Effective moisture conservation method for heavy soil under drip irrigation

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Abstract: Drip irrigation is one of the most efficient systems in delivering water to the plant root zone but it still allows relatively high evaporation from the saturated zone that develops under emitters especially in clay soils of low infiltration rates. Initial lateral water movement may take a long time in such soils thus exposing surface water to high evaporation. The vertical columns method induces water infiltration keeping the actual water surface deeper in the soil profile. The objective of this research is to compare between the effect of vertical compost and sand columns on the distribution of water in the root zone and the potential for water saving in clay soil. A field experiment was conducted and the results indicated that the vertical mulch allowed more water to remain in the soil profile thereby increasing the irrigation efficiency and has a significant effect on water storage at the 20-60 cm depth. Over time, as the soil is drying up, the significance of the vertical mulch factor increases. Considering the root zone profile as a whole, the compost columns (20 and 40 cm) as well as the 40 cm vertical sand column had higher water content than the surface irrigation plots.

Keywords: drip irrigation, vertical mulch, water saving

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1 Introduction

Historically, drip irrigation has been considered an efficient method of applying irrigation water while lessening evaporative losses, mainly because of reducing the wetted surface area, compared to that of a sprinkler or flood irrigation. Because of the high irrigation frequency of drip irrigation, an almost constant saturated, soil surface or water puddle exists beneath each emitter. This wetted area is susceptible to high evaporation, not only because of solar radiation, but also because of the advective forces of hot dry air drifting across the surrounding soil which provides a steep vapor pressure gradient that promotes evaporation.

The volume of soil wetted from a point source is mainly a role of the soil texture, structure, application rate and the total volume of water applied. Little attention has been paid to estimate the soil water distribution using trickle irrigation under realistic field conditions (Kao and Hunt, 1996; Al-Qinna and Abu-Awwad., 2001). Grimes et al. (1990) showed that water infiltration often becomes severely restricted as the growing season progresses and the plants are subjected to water shortages during the periods of high evaporation potential. Also in the semi-arid Mediterranean climate of Cordoba-Spain, Bonachela et al. (2001) assessed soil evaporation losses from emitter zones in young (5% ground cover) and mature (36% ground cover) olive orchards irrigated by drip. They noted a sharp discontinuity in soil evaporation at the boundary of the wet zone, with values decreasing sharply in the surrounding dry area. Evaporation from the wet zones was clearly higher than the suiting values of evaporation calculated presuming complete and uniform soil wetting, showing the effect of micro-scale advection. They estimated seasonal

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potential water saving of 18 to 58 mm in a mature orchard and 28 to 93 mm in a young orchard, by shifting from surface to subsurface drip, presuming daily drip applications and absence of rainfall during the irrigation season. Soil wetting patterns under surface and subsurface micro irrigation have been measured and/or analyzed theoretically by several authors such as Coelho and Or (1997), Assouline (2002), Cote et al. (2003), Gardenas et al. (2005), Singh et al. (2006), Wang et al. (2006), Nafchi et al. (2011) and Lazarovitch et al. (2007), Siyal and Skaggs (2009) to name only a few.

Two drip infiltration conditions were compared by Zhang et al. (2012) in a sandy loam soil field trial designed to study on dynamic of saturated zone radius, radial and vertical wetted distance. The results showed there was a positive linear correlation between saturated zone radius and application rate. The relationship between both the radial and vertical wetted distance and drip irrigation time can be described by a power function, respectively.

Vertical mulching makes many holes in the soil of a particular tree root zone with the purpose of creating many entryways for air, moisture, and nutrients to reach the roots of a given tree. This improves the overall health and vigor of any tree. In addition, it is an excellent technique used to reduce partially soil compaction within the critical root zones of trees. Soil compaction is harmful as it reduces the pore space in the soil normally filled with oxygen (micro-pores) and water (macro-pores). Vertical mulching will also lessen damage because of excessive water, preserve necessary aeration during wet periods, allow subsoil water penetration during dry periods, and promote forming fine feeder roots.

More recently Meshkat et al. (1998, 1999 and 2000) did a series of laboratory studies on vertical mulching, irrigating through a sand tube. Evaporation losses were compared between NI (normal drip) and STI (sand tube irrigation) and were found to be significantly less in the STI (Meshkat et al. 2000). The total evaporation after irrigation was 3.66 and 2.2 liters in NI and STI respectively, amounting to 39.8% evaporation drop. They also reported higher water content between 0.2-0.55 m soil depths in the STI treatments. Abu-Awwad (1998b) experimented with sand columns, under field conditions, on rainfed barley; varying the spacing between sand columns, he showed the presence of the sand columns increased the moisture stored in the soil especially in deeper soil layers. Compared to the control there was a significant increase in the water stored in the profile by 60%, 45%, and 38% where sand column spacing was one, two and three meters respectively. These results show that a significant quantity of water is transported to a deeper depth by the sand columns and the sand column acts as a sink of water flowing and decreases surface runoff. Yanni et al. (2004) studied the effect of gravel vertical mulching on delivering water in the root zone and the potential for water saving. The results showed the irrigation level has a significant effect on water storage at deeper soil layers, whereas the gravel mulch was effective in increasing soil water content at the 20-50 cm depth and became insignificant at deeper layers. Overtime, as the soil is drying up, the significance of the gravel increases. Considering the root zone profile as a whole, the Graveled plots had higher water content than the Non-Graveled plots.

The idea of vertical mulching is not new, but most of the previous studies were theoretical or laboratory. A few studies were done in the field ignoring some of field operations for orchards like using manure and compost as annual fertilizers. At the same time, many studies reported the best ways for adding manure or compost to tree, are buried in holes or in tunnels under the soil surface around the trees. For purpose of this study to focus on decreasing soil water evaporation and increasing the moisture conservation. It will be done by introducing some activities that already used in orchards such as adding compost to tree in holes beneath the drip emitters comparable with sand through which water can infiltrate faster instead of ponding and evaporating from the surface.

Because of the different nature and structure of the used soil than in previous studies and according to the data used by Yanni et al (2004), a field experiment was devised. Vertical mulching systems were designed to study the effects of sand and compost columns on water distribution and storage in the root zone and the potential of irrigation water saving. The aim was to gain data according to our soil condition (heavy clay soil not gravel). In addition, to study the soil behavior by using compost as a soil conditioner with different depths for mulch (20 and 40 cm) to decide which is suitable for the plant.

2 Materials and methods

A field experiment was carried out at the Research Farm of Agriculture Faculty, Benha University – Kalyobia Governorate, Egypt, during August and September 2012. The region is arid characterized, during that time of the year, by no rainfall, a high average temperature and relatively medium humidity resulting in a medium to high evaporative demand. The soil is clayey textured as shown in Table 1.

Two factors divided into four treatments (two types of mulch, sand and compost, with two depths (20 and 40 cm) in addition the control treatment (0 cm) in three replicates, were studied.

According to Dzingai (2010) rooting depth for orchard varies between 1.2 and 2 m. Where water supply is adequate, normally 100% of the water is extracted from the first 1.2 to 1.6 m. Also Castle and Krezdorn (1975) reported that rootstocks are typical of citrus trees with extensive root in which 50% of the fibrous roots were in soil depths greater than 0.7 m. Therefore, that is the reason for using a 40 cm as deep vertical mulch.

Table 1 Mechanical and physical characteristics of the soil

Soil depth/cm	Sand/%	Silt/%	Clay/%	Texture class	Organic matter/%	Bulk density/g cm^{-3}	Field capacityF.C/%	Wilting pointW.P/%
0-20	22.5	31	46.5	Clay	3.1	1.36	51.1	17.05
20-40	21.5	30.5	48	Clay	2.95	1.20	52.2	18.36
40-60	20.5	31	48.5	Clay	2.93	1.24	52.4	17.73

Compost is primarily used as a soil conditioner. The physical and chemical properties of the used compost (cattle manure and herbal plant residues (50:50)) are: pH 7.6, Electrical conductivity (EC) 3.1 ds/m, total organic matter values 32.7%, bulk density 0.625 g/cm^3. The moisture content 23.50%, water holding capacity value 3.7 g water/g dry and porosity 62.67% (Khater, 2012).

To mulch vertically, an auger 10 cm diameter and 40 cm long was used to make 12 deep holes in the soil (six holes in 20 and six holes in 40 cm deep). The depths of the vertical column were set to 0 cm {three Emitters for surface drip irrigation as a control (DI)}; 20 cm {three holes filled with sand (S20) and three holes filled with compost (C20)}; and 40 cm {3 holes filled with sand (S40) and three holes filled with compost (C40)}. A five-drip lines were setup with 4 L/h emitters for irrigation (irrigation duration was 12 h) as shown in Figure 1.

Soil samples were taken at 1st, 3rd, 5th and 7th day after irrigation by pressing a 60-cm-long, 4-cm-inside-diameter steel soil sampling tube into the soil profile of selected coordinate positions at 15, 30 and 45 cm from the emitters. The total sampling depth was 60 cm and the soil sampling layer increment was set to 20 cm. Replicate no. 1 (Figure 1) used only for measuring the wetted soil profile dimensions through cross section under emitters for each treatment at the 1st day after irrigation. The replicates No. 2 and 3 were used for soil moisture measurements. At the end of the experimental time, replicate No. 3 used for measuring the wetted soil profile dimensions under emitters for each treatment.

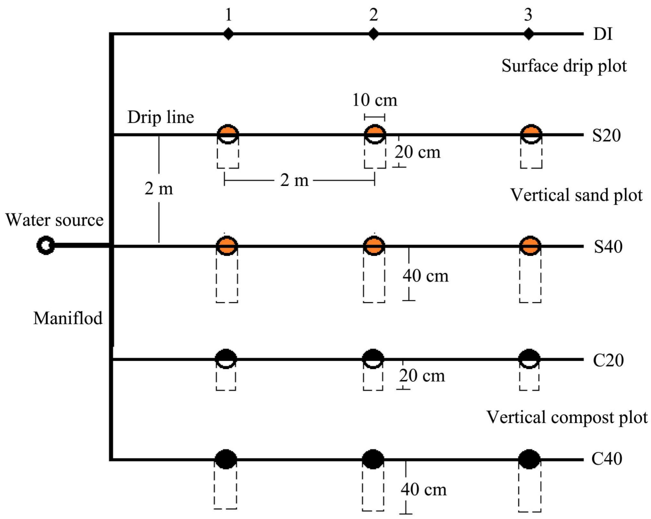

Figure 1 Schematic of experimental field system

The experiments were run for whole month (August) and it was irrigated four times (each eight days). The work repeated in September with the same technique in nearby experimental block to insure the obtained results. The average of all obtained data was calculated and introduced in the paper.

The soil water content was measured by gravimetric moisture, which was determined by calculating the proportion of water loss relative to dry soil weight after oven-drying the soil samples. The amount of water stored in the soil profile as a result of irrigation was calculated from soil moisture measurements. Soil water storage (amount of water stored) for each layer was calculated as:

$$SWS = (W_2 - W_1) \times D / 100$$

where, SWS is the soil water storage, mm; W_1 is the volumetric soil water contentsbefore irrigation, %, and W_2 is the volumetric soil water contents at 1st, 3rd, 5th and 7th day after irrigation, %; D is the thickness of the soil layer, mm.

3 Results and discussion

The field data were arranged in different orders to describe the water content in the root zone as a whole, as well as in the different soil layers and distances from the emitters. The analysis was done graphically and statistically for all vertical column events.

3.1 The dynamic of surface wetted radius

The surface wetted radius as a function of time for all treatments described as Figures 2 and 3. Results show the DI (control) produces the larger surface wetted radius when the irrigation times are same. It shows that surface wetted radius rapidly increases in 0-1 hour, after that increases slowly for the control but for the other treatments the surface wetted radius increases nearly as same rate as time. It is clear the porosity of sand and compost column led to more increase of vertical water movement than the horizontal wetted radius.

The relationship between wetted radius (Rw) and drip irrigation time can be described by a linear function: $Rw=ax+b$ (a and b are constants). The parameters for radial front measurements are summarized in Table 2. The coefficient a decreasing with increasing the column depth and this suggests the surface wetted radius is controlled by column depth and time.

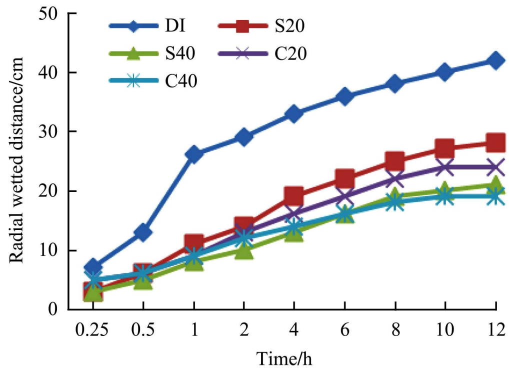

Figure 2 Radial wetted distance as a function of time for different apparent application rates

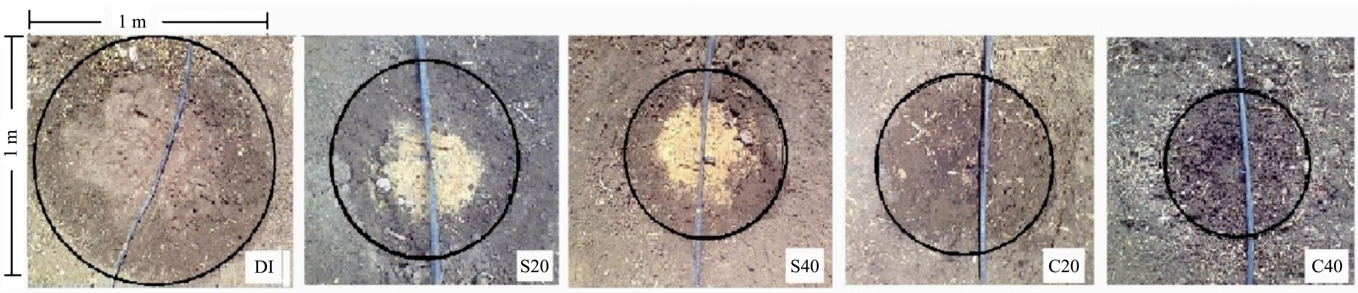

Figure 3 The horizontal wetted area at the end of irrigation time (12 h)

Table 2 Parameters for estimation of wetted distance in horizontal direction and corresponding R^2 value

	a	*b*	R^2
DI	4.2	8.33	0.89
S20	3.32	0.64	0.98
S40	2.42	0.69	0.99
C20	2.7	1.83	0.98
C40	1.95	3.36	0.96

3.2 Comparison of different vertical columns and DI vertical distributions of soil water content after irrigation with different sampling intervals

Figure 4 shows the vertical distributions of DI, S20, S40, C20 and C40 soil water content after 12-hr irrigation duration with four different sampling intervals. The sample intervals were set to 1st, 3rd, 5th and 7th day after irrigation. Figure 4 shows the vertical distribution of soil water content under drip irrigation could be divided into three different water-storage layers. The first layer, called the "quickly changing layer", was located 0–20 cm below the soil surface. Due to the influence of evaporation, the relative humidity of the surface soil profile varied considerably. According to site measurements, the soil water content of this first layer was saturated after drip irrigation; however, after six or more days there was little soil water content remaining in the surface soil profile. The second layer, called the "medium changing layer", was located 20–60 cm below the soil surface. Because of infiltration and redistribution of soil water content under drip irrigation, this layer incurred the most active soil water content changes. The third layer, called the "slightly changing layer", was located 60–more cm below the soil surface. According to Zhong et al. (2011), the soil water content in this water-storage layer changed slightly as a result of infiltration and redistribution of soil water content and root water uptake function.

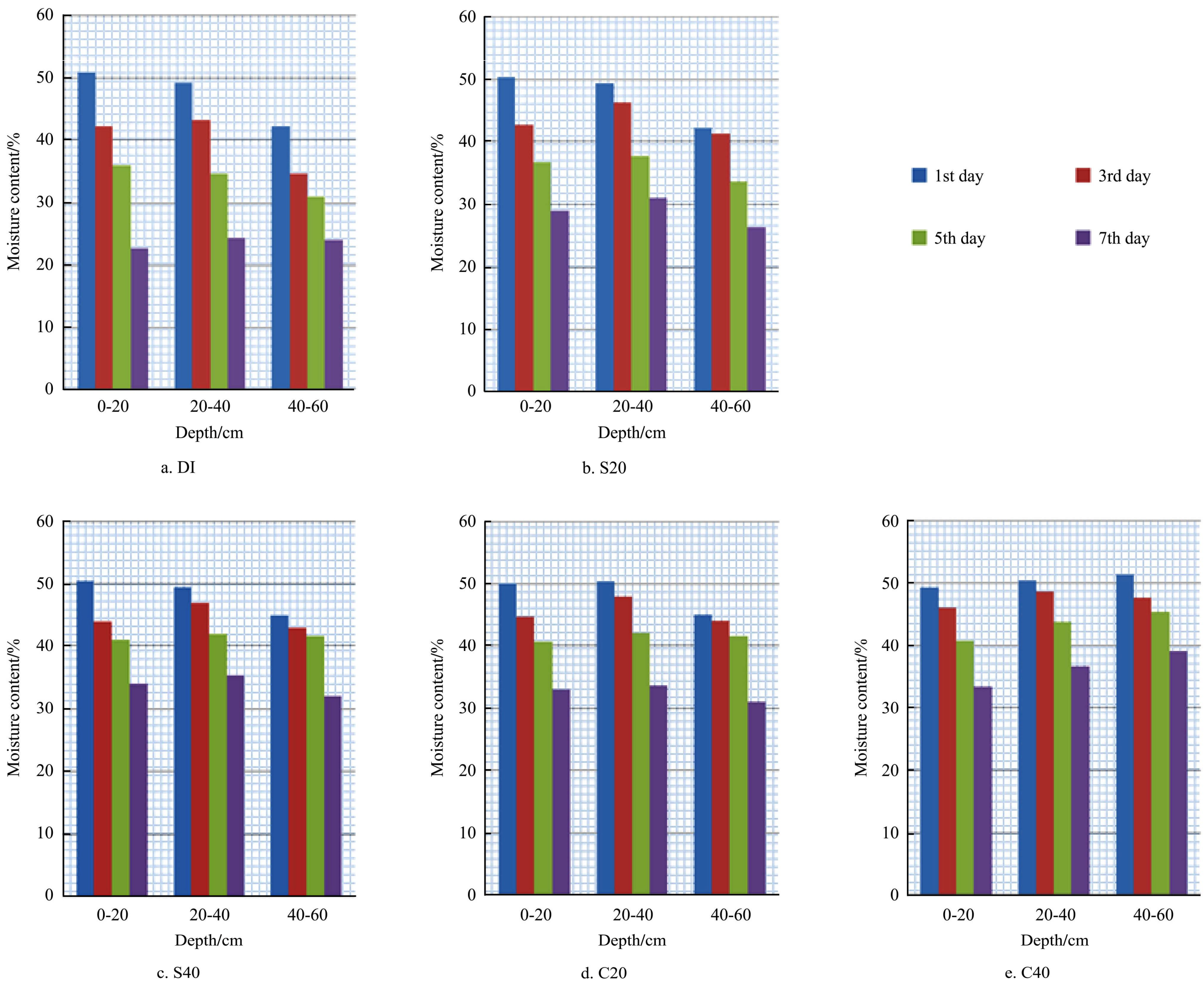

Figure 4 Soil moisture levels of different vertical columns and DI after irrigation with four sampling intervals (days)

Figure 4-S20 and C20 show the vertical distribution of soil water content under sand and compost respectively, showing that irrigation water was transferred to 20 cm below the soil surface with medium influence on the first water-storage layer. At the same conditions, Figure 4-S40 and 4-C40 show that irrigation water was transferred to the depth of 40 cm below the soil surface with low influence on the first water-storage layer.

There existed a 0 to 20 cm layer of low wetted radius than DI that could effectively lessen the evaporation loss of soil water content from the soil surface. Thus, this layer was functioned as an "umbrella" that decreases evaporation loss of irrigation water.

In the second water-storage layer (first rapid changing layer) located 20–40 cm below the soil surface, distributing soil water content was most affected by the sand and compost soil columns and its character. The third water-storage layer (second rapid changing layer) was located 40–60 cm below the soil surface. It was less affected than the second layer but the soil water content in both of these layers responded very differently (oppositely) under vertical columns compared to DI.

These data suggest that vertical mulch columns can effectively reduce water evaporation at the soil surface and improve the soil water content at soil depths from 20 to 60 cm. Moreover, the vertical distribution of soil water content of treatments S40, C20 and C40 were considered to be the "stable" soil water content distribution after the irrigation duration in the 5th and 7th day interval. Figure 4-C40 shows an optimal vertical distribution of soil water content. It can better irrigate trees especially in arid and semiarid regions that experience severe evaporation as well as in the clayey soil regions. It significantly reduces evaporating soil water from the soil surface. Figure 4-DI shows that DI cannot avoid evaporating soil water near the emitters in the drip line, and the highest amount of soil water occurred 20 cm which is little benefit to the orchards tree growth.

3.3 Comparison between treatments, over time, at each soil layer

The 0–5 cm layer the treatments did not show a wide difference in moisture content however in the other layers there were significant differences (Figure 5). In the 5 – 20 cm layer the C40 has by far the highest storage of water whereas the lowest is the DI. S40 and C20 have similar water content. Column depth and mulching type effect on water amount that soil can hold because the 40 cm is always shown to be most efficient in the presence of vertical columns. After irrigation, S20, S40, C20 and C40 had around 5%, 9%, 10% and 11% respectively more water than DI in the 5–20 cm layer. The trend continues in the same manner in the 20–60 cm layer with accentuated differences between treatments. The S20, S40, C20 and C40 had 9%, 14%, 13% and 18% respectively more water than DI at 60 cm depth as average for all treatment time (seven days). C40 treatment achieved highest water content in all the soil layers, also S40 and C20 became higher than the others.

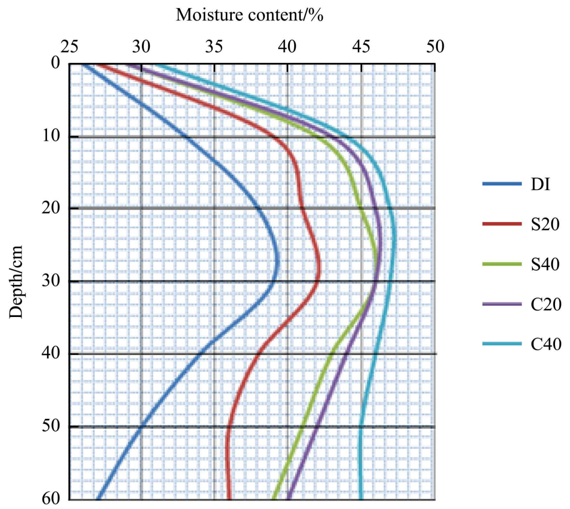

Figure 5 Vertical distribution of soil water content varied with soil depth for all treatments

3.4 Effect of the vertical columns on the soil water content over time.

Figure 6 shows the advantage of having vertical mulch in increasing the soil water content of almost the whole profile. Another important finding concerns the irrigation water content over time, where the tubed soil, after seven days of irrigation, held more water than the non-tubed soil. The C20 and S40 treatments have a similar trend to water storage range which has 46% more than DI as average for all treatment depths at the 7th day. The C40 treatment has the highest water content in all the soil layers (54% more than DI) while S20 shows only 20% in water storage more than DI.

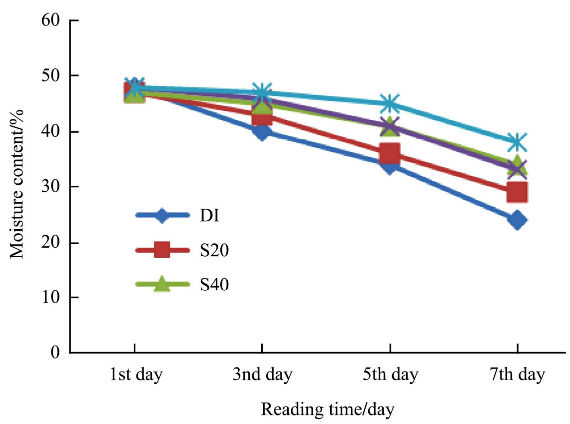

Figure 6 Effect of vertical tubing on soil water content along the experimental time

3.5 Comparisons between wetting patterns at different times

Cross sections were done on the first and last day after irrigation to measure and present the mean wetting patterns as influenced by the different vertical column types and depth as shown in Figure 7. The horizontal width of wetting was higher than the vertical wetting depth in the DI treatments.

In tubed soil, the area wetted at each emission point is usually small at the soil surface and expands to depth to form a bulb-shaped cross-section. The DI treatment, however, the resultant area wetted at the soil surface was wide and reduced with depth to form a semi spherical-shaped cross-section (Figure 7-DI). The semi spherical shape becomes very sharp at vertical tubes treatments and reduces to a "U" shape at S40, C20 and C40.

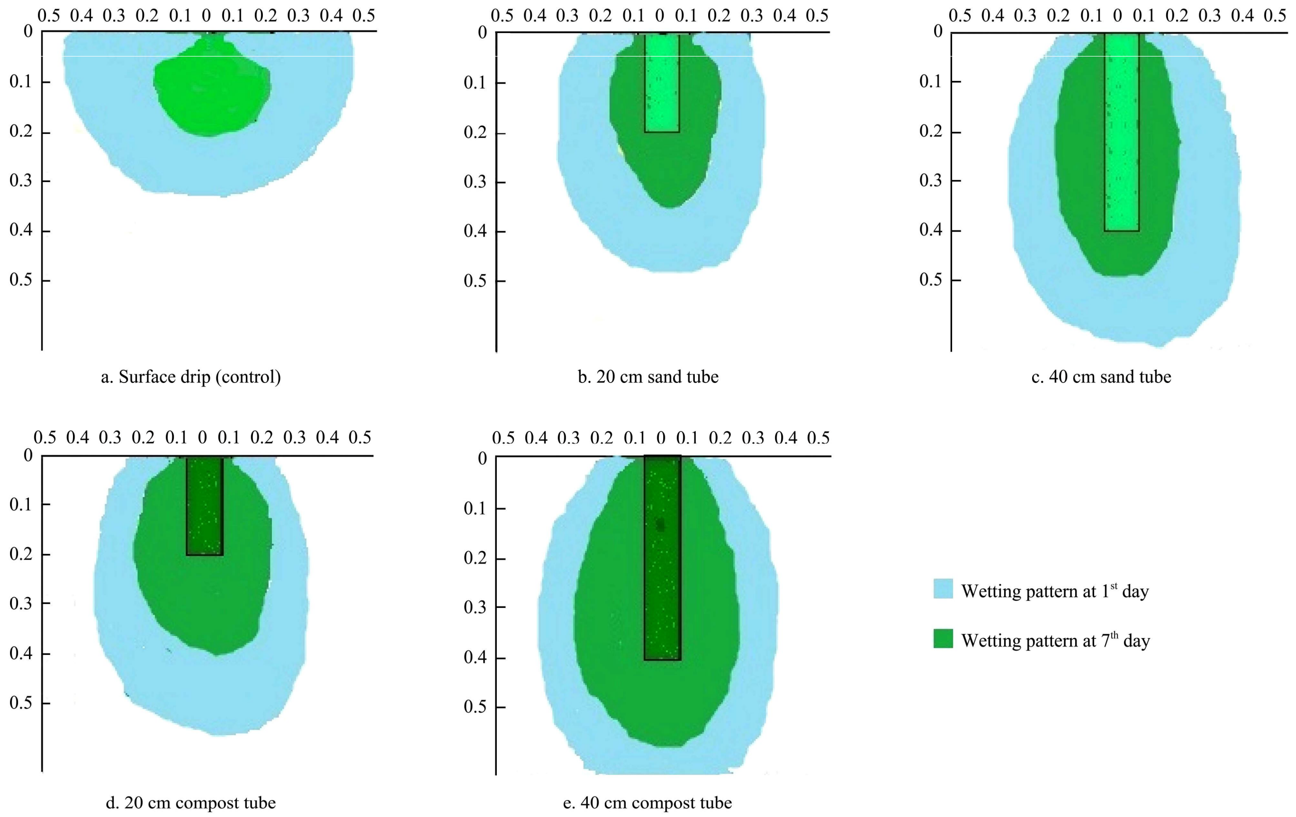

Figure 7 Schematic diagram for the vertical wetted area after 1st and 7th day

Soils suffering from surface crust or fine structure have the highest water loss potential due to evaporation from the large wetted surface area and runoff (Al-Qinna and Abu-Awwad, 1998; Abu-Awwad, 1998a). Selecting the suitable vertical mulch to be used on arid soils suffering from surface crust are thus important to enhance vertical water penetration and to reduce wetting soil surface, thereby lessening water loss by evaporation.

3.6 Statistical analysis

Analysis of variance for the vertical mulch level factor (Table 3) showed that at all soil depths, the mulching type and depth are significantly effective factors in soil water storage. Mean separation (Duncan's multiple range test) showed the C40 level had higher water content than the other levels at 40 and 60 cm depths. For the S40, C20 and C40 levels it was not significant at the surface layer (0-20 cm) and it was a slight variation in behavior noted between them noticed in the 40 cm depth. At 40-60 layer, it was significant only as time passes and the soil becomes drier specially for C40 because of the

Table 3 Statistical analysis of variance for the vertical mulch level factor

Treatments	Water content/%		
	0-20 cm	20-40 cm	40-60 cm
DI	38 a	38 a	33 a
S20	40 b	41 b	36 b
S40	42 c	44 ce	40 c
C20	43 c	43 c	40 c
C40	43 c	45 e	46 e

Note: LSD "least significance difference" 0.747 (at 5%).

compost physical properties that can saturate with more than 90% of moisture content (clayey soil saturated with 60% moisture content).

3.7 Impact of vertical mulch on soil water loss through evaporation

Using a vertical mulch, water can be transferred to 20–40 cm below the soil surface, leading to decrease the surface wetted area and reduce water loss due to evaporation from the soil surface. The root zone water content of treatments was compared to the DI calculating the amounts of water that can be saved. In addition, the difference in water content, which was solely due to the presence of vertical mulch, was calculated. The savings are considered in the case where C40 is used (11 L/emitter), while (8 L/emitter) savings are considered in the case where C20 and S40 mulch were used. If these values are applied to typical orchard areas at Kalyobia Governorate in Egypt (where the study had been conducted) a significant volume of water will be saved. Because of 30% of the district orchard area are large holdings, it will be easy to apply drip irrigation with vertical mulch instead of surface irrigation with minimum cost.

So, the water saving can be calculated as follows:

- considering 30% of orchards applied C20 or S40 (8 L/emitter saving)
- the total orchard area is 20000 ha, so 30% × 20000 = 6000 ha
- average number of trees = 500 tree/ha
- number of emitters = 2/tree
- average number of irrigation times in summer season=10

Then: the total water saving= 0.48 million m^3

It can be increased to 0.66 million m^3 in case of using C40.

Taking the previous values as a rough estimation, more than a half million cubic meters of water can be saved in the summer (water scarce period) in the case were vertical compost or sand mulches are used.

4 Conclusions

Reducing evaporation losses in drip irrigation can increase the water application efficiency and save water in regions where water scarcity has become a serious issue. In the vertical distribution of soil water content under vertical mulch tube discussed above, water could be transferred to the root zone of the plants through the sand or compost tube. Vertical mulching could more significantly reduce water loss compared to DI, especially in arid and semiarid regions that experience severe evaporation.

Under vertical mulch, water can be transferred to the soil layer at the depth of 20-40 cm below the soil surface. It decreases the surface wetted area by 75% comparable with surface drip irrigation and lessening water loss because of evaporation from the soil surface. Results showed the soil water content of C40 in the 7th day at whole profile was 14% water content higher than DI. Those will be sufficient for deep rootstocks for most orchards according to Castle and Krezdorn (1975) and Dzingai (2010). The soil water content for C20 and S40 were similar (9% and 10% over DI) and S20 showed low difference than DI.

A vertical mulch has the potential to reduce the evaporation loss of soil water from the soil surface. This has a positive impact on soil water content conservation, improves irrigation efficiency, and decreases evaporation in heavy or crusted soil regions. On the other hand, vertical mulching using compost can be used in the sandy soils as an add factor for moisture conservation in the root zone. Also benefits of study can be enlarged when using adding-compost (as an annual organic fertilizer of orchards) as the vertical mulch. It can be buried in column beneath the drip emitters with 20 or 40 cm depth according to the tree age. In this case the cost of vertical column structure can be reduced than if it is done separately.

Finally, this work considered as the first part of a research project to apply the introduced technique. The positive results will be used with banana (shallow roots) and orange trees (deep roots) to evaluate the wetted bulb when is full of roots up taking water during the irrigation season.

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