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Investigation effect of installation depths and dripper spacing on water productivity and sugarcane yield in subsurface drip irrigation

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ABSTRACT: According to recent droughts and severe water, use of subsurface drip irrigation for sugarcane production was very important approach in Iran. The experiment was conducted in a split-plot design, a basic design of complete random block with two factors and three replications. The first factor composed of 50 and 60 cm space in the main plots. The second factor includes different depths of water pipe installation (15, 20 and 30-cm) along with the conventional irrigation method (furrow irrigation). The results of analysis of variance of the effect of different treatments on qualitative traits showed that in both experiment periods, simple and interaction, effects of these treatments on all quality at traits (Pol%, Brix%, Purity% and R. S%) were non-significant at the $p<0.01$. The highest sugarcane and sugar yield and highest number of stalks obtained in 50-cm space of the drippers and 20-cm depth of drippers. On average, in two years of experiment, in 50-cm space of the drippers and 20-cm depth of the drippers higher WP of produced sugarcane and sugar was 6.6 and 0.73 $kg.m^{-3}$, respectively. It was about 47 and 43 percent higher than the average of WP per sugarcane and sugar of the control treatment, respectively. Comparing results of qualitative and quantitative yields of subsurface drip irrigation and conventional irrigation showed that most quantitative and qualitative traits of subsurface drip irrigation were higher than the furrow irrigation. Also, the results showed that moisture distribution is similar in both growth stages of sugarcane (Plant and Ratoon1), so that the moisture around the drippers and width of ridge to a depth of 80-cm (the depth of activity of sugarcane root) was appropriate and shape of moisture bulb is oval under the drippers. According to the results of two years and considering other experiment conditions, for regions with similar characteristics to this experiment, 20-cm depth for discharge pipe and 50-cm space of emitters on the lateral pipe are suggested.

Keywords: Dripper, moisture distribution, subsurface drip irrigation, sugarcane, water productivity.

INTRODUCTION

Sugarcane fields of south-west of Iran have heavy soil texture, high temperatures, and hot dry winds at spring and summer. Hydro-flume gated pipes were used for irrigation. Furrow irrigation were used in sugarcane fields. Due to a water crisis in Iran, increasing the efficiency of irrigation and water productivity (WP), can be promising. Electrical Conductivity (EC), of irrigation water was considered about 1.1 dS/m, in basic designs of this irrigation method and for each unit increasing salinity more than this amount, sugarcane yield is reduced by 10%. The maximum EC of irrigation water on Karoon River reads to 4.5 dS/m in downstream. EC of water is about 2.5 dS/m (mean of it: 1.5-3 dS/m). Water EC is an issue of importance to change from surface furrow irrigation to subsurface drip irrigation (SDI) (Anonymous., 2000-2018). SDI is an advanced irrigation system that minimizes water losses by soil evaporation, weeds and by percolation below the root system (Ayars et al., 2015). Sugarcane requires lots of water during the growing period, because it is sensitive to water stress, and is not compatible with long duration flooding. If groundwater level rises and covers the root zone, crop yield decreases due to root rot (Sheini-dashtghol et al., 2009). Compared to other irrigation methods, drip irrigation systems provide the possibility to apply lower volumes of water, more frequently and efficiently. If well designed, these systems make it possible to apply slow, steady and uniform amounts of water and nutrients within the plant's root zone, while minimizing deep percolation and maintaining high productivity levels (Rallo et al., 2011).

Recent research results, assessed the performance of a citrus crop under surface and subsurface drip irrigation, they revealed that, water savings were 23 percent in the SDI method treatment compared to the surface irrigation (SI) treatment without significant differences in either yield or fruit composition (Martínez-Gimeno et al., 2018). Evaluated sugarcane yield and quality was evaluated to various irrigation regimes applied with SDI and surface drip irrigation systems on eggplant and net profit generation in the Mediterranean Region of Turkey (Çolak et al., 2018). The main advantages of SDI are related to water savings because water is applied directly to the crop's root zone, which prevents losses due to direct evaporation from the soil, deep drainage, and if properly managed, it allows the maintenance of appropriate levels of soil moisture (Lamm and Camp, 2007). Some studies evaluated water storage in the soil profile using a SDI system at two dripper installation depths (0.2 and 0.4-m) and two water qualities (treated sewage effluent and freshwater) in two crop cycles of sugarcane in Brazil Campinas. They suggested that a depth of 0.2-m of drip pipe proved to be an ideal solution for both environmental management and water-use efficiency (dos Santos et al., 2016).

Some researchers (Reyes-Cabrera et al., 2016) evaluated water-use efficiency (WUE) for potatoes and soil moisture distribution uniformity for two drip tape installation depths (surface at 0.05 and subsurface at 0.15-m depth) as an alternative method to seepage irrigation. Measuring the volume of water, water table, and soil volumetric water content for two growing seasons, 2011 and 2012. They concluded that drip irrigation reduced water use by 48 and 88 percent in 2011 and 2012, respectively and higher WUE was obtained with drip compared to seepage irrigation for all varieties in 2012 The evaluation of SDI and sugarcane spacing on stalk yields, sugarcane technological quality, and the theoretical recoverable sugar yields was studied during four cycles. Results showed that irrigation increased stalk yields in the ratoon sugarcane cycles and the theoretical recoverable sugar yields increased in the last two ratoon sugarcane cycles. According to the rows spacing, double row planting produced the greatest stalk yields and theoretical recoverable yields was obtained in the plant sugarcane cycle and the second ratoon sugarcane cycle which showed the benefits to sugarcane properties of SDI over the four years of this research (Célia de Matos Pires et al., 2014).

Research has been done on the effect of soil moisture distribution and the wetting pattern under SDI, and the results showed that the moisture distribution pattern is one of the basic information for designing and managing an irrigation system. Awareness of the moisture distribution pattern has a great impact on the effectiveness of drip irrigation (Shaju., 2017).

An experiment was performed to determine the effect of moisture distribution in the soil on the quantitative and qualitative parameters of sugarcane under SDI with discharge of 1.6 and 3.5 lit/hr. Fluid pipes were installed at a depth of 30 cm and moisture values were measured using a time reflection technique. The results showed that the distribution of moisture in the soil in different layers was balanced during the experiments and there is a clear relationship between water holding capacity in the soil and the volume of wetted soil (Souza and Bizari., 2018).
The research was designed at three depths (0, 10 and 20-cm), and moisture was measured at three intervals of 0, 20 and 40 -cm. Samples were taken once every 30 days and 24-hours before and after drip irrigation modes of subsurface and surface per 10 and 20-cm depth. Based on the radius of the wetting pattern, a linear equation was determined between the two irrigation modes of subsurface and surface drippers per 10 and 20-cm depth (Maurice et al., 2016). Also, the results of research on SDI showed that the volume of wetting in most cases is oval and by increasing the amount of moisture in the soil profile, the moisture radius is increased relative to the depth of wetting under the drippers (Thorburn et al., 2003).

Given that SDI was used for the first time in sugarcane cultivation in Iran, there is no information on the effect of this irrigation management on sugarcane growth variables. The results of this study can be used for various planning, design and modeling of this product. Due to water crisis in Iran, this study aimed to evaluate different irrigation methods that can reduce the volume of consumed water for sugar yield by managing water consumption in the form of drip irrigation.

MATERIAL AND METHODS

The experiments were conducted for two cropping seasons in 2016-2017 and 2017-2018. This experiment was conducted in the form of split- plots with a basic design of complete random blocks with two factors and three replications. The first factor composted of 50 and 60-cm dripper spacing in the main plots. The second factor includes different depths of water pipe installation (15, 20 and 30-cm) along with the conventional irrigation method (furrow irrigation), as control in the sub-plots. Field experiment area was 0.8 ha for SDI, and 0.4 ha for control, combinations of 18 furrows with length 238-m and a row spacing of 1.83-m which contained eight treatment combinations, the number of furrows for each treatment was three furrows.

The experiment field was located in a warm and dry weather region at longitude 48˚ 33´ E, latitude 30˚ 59´ N and 7.6-meter height above sea level. Cultivar CP69-1062, the commercial cultivar of the area, cuttings were planted in a double row with 40 cm row spacing and handed straight to the stack. The pipes were placed in the middle of double rows. Before cultivating the fields, soil samples were collected at depths of 0-30, 30-60 and 60-90 cm. Soil analysis was done to determine EC, pH, cations and anions (Table 4), texture and bulk-density. In order to measure the bulk-density of soil, samples were collected from the distributed samples with sampler cylinders. Soil texture was determined by hydrometer method.

Soil bulk-density increased with depth which indicated a higher density of soil at lower depths. Sodium adsorption ratio (SAR) from the surface to depth decreased and was subject to changes in the amount of sodium. The soil was sodic-saline in the surface layer and saline in lower layers. Pressure plate apparatus was used for determining soil moisture content in field capacity (FC) and permanent wilting point (PWP), the results were 25.1 and 12.9%, respectively. Some physical and chemical properties of soil before the cultivator are presented in Table 1 and after the harvest and the beginning of the ratoon1 shown in Table 2. The design map is shown in Table 3.

The spaces between drippers on the pipes were 50 and 60-cm, for a discharge rate of 1.2 $L.hr^{-1}$. The depth of installation of emitters pipes were 15, 20, and 30 cm from the soil surface. Conventional irrigation of the area (furrow irrigation) was used as a control. Water used for irrigation was from the Karoon River, and the design of the pumping and filtration station was carried out with a preliminary analysis of irrigation water and TSS of 115 mg. l^{-1}. Results for analysis of irrigation water during planting period and region climate statistics are shown in Tables 4 and 5.

In general, sugarcane is resistant to high temperatures and humidity, and at temperatures below 30˚C, sugarcane growth stops. The measuring of soil moisture was done in root zone during growth at spaces of 0, 30 and 60 cm from the drippers sampling, soil acidity, EC of soil around the drippers and at depths of 0-30, 30-60 and 60-90 cm. In order to control the soil moisture content in sugarcane growth period, a number of moisture probes were installed in the field and by using time domain reflectometry (TDR), moisture content of the drippers and its distribution were controlled.

Depending on irrigation frequencies and irrigation water acidity, acid was injected into the irrigation water to prevent clogging of the drippers, and after a specified time it was discharged from the network. Regarding the presence of algae in irrigation water, chlorine gas was used in acid filtration before irrigation in field capacity (Jeihoni., 2014). The schematic pumping and filtration station are shown in Figure 1.

According to the design calculations, irrigation intervals in the peak period is calculated daily and in other periods calculated from equations 1 and 2:

$$I = d_n / ET_C \qquad (1)$$

$$ET_C = ET_0 . K_c \qquad (2)$$

Where: I = maximum irrigation period; d_n = irrigation requirement; ETc = real evapotranspiration of sugarcane; ET_0 = reference evapotranspiration which calculated by Meteorology data (Allen et al., 1998); Kc = sugarcane crop coefficient which determined by lysimeter.

Irrigation is based on sugarcane allowable depletion and irrigation period. Irrigation net depth, irrigation gross depth, leaching fraction and irrigation volume are calculated by equation 3 to 6:

$$d_n = (\boldsymbol{\theta}_{fc} - \boldsymbol{\theta}_{pwp}). D_{rz}. \rho_b. MAD. P_w \qquad (3)$$

Where: d_n = irrigation net depth, $\boldsymbol{\theta}_{fc}$ = mass moisture in field capacity (%) ,$\boldsymbol{\theta}_{pwp}$ = mass moisture in permanent wilting point (%), D_{rz} = root depth (mm); ρ_b = soil bulk-density ($g.cm^{-3}$); P_w = wetted percentage (%) and MAD = management allowable depletion (%), which was considered to be about 0.6 according to the warm and dry area (Sheini-dashtghol et al., 2009).

Gross irrigation depth is calculated from equation 4:

$$dg = \frac{\mathbf{dn}}{\mathbf{(1-LF).\ Ea}} \qquad (4)$$

Where: d_g = gross irrigation depth (mm); Ea = irrigation efficiency (%); LF = leaching fraction (%), which calculated by equation 5:

$$LF = \frac{\mathbf{ECiw}}{\mathbf{2\ ECe\ max}} \qquad (5)$$

Where: EC_{iw} = electrical conductivity of irrigation water ($dS.m^{-1}$) ,EC_{emax} = electrical conductivity of saturated soil juice ($dS.m^{-1}$) and V_g = gross volumetric of water requirement (lit); A = plot area (m^2).

After drought stress at the end of the growing season, the process of sugarcane treatment started. Twenty sugarcane stalks randomly were selected from each plot on a weekly study. The quality of juice was measured until the process of completion was completed and then the harvest was carried out. Some researchers stated that under drought stress and end of growing season, due to water crisis, less sucrose is produced but at the end sugar content of sugarcane increases (Bull., 1971). In this experiment three replications of each 10-m experimental treatment were selected and the number of stalks were counted and 20 stalks were weight: stalk density, total yield, yield of sugarcane (ton. Ha^{-1}) and number of stalks per hectare were measured and after yield and water productivity (yield ratio to volume of intake) were calculated based on the volume of water consumed during the growth period of sugarcane (irrigation and rainfall). A similar operation was repeated in the second year in ratoon 1. Also, in each plot in three length replications, 60

Table 1. Physicochemical characteristics, of soil before cultivation.

Depth (cm)	EC ($dS.m^{-1}$)	pH	ρ_b ($gr.cm^{-3}$)	Soil texture	Caption's ($meq.l^{-1}$)				SAR
					Na^+	Ca^{2+}	Mg^{2+}	K^+	
0-30	6.97	7.19	1.5	Si.C.L	51.3	11.09	11.52	0.18	15.3
30-60	4.75	7.28	1.57	Si.C.L	35.6	7.82	8.04	0.12	12.64
60-90	4.73	7.29	1.61	Si.C.L	32.4	9.89	10.82	0.01	10.07

Table 2. Physicochemical characteristics of soil after harvesting (start ratoon).

Depth (cm)	EC ($dS.m^{-1}$)	pH	ρ_b ($gr.cm^{-3}$)	Soil texture	Caption's ($meq.l^{-1}$)				SAR
					Na^+	Ca^{2+}	Mg^{2+}	K^+	
0-30	9.34	7.29	1.5	Si.C.L	75	14.4	15.1	0.24	19.5
30-60	6.59	7.43	1.57	Si.C.L	53.5	11.5	11.7	0.13	15.7
60-90	6.48	7.45	1.61	Si.C.L	49.3	12.4	13.8	0.13	13.6

Table 4. Irrigation water quality of Karoon river for sugarcane (September 2016 to December 2018)

EC ($dS.m^{-1}$)		pH		TDS ($mg.l^{-1}$)		TH ($mg.l^{-1}$)		Ave. Cation ($meq.l^{-1}$)			SAR	Class
Ave.	range	Ave.	range	Ave.	range	Ave.	range	Na+	Ca2+	Mg2+		
2.7	1.6-4.1	7.6	7 -8.2	1857	1100-2600	506	325-865	27.3	7.4	8.5	9.7	C_2S_2

Table 5. Average of meteorology parameters (1998-2018).

Ave. Temperature (°C)	Ave. Humidity (%)	Max absolute Temperature (°C)	Min absolute Temperature (°C)	Ave. yearly Precipitation (mm)	Ave. yearly evaporation (mm)	Max daily evaporation (mm)	Ave. wind speed (m.s-1)
25	45	52*	- 4.5**	157	3218	32***	2.4

*This is happened in June 1999; ** This is happened in February 2011; *** This is happened in June 2006.

stalks were selected randomly, weight and length of stalks were measured and qualitative and quantitative factors were measured in the lab.

After sugarcane extraction, for determining sugarcane qualitative factors, sucrose content in the juice (Polarization measurement) and soluble solid particles in sugarcane juice (Brix) were measured. POL content was measured by Saccharimeter and by applying POL number modified coefficient from related tables, the real POL number was calculated. Brix was measured by reflectometer. By dividing POL in Brix juice, purity (PTY) was calculated. Quality Ratio (Q.R) was calculated from equation as given by Leonardo et al. (2016). Where P.F was modification coefficient of purity percentage and extracted from related tables, Yield (Y), Recovery Sugar (R.S) and Sugar Yield (S.Y) were calculated from equation 9 to 11 De (Whalley., 2013).

$$\%\mathrm{POL} = \mathrm{Saccharimeter\ Reading}\ x\ \ \mathrm{Pool\ Factor} \quad (7)$$

$$\mathrm{QR} = \frac{\mathrm{P.F}}{\mathrm{Pol}} \quad (8)$$

$$\mathrm{Yield} = \frac{100}{\mathrm{Q.R}} \quad (9)$$

$$\mathrm{RS} = \mathrm{Yield\ x\ 0.83} \quad (10)$$

$$\mathrm{SY} = \mathrm{Y\ x\ RS} \quad (11)$$

Finally, the average of quantitative and qualitative functions and WP in SDI was compared with furrow irrigation. For data fitting and curves, EXCEL software was used and SAS statistical software was used for statistical analysis. Also, in order to draw the two-dimensional values of the moisture values, Surfer8 software was used and in drawing the shapes, kriging method was used.

RESULTS AND DISCUSSION

Analysis results of sugarcane and WP in the first year of the experiment

Mean Square variance analysis of qualitative and quantitative traits of sugarcane per different traits of the

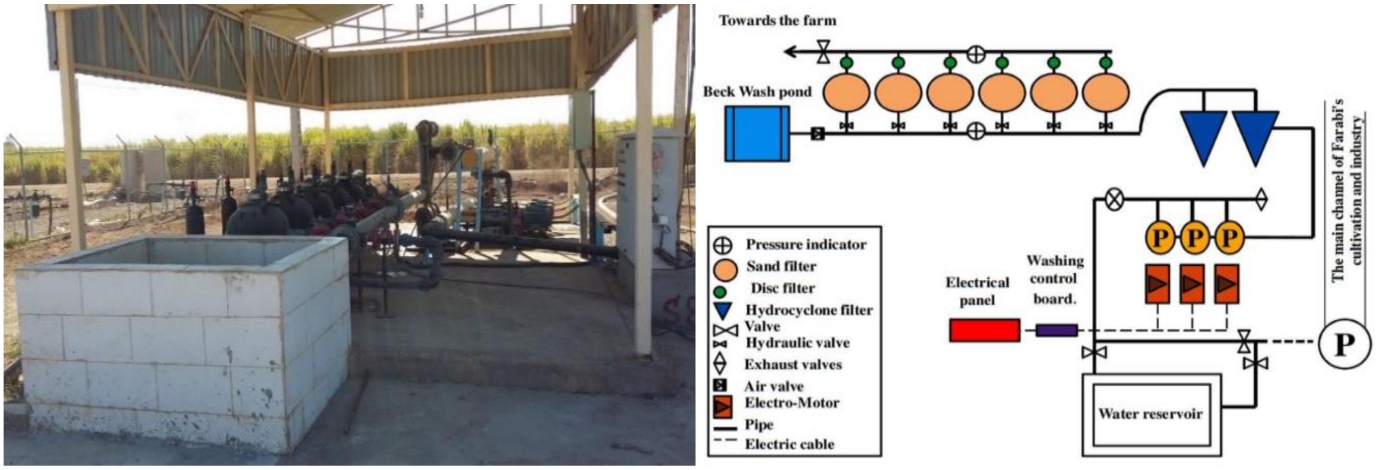

Figure 1. Schematic of pumping and filtration station and Experimental farm in subsurface drip irrigation(photographer: Sheini-Dashtgol, 2018).

Table 6. Mean Square variance analysis of qualitative characteristics of sugarcane.

Parameter	df	Brix (%)	Pol (%)	Purity (%)	RS*(%)	S.Y** (ton.ha^{-1})
Block	2	2.3^{ns}	0.0007^{ns}	0.4^{ns}	0.02^{ns}	3.35**
Space	1	0.4^{ns}	0.0002^{ns}	1.16^{ns}	0.03^{ns}	1.56**
Error a	2	1.77	0.0008	1.12	0.01	0.02
Depth	3	0.7^{ns}	0.31^{ns}	2.9^{ns}	0.06^{ns}	12**
Interaction	3	2.3^{ns}	0.28**	1.4^{ns}	0.03^{ns}	2.1^{ns}
Error b	12	1.9	0.09	0.9	0.02	2
Coefficient of variation (%)		7.4	6.9	1.1	1.8	13.1

RS*: Recovery Sugar; S.Y**: Sugar Yield.

Table 7. Mean Square variance analysis of quantitative characteristics of sugarcane.

Parameter	df	Sugarcane yield (ton.ha^{-1})	Number of stalk (in ha)	Sugarcane Length (cm)	WP per sugar (kg.m^{-3})	WP per sugarcane (kg.m^{-3})
Block	2	236^{ns}	7357971^{ns}	258**	0.002*	0.13*
Space	1	725**	510317815**	66.7**	0.004^{ns}	1.98**
Error a	2	2.1	4865787	0.9	0.008	0.005
Depth	3	610*	2269295705**	2441**	0.04**	17.13**
Interaction	3	680*	169355335**	540*	0.06**	2.8**
Error b	12	177.3	21775838	142.6	0.001	0.15
Coefficient of variation (%)		11.2	2.7	5.7	8.5	7.7

crop is presented in Tables 6 and 7. The results of variance analysis of the effect of different treatments on qualitative traits showed that in except to the significant effect of depth and distance treatments (p<0.01) on sugar yield, simple and interaction effects of these treatments on other qualitative traits (Pol%, Brix%, Purity% and RS%) were non-significant (Table 6). According to the results of the analysis of variance table, the effect of space treatments at p<0.05 probability level and depth and space interaction effects at (p<0.05) level on sugarcane yield was significant. Also, in terms of the number of stalks per hectare, there was a significant difference between the space, depth and interaction of their treatments at the (p<0.01) (Table 6). The results of variance analysis showed a significant effect of space and depth of treatments and the interaction between them at the (p<0.01) on stalk length. According to the results of analysis of variance, the effect of dripper spacing on WP per sugar produced was non-significant (Table 6), but the effect of dripper depth and the interaction between spacing

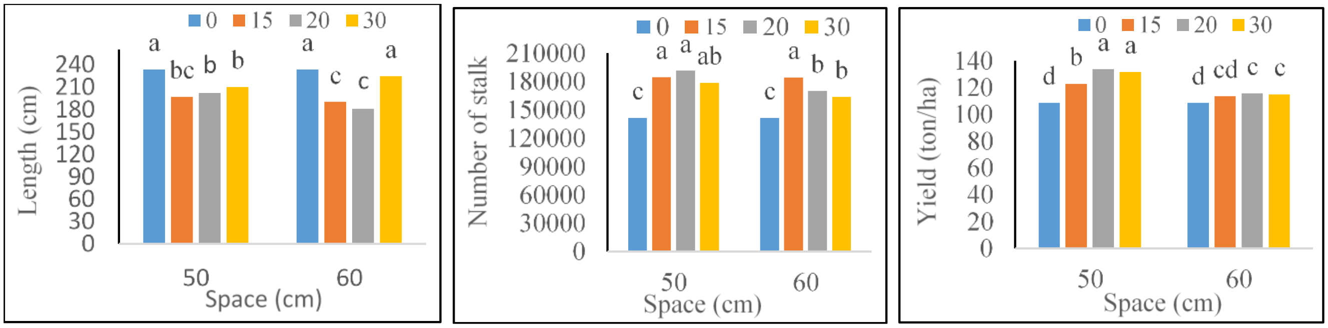

Figure 2. Interaction between dripper spaces and different installation depths on sugarcane yield, number of stalks per hectare and stalk length.

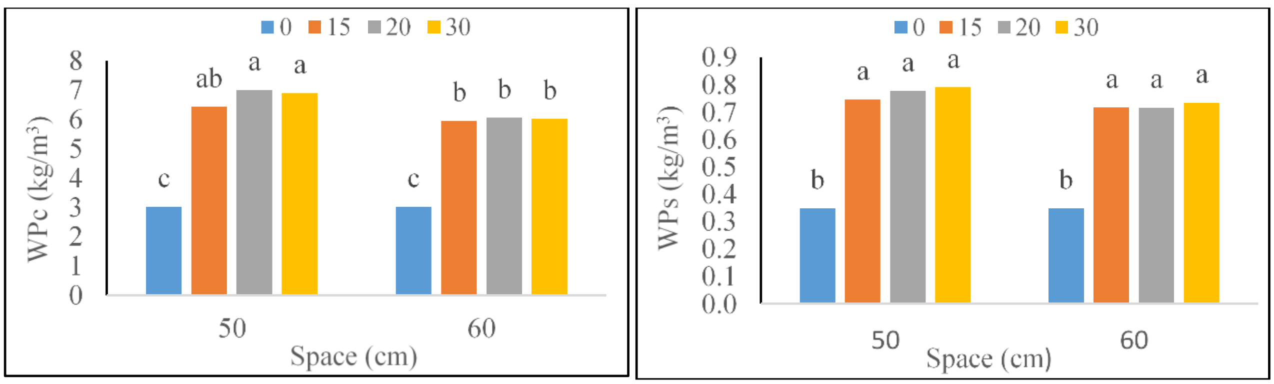

Figure 3. Interaction between dripper spaces and different installation depths on WP per sugarcane and sugar produced.

and installation depth on this trait was significant at the ($p<0.01$). The effect of all the studied treatments and their interactions on WP per sugarcane produced at the level of 1% probability was significant (Table 7).

The results of comparing the means in the first year of the experiment are shown in Figures 2 and 3. The results of the interaction effect between dripper spacing and different installation depths on sugarcane yield showed that there was a significant difference between conventional method and different installation depths at 50 and 60-cm droplet spaces. In general, the highest yield (133.9 ton. ha^{-1}) was obtained at a space of 50 and a depth of 20 cm and the lowest yield of cane (108.6 ton/ha) was obtained in the conventional method. The results of the effect of the interaction between dripper spaces and different installation depths show that there was a significant difference between the number of stalks per hectare, 50 and 60-cm between droplets, between the conventional method and different installation depths. The highest number of stalks per hectare (191333 stalks per hectare) was obtained at a space of 50 and a depth of 20 cm and the lowest number of stalks (141426 stalks per hectare) was obtained in the conventional method. The results of interaction between the dripper spacing and the installation depth on the stalk length showed that there was a significant difference between the conventional method and installation depth spaces between 50 and 60 cm droplets. At a space of 60 cm from the drippers, among the different installation depths, the highest stalk length (224. 7 cm) was obtained at a depth of 30 cm (Figure 2).

Due to the results of the interaction between the droplet spaces and different application depths on WP per sugarcane production, no significant difference was observed between the different application depths in both studied spaces. However, there was a significant difference between the conventional method of irrigation and different installation depths in terms of water efficiency per sugarcane produced. In the interaction between the dripper spaces and different installation depths done, there was a significant difference between WP for sugar produced, at a space of 50 and 60 cm from the drippers, between the conventional method and different installation depths. The highest WP per sugarcane and sugar production was 7 and 0.78 $kg.m^{-3}$ at space between the drippers of 50 cm and the installation depth of application of 20 cm. The lowest WP for sugarcane and sugar production was 3.02 and 0.35 kg.m-3 at control treatment (Figure 3). The results are in conformity with Rallo et al. (2011), Martínez-Gimeno et al. (2018), Lamm and Camp (2007), Santos et al. (2016) and Reyes-Cabrera et al.

Table 8. Mean Square variance analysis of qualitative characteristics of sugarcane.

Parameter	df	Brix (%)	Pol (%)	Purity (%)	R.S (%)	S.Y (ton.ha^{-1})
Block	2	0.1^{ns}	0.4^{ns}	2.7^{ns}	0.27^{ns}	18.8**
Space	1	0.3^{ns}	0.46^{ns}	0.5^{ns}	0.36^{ns}	12.6*
Error a	2	0.7	1.3	4.4	0.37	1.8
Depth	3	0.35^{ns}	0.76^{ns}	3.4^{ns}	0.36^{ns}	3.1^{ns}
Interaction	3	0.3^{ns}	0.4^{ns}	1^{ns}	0.13^{ns}	3.9^{ns}
Error b	12	0.71	1	2.2	0.32	2.2
Coefficient of variation (%)		3.9	5.3	1.7	4.8	11.9

Table 9. Mean square variance analysis of quantitative characteristics of sugarcane.

Parameter	df	Sugarcane yield (ton.ha^{-1})	Number of stalk (in ha)	Sugarcane Length (cm)	WP per sugar (kg.m^{-3})	WP per sugarcane (kg.m^{-3})
Block	2	1049**	18591632^{ns}	958**	0.05**	3**
Space	1	1162**	1891693^{ns}	1666**	0.03*	3.5**
Error a	2	40.5	250394069	50	0.005	0.12
Depth	3	522*	270327696^{ns}	565**	0.06**	5.1**
Interaction	3	731*	235440566^{ns}	418**	0.01^{ns}	0.7^{ns}
Error b	12	100	131845975	3215	0.006	0.3
Coefficient of variation (%)		9.5	7.1	3	13.3	10.5

(2016). Some researchers showed that subsurface drip irrigation can increase the quantitaty and qualitaty of sugarcane and is considered a good method for sugarcane cultivation (Çolak et al., 2018). Finally, according to results and consider other conditions, with the space of 50 and 20-cm the installation depth of drippers was suggested.

Analysis results of sugarcane and WP in the second year of the experiment

Mean Square variance analysis of qualitative and quantitative characteristics of sugarcane for different traits of the crop is presented in Tables 8 and 9. The results of variance analysis of the effect of different treatments on quality traits showed that in except to the significant effect of space treatments at $p<0.05$ on sugar yield, simple and interaction effects of these treatments on other qualitative traits (Pol%, Brix%, Purity% and R. S%) were non-significant (Table 8). According to the results of Table 9, the effect of space treatments at $p<0.01$ and depth and interaction effects of depth and space at $p<0.05$ on sugarcane yield was significant. According to the results of analysis of variance, the effect of all the studied treatments on the number of stalks per hectare was insignificant, while the effect of space and depth treatments and the interaction between them at $p<0.05$ on stalk length was significant. According to the results, although the effect of space and depth of treatment on WP per sugar and sugarcane produced at the level of probability of one and five percent was significant, however, the interaction of those treatments on these traits was statistically non-significant (Table 9). The results of means comparing in the second year of the experiment (Ratoon 1), are shown in Figures 5 and 6. The results of the interaction between the dripper spaces and different installation depths on sugarcane yield showed that there was a significant difference between the conventional method and different installation depths between 50 and 60 cm of drippers. The highest yield of sugarcane (124.7 ton. ha^{-1}) was obtained at a space of 50 and a depth of 20 cm and the lowest yield of cane (89.7 ton. ha^{-}1) was obtained at a space of 60 and a depth of 30 cm. The results of the interaction between the dripper spaces and installation depths on stalk length showed that there was a significant difference between the conventional method and different installation depths. At a space of 50 cm from the drippers, there was no significant difference between the conventional irrigation method and the installation depth of 30 cm in terms of stalk length (Figure 4).

According to the results of Figure 5, the conventional irrigation method and different dripper spaces in terms of WP for sugarcane, a significant difference was observed. The highest WP for sugar produced (5.7 kg.m^{-3}) was obtained at space of 50 cm and the lowest (4 kg.m^{-3}) was obtained in the conventional irrigation method. The results of comparing the means showed that there was a

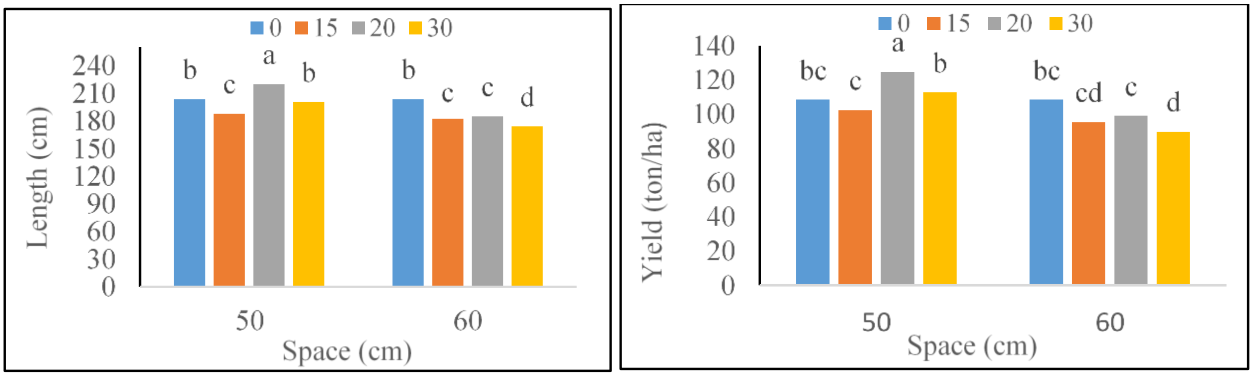

Figure 4. Interaction between drippers spaces and different installation depths on sugarcane yield and stalk length.

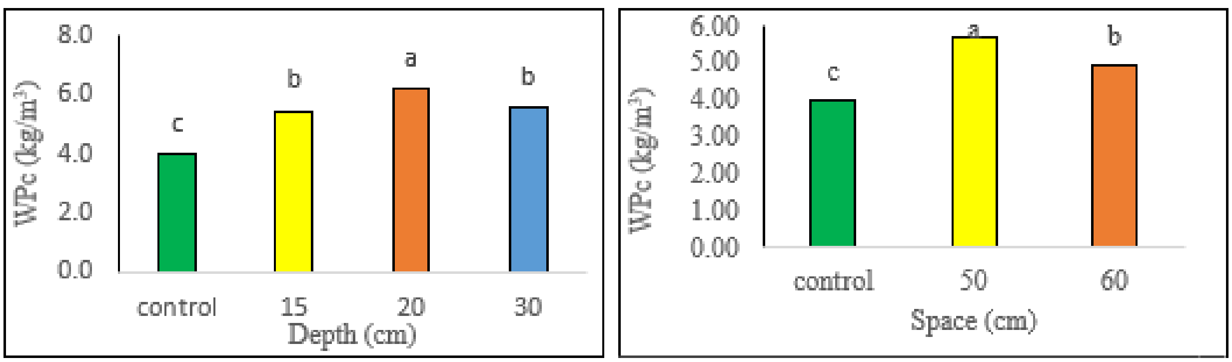

Figure 5. The effect of different drippers spaces and installation depths on WP per sugarcane produced and comparison with control treatment.

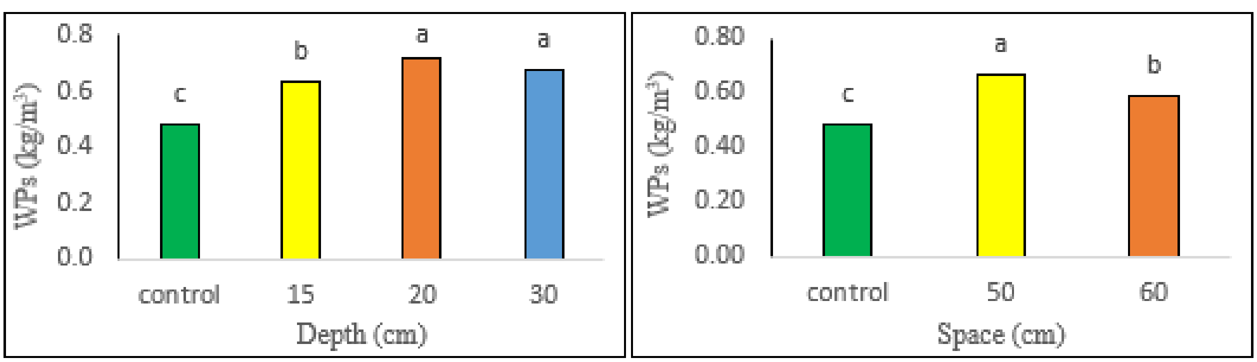

Figure 6. The effect of different drippers spaces and installation depths on WP per sugar produced and comparison with control treatment.

significant difference between the conventional irrigation method and different installation depths in terms of WP for sugarcane produced. The highest WP for sugarcane produced (6.2 kg.m^{-3}) was obtained at a depth of 20 cm and the lowest (4 kg.m^{-3}) was obtained in the conventional irrigation method (Figure 5). Comparison of the means showed that there was a significant difference between the conventional irrigation method and different dripper spaces in terms of water efficiency per sugar production. The highest WP for sugar produced (0.67 kg.m^{-3}) was obtained at a space of 50 cm and the lowest (0.48 kg.m^{-3}) was obtained in the conventional irrigation method. Comparison of the means showed that there was a significant difference between the conventional irrigation

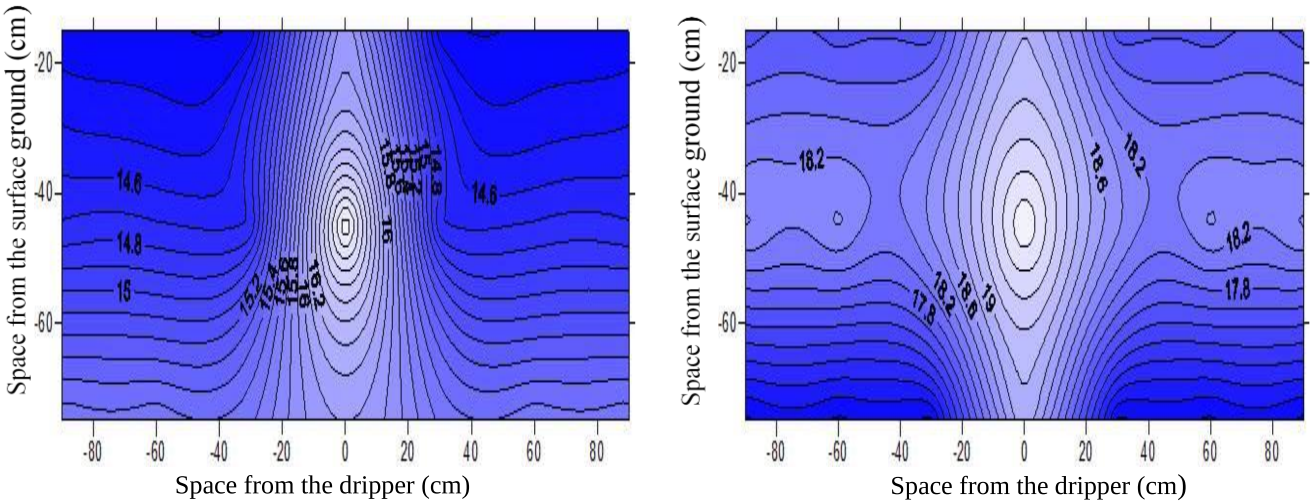

Figure 7. The average of moisture distributed around the drippers installation depth of 15-cm (the drippers spaces from the right to the left are 50 and 60-cm).

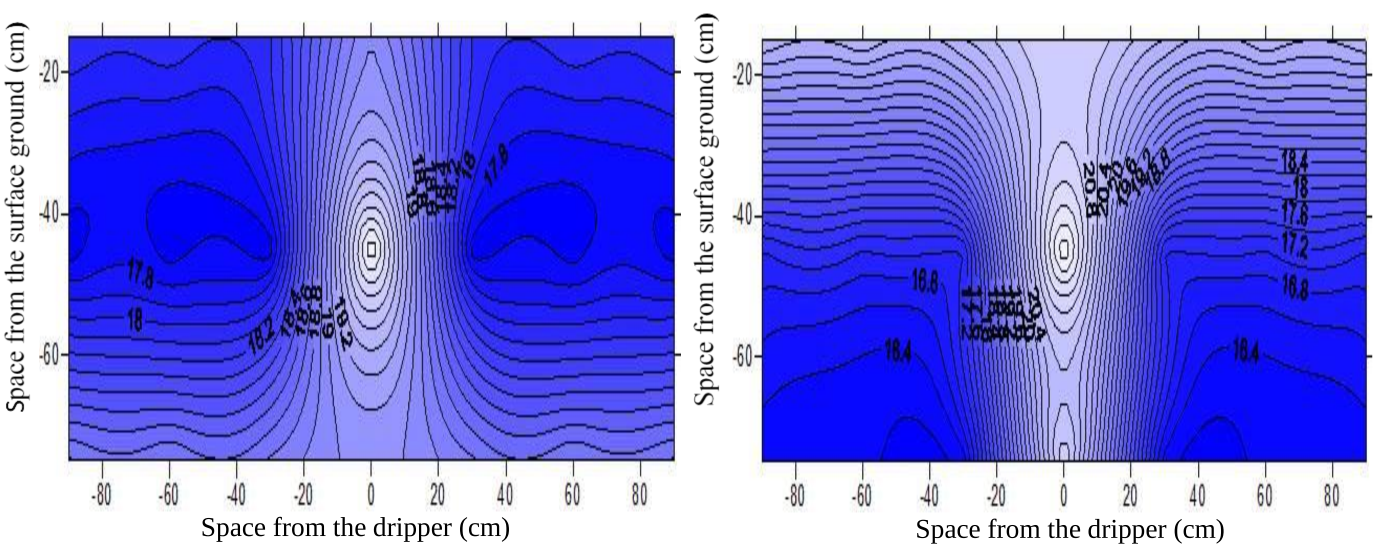

Figure 8. The average of moisture distributed around the drippers installation depth of 20- cm (the drippers spaces from the right to the left are 50 and 60-cm).

method and different installation depths in terms of WP for sugar produced. The highest WP for sugar produced (0.7 kg.m^{-3}) was obtained at a depth of 20 cm and the lowest (0.5 kg.m^{-3}) was obtained in the conventional irrigation method (Figure 6). The results are in agreement with Martínez-Gimeno et al. (2018), dos Santos et al. (2016), Reyes-Cabrera et al. (2016) and Célia de Matos Pires et al. (2014). Dalri and Cruz (2008) suggested that the use of SDI can increase the quantitative and qualitative yield of sugarcane and is considered a good method for sugarcane cultivation. Finally, according to results and considering other conditions, space of 50 cm and 20 cm of the installation depth of drippers was suggested.

Moisture distribution around drippers in the first year of experiment

The average of moisture distributed around the drippers' installation depth are shown in Figures 7 to 12. Based on the figures, the results showed that moisture distribution is similar in both growth stages of sugarcane. The moisture around the drippers and width of ridge to a depth of 80 cm (active root depth) is appropriate and shape of moisture bulb is oval under the drippers. By moving away from the water pipe, the average values of mass moisture have a downward trend, which can be said there was a linear relationship between them. This is consistent with the

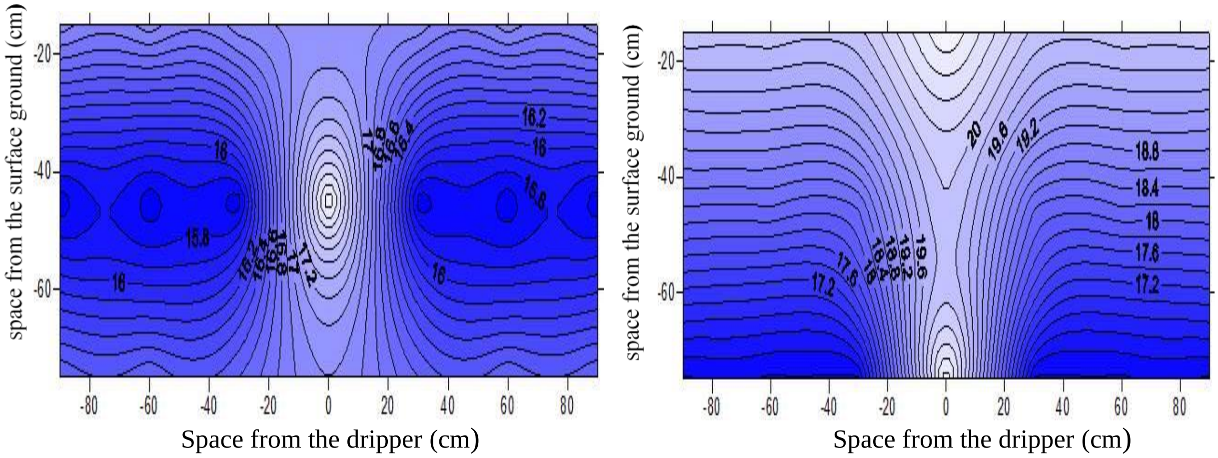

Figure 9. The average of moisture distributed around the drippers installation depth of 30-cm (the drippers spaces from the right to the left are 50 and 60-cm).

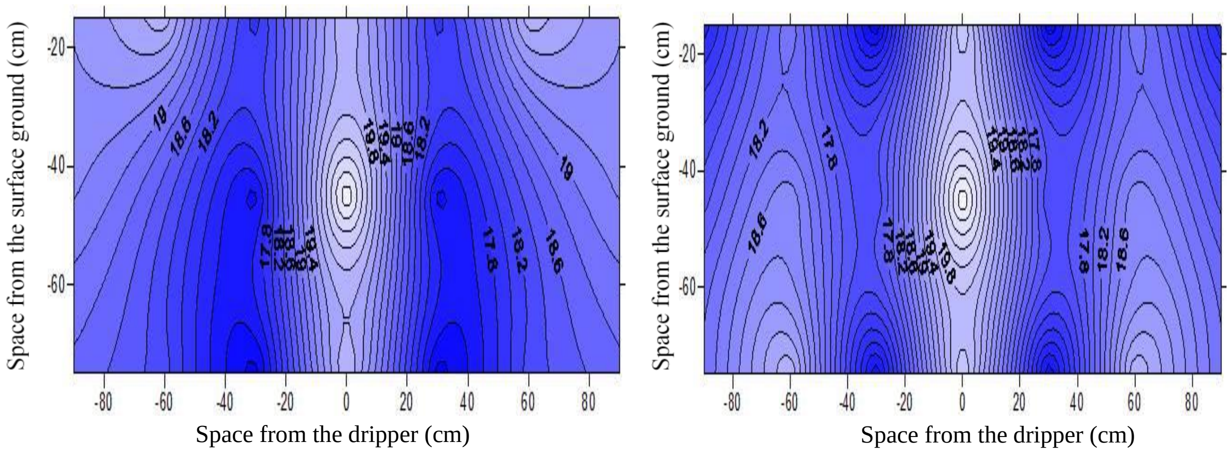

Figure 10. The average of moisture distributed around the drippers installation depth of 15-cm (the drippers spaces from the right to the left are 50 and 60-cm).

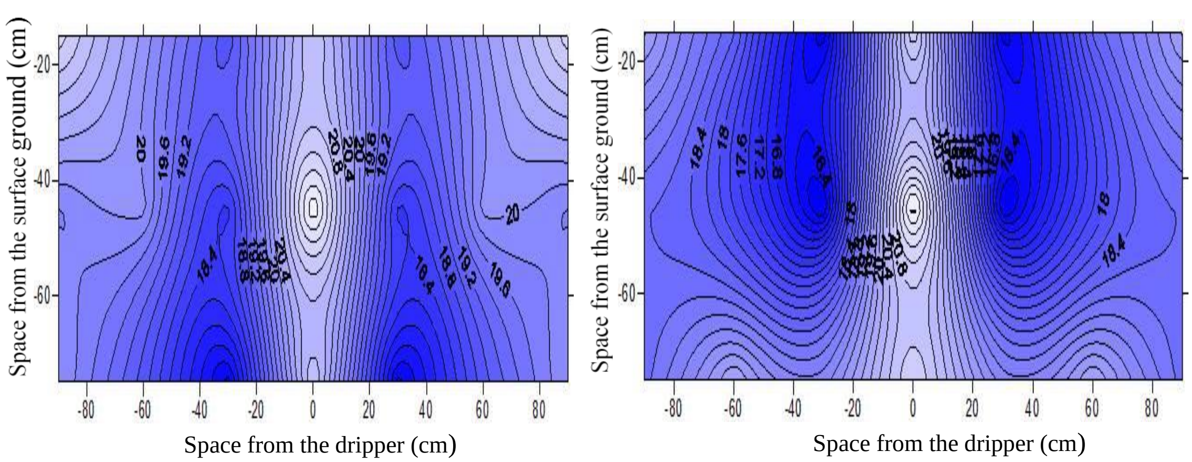

Figure 11. The average of moisture distributed around the drippers installation depth of 20-cm (the drippers spaces from the right to the left are 50 and 60-cm).

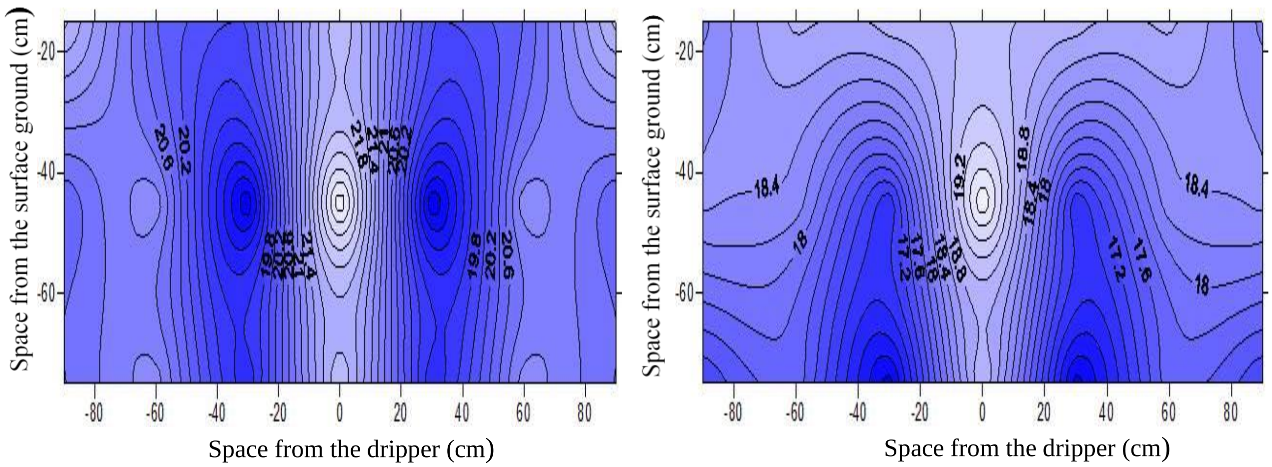

Figure 12. The average of moisture distributed around the drippers installation depth of 30-cm (the drippers spaces from the right to the left are 50 and 60-cm).

previous findings reported by Souza and Bizari. (2018). The mass percentage of moisture at lower depths in all experimental treatments was higher than the soil above the drippers. The overall shape of the moisture distribution pattern was more similar at depth of 15 and 20 cm, and the moisture distribution pattern at this depth was more consistent with the sugarcane root distribution pattern. Thorburn et al. (2003) reported similar result in the previous study in the area. Their results showed that the volume of wetting was oval in most cases, and by increasing the moisture in soil profile, moisture radius will be increased than the wetting depth under drops. Another note that can be deduced from the Figures 7 to 12 is that the maximum moisture range was at a depth of 30 to 60 cm and at a space of 30-cm from the discharge pipe. Wang et al. (2018) reported a maximum moisture distribution at installation depth of 20 cm and a depth of 0 to 60 cm which was also in agreement with this finding. In SDI, where water is provided to the plant in part and continuously, the plant reacts to the rooting horizontally and vertically to make it more resistant. This result was consistent with the results of Smith et al. (2005). In their results, they reported that more drought-resistant sugarcane species have deeper roots, and the plant was more branched to better absorb water and nutrients.

Conclusions

According to recent droughts and severe water crisis in Iran, SDI was implemented in sugarcane for the first time. Results of this experiment showed that in both experiment periods (plant and Ratoon 1), the highest sugarcane yield was in 50 cm space of the drippers and 20 cm depth. The highest number of stalk density was in 50 cm space of emitters and 20 cm depth. Sugarcane qualitative increased by decreasing water consumption and this is caused due to high water productivity for produced sugar and sugarcane, so that on average, two yield of experiment in 50 cm space of the drippers and 20 cm depth of the drippers produced higher WP of sugarcane and sugar as 6.6 and 0.73 kg.m^{-3}, respectively. It was about 47 and 43 percent higher than the average WP per sugarcane and sugar of the control treatment, respect-tively. Comparing resulted of qualitative and quantitative traits of subsurface drip irrigation and conventional irrigation showed that most of quantitative and qualitative factors of SDI were higher than the surface irrigation. Also, the results showed that moisture distribution is similar in both growth stages of sugarcane, so that the moisture around the drippers and width of ridge to a depth of 80 cm is appropriate and shape of moisture bulb is oval under the drippers. By moving away from the water pipe, the average values of mass moisture have a downward trend, which can be said there was a linear relationship between them. Due to the discharges of the drippers and considering the uniformity of moisture distribution, soil surface salinity, removal of surface evaporation and development of sugarcane root, for regions with similar characteristics to this experiment, 20 cm depth for discharge pipe and 50 cm space of drippers on the lateral pipe are recommended. But given the high evaporation on some days and the long duration of an irrigation cycle due to the low emitter discharge, 2 lit.hr^{-1} discharge at 50 cm space from the dripper can be a good option.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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