation using Gated Pipes FI = Furrow Irrigation

Irrigation water requirements:

The amount of irrigation water for sunflower was applied by flow meter after it was calculated according to equation 1.

$$IW = \left[\frac{ETo * Kc * Kr * I}{Ea(1-LR)}\right] * 4.2 \qquad (1)$$

Where:
IW = Irrigation water applied m3 /fed. /irrigation
ET0 = Reference evapotranspiration (mm/day)
Kc = Crop coefficient.
Kr = Reduction factor [25]
I = Irrigation intervals, day.
Ea = Irrigation efficiency.
LR = Leaching requirement = 10% of the total amount water delivered to treatment.

Experimental design:

The applied statistical design of the experiments used was split plot one with four replications; irrigation systems and water treatments were assigned in the main plots and sub main plots, respectively.

Measurements and calculations:

Seed yield:

At harvest time, heads of ten guarded sunflower plants were randomly harvested from the inner rows in each sub main plot and were dried under sunshine for one week then weighted to determine seed yield per feddan.

Oil yield:

Seed oil percentage was determined by using Soxhelt apparatus and petroleum ether 40 – 60°C as a solvent according to the method prescribed by A.O.A.C. [8].

Water use efficiency of seed yield:

Water use efficiency is an indicator of effectiveness use of irrigation water for crop production. Water use efficiency of seed yield was calculated from the following Equation (2):

$$WUE\ of\ seed\ yield\ (kg/m^3) = \frac{Total\ seed\ yield\ (kg/fed.)}{Total\ applied\ irrigation\ water\ (m^3/fed.)} \qquad (2)$$

Water use efficiency of oil yield:

Water use efficiency of oil yield was calculated from Equation (3):

$$WUE\ of\ oil\ yield\ (kg/m^3) = \frac{Total\ oil\ yield\ (kg/fed.)}{Total\ applied\ irrigation\ water\ (m^3/fed.)} \qquad (3)$$

Soil moisture content distribution:

Water distribution in the soil profile was presented in charts. For each treatment, four locations were taken along the furrow of plants under gated pipes irrigation system at spacing 15 m; however three locations were taken along the row or furrow of plants under the other two irrigation systems (surface drip and furrow irrigation). The soil water content was determined using the gravimetric method. Soil samples were collected by soil auger. Moisture content for each treatment was measured at 0.10 m increments to a depth of 0.70 m before irrigation and 48 hours after irrigation.

Results and Discussion

Seed yield and its WUE:

Data in Tables (5 and 6) showed the effect of irrigation systems (surface drip irrigation, modified surface irrigation using gated pipes and traditional furrow irrigation), irrigation regimes (100%, 75% and 50% Etc) and their interaction on seed yield and WUE of sunflower crop.

Effect of irrigation systems:

In the first season data showed that the higher value for WUE was found at drip irrigation followed by gated pipes. However, the lowest value was obtained at furrow irrigation system. Furthermore, the differences between the three systems of irrigation were not significant for seed yield productivity. Moreover, in the second season both drip irrigation and gated pipes irrigation systems were significantly and equal effect in WUE criteria. However, the lowest significant value for WUE criteria was shown by furrow irrigation system.

Effect of irrigation regimes:

Data in Tables (5 and 6) presented the effect of irrigation regimes; i.e. 100%, 75% and 50% ETc on seed yield productivity and WUE of sunflower crop (*Helianthus annuus* L.*)* in 2012 and 2013 experimental seasons. It is clear from Tables (5 and 6) that a quite similar trend was obtained in both experimental seasons regarding the effect of irrigation treatments on the studied parameters. In both seasons, seed yield and WUE were increased significantly at 75 % ETc. Regarding the other water regimes 100 % and 50 % Etc, it was found that. the full water regime (100% ETc) ranked second and the irrigation (50 % ETc) ranked third concerning the productivity of sunflower, seed yield and its WUE criteria.

Table 5: Effect of irrigation systems, water regimes and their interaction on sunflower seed yield (kg/fed.) in both experimental seasons.

Irrigation Systems	Water regimes (ETc)				Water regimes (ETc)			
	100%	75 %	50 %	Mean	100%	75 %	50 %	Mean
	1st season				2nd season			
SD	1320a	1216bc	1010f	1182	1145de	1505a	917.0f	1189
GP	1169cd	1252ab	1197bc	1206	1414ab	1159de	1302bc	1292
FI	1083e	1292a	1119de	1164	1085e	1257cd	1124e	1155
Mean	1190b	1253a	1109c		1215b	1307a	1114c	
L.S.D $_{0.05}$	Irrigation systems: N.S Water regimes: 40 Interaction: 69				Irrigation systems: N.S Water regimes: 75 Interaction: 130			

Table 6: Effect of irrigation systems, water regimes and their interaction on WUE for sunflower seed yield (kg/m^3) in both experimental seasons.

Irrigation Systems	Water regimes (ETc)				Water regimes (ETc)			
	100%	75 %	50 %	Mean	100%	75 %	50 %	Mean
	1st season				2nd season			
SD	0.60b	0.66a	0.69a	0.65a	0.48cd	0.76a	0.60b	0.61 a
GP	0.42d	0.56c	0.69a	0.56b	0.48c	0.49c	0.72a	0.57 a
FI	0.30e	0.45d	0.52c	0.42c	0.29e	0.42d	0.50c	0.40 b
Mean	0.44c	0.56b	0.64a		0.42c	0.56b	0.60a	
L.S.D $_{0.05}$	Irrigation systems: 0.04 Water regimes: 0.02 Interaction: 0.04				Irrigation systems: 0.13 Water regimes: 0.04 Interaction: 0.07			

Many investigators showed similar results regarding the influence of water stress on sunflower seed yield and its related characters. Among them are: Khalifa and Awad [26], Andani *et al*. [7], Mekki *et al*. [28], Razi and Assad [32] and Ashoub *et al*. [11]. Moreover, El-Noemani (2009) on pea (*Pisum sativum* L.) plants showed much closed results in the same concern.

Effect of interaction:

The effect of interaction between irrigation systems and irrigation regimes on seed yield productivity and its WUE criteria is exhibited in Tables (5 and 6). Data showed that significant differences due to interaction were attained in the two mentioned parameters in both experimental seasons. It is worthy to mention that in most cases the highest significantly affected values of WUE for seed yield in two seasons were exhibited when the plants were irrigated at either 50% or 75% ETc under surface drip irrigation system. The highest significant interaction values of seed yield productivity were 1320 and 1292 kg / fed. in first season at 100% ETc under surface drip irrigation system and at 75% ETc under furrow irrigation system, respectively. With regard to the highest interaction value of seed yield productivity in the second season, it was also recorded by using 75% ETc under surface drip irrigation system. Meanwhile, the lowest significant interaction values of seed yield productivity were 1010 and 917 kg /fed. at irrigation with 50% ETc under surface drip irrigation system in the first and the second season, respectively.

Oil yield productivity and its WUE criteria:

Data in Tables (7 and 8) demonstrated the effect of irrigation systems (surface drip irrigation, modified surface irrigation using gated pipes and traditional furrow irrigation), irrigation regimes (100%, 75% and 50% Etc) and their interaction on oil yield and its WUE criteria of sunflower plants.

Effect of irrigation systems:

In the first season surface drip irrigation system surpassed significantly the other two systems in WUE for oil yield. On the other hand, with regard to oil yield productivity it was not significantly affected by irrigation systems. In the second season, the picture was somewhat different, where surface drip and gated pipes irrigation systems showed significant superiority against the other irrigation system (furrow irrigation). Moreover, in the second season there were no significant differences among irrigation systems in oil yield productivity.

Our results regarding the reduction in oil content and/or oil yield caused by water stress are in great agreement with the findings of many research workers. Among them are; Kandil [23], Attia [12], Abdel-Halem *et al*. [2], El-Kafoury *et al*. [15] and Esmail [19].

Effect of irrigation regimes:

Data in Tables (7 and 8) illustrated the effect of irrigation regimes, i.e. 100%, 75% and 50% of crop evapotranspiration (ETc) on oil yield productivity and its WUE criteria of sunflower plants (*Helianthus annuus* L.*)* in 2012 and 2013respectivily. It is clear from the obtained results that in the two seasons, oil yield productivity showed significant increases when sunflower plants were irrigated at 75% compared with either 50% or 100% ETc. It is obvious from data in the figure that the highest value of WUE criteria for oil yield was achieved by 50% in both experimental seasons. In addition, 100% ETc exhibited significantly the lowest values in the same regard in both seasons.

Our results regarding the reduction in oil content and/or oil yield caused by water stress are in great agreement with the findings of many research workers. Among them are, Abdel-Gawad *et al*. [1], El-Wakil and Gaafar, [17], Ashoub [10] and Esmail [19].

Effect of Interaction:

Effect of interaction between irrigation systems and irrigation regimes on oil yield productivity and its WUE criteria is illustrated in Tables (7 and 8). It is worthy to mention that the highest values of oil yield productivity were obtained from 75% ETc under surface drip irrigation system in both growing seasons. However, the highest values of WUE for oil yield were obtained when sunflower plants were irrigated with 75% ETc under surface drip irrigation system in both experimental seasons. However, WUE for oil yield tended to decrease with excessive irrigation water 100% ETc under furrow irrigation system in both growing seasons.

Table 7: Effect of irrigation systems, water regimes and their interaction on sunflower oil yield (kg/fed) in both experimental seasons.

Irrigation Systems	Water regimes (ETc)				Water regimes (ETc)			
	100%	75 %	50 %	Mean	100%	75 %	50 %	Mean
	1st season				2nd season			
SD	464ab	473.0a	365.7d	434	445.0c	625.7a	346.7e	472
GP	427.7c	436.7bc	412.7c	426	479.3bc	429.3cd	532.3b	480
FI	341.7d	436.0bc	418.7c	399	367.7de	466.7bc	426.7cd	420
Mean	411.2b	448.6a	399.0b		430.7b	507.2a	435.2b	
L.S.D $_{0.05}$	Irrigation systems: N.S Water regimes: 18.66 Interaction: 32.32				Irrigation systems: N.S Water regimes: 42.32 Interaction: 73.30			

Table 8: Effect of irrigation systems, water regimes and their interaction on sunflower WUE for oil yield (kg/m^3) in both experimental seasons.

Irrigation Systems	Water regimes (ETc)				Water regimes (ETc)			
	100%	75 %	50 %	Mean	100%	75 %	50 %	Mean
	1st season				2nd season			
SD	0.21c	0.26a	0.25ab	0.24a	0.19c	0.32a	0.22b	0.24a
GP	0.15d	0.19c	0.24b	0.20b	0.16c	0.18c	0.29a	0.21a
FI	0.09e	0.15d	0.20c	0.15c	0.01d	0.15c	0.19c	0.15b
Mean	0.15c	0.20b	0.23a		0.15b	0.22a	0.24a	
L.S.D $_{0.05}$	Irrigation systems: 0.02 Water regimes: 0.01 Interaction: 0.02				Irrigation systems: 0.05 Water regimes: 0.02 Interaction : 0.04			

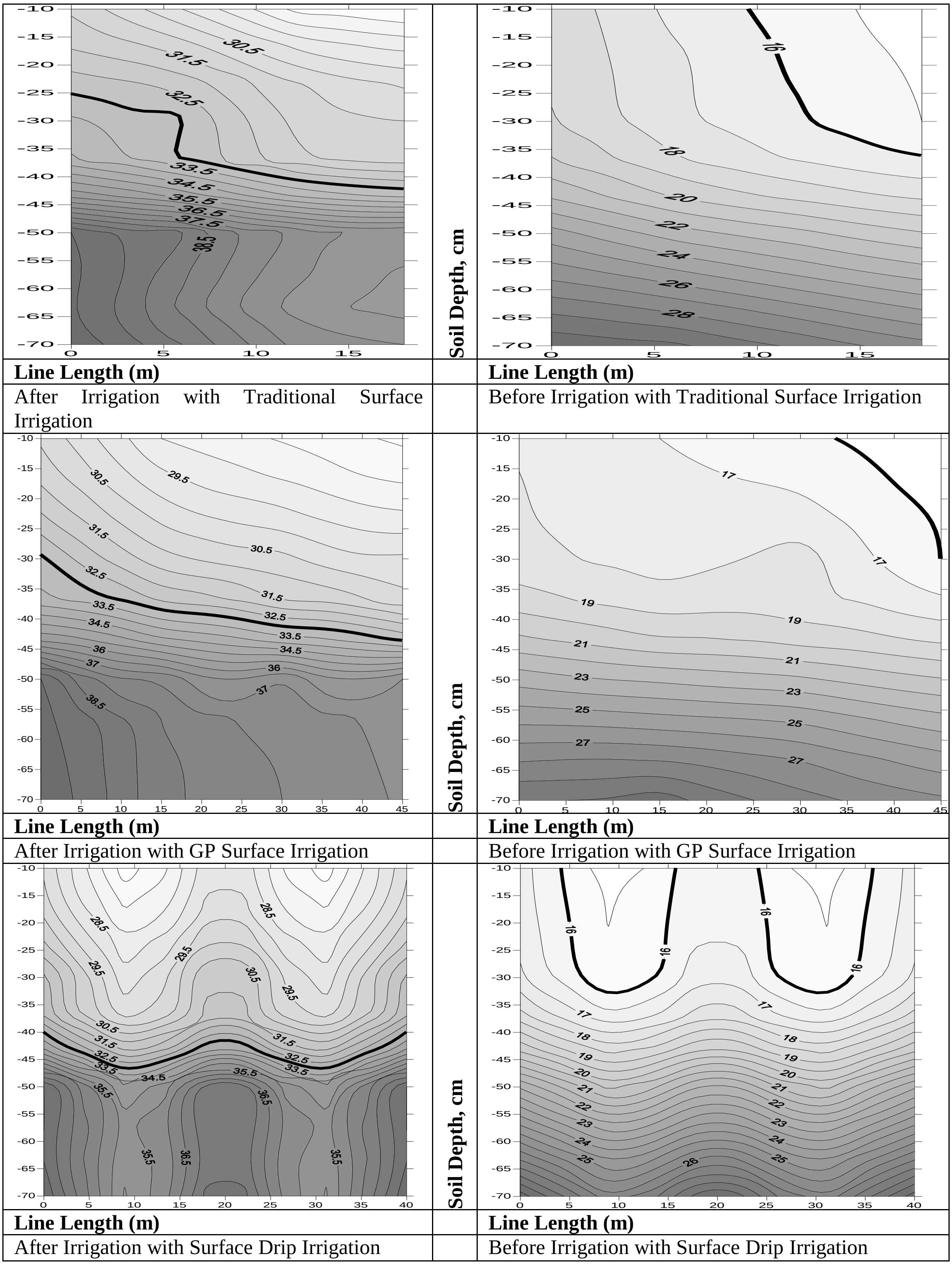
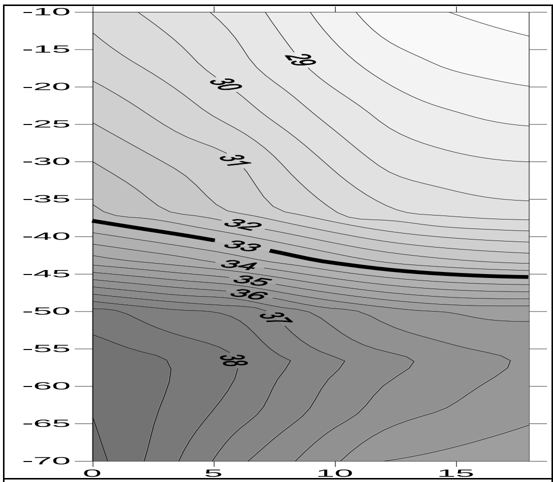
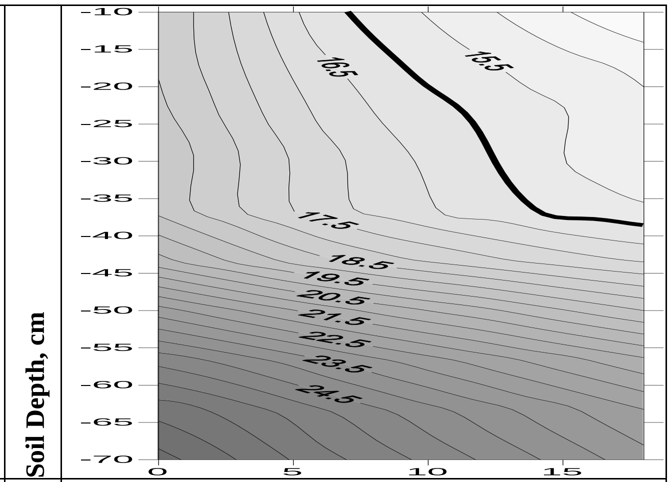


Fig. 1: Soil moisture distribution in root zone under irrigation systems at 100% Etc irrigation requirements.



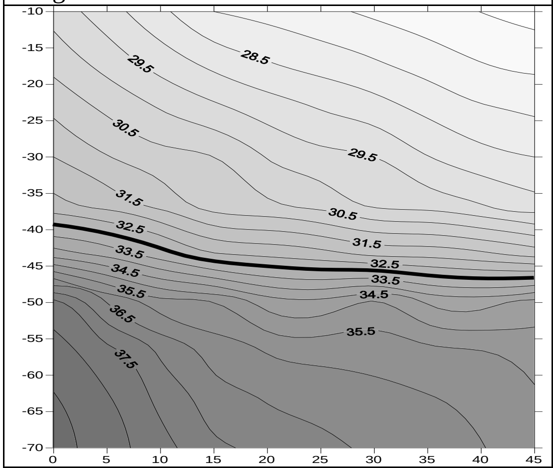


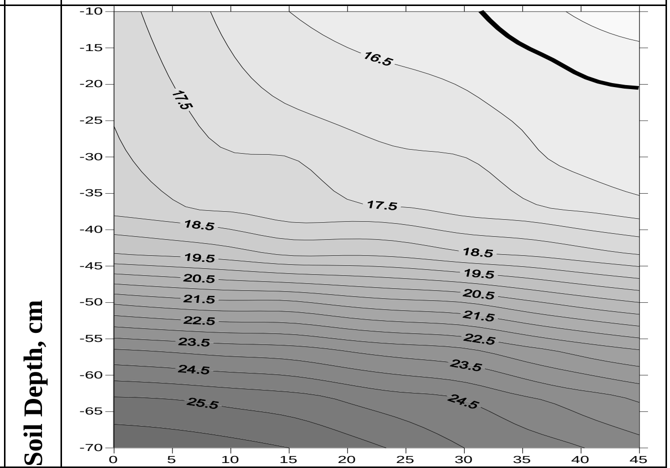
Line Length (m)

After Irrigation with Traditional Surface Irrigation

Line Length (m)

Before Irrigation with Traditional Surface Irrigation



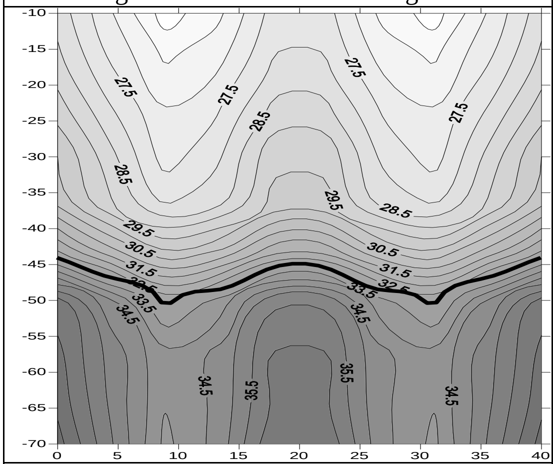


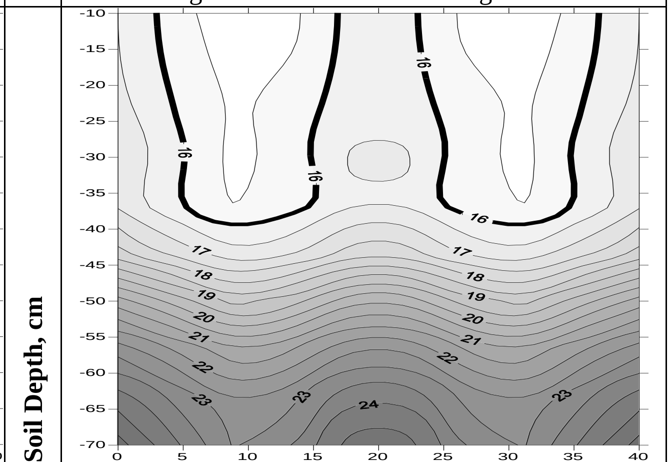
Line Length (m)

After Irrigation with GP Surface Irrigation

Line Length (m)

Before Irrigation with GP Surface Irrigation





Line Length (m)

After Irrigation with Surface Drip Irrigation

Line Length (m)

Before Irrigation with Surface Drip Irrigation

Fig. 2: Soil moisture distribution in root zone under irrigation systems at 75% Etc irrigation requirements.

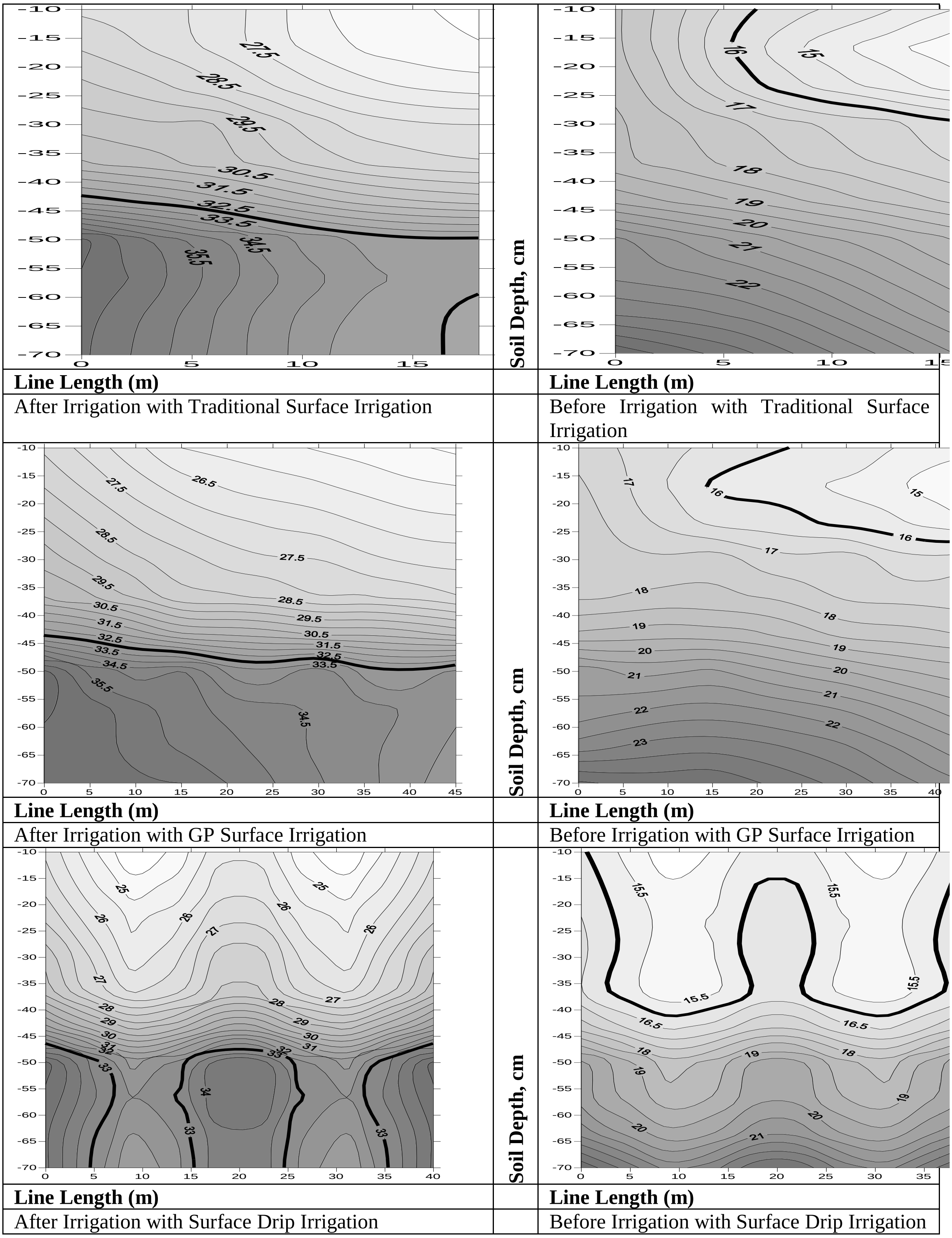


Fig. 3: Soil moisture distribution in root zone under irrigation systems at 50% irrigation requirements.

Soil moisture content distribution:

Figs. 9, 10 and 11 indicates the soil moisture distribution "SMD" under the three irrigation systems (surface drip, gated pipes and furrow irrigation) and the three rates of irrigation water for sunflower crop. Fig. 9 represent that "SMD" before and after irrigation under the three irrigation systems and 100% of ETc. Bold contour line 33 represent the field capacity after irrigation and bold contour line 16 represent the wilting point before irrigation.

Minimum water stress before and after irrigation occurred under GP then surface drip and then traditional furrow irrigation this may be due to increasing distribution uniformity of GP and surface drip irrigation systems than furrow irrigation. Reduction in average depth of contour line of field capacity after irrigation and reduction in average depth of contour line of permanent wilting point before irrigation indicates a decline in the influence of water stress on the cultivated plants.

Fig. 10 represents the "SMD" before and after irrigation under the three irrigation systems and 75% ETc. Bold contour line 33 represent the field capacity after irrigation and bold contour line 16 represent the wilting point before irrigation. Minimum water stress before and after irrigation occurred under GP then Surface drip then traditional furrow irrigation this may be due to increasing of distribution uniformity of GP and surface drip irrigation systems than furrow irrigation. Reduction in average depth of contour line of field capacity after irrigation and reduction in average depth of contour line of permanent wilting point before irrigation indicates a decline in the influence of water stress on the cultivated plants. There is a small increase in water stress under 75% of ETc compared with 100% of ETc.

Fig. 11 represents the "SMD" before and after irrigation under the three irrigation systems and 50% ETc. Bold contour line 33 represent the field capacity after irrigation and bold contour line 16 represent the wilting point before irrigation. Minimum water stress before and after irrigation occurred under GP then surface drip then traditional furrow irrigation also, this may be due to increasing of distribution uniformity of GP and surface drip irrigation systems than furrow irrigation. Reduction in average depth of contour line of field capacity after irrigation and reduction in average depth of contour line of permanent wilting point before irrigation indicates a decline in the influence of water stress on the cultivated plants. There is a big increase in water stress under 50% of ETc compared with 75% and 100% of ETc.

Conclusions:

Form the results obtained in this investigation the following conclusions could be figured out:

1. Surface drip and gated pipes systems are recommended for growing sunflower crop due to their superiority in WUE for both seed and oil yields.
2. Irrigation at 75% of Etc; i.e. 1556 m^3 / fed / season is recommended for irrigating sunflower crop due to increases in seed yield/ fed. (1280 kg/fed.), oil yield/ fed. (478 kg/fed) and WUE for both seed yield (0.62 kg/m^3) and oil yield (0.232 kg/m^3).
3. Finally, it could be concluded that under the conditions of the experiment or any other similar conditions, irrigation at 75% ETc, using SD or gated pipes irrigation systems are recommended due to its superiority in seed yield with higher water use efficiency.

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