



## Effect of water distribution patterns on productivity, fruit quality and water use efficiency of *Ziziphus jujuba* in arid regions under drip irrigation system

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### Abstract

A field experiment was carried out at the Agriculture Experimental Station of King Abdulaziz University located at Hada Alsham to study the effect of water distribution patterns on productivity of *Ziziphus jujuba* under arid conditions. Three water distribution treatments giving the same amount of water were investigated. The first treatment (T1) contained 8 drippers with a discharge of 4 l/h, the second treatment (T2) 4 drippers with a discharge of 8 l/h and the third one (T3) contained 2 drippers with a discharge of 16 l/h. The drippers were installed to distribute water in a circle with a diameter of 1 m around tree for the two growing seasons of 2009-2010 and 2010-2011. Results revealed that increasing number of drippers with low discharge distributed irrigation water homogeneously around trees and covered large area of tree roots. T1 significantly increased branch length, number of branches, collar diameter, soil moisture content and fruit yield and quality. The increase in these parameters was gradually decreased in T2 followed by T3. Increasing number of drippers from 2 to 8 and decreasing dripper discharge from 16 to 4 l/h around tree increased fruit yield by about 78.3% and 69.4% in the first and second seasons, respectively.

**Key words:** Water distribution, *Ziziphus jujuba*, drip irrigation, arid regions.

### Introduction

Expanding agricultural production in arid and semi-arid regions is faced by two main problems, water scarcity and water salinity. Due to drought in arid and semi-arid regions, agricultural activities mainly depend on groundwater. The majority of groundwater in these regions is brackish water because of its high level of salinity. Under the current study irrigation water salinity was 3200 ppm. Using saline water in irrigation to obtain economic agricultural production requires certain types of cultivars.

*Ziziphus* varieties are considered one of the best trees that can be successively grown under such conditions, beside they have high tolerance of water stress. *Ziziphus jujuba* originated in China and traveled beyond Asia and Middle East centuries. Jujube tree is called in Arab countries as sider, nabk or ber<sup>1</sup>. Jujube is one of the world's most nutritious fruit rich in P, K and Fe<sup>2</sup>, vitamin C and amino acids<sup>3</sup>. Jujube fruits contain various types of bio-active substances, such as triterpenic acid and flavonoids that have a wide pharmacological effect on humans<sup>4</sup>.

Regular watering for jujube is important to obtain higher fruit production and quality. Periodic data on vegetative growth, physical plant conditions, nutrient availability in soil and nutrient levels in leaves showed that all *Ziziphus* varieties can be grown with moderately saline irrigation water. However, their growth and greenery effect will be adversely affected when the irrigation water salinity is greater than 10 dS.m<sup>-1</sup><sup>5</sup>. Salinity tolerance of various fruit crops, including *Ziziphus*, has been investigated by several researchers<sup>6-9</sup>. They found that, all *Ziziphus* species showed a greater degree of tolerance to soil salinity than other fruit crops.

However, *Z. rotundifolia* had the maximum tolerance to high soil salinity (up to 20.25 dS/m).

The idea of the current study is based on the assumption of increasing *Ziziphus* productivity with the same amount of water by distributing irrigation water in a way that meets root distribution patterns. The assumption was guided from the previous studied on root pattern distribution of fruit crops especially *Ziziphus*. *Ziziphus* root density was much higher at the nearest distance from tree trunk<sup>10,11</sup>. The distribution of feeder roots was 71.54% at nearest radial distance from tree trunk (0-70 cm)<sup>12</sup>. The spatial distributions of *Ziziphus jujuba* roots under drip irrigation and natural conditions had been studied<sup>13</sup>. The results showed that under the two conditions, the absorbing root of *Z. jujuba* was mainly distributed in the range of 0-30 cm in horizontal direction and in the soil layer of 0-40 cm in vertical direction. However, its conducting root was mainly distributed in the range of 0-30 cm in horizontal direction. In vertical direction, its conducting root was mainly distributed in the soil layer of 0-60 cm under natural condition and 0-80 cm under drip irrigation condition. An experimental study was carried out on rooting pattern of nine years old trees of *Ziziphus* during post-rainy season (October 2007) and spring season (March 2008)<sup>14</sup>. They observed that root density was found maximum at nearest radial distance from tree trunk, i.e. 0-80 cm (71.20 and 86.72% during post rainy and spring season, respectively) and an increase in distance from the tree trunk resulted in reduction of root density considerably. Also they observed that maximum root density was found at deeper

soil layers, i.e. at 25 – 50 cm soil depth, during post rainy and at 50 – 75 cm soil depth during spring season. Distribution of feeder roots (< 0.2 cm in diameter) revealed that these were maximum at 0–80 cm distance from tree trunk during post rainy and spring season. Thus, it emphasizes the need to maintain adequate moisture in *Ziziphus* orchard during spring and summer months. Precipitation increased water content of shallow soil layers in wet season, which promoted new root growth in the shallow soil<sup>15</sup>. Most of the new roots were fine roots and the average diameter was 0.16 mm. The increased fine roots were able to enhance water uptake from the shallow soil. The contribution of shallow soil water significantly affected the water balance and stress degree in *Z. jujuba*.

The objective of this study was to investigate the change of water distribution patterns on growth characteristics, fruit yields, fruit quality and water use efficiency of *Ziziphus jujuba* irrigated by high irrigation water salinity level (3200 ppm).

### Materials and Methods

**Cultural practices and experimental design:** The present study was conducted during the two successive seasons of 2009-2010 and 2010-2011 at the Agriculture Experimental Station of King Abdulaziz University (KAU) located near Hada Alsham village, 110 km north east of Jeddah, KSA. The soil texture was sandy clay loam. The trees were planted at 4 m x 5 m spacing and pruned in late May by removal of all primary branches leaving 40 cm from base of the trunk. Pruning is necessary in *Ziziphus* to maintain productivity of the fruit trees and to improve the quality of fruits. Trees were subjected to the same cultural practices usually done in the orchard. In mid June of both seasons, trees were fertilized with organic manure and superphosphate at a rate of 12 and 1.5 kg per tree, respectively, and 3 kg of urea (46 % N) and 1.5 kg of potassium sulphate (48 % K<sub>2</sub>O) per tree were added in three equal doses starting in mid June, July and August. Nine trees were selected as uniform as possible and were subjected to three water distribution patterns treatments with three replications (1 replicate = 1 tree). The experiment was designed as randomized complete block design (RCBD).

**Treatments:** Three treatments of water distribution patterns for one selected discharge were investigated. The selected discharge was 32 l/h. Water requirement of trees was added every two days based on previous studies carried-out at the same orchard which ranged from 32 to 64 l/day/tree. Drip irrigation system was used. A circle with a diameter of 1 m from drip line was laid around the trunk. Three types of drippers were distributed in the circle to represent the investigated treatments as follows:

1. T1 consisting of 8 drippers with a discharge of 4 l/h (4 x 8 = 32 l/h) and a distance of 25 cm between consecutive drippers.

2. T2 consisting of 4 drippers with a discharge of 8 l/h (8 x 4 = 32 l/h) and a distance of 50 cm between consecutive drippers.

3. T3 consisting of 2 drippers with a discharge of 16 l/h (2 x 16 = 32 l/h) and a distance of 50 cm between consecutive drippers.

Irrigation water treatments were supplied directly after pruning of the first season (May 2009) and continued until the end of March 2011. The

supplied irrigation water gradually increased until reaching its peak in summer and gradually decreased until the end of the season. Irrigation water salinity level used in the experiment was 3200 ppm. Soil water content was measured weekly using a gravimetric method for six weeks after fruit setting during the growing seasons. It was measured under the drippers and at the middle of two adjacent drippers at 10 and 50 cm depth.

**Growth characteristics:** The monitored growth characteristics included main branch length, collar diameter of the main branches and number of secondary branches on the main branch. After two months of pruning 4 main branches represented North, South, West and East directions were selected to measure the previous parameters. Collar diameter was measured at the base of main branches. The measurements were collected once a month up to the end of growing seasons. Average of the collected data from of the selected branches for each tree was taken and statistically analyzed to represent branch length, collar diameter and number of secondary branches.

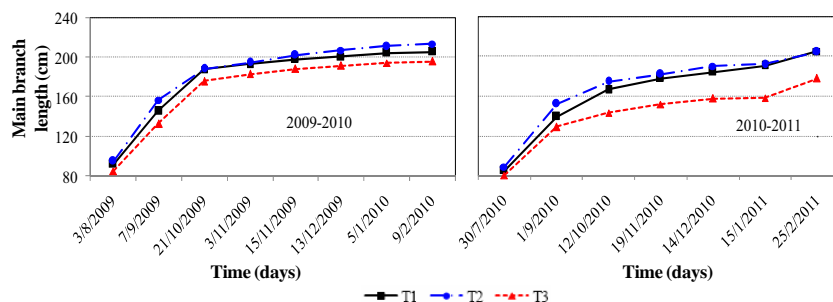
**Fallen percent, total yield and fruit dry matter:** After complete fruit setting, total number of fruits in the monitored branches was recorded (N1), and recorded again directly before harvesting (N2). Fallen percent was calculated as  $\text{Fallen \%} = \text{N1}/\text{N2} \times 100$ . In both seasons fruits from each tree (replicate) were harvested when the fruit color turning to light green. Each treatment was harvested two or more times during the harvest season. All harvested fruits were weighed to record the total yield (kg/tree) and the average fruit weight (g). A flesh of 20 fruits was collected, and its fresh weight was recorded, oven dried at 70°C, and fruit dry matter calculated.

**Fruit physical characteristics at harvest:** A sample of 20 fruits for each replicate was randomly collected in both seasons and the following fruit characteristics were determined: average fruit weight (g), average fruit length and width (cm), average fruit shape index (fruit length/fruit width), average seed weight (g) and average flesh weight (g).

### Results

**Growth characteristics:** Results of main branch length along the growing season are presented in Fig. 1. The branch length was almost similar in T1 and T2 but higher than that in T3 in both growing seasons. The reduction in branch length of T3 was higher in the second season than that in the first one.

Results of maximum branch length recorded at harvest are presented in Table 1. They indicate that maximum branch length



**Figure 1.** Main branch length as affected by water distribution patterns in both growing seasons.

**Table 1.** Effect of water distribution patterns on growth characteristics of *Ziziphus jujuba*.

Treatments	The first season (2009-2010)			The second season (2010 - 2011)		
	Main Branch length (cm)	Number of secondary branches	Collar diameter (cm)	Main branch Length (cm)	Number of secondary branches	Collar diameter (cm)
T1	205.66 <sup>a</sup>	16.5 <sup>a</sup>	1.64 <sup>a</sup>	205.33 <sup>a</sup>	14.41 <sup>a</sup>	2.71 <sup>a</sup>
T2	210.66 <sup>a</sup>	15.00 <sup>b</sup>	1.47 <sup>b</sup>	204.67 <sup>a</sup>	14.50 <sup>a</sup>	2.54 <sup>b</sup>
T3	195.66 <sup>b</sup>	15.16 <sup>b</sup>	1.36 <sup>b</sup>	176.67 <sup>b</sup>	13.58 <sup>a</sup>	2.30 <sup>c</sup>
L.S.D. <sub>05</sub>	6.13	0.59	0.14	3.29	1.00	0.11

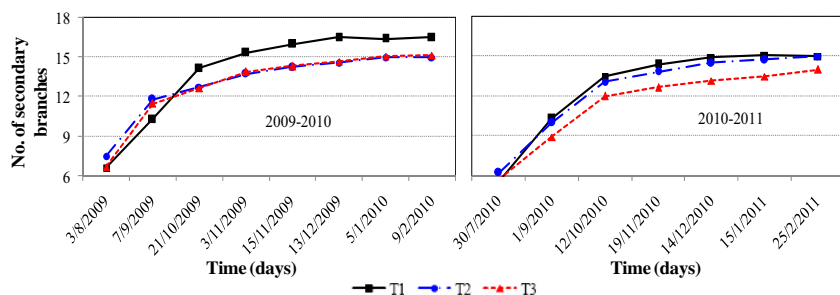
Means with different superscripts differ significantly (P<0.05).

was almost similar for T1 and T2 but both were significantly higher than that in T3, especially at the second growing season. Number of secondary branches along the growing season is presented in Fig. 2. Results show that number of secondary branches is higher in T1 than in T2 and T3 during the first season. However, the number of secondary branches was similar in T2 and T3. During the second season, number of secondary branches was similar in T1 and T2 but higher than that in T3. Results of final number of secondary branches recorded during harvest are presented in Table 1. They indicate that T1 significantly increased number of secondary branches compared to T2 and T3 in the first season. No significant differences were found among treatments during the second season.

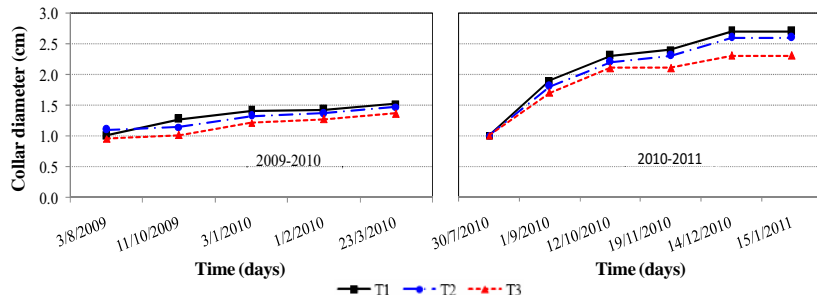
The effect of water distribution treatments on collar diameter is presented in Fig. 3. Results indicate that small differences were found among treatments during the first season. However, the differences in the second season were much higher than that in

differences among treatments in the second season where the highest collar diameter was recorded in T1 followed by T2 and T3, respectively (Table 1).

**Yield components and fruit yield:** Results of yield components and fruit yield kg/tree are presented in Table 2. The least significant fallen % was obtained from T1 during the first growing season followed by T2 and highest in T3. No significant differences in fallen % were found among treatments in the second season. Results indicated that fruit weight was significantly affected by water distribution patterns. The significantly highest fruit weight was obtained from T1 followed by T2 and T3, respectively, in the first and second growing seasons. Similar trend was found in total yield kg/tree, where the highest significant yield was obtained from T1 followed by T2 and T3, respectively, for both growing seasons (Table 2). Results of fruit dry matter % indicate that the differences among treatments were not significant in both seasons.



**Figure 2.** Number of secondary branches as affected by water distribution patterns in both growing seasons.



**Figure 3.** Collar diameter as affected by water distribution patterns in both growing seasons.

the first one. The highest collar diameter was obtained from T1 followed T2 and T3, respectively, during both growing season. Results of collar diameter at harvest presented in Table 1 revealed that collar diameter in the second season was higher than that in the first one. T1 significantly increased collar diameter compared to T2 and T3 in the first season, however, the differences between T2 and T3 were not significant. There were significant

**Physical fruit quality:** The effect of water distribution patterns on physical fruit quality are presented in Table 3. Results reveal that fruit flesh weight was significantly affected by water distribution patterns. The highest flesh weight was obtained from T1 followed by T2 and T3, respectively, during both seasons. Similar trend was found in seed weights during the first season while the differences in seed weight in the second season were not significant (Table 3). Results of fruit length and width of T1 and T2 were almost the same in both seasons but both of them were significantly higher than that obtained from T3 in both seasons (Table 3). No significant differences were found among treatments in fruit shape during both seasons except for T3 in the second season where it was least.

**Water use efficiency:** Under current study, water use efficiency (WUE) is defined by increasing the production per unit of water. WUE for T1 was calculated from dividing total fruit yield of T1/ total fruit yield of T3, and the increase in fruit

**Table 2.** Effect of water distribution patterns on yield components and fruit yields (kg/tree) of *Ziziphus jujuba*.

Treatments	The first season (2009-2010)				The first season (2010 - 2011)			
	Fallen (%)	Fruit weight (g)	Total fruits yield (kg/tree)	Fruit dry Matter (%)	Fallen (%)	Fruit weight (g)	Total fruits yield (kg/tree)	Fruit dry matter (%)
T1	27.20 <sup>b</sup>	14.26 <sup>a</sup>	22.24 <sup>a</sup>	22.4 <sup>a</sup>	46.83 <sup>a</sup>	14.03 <sup>a</sup>	18.43 <sup>a</sup>	21.23 <sup>a</sup>
T2	33.00 <sup>ab</sup>	13.68 <sup>b</sup>	20.50 <sup>b</sup>	22.6 <sup>a</sup>	40.63 <sup>a</sup>	12.93 <sup>b</sup>	17.63 <sup>b</sup>	23.53 <sup>a</sup>
T3	39.48 <sup>a</sup>	12.55 <sup>c</sup>	12.47 <sup>c</sup>	21.93 <sup>a</sup>	38.00 <sup>a</sup>	11.36 <sup>c</sup>	10.88 <sup>c</sup>	22.88 <sup>a</sup>
L.S.D. <sub>05</sub>	10.33	0.47	0.83	1.75	14.11	1.04	1.81	2.39

Means with different superscripts differ significantly (P<0.05).

**Table 3.** Effect of water distribution patterns on fruit physical characteristics of *Ziziphus jujuba* at harvest.

Treatments	The first season (2009-2010)					The first season (2010-2011)				
	Flesh weight (g)	Seed weight (g)	Fruit Length (cm)	Fruit width (cm)	Fruit shape	Flesh weight (g)	Seed weight (g)	Fruit Length (cm)	Fruit width (cm)	Fruit shape
T1	13.26 <sup>a</sup>	1.00 <sup>a</sup>	3.14 <sup>a</sup>	2.96 <sup>a</sup>	1.06 <sup>a</sup>	13.12 <sup>a</sup>	0.99 <sup>a</sup>	3.10 <sup>a</sup>	2.92 <sup>a</sup>	1.06 <sup>a</sup>
T2	12.72 <sup>b</sup>	0.96 <sup>b</sup>	3.05 <sup>a</sup>	2.84 <sup>a</sup>	1.07 <sup>a</sup>	11.94 <sup>b</sup>	0.96 <sup>a</sup>	3.09 <sup>a</sup>	2.83 <sup>a</sup>	1.09 <sup>a</sup>
T3	11.68 <sup>c</sup>	0.88 <sup>c</sup>	2.92 <sup>b</sup>	2.70 <sup>b</sup>	1.08 <sup>a</sup>	10.40 <sup>c</sup>	0.90 <sup>a</sup>	2.75 <sup>b</sup>	2.64 <sup>b</sup>	1.04 <sup>b</sup>
L.S.D. <sub>05</sub>	0.43	0.038	0.097	0.127	0.03	0.98	0.18	0.10	0.13	0.034

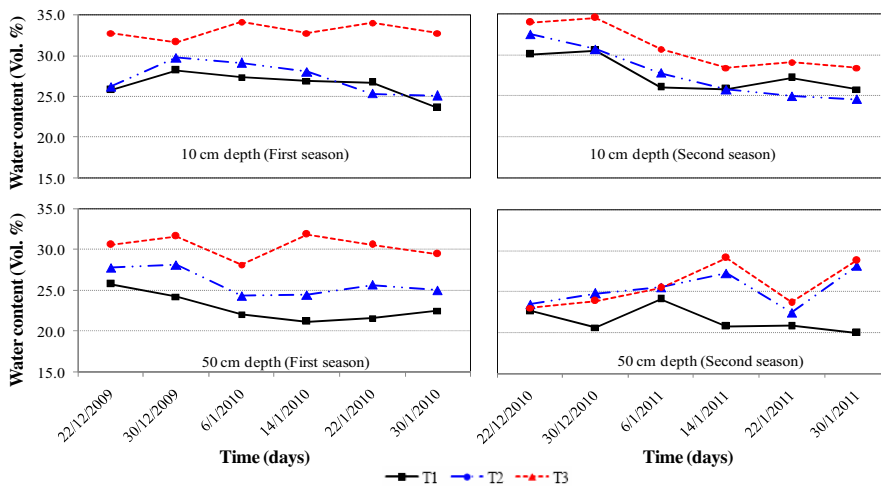
Means with different superscripts differ significantly (P<0.05)..

production taken in percent as presented in Table 4. Results indicated that T1 increased the fruit production per unit of water by 78.34 and 69.39% compared to T3 for the first and second growing seasons, respectively. T2 followed the same trend and increased the production by 64.39 and 62.04% compared to T3 for the first and second growing season, respectively.

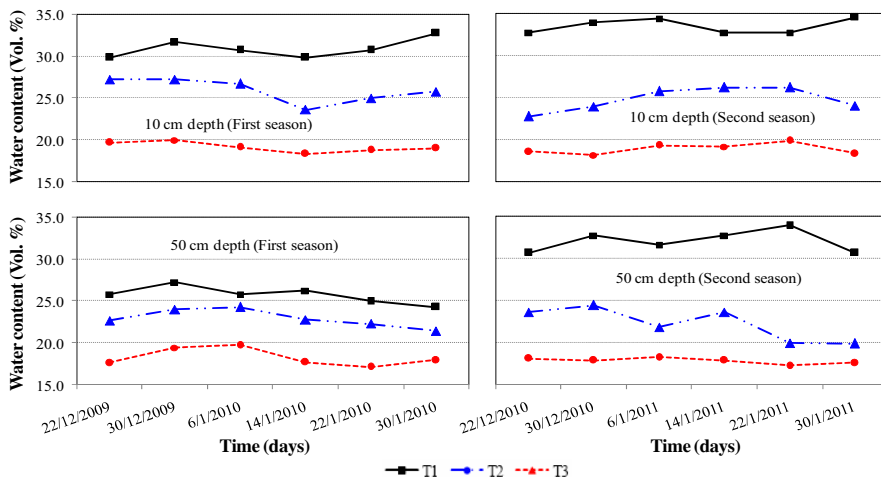
**Table 4.** Increase in fruit yield production (%) as results of changing water distribution pattern.

Treatment	The first season		The second season	
	Fruits yield kg/tree	Increase in fruits production (%) in relation to T3	Fruits yield kg/tree	Increase in fruits production (%) in relation to T3
T1	22.24	78.34	18.43	69.39
T2	20.50	64.39	17.63	62.04
T3	12.47	-	10.88	-

**Soil water content:** Results of soil water content under drippers during both growing seasons are shown in Fig. 4. Highest soil water content at 10 cm depth for both growing seasons was found in T3 compared to T2 and T1, however, the soil water content of T1 and T2 were almost similar. At 50 cm depth, the highest soil water content during the first season was obtained from T3 followed by T2 and T1, respectively. During the second season, soil water content of T2 and T3 was similar but higher than that in T1. Soil water content at the middle distance between two adjacent drippers is presented in Fig. 5. Results show reverse order for soil water content distribution at 10 and 50 cm depth compared to the distribution under drippers. The highest soil water content was obtained from T1 followed by T2 and the least soil water content was recorded in T3 for both growing season (Fig. 5).



**Figure 4.** Effect of water distribution patterns on soil water content under drippers.



**Figure 5.** Effect of water distribution patterns on soil water content at the middle distance between drippers.

### Discussion

Results indicated that the branch length in T1 and T2 was similar but higher than that in T3. T1 gave the highest number of secondary branches and collar diameter followed by T2 and T3, respectively. The results might be due to the fact that water distribution around the tree in T1 followed by T2 was met by root distribution pattern and its maximum density was found at nearest radial distance from tree trunk. When water distribution pattern is met by root distribution system, water uptake is increased supplying the tree water requirement, which increased branch length, number of secondary branches and collar diameter<sup>14</sup>. In T3, the distribution of water around the tree only meets a small area of root distribution, thus resulting in water stress which normally reduces plant growth. Increasing water stress significantly reduced rate of stem length, number of leaves/plant and leaf area while irrigation at 100% from available water level gave the highest significant stem length and leaf area of *Ziziphus jujuba*<sup>16,17</sup>. Results are also in line with those that the increase in collar diameter, crown diameter and fruit production of three *Ziziphus jujuba* cultivars were due to the enhancement of water and fertilizer supply<sup>18-22</sup>.

Results of fruit components and fruit yield indicated that the best water distribution treatment was T1 because it

gave the highest fruit weight and total fruit yield followed by T2 and T3. The results might be due to the pattern of water distribution around the tree. In T1, the pattern of water distribution almost fully met the root distribution as explained previously. Supplying available amount of water increased the fruit weight and total fruit yield in T1 followed by T2 and T3, respectively. The obtained fruits weight was almost similar with those that the heaviest fruit weight for Kaithli cultivar in semi-arid conditions was 17.8 g while it was 14.32 from Umran cultivar<sup>23</sup>. Water supply was the single most important factor determining productivity and quality of *Ziziphus jujuba* in dry areas followed by fertilizer application. Therefore, supplying the most important factor which is water in the present study may explain the increase in fruit production<sup>19</sup>. Moreover, fruit yield of *Ziziphus jujuba* increased by 60% when irrigated at 60-65% minimum soil moisture content<sup>22</sup>.

Generally the total yield production under current study is considered lower than that reported by many researchers<sup>19</sup>. This reduction in fruit production might be due to the high irrigation water salinity level (3200 ppm) used under current study. Increasing irrigation water salinity adversely affects on growth characteristics and yield of *Ziziphus* varieties<sup>5</sup>.

Fruit flesh weight, length, diameter and shape are of commercial importance for fruits marketing and trade/business. Generally, the quality is impaired when the fruits have large size with high flesh weight while small sized fruit with low flesh weight were considered of low quality<sup>24,25</sup>. The main source controlling fruit size is soil water content. Under high-available soil moisture, root may absorb more water. Absorbing more water resulted in an increase in fruit size and a reduction in the total soluble solid due to the dilution by water. These results are confirmed by the present study (Table 3), where fruit flesh weight, length and diameter were gradually decreased from T1 to T3. The decrease in the previous quality parameters might be mainly due to the reduction of the wetted root area because of reducing number of drippers around tree from eight in T1 to two in T3. The effect of water restriction, especially during the final stage of rapid fruit growth is met by decreasing in fruit flesh weight and size but increasing in total fruit soluble solids<sup>23, 24, 26-29</sup>.

The results presented in Table 4 ensure that under the condition of limited amount of irrigation water supply drip irrigation with low discharge drippers works better and enhances irrigation water distribution in root zone. In such a way of distribution, maximum water uptake by plant with minimum losses by deep percolation out of the root zone could have been occurred. That resulted in an increase of fruit production per unit of water in T1 and T2 compared to T3. The results are in line with those that plant production depends on the amount of water used for growth, where the variation in WUE is particularly important in those circumstances where growth ceases as a result of depletion of a finite and limiting water source<sup>30,31</sup>.

Increasing soil water content in T3 under drippers followed by T2 and T1 (Fig. 4) in both growing seasons for both investigated depths might be due to the dripper discharge which was 16 l/h in T3, 8 l/h in T2 and 4 l/h in T1. Increasing discharge develops a wide wetting zone in horizontal and in vertical directions, so that the highest soil water content under drippers was obtained from T3 followed by T2 and then T1. In on-surface drip irrigation, a small wetted bulb is created underneath each dripper. The volume of wetted soil and the pattern of water front, its area, and velocity

are special parameters that affect the water distribution in both vertical and horizontal directions. These parameters are indispensable for designing and operating the drip irrigation systems. Moreover, they are affected by both the amount of irrigation water and the discharge of the drippers, as well as the soil physical properties<sup>32</sup>. Increasing dripper discharge in sandy soil increased the wetted area more than 30 cm in horizontal direction and more than 50 cm in vertical direction<sup>30</sup>.

A reverse behavior in soil water content distribution was found at the middle distance between drippers compared to under drippers. The highest soil water content was found in T1 followed by T2 and T3 (Fig. 5). The results might be due to the overlapping coverage of the adjacent drippers in T1 and emitter to emitter coverage in T2 because the distance between drippers were 25 and 50 cm in T1 and T2, respectively. With increasing the amount of irrigation water or decreasing the distance between drippers in a fine sandy soil the depth and width of wetted zone significantly increased and resulted in emitter-to-emitter coverage<sup>33</sup>. The least soil water content measured in T3 might be due to the fact that the distance between two adjacent drippers was 1 m, which is difficult to cover the whole root zone area especially in light texture soils. Using high discharge emitters in drip irrigation system in light soil may result in overlapping the wetted zone in horizontal direction when the distance is less than 30 cm. In the same time, they may result to push the water deeply out of root zone. Therefore, it is advisable to use low discharge rate emitters and increasing the operating time to save more water<sup>30</sup>.

## Conclusions

The results of this study revealed that, water distribution patterns are very important technique for increasing *Ziziphus* production in arid conditions. Increasing number of drippers with low discharge distributed irrigation water homogeneously around the trees by covering large area of tree roots. This mechanism enhanced water uptake and resulted in a significant increase in branch length, number of branches, collar diameter, soil moisture content, fruit yield and fruit physical quality. Increasing number of drippers from 2 to 8 and decreasing dripper discharge from 16 to 4 l/h around tree increased fruit yield by about 78.3%. In conclusion, changing water distribution pattern to cover larger area of tree roots could be practical technique to highly increase fruit production with the same amount of irrigation water under arid conditions.

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