Water stress management for sunflower under heavy soil conditions

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Abstract: An experiment was performed for two seasons to test the impact of water stress and drip irrigation lateral arrangements on yield and water productivity of the sunflower crop (seed and oil). Water stress treatments were full crop evapotranspiration 100% ETc (FI_{100}), 80% ETc (DI_{80}), 60%ETc (DI_{60}) and 100-60% ETc (DI_{100-60}). The DI_{100-60} treatment was applied as 100% ETc up to seed formation then reduced to 60% ETc. The drip irrigation lateral arrangements were single planting row per one drip line with 2 L h^{-1} drippers (T_1) and double planting rows per one drip line with 4 L h^{-1} drippers (T_2). Results revealed that applying water stress by either DI_{80} or DI_{100-60} produced almost the same or more yield of sunflower seeds and oil than that obtained from full irrigation FI_{100}, besides saving about 20% of irrigation water. These two water stress treatments maximized water use efficiency (WUE). The highest seed yields were 4.51 and 4.34 Mg ha^{-1} obtained from T_1 and T_2 under DI_{100-60} respectively. The oil yield values were taken the same trend as seed yield. Accordingly, it could be recommended that irrigating row crops such as sunflower under clay soil conditions could be done by using one lateral line of 4 L h^{-1} drippers per two planting rows and applying DI_{80} or DI_{100-60} water stress strategy, leading to increase seed and oil yield, maximizing water productivity, reducing the cost of drip lines by 50% and saving water by about 20%.

Keywords: limited irrigation, drip system: water productivity, sunflower, clay soil

Citation: Mostafa, H., M. El-Ansary, M. Awad, and N. Husein. 2021. Water stress management for sunflower under heavy soil conditions cooling effectiveness. Agricultural Engineering International: CIGR Journal, 23 (2):76-84.

1 Introduction

For a specific situation, the optimum amount of water applied would be that which produces the maximum benefit or crop yield, per unit of land or per unit of water, depending on whether the goal is to maximize income or food output and whether water or land is the most limiting resource. The other levels of distributed water are the levels of deficit at which net returns would be equal to those produced by maximum irrigation (Ashraf and Harris, 2005; Skaggs et al., 2004). Deficit irrigation succeeds in increasing water efficiency for various crops without causing drastic reductions in yields (Geerts and Raes, 2009; Ali et al., 2007). Under crop conditions soil wetting and drying is continuous processes. The soil water content patterns in this case also rely on water control, number of drippers, location of drippers, initial soil water content and lateral positioning in respect of the plant path (Gardenas et al., 2005; Wang et al., 2011). Mahmood et al. (2019) concluded that sunflower (*Helianthus annuus L.*) offers less than one crop response factor which indicates the crop is more tolerant and partially recovers from stress and it has a high performance under water stress. Moreover, the findings showed that the vegetative stage of growth was more successful in increase the seed yield than irrigation in the middle and later stages.

Received date: 2020-05-15 **Accepted date:** 2020-08-30

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Sunflower canopy and biomass were reduced by applying deficit irrigation, while the density of the root length compared with complete irrigation was improved and the yield was not significantly affected (Mila et al., 2017). Reductions in seed yield at maturity were dictated by reductions in single seed weight, while drought did not affect seed volume as studied by Keipp et al. (2020). The distribution of dissolved salts in the soil profile follows the water flux pattern with a tendency to accumulate at the periphery of the wet soil mass, and the salt accumulation is much greater near the surface than in the deeper layers and increases with distance from the emitters (Parida and Das, 2005; Phocaides, 2007; Kassab et al., 2012). Consideration of water savings, a mild water deficit of 100% and 75% ETc as an alternate irrigation period was found to be the ideal sunflower irrigation deficit plan (Kaviya et al., 2018). Karaa et al. (2007) found that sunflower water use efficiency (WUE) ranged from 0.64 to 0.86 kg m^{-3} among treatments (100% and 60% ET_c), while WUE ranged from 3.23 to 4.8 kg m^{-3} at biomass level.

The objective of this research was to study the impact of water stress on soil moisture and salt distribution patterns under various lateral drip irrigation arrangements, vegetative production, yield, and sunflower WUE.

2 Materials and methods

2.1 Site description

During the summer seasons of 2017 and 2018, field experiments were performed at the experimental farm of the Faculty of Agriculture, Benha University (Kalyobia Governorate, Egypt) to attain the objectives of this research. This location represents clay soil conditions of the Nile Delta region. The sunflower growing season ranges from July to early October. The experimental site's dominant soil was clay textured all over the profile (1.62% coarse sand, 21.12% fine sand, 28.04% silt and 49.22% clay). The field capacity, wilting point and electrical conductivity values were 36%, 17.25% and 1.2 dSm^{-1}, respectively.

2.2 Irrigation treatments and experimental design

Polyethylene (PE) laterals of 16 mm diameter with non pressure-compensating built-in drippers were used. To ensure similar water application rate per row for both lateral arrangements, laterals with drippers of 2 L h^{-1} discharge spaced at 0.3 m apart were used with 0.6 m spacing between laterals in treatment denoted as T_1 (one lateral of 2 L h^{-1} drippers for each planting row), and laterals with drippers of 4 L h^{-1} at 0.3 m apart were used with spacing of 1.2 m between laterals to irrigate treatment denoted as T_2 (one lateral of 4 L h^{-1} drippers for two planting rows). The average operating pressure was 100 kPa at the lateral's inlet valve. Full irrigation and three water stresses were applied for irrigating sunflower crop i.e. full irrigation at 100% ETc (FI_{100}), 80% ETc (DI_{80}), 60% ETc (DI_{60}) and 100%-60% ETc (DI_{100-60}). The DI_{100-60} treatment was applied as 100% ETc to seed formation then reduced to 60% ETc till harvesting. The experimental design was split plot design as the main plots were for lateral arrangement treatments T_1 and T_2, while the sub-main plots were for water stress treatments FI_{100}, DI_{80}, DI_{60} and DI_{100-60} in three replicates. for all treatments.

2.3 Crop measurements

Sunflower Sakha 53 variety was sown in July by seeds rate of 7-10 kg ha^{-1} in the two successive experimental seasons. At harvest time, heads of ten guarded plants were randomly drawn from the inner rows in each sub-main plot and were separately harvested, bagged and dried under sunshine for one week. Grain and oil yield, yield components and plant characteristics were measured.

The extraction method (Soxhelt apparatus and petroleum ether 40-60 ^{O}C as a solvent) was used to separate oil from seeds and calculate the percentage of oil as described by Barthet and Daun (2004) and oil yield (Mg ha^{-1}) was calculated as described by Sezen et al. (2019).

2.4 Crop water requirement

Values of daily evapotranspiration (ETo) were obtained from data predicted by Central Laboratory for Agricultural Climate (CLAC) which are always available 5 days beforehand. Kc for sunflower during the growing season was obtained from FAO (2001). The obtained ET_o and Kc were used to calculate water requirement for sunflower (m^3 ha^{-1}/irrigation) by the following equation of Keller and Karmeli (1975):

$$IW = \left[\frac{ET_o \times K_c \times K_r \times I_1}{E_a}\right] \times 10 + LR \quad (1)$$

Where:

IW = Irrigation water applied under drip irrigation system, m^3 ha^{-1}/ irrigation.

ET_o = Reference evapotranspiration (mm day^{-1}).

Kc = Crop coefficient.

Kr = Reduction factor

I_1 = Irrigation intervals with drip irrigation system, day.

Ea = Drip irrigation system's irrigation efficiency,%.

LR = Leaching requirement (10% of the total amount water), m^3 ha^{-1}/ irrigation.

The ETo was determined using the formula Penman – Monteith equation (Allen et al., 1998) and crop evapotranspiration as ETc= Kc × ETo.

2.5 Soil moisture distribution

According to Liven and F.C. Van (1979), the distribution of soil moisture was determined. Forty-eight hours after each irrigation event, samples were taken perpendicularly to the lateral using auger 20/8, at 0, 15 and 30 cm from the emission point throughout the root zone layers at depths of 0-20, 20-40 and 40-60 cm for various irrigation treatments. The contour maps for the moisture and salt distribution pattern were produced using SURFER (version 10). Soil moisture content (SMC, %) was determined as a percentage on dry weight base as follows:

$$SMC = 100\ (W_1 - W_2)\ /\ W_2 \quad (2)$$

Where:

W_1 = Wet weight of soil sample (g)

W_2 = Oven dried weight of soil sample (g) at 105 °C for 24 hours.

2.6 Salt distribution patterns

The soil salinity content was measured in saturated soil extract (1:5) for all treatments and determined for all soil samples by measuring the electrical conductivity. The electrical conductivity (EC) in dSm^{-1} was measured using EC meter (EC Meter: ORION 105 Model, USA, 0.5% accuracy) for each gravimetric soil sample and the contour maps for the salt distribution pattern were derived using the same method as described for the moisture distribution pattern.

2.7 Growth and yield parameters

For estimating growth parameters, a random sample of three plants from each plot were taken at 45, 65 and 85 days after sowing in the first and second season to obtain plant height (cm), number of leaves, weight of 1000-grain, grain yield, oil yield and total yield.

2.8 Water use efficiency

Water use efficiency (WUE) is an indicator of the effectiveness of water irrigation use for increasing crop yield. WUE of seed and oil yield was calculated as (Abd El-Rahman, 2009):

$$\text{WUE (kg m}^{-3}\text{)} = \frac{\text{total yield (kg ha}^{-1}\text{)}}{\text{total applied irrigation water (}m^3\text{ha}^{-1}\text{)}} \quad (3)$$

2.9 Statistical analysis

All data were analyzed statistically according to Snedcor and Cochran (1982). Means between treatments were compared at a probability of p<0.05 using the Least Significant Difference (LSD).

3 Results and discussions

3.1 Soil moisture distribution patterns

For FI_{100} and DI_{100-60} the moisture distribution under double rows per lateral (T_2), revealed a great difference, especially at 35 cm soil depth as shown in Figure 1.

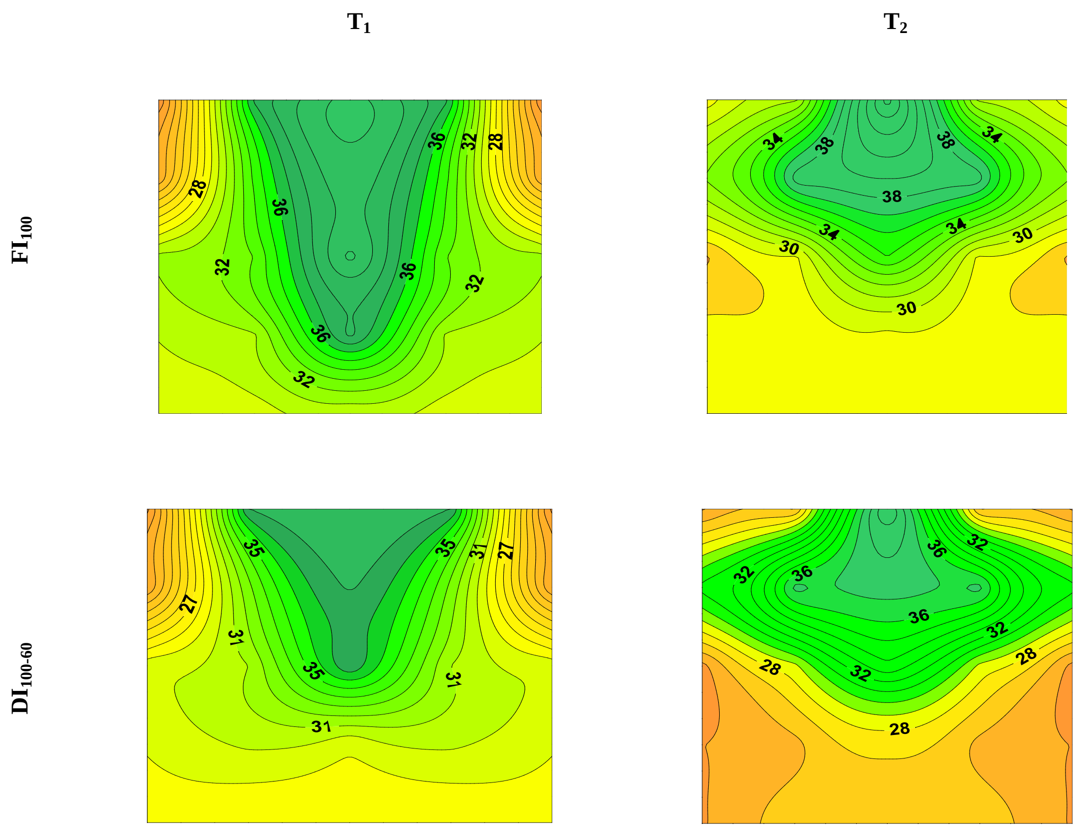
The soil moisture content values show vertical distribution in descending order through the root zone depth from 0-60 cm. Soil moisture content just beneath the dripper was 43% at the surface (0-15 cm) and 25% at the bottom (45-60 cm) for both FI_{100} and DI_{100-60} treatments. Similar moisture distribution patterns were experienced for DI_{80} and DI_{60} with different values of moisture contents ranged from 40%-25% and 37%-24% at the corresponding soil layers of 0-15 and 45-60 cm depth, respectively. At T_1 where the lower discharge (2 L h^{-1}) drippers were used under single planting row per lateral, the moisture distribution patterns differed widely through the soil root zone (0-60 cm). The soil moisture content values for both FI_{100} and DI_{100-60} treatments ranged from 38% to 33%, for DI_{80} it ranged from 39% to 31%, and for DI_{60} it ranged from 34% to 25%, respectively. The distance between laterals for T_1 was relatively closer (half) as compared with the distance between laterals in T_2 treatments. As well as the emitter discharge of 2 L h^{-1} resulted in a vertical and narrow moisture distribution pattern in the root zone. These results agreed with Mostafa et al. (2018).

It could also be noticed in T_2 patterns that due to the higher dripper discharge (4 L h^{-1}) under clay soil conditions, the horizontal distribution of moisture patterns was more widely spreader than the vertical distribution. This may help irrigating two planting rows on both sides of the lateral line as in the T_2 treatments.

3.2 Salt distribution patterns

The lowest values of EC were found under the drippers (ranging from 1.47 to 1.74 dSm^{-1} and 1.41 to 2.03 dSm^{-1}, for both T_1 and T_2, respectively) as noticed from the EC distribution patterns (Figure 2). While, the highest EC values were, as expected, at the fringes of the wetted area.

With regard to the impact of water stress on EC values, similar values were obtained for the first two deficit treatments FI_{100} and DI_{100-60} as EC ranged from 1.32 to 2.05 dSm^{-1} under T_2 arrangement. Whereas the EC ranged from 1.41 to 2.08 and 1.50 to 2.08 dSm^{-1}, for the DI_{80} and DI_{60}, respectively. Under T_1 arrangement the EC values for FI_{100} treatments ranged from 1.77 to 2.0 dSm^{-1}. While the EC values for the DI_{100-60}, DI_{80} and DI_{60} treatments ranged from 1.70 to 2.12 dSm^{-1}, 1.40 to 1.74 dSm^{-1} and 1.90 to 2.21 dSm^{-1}, respectively. So, it could be said that, salt accumulation slightly increased with water stress i.e. when irrigating by water less than required as described by Mostafa et al. (2018).



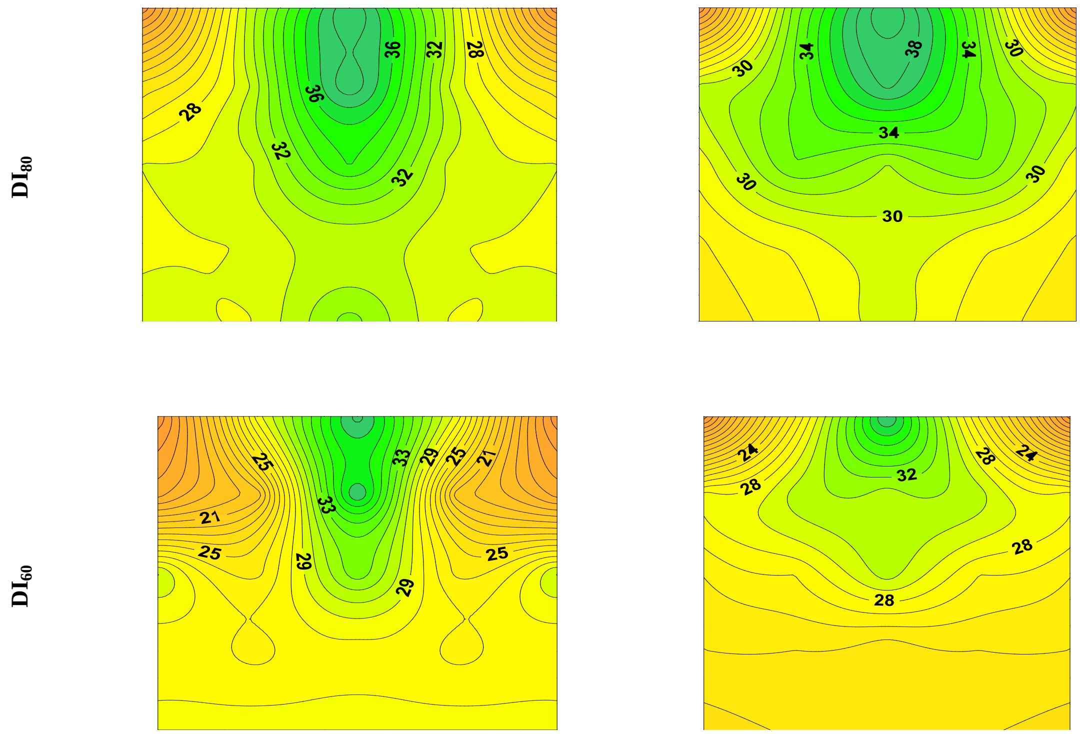
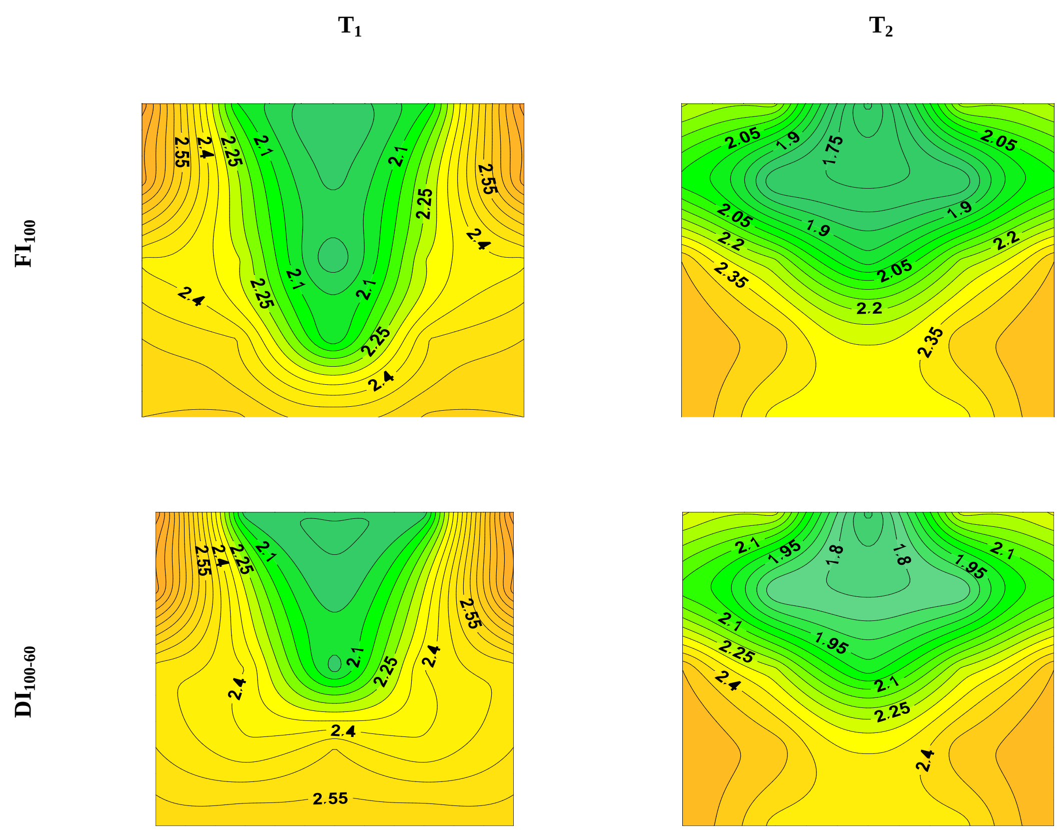


Figure 1 Soil moisture distribution patterns for water stress (DI) treatments under drip lateral arrangements T_1 and T_2



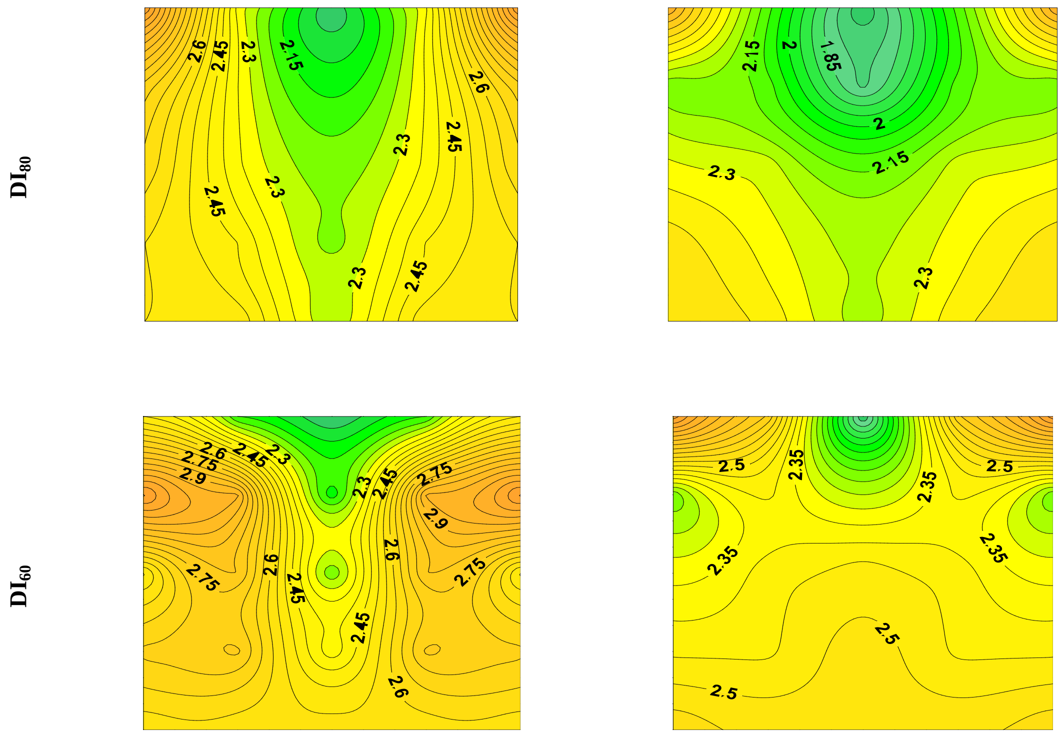
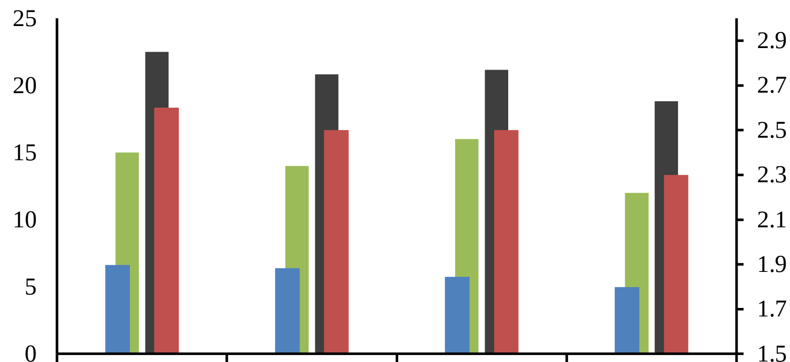


Figure 2 Salt distribution patterns (EC) for water stress treatments FI_{100}, DI_{100-60}, DI_{80} and DI_{60} under drip irrigation lateral arrangements T_1 and T_2

3.3 Water stress and sunflower growth parameter

The average values for two seasons revealed that plant height and head diameters were significantly (p<0.05) affected by water stress (Figure 3). Plant height increased by increasing level of applied irrigation water where FI_{100}, DI_{100-60} and DI_{80} resulted in plant heights of 189.7, 188.3 and 184.5 cm, respectively, whereas irrigation at 60% of ETc (DI_{60}) resulted in 179.8 cm. These results agreed with Dinakar et al. (2012).



	FI 100	DI 100-60	DI 80	DI 60
No of leaves	15	14	16	12
head diamter (cm)	22.5	20.83	21.17	18.83
plant hight (m)	1.897	1.883	1.845	1.798
stem diamter (cm)	2.6	2.5	2.5	2.3

Figure 3 Effect of water stress on sunflower growth parameters

The highest values for head diameter were 22.5 cm and 21.17 cm obtained from FI_{100} and DI_{80} treatments, respectively and the lowest value (18.83 cm) was recorded from DI_{60} treatment. Thus, this means that there was only around 6% reduction in sunflower head diameter versus 20% reduction in irrigation water applied by DI_{80} (20% water saving), which agrees with Mirshekari (2012) and Nezami et al. (2008). On the other hand, there were no significant differences (p>0.05) in stem diameter and number of leaves among all irrigation treatments.

3.4 Water stress and sunflower yield components

Data in Table 1 revealed that the highest value of 1000 grain weight (91.23 g) was obtained from DI_{80} treatment. There were no significant differences (p>0.05) in weight of 1000 grains between FI_{100} and DI_{100-60} treatments. Also, there were no significant differences in seed yield and seed weight per head between FI_{100} and DI_{80} treatments, whereas these treatments differed significantly (p<0.05) from those recorded due to both DI_{60} and DI_{100-60}. For oil yield, results indicate that the highest value was 1.58 Mg ha^{-1} yielded from DI_{100-60} treatment, while the least value (1.21 Mg ha^{-1}) was obtained from DI_{60} treatment. Accordingly, it could be stated that applying either water stress strategies DI_{80} or DI_{100-60} could produce almost more yield of sunflower seeds and oil than that obtained from full irrigation FI_{100}, in addition to save around 20% of water for irrigation. Similar data were noticed by Phiri and Zimba (2018) and Kaviya et al. (2018).

Table 1 Effect of deficit irrigation and system layout on sunflower yield, yield components and WUE

Water stress treatment	Water applied (m^3ha^{-1})	System layout	1000-grain weight (gm)	Seed weight per head (gm)	Seed yield (Mg ha^{-1})	WUE for seed yield (kg m^{-3})	Oil yield (Mg ha^{-1})	WUE for oil yield (kg m^{-3})
FI_{100}	3953	T_2	87.58	86.43	3.36	0.85	1.28	0.330
		T_1	82.16	109.8	4.27	1.08	1.66	0.423
DI_{80}	3162	T_2	90.26	93.46	3.63	1.29	1.40	0.497
		T_1	92.20	106.6	4.14	1.47	1.60	0.570
DI_{60}	2372	T_2	81.59	80.10	3.01	1.27	1.16	0.470
		T_1	84.77	102.3	3.27	1.40	1.26	0.530
DI_{100-60}	3580	T_2	84.05	111.6	4.34	1.21	1.49	0.420
		T_1	88.05	116.0	4.51	1.26	1.66	0.467
L.S.D p<0.05			11.5	8.89	0.35	0.14	0.17	0.090

3.5 Water stress and water use efficiency

Table 1 showed that no significant differences (p>0.05) were found in WUE for seed yield between water stress treatments and also WUE for oil yield but there were significant differences between water stress treatments and full irrigation treatment FI_{100}. However, the maximum WUE average value between T_1 and T_2 was 1.38 kg m^{-3} obtained from DI_{80}, in spite of the amount of irrigation water applied in DI_{80} treatment was 20% less. Similarly, the highest average values of WUE for DI_{80} and DI_{60} were 0.53 and 0.50 kg m^{-3} for oil yield, respectively, and the lowest for FI_{100} was 0.37 kg m^{-3}. Also, there were no significant differences between both lateral arrangements for all irrigation treatments. These findings lead to conclude that irrigation may be reduced not more than DI_{80} (20% less water than that required for full irrigation) in order to maximize water productivity, as agreed with Demir et al. (2006), who found that in the case of more limited irrigation, the restriction of irrigation water during the flowering period could be avoided.

3.6 Effect of irrigation lateral arrangements on seeds and oil yields under different water stress treatments

Seeds and oil yields for FI_{100} under T_2 were lower by 21% and 24%, respectively, than those obtained from FI_{100} under T_1(Table 1), given the fact that both two treatments had taken the same amount of water. Though DI_{80} under T_2 decreased seeds and oil yields by 12% and 13%, respectively, compared to DI_{80} under T_1. Similarly, the yield reduction for DI_{60} under T_2, was 8% and 11% in seeds and oil yields, respectively, compared with DI_{60}

under T_1. While the DI_{100-60} under T_2 treatment yielded 4% and 10% less seeds and oil yields than that obtained under $T_{1.}$, respectively. This treatment still yielded higher than that of all other treatments. Therefore, irrigating row crops such as sunflower could be done either by one lateral of 2 L h^{-1} drippers per each planting row and 80% ET_c, or by one lateral of 4 L h^{-1} drippers per two planting rows and 100%-60% ETc water stress strategy, taking an additional advantage of reducing the cost of laterals by 50%. Such findings agreed with Mahmood et al. (2019) since the growth stage stated to be the most receptive to irrigation was early stage compared to other stages.

4 Conclusion

This study investigated the water stress management with drip irrigation for sunflower grown in heavy soil conditions to encourage farmers to use drip irrigation systems in their clay soil fields, at best management, as a tool for maximizing seed and oil yield, increasing WUE and saving water to irrigate new areas.

Results revealed that using 4 L h^{-1} dripper discharge under heavy soil conditions resulted in wide horizontal distribution of moisture patterns more than the vertical distribution. This may be help irrigating two planting rows by one lateral line as in the T_2 treatments. Salt accumulation slightly increased with water stress. Applying water stress strategies by either DI_{80} or DI_{100-60} could produce almost the same or more yield of sunflower seeds and oil than that obtained from full irrigation FI_{100}, in addition to save around 20% of water for irrigation. These two water stress treatments leaded to maximize water productivity. The oil yield takes the same trend as seed yield. Accordingly, it could be recommended that irrigating row crops such as sunflower under heavy soil conditions could be done by using one lateral line of 4 Lh^{-1} drippers per two planting rows and applying DI_{80} or DI_{100-60} water stress strategy, taking many advantages such as increasing seed and oil yield, maximizing water productivity, reducing the cost of drip lines and saving water by about 20%.

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