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Effect of mulching and subsurface drip irrigation on soil water status under arid environment

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Abstract

Aim of study: We investigated water evaporation of the soil surface and the soil water distribution under different mulching techniques using subsurface drip irrigation (SDI) system.

Area of study: The experiment was conducted at the Agricultural Research and Experimental Farm in Dirab, Riyadh, Saudi Arabia, locating 24.4195° N, 46.65° E, and 552 m altitude.

Material and methods: The two types of soil surface mulching were black plastic film (BPF) and palm tree waste (PTW), with no mulching (NM) as control. The two drip line depths from the soil surface (D_L) were 15 cm and 25 cm, and surface drip irrigation (DI) was the control.

Main results: In SDI, the use of BPF or PTW mulching resulted in enhanced water retention capacity of the soil and an approximately 6% water saving, compared with NM. The amounts of water saved at D_L of 15 cm (19-24 mm) were greater than those at D_L of 25 cm (15-20 mm), whereas the DI used the highest amount of applied water. The distribution of soil water content for BPF and PTW were found to be more uniform than NM.

Research highlights: It is advised to mulch the soil with PTW due to lower costs and through a D_L of 15 cm.

Additional key words: palm tree waste mulching, plastic film mulching, soil water distribution

Abbreviations used: BPF (black plastic film); DI (surface drip irrigation); FC (field capacity); LSD (least significant difference); M (mulching type); NM (no mulching); PTW (palm tree waste); RCBD (randomized complete block design); S (spacing from the drip line); SDI (subsurface drip irrigation). **Nomenclature:** A, B, and C (constants); D_i (soil depth at the i^{th} sensor); D_L (drip line depths from the soil surface); D_w (depth of water added to reach the soil field capacity); F_A (frequency readings in the air); FC_i (field capacity of the soil at the i^{th} sensor); F_S (frequency readings in the soil); F_w (frequency readings in the water); θ_v (volumetric soil water content); θ_{vi} (soil water content at the i^{th} sensor).

Authors' contributions: Conceived and designed research: AAA, MAM and MAA. Performed the experiments: AAA and MAM. Analyzed the data and wrote the paper: MAM, and MAA. Revised of the manuscript: AAA and MAM.

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Introduction

A weak water management system causes the highest water loss during irrigation (Al-Amoud, 2010), having a significant influence on the limited resources of water and on agriculture (Al-Shayaa *et al.*, 2012). Therefore, drip irrigation methods have been adopted because it is

believed to be the most efficient and worthwhile source for stabilizing the use of water when compared to other methods. In surface drip irrigation (DI), water loss can be decreased because of less water evaporation and deep percolation (Al-Amoud, 2010). Despite these advantages, several disadvantages have been observed in the application of the DI system owing to its traditional

methodology including the risk of destruction, direct exposure of the drip lines to the sun, and the occurrence of salinity. Thus, subsurface drip irrigation (SDI) has been suggested as a more useful method because it used less water than that of DI due to decrease the level of evaporation from the soil surface (Ayars *et al.*, 1995; Çolak *et al.*, 2018). SDI can be used to manage the amount of added water without causing any severe effects on the environment as a result of flow removal and deep penetration (Zin El-Abedin *et al.*, 2015). Overall, this method is able to enhance the production of crops by reducing water waste (Dukes & Scholberg, 2005; Enciso *et al.*, 2005; Soussa, 2010). SDI is a more efficient irrigation tool than the DI system because it provides water to the root zone (Irmak *et al.*, 2016). However, the efficiency of this system can be disturbed depending on the distance between the emitters and the lined depth of the drip lines (Enciso *et al.*, 2005).

Some precautionary measures should be followed when applying an SDI system. Bryla *et al.* (2003) suggested that for an efficient installment of an SDI system, the drip line depth under the soil surface is the most important factor that must be considered during the design process. There are several studies on SDI carried out in different crops. Patel & Rajput (2009) studied the effect of the buried depth of the drip lines and the different irrigation levels on the production of onions under an SDI system in sandy loamy soil. The best result was achieved at a buried drip line depth of 10 cm. Çolak *et al.* (2017) showed that SDI received slightly less water than the DI due to reduced evaporation losses in eggplant. Al-Ghobari & Dewidar (2018) reported that soil water contents in SDI were greater than those in DI during growth stages of the tomato.

In the field of agriculture, apart from the SDI system, which plays a vital role in the reduction of water usage, several other techniques have been explored to enhance water absorption, such as mulching at the soil surface (Hapeman & Durham, 2003). These techniques have been widely used to hinder the water evaporation rate from the soil surface and improve crop growth environments, thereby increasing crop yields (Dukes & Scholberg, 2005; Zhang *et al.*, 2009; Bu *et al.*, 2013; Li R *et al.*, 2013; Li S *et al.*, 2013; Haque *et al.*, 2018). In last years, the crop straw is one technique for mulching of the soil surface that can reduce evaporation loss from

the soil surface, improve physicochemical properties of soil, and enhance biological activity (Blanco-Canqui & Lal, 2007; Jordán *et al.*, 2010; Sharma *et al.*, 2011; Jiménez *et al.*, 2017). Li R *et al.* (2013) and Li S *et al.* (2013) found that straw mulching has saved about 35% of all water sources during maize growth period. Presently, plastic film mulching is a well-evolved technique for agriculture in arid, semiarid and sub-humid areas, especially where irrigation is not available (Dong *et al.*, 2009). Plastic film mulching has been shown to improve thermal conditions and increase topsoil water storage (Wang *et al.*, 2015; Liang *et al.*, 2018) promoting crop growth and water use efficiency (Fan *et al.*, 2016; Wu *et al.*, 2017). Ma *et al.* (2018) showed that plastic film mulching increased soil moisture in topsoils (0-20 cm) and yields of spring maize and potato in Northwestern China. A combination of SDI and plastic film mulching has been the best method to produce vegetables (Coelho *et al.*, 2009) and melons (Baghani *et al.*, 2010).

Under an arid climate, the application of an SDI system with mulching can potentially minimize the evaporation rate. Therefore, the aims of the present study were to: (1) explore the reduction of evaporation using different soil surface mulching, *e.g.* black plastic film (BPF) and palm tree waste (PTW), in combination with SDI; (2) analyze the status of the volumetric soil water content (θ_v) under an SDI, being a functional unit in the variation of drip line depth and soil surface mulching.

Material and methods

Field conditions

The experiment was conducted at the Agricultural Research and Experimental Farm in Dirab, Riyadh, Saudi Arabia (lat. 24.4195° N, long. 46.65° E, and 552 m above sea level elevation) from June to September 2018. Monthly averages of climatic data during experimental period are described in Table 1. The average air temperatures recorded were between 34.6 and 37.4°C, whereas the means of relative humidity recorded were between 10.1% and 13.7%. The recorded intermediate maximum wind speeds fall approximately between 6.6 and 5.6 m s⁻¹, and the recorded mean

Table 1. Climatic parameters (average) during the experimental months in 2018

Month	Air temperature (°C)	Relative humidity (%)	Wind speed (m s ⁻¹)	Solar radiation (MJ m ⁻² day ⁻¹)
June	36.6	10.1	5.6	24.7
July	37.4	11.8	6.1	24.8
August	35.8	13.7	6.6	23.4
September	34.6	13.5	5.6	23.2

solar radiations fall between 23.2 and 24.8 MJ m⁻² day⁻¹. Finally, there was no rainfall during the experimental months.

To investigate the physical and chemical properties of the soil, three samples were collected from different depths in various plots. Table 2 presents the values of the soil texture, field capacity (FC), wilting point, soil bulk density, and initial water content at different soil depth levels from the experimental locations. Finally, the chemical properties of the soil samples from different experimental sites are given in Table 3. The chemical properties of the irrigation water were analyzed by knowing an electrical conductivity value of 2.5 mS cm⁻¹, pH of 7.48, and total dissolved solids of 2880 mg L⁻¹. Both the soil and water present in the experimental samples were of reasonable quality to conduct the present study.

Experimental design

The field experiments were designed and executed as follows: the irrigation system was fixed by incorporating a tanks, pump unit, pressure gauges, ball valve, filtration system, pressure regulator, air relief valve, control panel, flow-meter, solenoid valve, main lines, sub-main lines, drip lines, connectors, and line end-caps (Fig. 1). This system was made using a main PVC pipe

with an inside diameter of 75 mm that had direct contact with the main water source. A second PVC pipe with an inner diameter of 21 mm was used to transfer the water to the drip lines. The drip lines had an inner diameter of 16 mm and a thickness of 1 mm. The drip lines were buried manually in SDI. Two fiberglass tanks were used to pour water into the network. The first tank had a capacity of 2000 L and the second tank had a capacity of 5000 L. Two drip line depths from the soil surface (D_L) of 15 and 25 cm and DI were applied in three blocks. Each block was divided into three plots to randomly allocate the three soil surface mulching treatments (NM = no mulching, BPF mulching, and PTW mulching), in a randomized complete block design (RCBD) with three replications. Each plot had three experimental units. Each one had three drip lines of 4.5 m long, 70 cm spacing. The distance between emitters was 30 cm. The in-line emitter discharge was 4 L h⁻¹ at operating pressure of 150 kPa.

Applied irrigation water

A water irrigation schedule was created to supply a reasonable amount of water via proper management. The basic aim was to intensify the effectiveness of the irrigation by providing enough water that could increase the θ_v to an adequate level.

Table 2. Physical properties of three soil samples from the experimental site

	Soil depth (cm)	Particle size distribution (%)			Soil texture	Initial water content (%)	Field capacity (%)	Wilting point (%)	Soil bulk density (g cm ⁻³)
		Clay	Silt	Sand					
Plot 1	0-25	3.2	22.5	74.3	Loamy sand	1.22	14.58	3.04	1.51
	25-50	3.2	22.5	74.3	Loamy sand	1.36	15.99	3.39	1.41
Plot 2	0-25	3.2	15	81.8	Loamy sand	1.22	14.86	3.05	1.52
	25-50	1.95	16.25	81.8	Loamy sand	1.15	15.15	2.45	1.40
Plot 3	0-25	4.45	16.25	79.3	Loamy sand	1.37	17.57	3.05	1.50
	25-50	0.7	12.5	86.8	Sand	0.93	14.81	2.06	1.40

Plots 1, 2, 3: drip line depth = 0 cm, 15 cm, and 25 cm, respectively.

Table 3. Chemical properties of soil samples from experimental site.

	Soil depth (cm)	Electrical conductivity (dS m ⁻¹)	pH	Calcium carbonate (%)	Sodium (mg L ⁻¹)	Potassium (mg L ⁻¹)	Phosphorus (mg L ⁻¹)
Plot 1	0-25	1.47	7.85	25.54	61	116	31.1
	25-50	2.4	7.73	27.04	181	115	21.8
Plot 2	0-25	3.4	7.8	25.37	237	109	12.5
	25-50	2.37	7.87	24.75	139	110	9.3
Plot 3	0-25	3.09	7.81	24.75	330	81	24.9
	25-50	2.05	7.91	23.34	218	70	34.2

Plots 1, 2, 3: drip line depth = 0 cm, 15 cm, and 25 cm, respectively.



Figure 1. Experimental layout.

The irrigation time was changeable owing to the planned irrigation treatment. The sensors were used to monitor the θ_v before and after irrigation. Scheduling consisted of applying the right amount of water at the right time. Its purpose was to maximize the irrigation efficiency by applying the appropriate amount of water needed to replenish the soil water to the desired level. In the present study, because there were no crops planted, the applied water was controlled based on the FC of the soil. The water depth was calculated for each soil depth from 10 to 50 cm and cumulated. The depth of water added to reach the soil FC (D_w) was calculated using Eq. (1):

$$D_w = \sum_{i=1}^n D_i (FC_i - \theta_{vi}) \quad (1)$$

where D_w is in mm, n is the number of sensors, D_i is the soil depth at the i^{th} sensor, FC_i is field capacity of the soil at the i^{th} sensor and θ_{vi} is soil water content at the i^{th} sensor.

Measurement of soil water content

For constant monitoring of the water content in the soil, EasyAG probes (Sentek Sensor Technologies, Stepney, Australia) were installed, which provide a θ_v profile for irrigation and management applications. These probes include several sensors that measure the soil water at

multiple depths. The probes create a high-frequency electrical field around each sensor that extends through the assessment tube into the soil. The electrical capacitance from the probe provided a θ_v . This was converted from a scaled frequency reading (Eq. 2) using a calibration equation (Eq. 3), which was based on field data:

$$SF = \frac{(F_A - F_s)}{(F_A - F_w)} \quad (2)$$

$$SF = A\theta_v^B + C \quad (3)$$

where, F_A , F_s , and F_w are frequency readings in the air, soil, and water, respectively, and A , B , and C are constants (Table 4). The θ_v can be directly obtained from the constants A , B , and C from Eq. (4):

$$\theta_v = \left(\frac{SF - C}{A} \right)^{\frac{1}{B}} \quad (4)$$

Each plot had three probes planted to record the values of θ_v at soil depths of 10, 20, 30, 40, and 50 cm. The first probe was placed directly at the emitter, the second was at 15 cm spacing from the drip line (S), and the third was at S of 30 cm, as shown in Fig. 2. The SURFER 13 software program was used to display θ_v distribution in soil profiles by contour maps using the Kriging method. A total of 15 data points were used to develop θ_v lines for each treatment. The contour maps were derived considering that there was symmetry around the emitter for both left and right sides.

Table 4. Constants of Equation (3) for three sensors after calibration

Sensor location	A	B	C	R ²
Directly on drip line	60.619	0.109	-71.356	0.942
At spacing of 15 cm from drip line	476.132	0.014	-485.695	0.844
At spacing of 30 cm from drip line	507.365	0.011	-513.789	0.751



Figure 2. Installation of EasyAG probes in the plot: (a) buried drip line; (b) drip line on the soil surface.

Statistical analysis

An analysis of variance following a RCBD was conducted on the average θ_v using the SAS statistical package to determine the effects of treatment (D_L and mulching type, M) on the measured parameters. The treatment means were separated through a least significant difference (LSD) test with a level of statistical significance of 0.05.

Results and discussion

Applied water

Fig. 3 shows that 89.45% and 94.04% of water in NM treatment were applied in the BPF and PTW treatments, respectively, at the DI ($D_L = 0$ cm). The BPF and PTW treatments at D_L of 15 cm are 6.79% and 4.94% water savings, respectively, whereas approximately 69 mm of water was applied in the NM treatment. At D_L of 25 cm, the quantity of water applied in the NM treatment was ~ 73 mm; 7.02% and 5.26% water savings were achieved in the BPF and PTW treatments, respectively. As shown in Fig. 3, under any type of mulching, the amount of water was higher when the DI was used (*i.e.*, $D_L = 0$ cm) because of higher evaporation rates from the soil surface (Al-Ghobari & El-Marazky, 2012; Çolak *et al.*, 2018). SDI (*i.e.*, D_L of 15 cm and 25 cm) under any type of mulching was saved along with the applied water. The amounts of applied water at D_L of 15 cm were 5.26%, 5.03%, 4.94%, re-

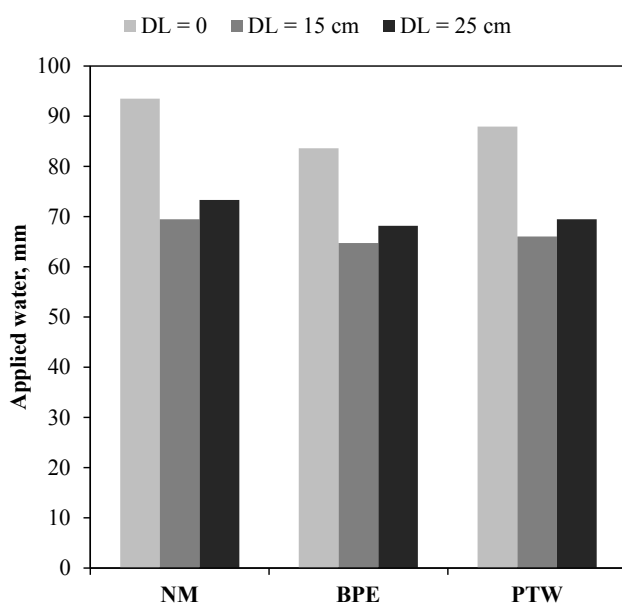


Figure 3. Applied water under different mulching types (no mulching, NM; black plastic film, BPF; palm tree waste, PTW) at different drip line depths from the soil surface (D_L).

spectively, lower than those at D_L of 25 cm for NM, BPF, and PTW mulching. Therefore, a BPF or PTW mulching combined with SDI retains the moisture and decreases the required water amount to prevent water evaporation from the soil surface (Gan *et al.*, 2013). However, it is better to use PTW mulch, because it does not require any additional costs, at D_L of 15 cm.

Effect of mulching type on soil water content

Figure 4 shows the average θ_v values in the soil depths for DI, D_L of 15 cm and D_L of 25 cm under NM, BPF, and PTW treatments. The BPF treatment had higher θ_v values than that of the NM and PTW treatments in both the DI and SDI systems. For the DI with BPF mulching, the θ_v values were approximately 14.79%, 13.69%, and 13.27% directly at the emitter (S of 0 cm), S of 15 cm, and S of 30 cm, respectively (Fig. 4). The θ_v values for the PTW treatment were 14.55%, 13.63%, and 13.15%, at S of 0 cm, S of 15 cm, and S of 30 cm, respectively. The θ_v values for the BPF treatment were 4.08%, 1.33%, and 1.76% higher than that of the NM treatment at S of 0 cm, S of 15 cm, and S of 30 cm, respectively. The θ_v values for the PTW treatment were 2.39%, 0.89%, and 0.84% higher than that of the NM for S of 0 cm, S of 15 cm, and S of 30 cm, respectively.

For D_L of 15 cm, the θ_v values for the BPF treatment were also higher than those of the NM and PTW treatments (Fig. 4). The θ_v values at S of 0 cm were approximately 15.05% and 14.72% for the BPF and PTW treatments, respectively (*i.e.*, the θ_v values were 3.65% and 1.38% higher, respectively, than that of the NM treatment). The θ_v values for the BPF and PTW treatments were 1.02% and 0.58% higher, respectively, at S of 15 cm than that of the NM treatment, whereas the θ_v values increased by 1.58% and 0.75%, respectively, at S of 30 cm. For D_L of 25 cm, the θ_v values at S of 0 cm were 2.74% and 1.13% higher for the BPF and PTW treatments, respectively, than that of the NM treatment (Fig. 4). Additionally, the θ_v values increased by 3.97% and 2.91%, respectively, at S of 15 cm, and the θ_v values increased by 3.15% and 2.20%, respectively, at S of 30 cm.

The comparison of θ_v values average across the experimental treatments is summarized in Table 5. The M had very significant ($p < 0.01$) effects on the average θ_v values when measured at S of 0 cm and S of 15 cm and significant ($p < 0.05$) effect at S of 30 cm, irrespective of the D_L treatments. The BPF treatment provided a higher average θ_v value than that of the NM treatment, with a significant increase of 3.50%, 2.18%, and 2.25% at S of 0 cm, S of 15 cm and S of 30 cm, respectively. This was because that BPF mulching stopped the move-

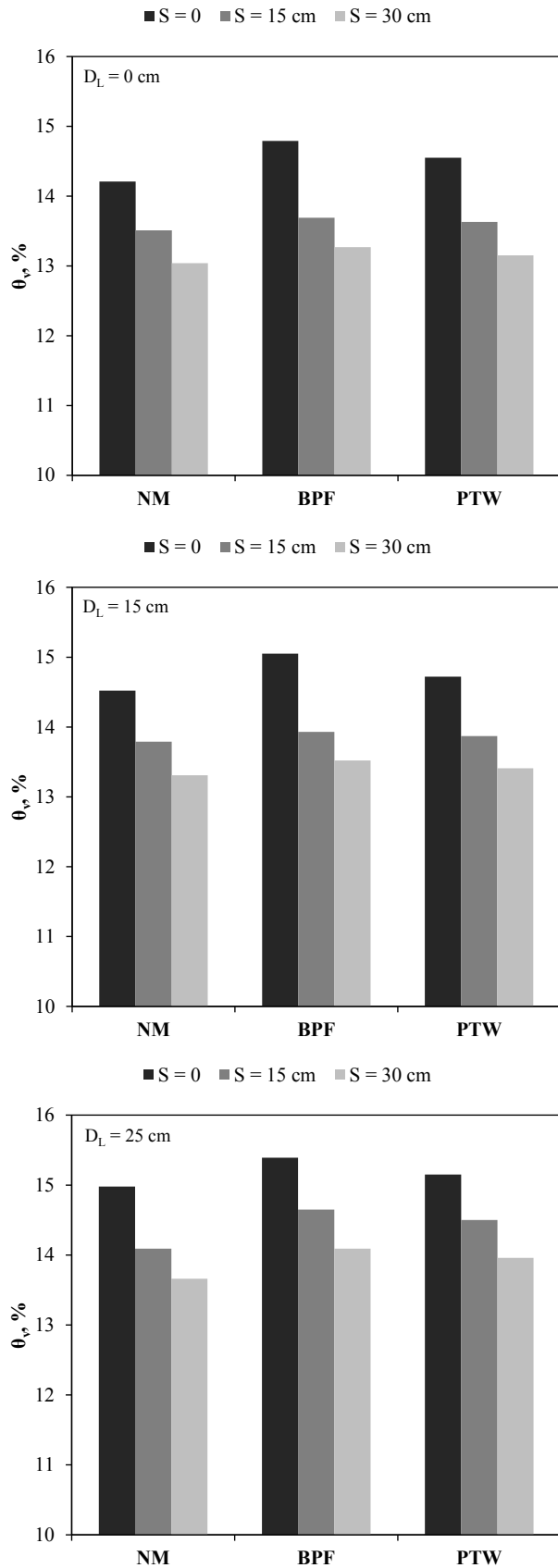


Figure 4. Average volumetric soil water content (θ_v) under different spacing from drip line (S) and mulching types (no mulching, NM; black plastic film, BPF; palm tree waste, PTW) at different drip line depths from the soil surface (D_L).

ment of water vapor from the soil surface to the air (Dong *et al.*, 2018). When the PTW covered the soil, the increase in θ_v was significant (1.65% and 1.45%, respectively) at S of 0 cm and S of 15 cm and insignificant at S of 30 cm, comparing with NM treatment, consistent with the results of Liu *et al.* (2018). This was because the rate of water vapor flux through covered PTW was slow compared to the rate of water loss from wet soil surface (Li R *et al.*, 2013; Li S *et al.*, 2013). BPF treatment showed significant increases (1.82%) in θ_v , compared to PTW at S of 0 cm, but significant difference were not observed at S of 15 cm and S of 30 cm. Thus M, which had an effect in the covered soil, retained higher moisture levels, leading to better root growth than that of the uncovered soil. Although it is cost-effective to purchase BPF, this type of mulching system can be replaced by PTW, which is available to farms at no extra cost.

Effect of depth of drip line on soil water content

Figure 4 shows that the D_L of 25 cm for the NM treatment had the highest average θ_v value (14.98%) at S of 0 cm, which was 5.42% and 3.17% higher than that at DI and D_L of 15 cm, respectively. The θ_v values at S of 15 cm for the NM treatment were approximately 13.79% and 14.09% for D_L of 15 cm and 25 cm, respectively, *i.e.*, the θ_v values were 2.07% and 4.29% higher, respectively, than that of the DI system. The θ_v values at S of 30 cm for DI were 2.03% and 4.54% lower than that of the D_L of 15 cm and 25 cm, respectively. This result is consistent with Mokh *et al.* (2014), who explained that the D_L in SDI system influenced θ_v values during the two cropping periods of potato, and increasing the D_L lead to increased θ_v values.

For BPF and PTW treatments, Fig. 4 shows that the θ_v values for the DI system were lower than those of the SDI system. A D_L of 25 cm with the BPF treatment produced the highest θ_v value of 15.39% at S of 0 cm compared to the DI and D_L of 15 cm, which was 4.06% and 2.26% higher, respectively, whereas at S of 15 cm θ_v values increased by 7.01% and 5.17%, and at S of 30 cm values increased by 6.18% and 4.22%. The θ_v values in the PTW treatment under different D_L showed a similar trend, being 4.12%, 6.38%, and 6.16% higher for D_L of 25 cm than those of DI at S of 0 cm, S of 15 cm, and S of 30 cm, respectively. The θ_v values for D_L of 15 cm were 2.84%, 4.34%, and 3.94% lower than those of D_L of 25 cm at S of 0 cm, S of 15 cm, and S of 30 cm, respectively.

Irrespective of M treatments, Table 5 shows that D_L had a significant ($p < 0.01$) effects on the average θ_v

Table 5. Results of variance analysis of θ_v values under mulching type (M), drip line depth from the soil surface (D_L) at different spacing from the drip line (S).

Treatments	S = 0 cm	S = 15 cm	S = 30 cm
M	**	**	*
No mulching	14.57 c	13.79 b	13.33 b
Black plastic film	15.08 a	14.09 a	13.63 a
Palm tree waste	14.81 b	13.99 a	13.51 ab
<i>LSD</i> 0.05	0.17	0.11	0.19
D_L	**	**	**
Surface drip	14.52 c	13.61 c	13.15 c
Subsurface drip at 15 cm depth	14.76 b	13.86 b	13.41 b
Subsurface drip at 25 cm depth	15.14 a	14.42 a	13.91 a
<i>LSD</i> 0.05	0.17	0.11	0.20
$M \times D_L$	ns	*	ns

Mean values in columns followed with different letters are significantly different based on LSD test at $p < 0.05$. *: Significant at the 5% of probability level ($p \leq 0.05$). **: Significant at the 1% of probability level ($p \leq 0.01$). ns: non-significant.

values at different S, being D_L of 25 cm the treatment showing the highest value, unlike in the DI. Significant differences between D_L treatments were observed at S of 0 cm, S of 15 cm and S of 30 cm, the average θ_v value at D_L of 25 cm were 4.27%, 5.95%, and 5.78% higher than those of the DI, while 2.57%, 4.04%, and 3.73% higher than those of the D_L of 15 cm, respectively. The θ_v values' variance between D_L of 15 cm and D_L of 25 cm treatments are only small. So, the D_L should be at 15 cm to reduce the cost of drilling. The deepening of the drip line away from the sun results in increasing θ_v value due to a lack of moisture loss (Solomon, 1993).

Soil water distribution

Figure 5 show that the θ_v distribution was affected by M and D_L under different S. The best uniformity of θ_v distribution contour lines throughout the soil profile was obtained under SDI (D_L of 15 cm and D_L of 25 cm). However, the distribution of the θ_v for different M treatments indicated that the D_L of 15 cm and D_L of 25 cm had more uniform bulb distribution at S of 0 cm. In contrast, the θ_v distribution in S of 15 cm and S of 30 cm was similar and more uniform than that obtained with the DI. The θ_v bulb's spread decrease as S increases horizontally under any M and any D_L . Similarly, Assouline (2002), Grabow *et al.* (2006), Badr (2007), Shirahatti *et al.* (2007), and Nasrabad *et al.* (2013) showed that the θ_v value decreased horizontally as the S increased. In sandy soil, the emitters need to be closer together because the water does not move as far horizontally (Arbat *et al.*, 2010). Moreover, in

an SDI system, the vertical movement of the θ_v level was found to be higher than the horizontal movement (Bajracharya & Sharma, 2005; Al-Ghobari & El-Marazky, 2012; Douh *et al.*, 2013).

Table 5 shows that binary interactions between the M and D_L had ($p < 0.05$) significant effect on the θ_v values at S of 15 cm only. BPF and PTW mulching at 0-20 cm soil layer increased θ_v values by 0.96% and 1.25%, respectively, more than that of NM in DI (Fig. 5). The corresponding values of θ_v were increased by 3.05% and 2.91% for D_L of 15 cm while 5.56% and 5.41% for D_L of 25 cm. This agrees with Wang *et al.* (2009) and Liu *et al.* (2014). Ma *et al.* (2018) found that plastic film mulching increased the θ_v significantly (12.9%) for the 0-20 cm soil layer, compared with traditional approach. Using mulching (*e.g.*, BPF and PTW) holds water evaporation and encourages water movement to the topsoil layers promoting θ_v during initial stage of crop growth (Gan *et al.*, 2013). With SDI, the surface soil layer is not completely wetted (*i.e.* lower moisture) as in the case of DI. Therefore, with SDI the upper soil layers remain relatively dry, thereby reducing the direct soil evaporation as compared to DI (Solomon, 1993). At the 0-40 cm soil layer, being the normal root depth for most crops, the average θ_v value in S of 15 cm was 13.87% for the D_L of 15 cm and 14.13% for the D_L of 25 cm under NM treatment (Fig. 5a). This observation agrees with the results reported by Badr & Abuarab (2011), who suggested that a D_L of 30 cm is deemed the active root zone in vegetable crops, and the improved activity was attributed to the enhanced capacity to restore water, particularly for sandy soils. In contrast, a D_L of greater than 10 cm is advisable to prevent the wetting of the soil surface dur-

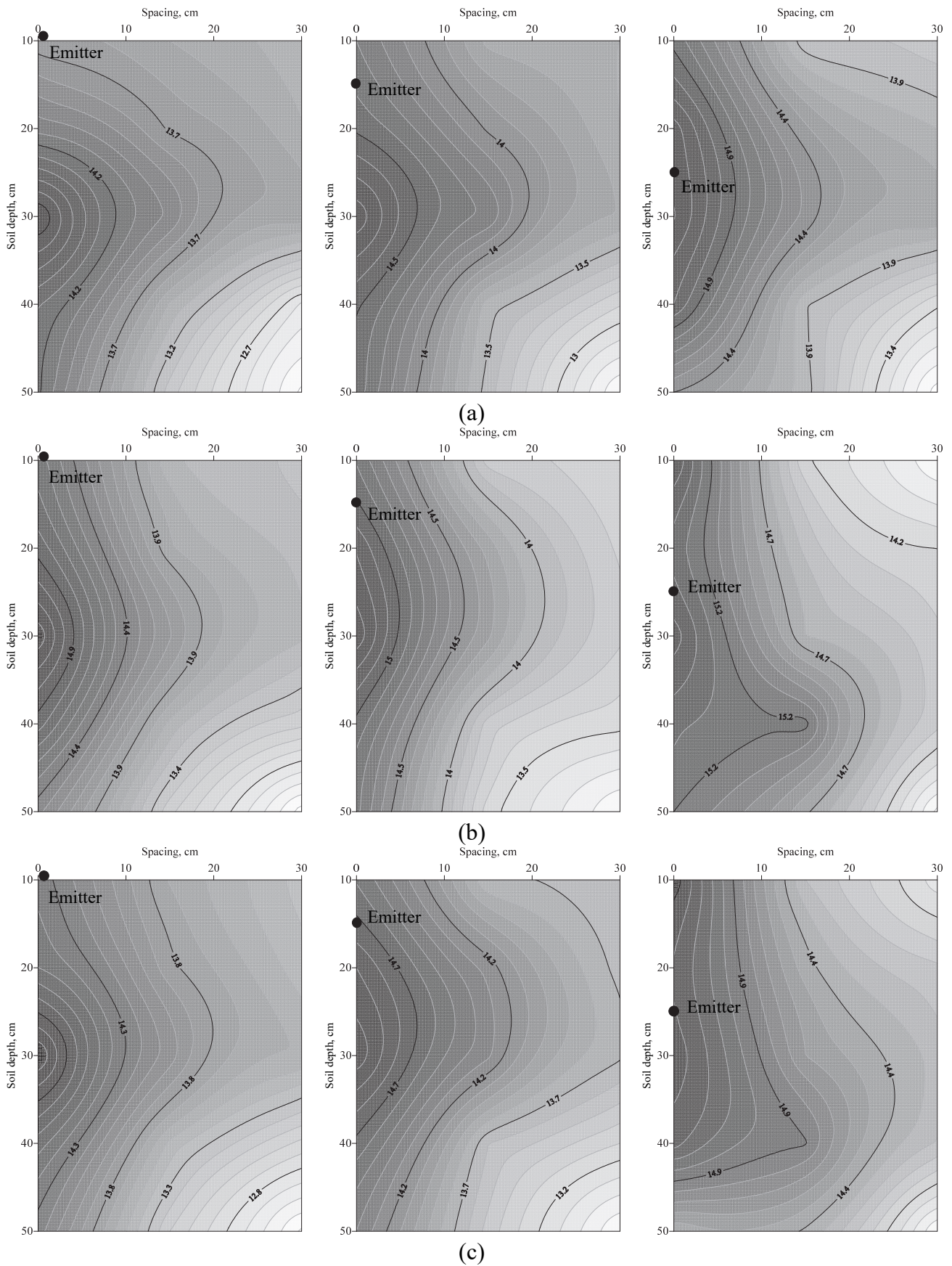


Figure 5. Soil water distribution through the emitter at different drip line depths after irrigation for 24 h: (a) no mulching; (b) black plastic film mulching; (c) palm tree waste mulching.

ing irrigation in loamy soil (Rodríguez-Sinobas *et al.*, 2012). The corresponding values were 14.02% and 14.63% under BPF treatment (Fig. 5b), while 13.97% and 14.54% under PTW treatment (Fig. 5c). The increased moisture retention capacity of BPF and PTW treatments could be attributed to less non-productive water losses from the soil, which play a vital role in the management and growth of crop (Zhao *et al.*, 2014; Dong *et al.*, 2018; Li *et al.*, 2018). Because of vapors, the water was further trapped within the mulch, resulting in fog, which again dropped into the upper soil layer, as reported by Ashrafuzzaman *et al.* (2011). The θ_v distribution contours show a saturation bulb under the emitters that moves downward as the D_L increases (Fig. 5). Clearly, the θ_v distribution became more controllable moving downward when applying BPF and PTW at D_L of 25 cm than at D_L of 15 cm. This is consistent with Thorburn *et al.* (2003), who showed that the D_L controlled the amount of water reaching the surface and the upward spread of the θ_v toward the soil surface. The shape of the bulb also changed from a near-circle to an ellipse when the BPF and PTW mulching were used. BPF mulching at D_L of 25 cm largely allowed the downward movement of θ_v (Fig. 5b). Fig. 5c shows similar results but with less θ_v moved downward when the PTW mulching was applied at D_L of 25 cm. It is better to use D_L at 15 cm and PTW mulching, that is less expensive to install, giving slightly less θ_v values than those of BPF mulching at D_L of 25 cm.

In summary, the present study illustrated the influence of the D_L under different M in a SDI system for the θ_v distribution in a soil profile. The inclusion of BPF or PTW mulching on the soil surface was found to enhance the water retention capacity of the soil. The SDI system reduced the required water amount when the drip line was mulched with BPF by a small value compared to when the drip line was mulched with PTW. Therefore, it is recommended that the methodology of an SDI system would provide a useful method for treating soil through the installation of a D_L at 15 cm and by mulching the soil with PTW where no additional cost is required. Such treatment will provide an active zone of soil to the roots of vegetables crops. Therefore, we believe that the soil treatment strategy outlined in the present study could restore high levels of water resources in the loamy land of Saudi Arabian farms at a significantly low cost.

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