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MANAGEMENT OF SUB-SURFACE DRIP IRRIGATION SYSTEM AND WATER SAVING IN GREENHOUSE

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SUMMARY- The main objective of this study was to evaluate the suitability of sub-surface drip irrigation system at different depths of lateral line and at different spacing between drippers in greenhouse. For this goal, field experiment was conducted at Inshas Experimental Station (IES), Water Management Research Institute (WMRI), National Water Research Center (NWRC), Ministry of Water Resources and Irrigation (MWRI), Sharkiya Governorate, Egypt. Hot-pepper plants (Calcium Annul) were transplanted under greenhouse and irrigated by sub-surface drip irrigation system with different burial depths (0, 20 and 25 cm) and different distances between drippers (30 and 50 cm). The results demonstrated that, water consumption of Hot-pepper, which was determined using the equation of class A pan evaporation during initial, development and harvesting stages were 11.82 %, 21.98 %, and 66.20 % from the total water application for all treatments. For sub-surface drip lateral treatments, the average rate of growing was the highest at 20 cm depth of lateral line beneath the soil surface with both 30 cm and 50 cm of emitter spacing, where it was 13.95 and 13.94 cm/month respectively. In case of sub-surface drip laterals, the wider emitter the higher yield at all depths. On contrary, in case of surface drip laterals, the closer emitters the higher yield. The results recommended that the surface drip (zero depth) effective than 20 and 25 cm depths. Hence, the zero depth of lateral resulted in higher yield and more efficient of fertilizer uses. The highest gross margin (283.2 LE/treatment/season) was recorded by surface drip irrigation system (zero depth) with 50 cm spacing followed by 30 cm spacing (279.1 LE/treatment/season). This due to high value of total revenue and fruits yield, which affected by the distance between drippers and the depth of lateral line that effect on optimal moisture and salt distribution patterns and nutrient elements in the root zone.

Key words: Surface drip, Sub-surface drip, Water management, Water saving, Hot pepper, Greenhouse.

INTRODUCTION

As land and water resources become increasingly limited for agriculture in many parts of the world, there has been a rapid upsurge in the production of high value crops under plastic and glass greenhouses. Intensive systems are more and more requested in order to get maximum yield with minimum use of these resources.

Protected agriculture has enabled many countries to greatly extend their food production capability. According to the FAO (1990a), in Mediterranean and arid climates, nearly 200.000 ha are under off- season protected cultivation. This protected area is the equivalent to 1.000.000 ha or more in terms of horticulture production of open field area and to the output of some 10.000.000 ha, in terms of crop value. Studies showed that the greenhouses area in Egypt is about 126 ha (300 feddans) (FAO, 1990a).

From the practical point of view, normally the greenhouse grower is not especially interested in water saving. The scarce knowledge about the suitability of irrigation systems and water requirements among growers induce them to over-irrigate (in order to avoid potential yield reductions). A proper information on the irrigation systems and water requirements, spreaded at the farm level, can help to overcome this lack of information to reduce the water demand and simultaneously increase the yield. Drip irrigation system as a modern system of irrigation can supply water wisely.

Not only the amount of water applied is the main factor on reclaimed land but also the water distribution in the root zone and the prevention of water movement in soil profile by seepage or evaporation. The draw way of the drip irrigation system in sandy soils is a narrow water column under the emitter, conducting water to great depth in soil profile. To prevent this, a horizontal treatment should be applied to the top soil, so that the water will move horizontally due to the peel of capillary. Appling both surface and sub-surface drip irrigation systems efficiently in greenhouses, depends upon the interaction between emitter spacing and the depth of lateral line beneath the soil surface.

A well-designed drip irrigation system must be properly managed (avoiding clogging) to preserve high emission uniformity, in order to reach a better water use efficiency, limiting the environmental impact of leached fertilizers and salts. The use of the class an evaporation pan is a simple and reliable method to quantify evapotranspiration (ET) inside the greenhouse in Mediterranean areas. A wide range of techniques and cultural practices to reduce the water requirements, increase the water availability and raise the yields can contribute to save water and improve the water use efficiency and productivity (Castilla, 2000).

Phene et al. (1992) reported that, sub-surface drip irrigation, in which the laterals are buried permanently at 20-60 cm below the soil surface, has been used to provide the control and uniformity of water and fertilizer distribution necessary to maximize tomato yield and water-use efficiency. Yields of red tomatoes exceeding 200 Mg/ha (80 Mg/fed) were achieved in large yield plot experiments with cv. UC-82B. Commercial yields of 150 Mg/ha (60 Mg/fed) were also achieved in large-scale field applications with a lower degree of control.

Cafe and Duniway (1996) showed that, the location of emitters had major effects on incidence of diseased pepper plants, severity of root symptoms, yield, shoot dry weight, level of soil moisture and plant leaf water potential. Disease levels were highest with emitters at the soil surface and in the pepper plant row. The sub-surface (15 cm deep) position gave the most efficient control in the field without reducing yields in no infested plots.

El Awady et al. (2003) reported that, evaporation decreased with increasing drip line depth and evapotranspiration from sub-surface drip irrigation could be reduced to 40 % when the drip line is buried at a depth of 15 cm compared with irrigation from surface drip line, with sorghum crop. They also added that sorghum growth increased by 69 % by weight under sub-surface drip compared with surface drip line, Experiment on spinach showed a similar trend of enhanced growth with optimum drip line depth of 20 cm. Surface mulching increased crop yield by 40 % in spinach with surface drip line and with less pronounced effect on sorghum. Underneath foil mulch) enhanced root growth, in general and gave 18% increase in the yie1d of spinach.

El-Gindy et al. (1996) showed that, two field experiments were conducted at Maryout, Egypt, to evaluate the use of surface and sub-surface drip irrigation for vegetable crops production. The soil was a Typic Calciorthid, which was only marginally suitable due to salinity and high carbonate content. Irrigation water quality was moderate. Soil moisture, salinity, root density, yield, and water use efficiency were considered for cucumber (Cucumis sativus) under plastic and open field tomatoes (Lycopersicon esculentum) for both irrigation systems. Less salt accumulation and more dense roots were observed under sub-surface drip irrigation in both cucumber and tomatoes. Crop yield and water use efficiency were slightly higher when applying 4 liters/h daily through sub-surface drip irrigation. Therefore, sub-surface drip irrigation may be more suitable for vegetable production in the highly calcareous soil of Maryout. Irrigation scheduling in such soil was of major importance.

The main objective of this study was to evaluate the suitability of sub-surface drip irrigation system at different depths of lateral line and at different spacing between emitters in greenhouse. The evaluation of the performance was from the point of view of the following parameters:

1. The actual seasonal water consumption for the Hot-pepper plants and the value of water consumption throughout the different growing stages with surface and sub-surface drip systems in greenhouses.
2. The percentage values of water savings, which may be existed as a result of using different depths and the spacing between emitters.
3. The soil moisture and salt distribution in soil profile under each irrigation system in greenhouse.

4. Plant growth and roots distribution of Hot pepper plants under each irrigation system in greenhouse in sandy soil.
5. The yield and its relation to water and fertilizer applied for each irrigation system.
6. Carrying out, a simplified cost analysis, which may be used in comparing between the suitability of each irrigation system in greenhouses.

MATERIALS AND METHODS

Field experiment was conducted at IES for WMRI, NWRC, MWRI, Sharkiya Governorate, Egypt. Hot-pepper (calcium Annul) plants, which were transplanted under greenhouse, were irrigated by sub-surface drip with different treatments of burial depths (0, 20 and 25 cm) and distance between drippers (30 and 50 cm) (Fig.1).

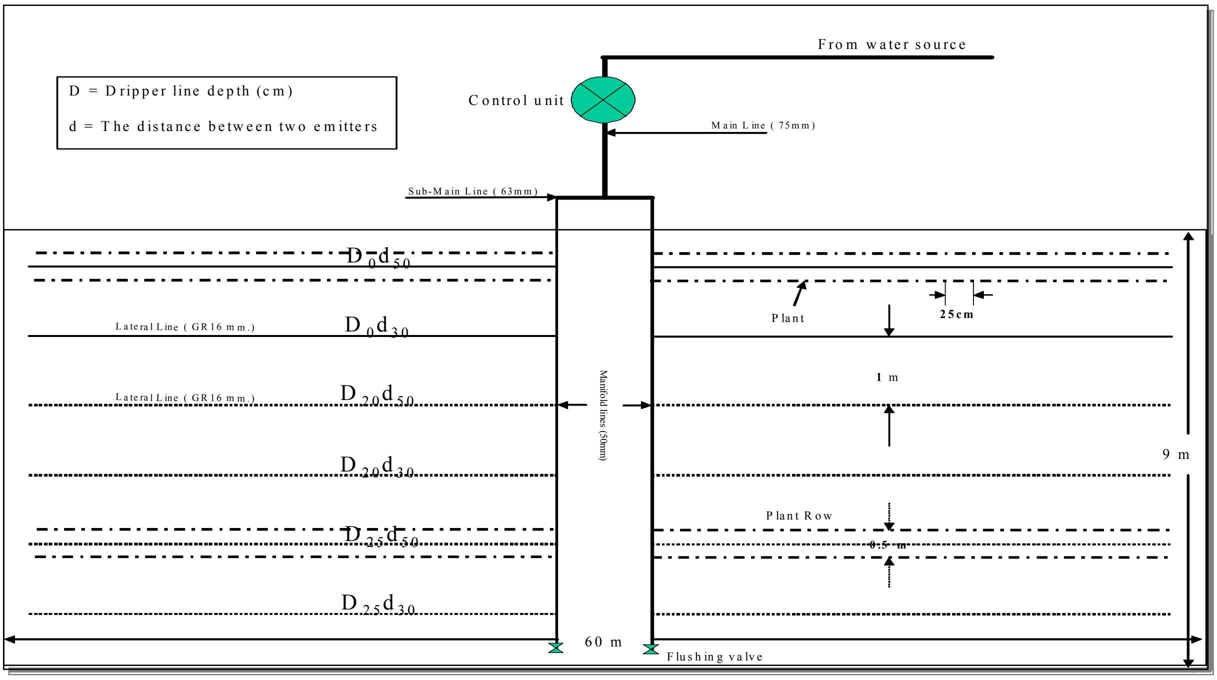

Fig.1. Layout of experimental irrigation system under greenhouse

Experimental site

The experimental site had the following characteristics: (longitude 31.35 E°, latitude 30.24 N° and altitude 25.5 m). The soil texture is sandy with field capacity of 8.04 %, wilting point 3.7 %, soil bulk density of 1.49-gm/cm^3 and infiltration rate 12.47 cm/hr. The total experimental area was 540 m^2 (1/8 feddan) cultivated under greenhouse with Hot pepper (calcium Annul). The irrigation water source was surface water (El-Esmaliya canal). The chemical analysis of irrigation water is presented in *Table 1* and soil physical and chemical properties are shown in *Tables 2* and *3*.

Table 1. Chemical analysis of the used water in irrigation

pH	EC (dSm^{-1})	Cations (meq/l)				Anions (meq/l)				SAR*
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{--}	
7.55	0.38	1.8	0.67	1.04	0.15	-	3.38	0.56	0.13	0.99

* SAR = Sodium Adsorption Ratio

Table 2. Soil physical properties of Inshas site

Profile No.	Depth (cm)	pH	EC (dSm^{-1})	Cations (meq/l)				Anions (meq/l)				SAR*
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{--}	
1	0-15	7.5	0.15	0.9	0.6	0.3	0.01	-	1.00	0.64	1.17	0.35
	15-30	8.2	0.15	0.6	0.9	0.3	0.01	-	1.10	0.64	0.07	0.35
	30-45	8.1	0.82	6.6	3.0	0.3	0.03	-	2.15	0.88	6.90	0.14
	45-60	7.7	0.75	6.5	1.5	0.3	0.03	-	4.73	0.80	2.81	0.15
	60-75	7.4	0.67	5.4	1.8	0.4	0.01	-	2.15	0.96	4.51	0.21
	75-90	7.3	0.54	6.0	0.6	0.6	0.05	-	1.27	0.64	5.35	0.33
Mean	0-90	7.7	0.51	4.33	1.40	0.37	0.02	-	2.07	0.76	3.47	0.25

* SAR = Sodium Adsorption Ratio

Table 3. Soil chemical properties of Inshas site

Profile No.	Depth (cm)	Bulk density, g/cm^3	Field capacity, (%)	Particle size dist., (%)				Wilting Point*, (%)	Hydraulic Conductivity, (cm/s)	Soil texture
				Sand	Silt	Clay	Organic matter			
1	0-15	1.40	9.60	87.6	5.3	5.8	1.3	3.7	3.5×10^{-3}	Sandy
	15-30	1.52	8.80							
	30-45	1.51	7.90							
	45-60	1.54	7.56							
Mean	0-60	1.49	8.04	87.6	5.3	5.8	1.3	3.7	3.5×10^{-3}	Sandy

* Calculated on volume basis

Experimental procedure

The Hot-pepper plants (calcium Annul) were transplanted in 5 January 2005 (Fig. 2). Seeds were planted in a small area as a nursery for preparing the seedlings, which were transplanted at the age of 40 days to the experimental location.

Seedlings were homogeneous and had the same height. The seedlings were planted 25 cm apart on the row and 50 cm in spacing between rows. The seedlings were irrigated directly after transplanting. Usual practices were applied to the plants from fertilization, weed and pest control using the recommended dozes of fertilizer and pesticides. For each treatment, one square meter was selected randomly and replicated three times for plant measurements (plant height each month, plant numbering and yield every 15 days). The obtained values of plant height were averaged for each treatment. The flowering stage started after 40 days of transplanting for different treatment. After 55 days of flowering, fruits were picked after two weeks along four months for all treatments. Fruit weights were recorded for each experimental plot and the total yield for each treatment was obtained.

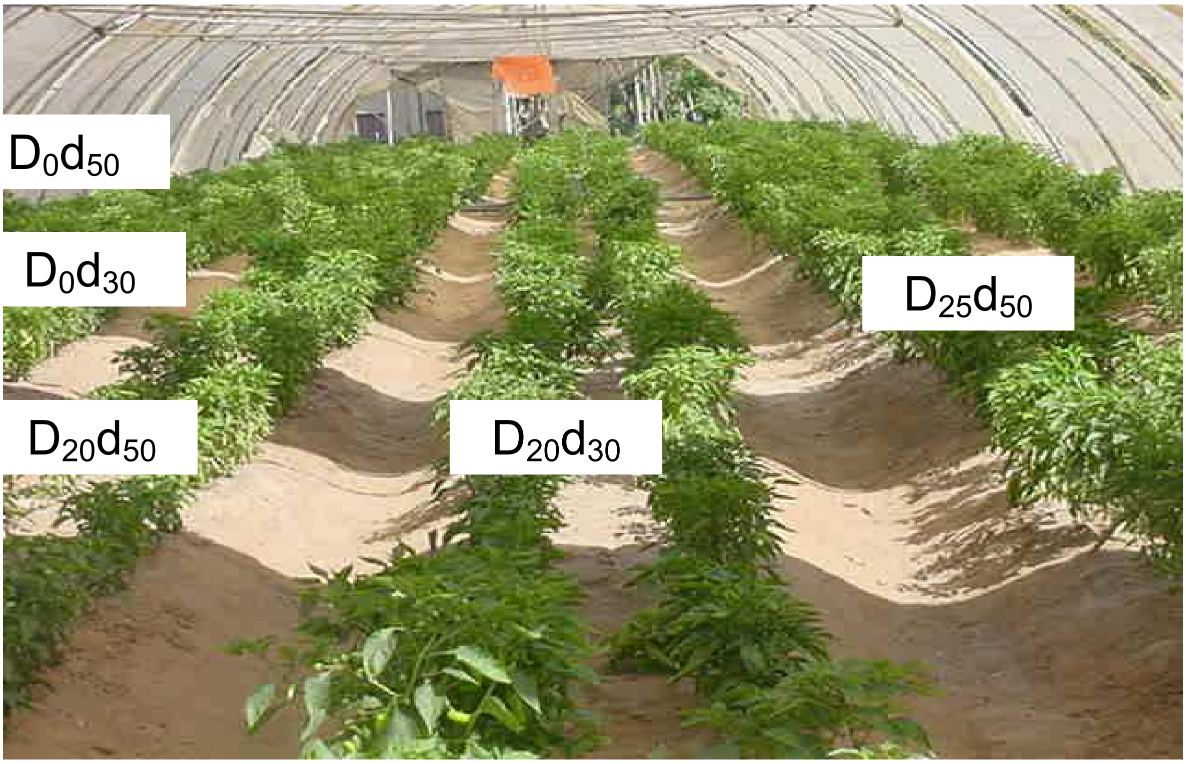

Fig. 2. Experimental procedure for drip irrigated Hot pepper under greenhouse.

Crop water requirements calculation

The evaporation pan as shown in Fig. 3 was established inside the greenhouse to provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface.

Fig. 3. Class A pan evaporation for measuring evaporation E_{pan} in greenhouse

In a similar fashion the plant responds to the same climatic variables but several major factors may produce significant differences in loss of water (Doorenbos and Pruitt model, 1977). Reference crop evapotranspiration (ETp) can be obtained from the following equation:

$$ETp = Kp.\ Epan \qquad (1)$$

Where:

Epan: pan evaporation in mm/day and represents the mean daily value of the period considered; and
Kp: pan coefficient (0.7).

ETp was calculated from equation 1 and has been used in calculating the gross irrigation requirements (IRg) from the following equation given by FAO Irrigation and Drainage Paper (36), (1980) as follows:

$$IRg = (A.\ ETp.\ Kc.\ Kr + Lr) / Ea \qquad (2)$$

Where:

IRg: gross irrigation requirements, (l / day);
A: the total area allocated to each plant, (m^2 / plant);
Etp: average potential evapotranspiration, (mm / day) which can be calculated by equation 1 that equation related to the locally measured metrological station and pan evaporation data;
Kc: the crop factor according to the months within the growing season;
Kr: reduction factor of minimum of Gc / 0.85 where, Gc is the area shaded by the crop as percentage of the total area percentage, in this study Kr was taken as 100% for row crops;
Ea: the irrigation efficiency in %; and
Lr: the extra amount of water needed for leaching, it can be calculated according to FAO irrigation and drainage paper (29), (1985) as follows:

$$Lr: Ecw / \text{maximum } Ece \ \ (\text{Unit}) \qquad (3)$$

Where:

Ecw: salinity of the applied irrigation water, (dS / m); and
Ece: average soil salinity tolerated by the crop as measured on a soil saturated extract.

Moisture distribution patterns

It is important to wet a relatively large part of the potential root system and to have a large enough volume of moist soil to promote root intention and water uptake. Water distribution in soil profile for Hot pepper treatments was presented by contour maps. For each treatment, nine locations around the selected plant was considered and spacing at 12.5 cm for the samples which located parallel with plants row but at 25 cm for the samples which located perpendicular to plants row. Moisture content for each location has been measured at the surface and the depth of 60 cm with 15 cm increment. This procedure was carried out for all treatments twice along the season; one before irrigation and the other was 24 hours after irrigation. The contour maps were derived considering that; there is symmetry around the irrigation line for both left and right hand side. The total number of moisture data points was 36 points, 24 of them were measured and 12 were obtained symmetrically.

These 36 points were arranged in a matrix of 3 columns and 4 rows and the program (SURFER 8) was used for developing moisture content lines. Kriging method was used for the calculation of the intermediate points at equal distances. Each intermediate point was estimated from neighbors, using a linear regression model. Contour maps for moisture distribution with depth were constructed by averaging the data of three columns in each layer for each depth. This will produce a plane of contours parallel to the irrigation line for each treatment under greenhouse.

Salt distribution patterns and movements

Salt distribution and accumulation under different irrigation systems is an important factor in the evaluation of each system. Whereas, the accepted system, produces a remarkable moisture distribution in root zone and remove salts. Electrical conductivity (EC) in dS/m for each moisture sample has been measured. The values of EC were used in constructing the contour maps of salt distribution for each system. The same procedure in deriving contour maps for moisture distribution was used in obtaining the contour maps for salt distribution for each irrigation system. The procedure of salt distribution was carried out at the end of the agricultural season.

Root system distribution

For each treatment, the root zone was divided into four layers each having the dimension of 25 cm width, 50 cm length and 15 cm in depth. The hall weight of roots for each treatment was measured and separating the soil from the layer by a coarse sieve derived the weight of roots in each layer. This procedure was carried out at the end of the growing season for an individual plant for each treatment. The percent of root weight in each layer can be used in differentiation between treatments.

Water use efficiency

Water use efficiency was used to evaluate various irrigation regimes which produce maximum yield per unit of water consumed by the crop or applied in the field. The crop water use efficiency (CWUE) is expressed as kg fruits/m^3 water applied for Hot pepper (Begg and Turner, 1976).

Cost analysis

Cost analysis of irrigation systems was derived due to the capital cost for each irrigation system. Cost analysis was carried out by using the current dealer prices for equipment and installation according to year 2005 prices level and Hot pepper production cost, which was determined according to agricultural census issues of Ministry of Agriculture (MOA) in 2005. The determination of the irrigation system cost depends on many factors such as irrigation system components price, energy requirements, fuel costs and labor costs. Therefore, the total irrigation costs are divided into two categories, fixed costs and variable costs; it was calculated by following equation (Hunt, 1983):

$$Tc = Fc + Vc \tag{4}$$

Where:

Tc: the total irrigation cost (LE);
Fc: the fixed cost of the irrigation system (LE); and
Vc: the variable cost (LE).

The following equation was used to determine the fixed cost:

$$Fc = Dc + Ic \tag{5}$$

Where:

Fc: the fixed cost (LE);
Dc: the depreciation (LE); and
Ic: the interest rate (12% for irrigation system equipments).

The annual depreciation can be calculated using the following equation:

$$D = (P-S)/L \quad (6)$$

Where:

P: Purchase price (LE);
S: Salvage value (LE); and
L: Time between purchasing & sale (years).

Variable costs include repair and maintenance, fuel and lubricate of pump, and labors. The actual estimate of variable costs is usually based on operation hours, the following equations were used to determine variable costs component:

$$Rc + Mc = 3\% \text{ drip irrigation systems respectively} \quad (7)$$

Where:

Rc+Mc: the repairing and maintenance (LE); and
Fc: fixed cost of the irrigation system (LE).

$$fc = fcr * fp \quad (8)$$

Where:

fc: the fuel cost (LE/hr);
fcr: the fuel consumption rate (lit/hr); and
fp: the fuel price (LE/lit).

The Cost for pump operator and irrigation labor were estimated by multiplying the cost of one hour by the number of irrigation events and by total required labor hours per one irrigation events.

$$\text{Total costs} = \text{Fixed costs} + \text{Variable costs} + \text{Agricultural costs} \quad (9)$$

RESULTS AND DISCUSSION

Water application depth

The growing season of hot pepper cultivated in green houses was divided into three stages, which are initial stage, development stage and harvesting stage. *Table 4* presented water application depth for each stage and total water applied for all treatments. The presented results showed that, the water consumption during initial, development and harvesting stages are 11.82 %, 21.98 % and 66.20 % from the total water application for all treatments. The highest percentage of water consumption during the harvesting stage (66.20 %) was due to increase the rate of growing of the hot pepper fruits that needs a lot of water comparing with both initial and development stages. The presented data in Table 4 showed that emitter, spacing and lateral depth almost did not effect on water application depth, which means that the water application depth during the growing season depends only on the climatic condition and soil status in the green house besides the rate of growing of the hot pepper.

Table 4. Water application depth (mm) for different growing stages at different emitter spacing and lateral depth

Days from Trans planting		Growing stage	KC	Water application depth (mm)					
				D_0d_{30}	D_0d_{50}	$D_{20}d_{30}$	$D_{20}d_{50}$	$D_{25}d_{30}$	$D_{25}d_{50}$
From 05/01/2005 To 01/03/2005	54 days	Initial	0.6	5.30	5.30	4.87	4.87	4.87	4.87
Percent from total water applied				11.82	11.82	11.82	11.82	11.82	11.82
From 02/03/2005 To 15/04/2005	44 days	Developme nt	1.02	9.86	9.86	9.05	9.05	9.05	9.05
Percent from total water applied				21.98	21.98	21.98	21.98	21.98	21.98
From 16/04/2005 To 24/06/2005	69 days	Harvest	1.05	29.68	29.68	27.26	27.26	27.26	27.26
Percent from total water applied				66.20	66.20	66.20	66.20	66.20	66.20
Total water applied (mm)				**44.83**	**44.83**	**41.17**	**41.17**	**41.17**	**41.17**

Soil moisture distribution pattern in soil profile

To study how much water that soil maintain in root zone post irrigation, the soil moisture content was measured within soil depth and around the pepper plant 24 hours after irrigation. Figure 4 demonstrates the contour maps of soil moisture distribution with soil depth for all treatments at 24 hours after irrigation. Generally, for all treatments the value of soil moisture content increased with depth and spread horizontally according to both the depth of lateral line and emitter spacing. The best and highest uniform distribution of soil moisture was observed when the lateral line buried at 20 cm depth beneath the soil surface with 30 cm of emitter spacing. This was due to the highest value of soil moisture (12.5%), which recorded to a depth up to 50 cm of soil profile. The other subsurface drip laterals recorded a remarkable uniform distribution of soil moisture either with 30 cm or 50 cm spacing. As for the surface drip lateral, the results recommended the 30 cm spacing, where the distribution of soil moisture was the best. It gave a gradual increase of soil moisture down ward with soil depth. In addition gave a uniform distribution of soil moisture horizontally around the pepper plant.

Salt distribution pattern in soil profile

Salt accumulation in root zone is considered as a fetal problem, which existed in both surface and subsurface drip irrigation systems. For all tested treatments, salt distribution and accumulation in root zone were measured as value of EC both down ward with soil depth and horizontally around the pepper plant. Figure 5 showed the contour maps of the distribution of salts for all treatments at the middle of the growing season. The results in Figure 5 showed that, for surface drip lateral treatments, the value of EC decreased when moving downward with soil depth and spread horizontally to cover all the profile of root zone. In addition the lowest values of EC were located at effective surface layer of soil profile. For sub surface drip lateral treatments, the value of EC increased when moving down ward with soil depth except for the sub surface treatment (the lateral buried at 20 cm depth beneath the soil surface with 30 cm spacing) where the value of EC decreased down ward with soil depth. As for the value of spacing, it can be noticed that, the lower the spacing the lower the value of EC. This was occurred for both surface and sub-surface drip lateral treatments. Closer the spacing lower the value of EC. Therefore, the 30 cm spacing might be recommended to achieve the lowest accumulation of salt in root zone besides having a uniform distribution of salts that can be reflected in increasing the yield.

Growth indicators

The most important growth indicators of hot pepper plants, which were plant height and fruits yield were studied as following:

D_0d_{30}= zero depth with 30 cm emitter spacing
$D_{20}d_{30}$= 20cm depth with 30 cm emitter spacing
$D_{25}d_{30}$= 25cm depth with 30 cm emitter spacing
D_0d_{50}= zero depth with 50 cm emitter spacing
$D_{20}d_{50}$= 20cm depth with 50 cm emitter spacing
$D_{25}d_{50}$= 25cm depth with 50 cm emitter spacing

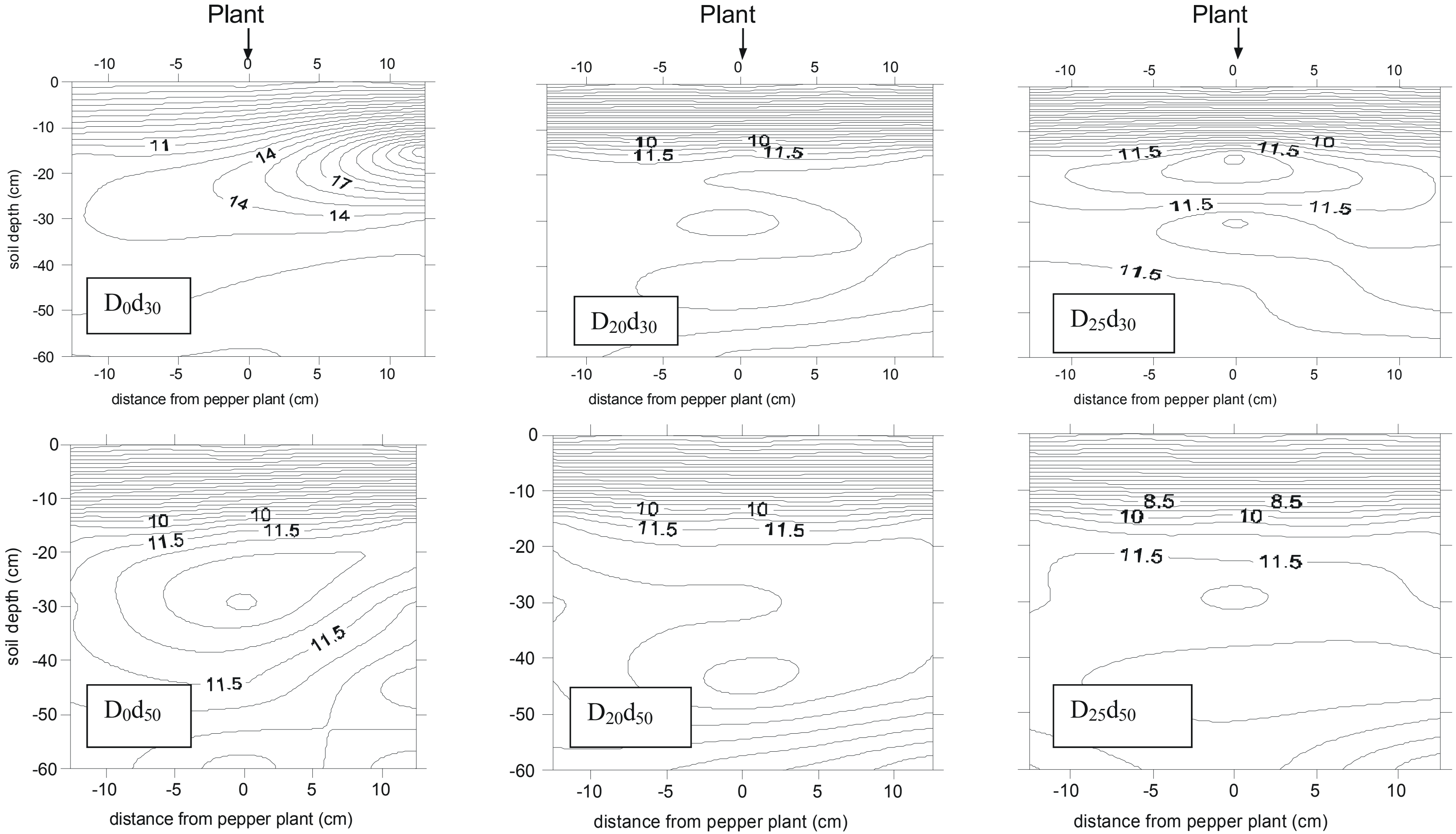

Fig. 4. Contour maps of soil moisture distribution in soil profile at 24 hr after irrigation

D_0d_{30}= zero depth with 30 cm emitter spacing
D_0d_{50}= zero depth with 50 cm emitter spacing
$D_{20}d_{30}$= 20cm depth with 30 cm emitter spacing
$D_{20}d_{50}$= 20cm depth with 50 cm emitter spacing
$D_{25}d_{30}$= 25cm depth with 30 cm emitter spacing
$D_{25}d_{50}$= 25cm depth with 50 cm emitter spacing

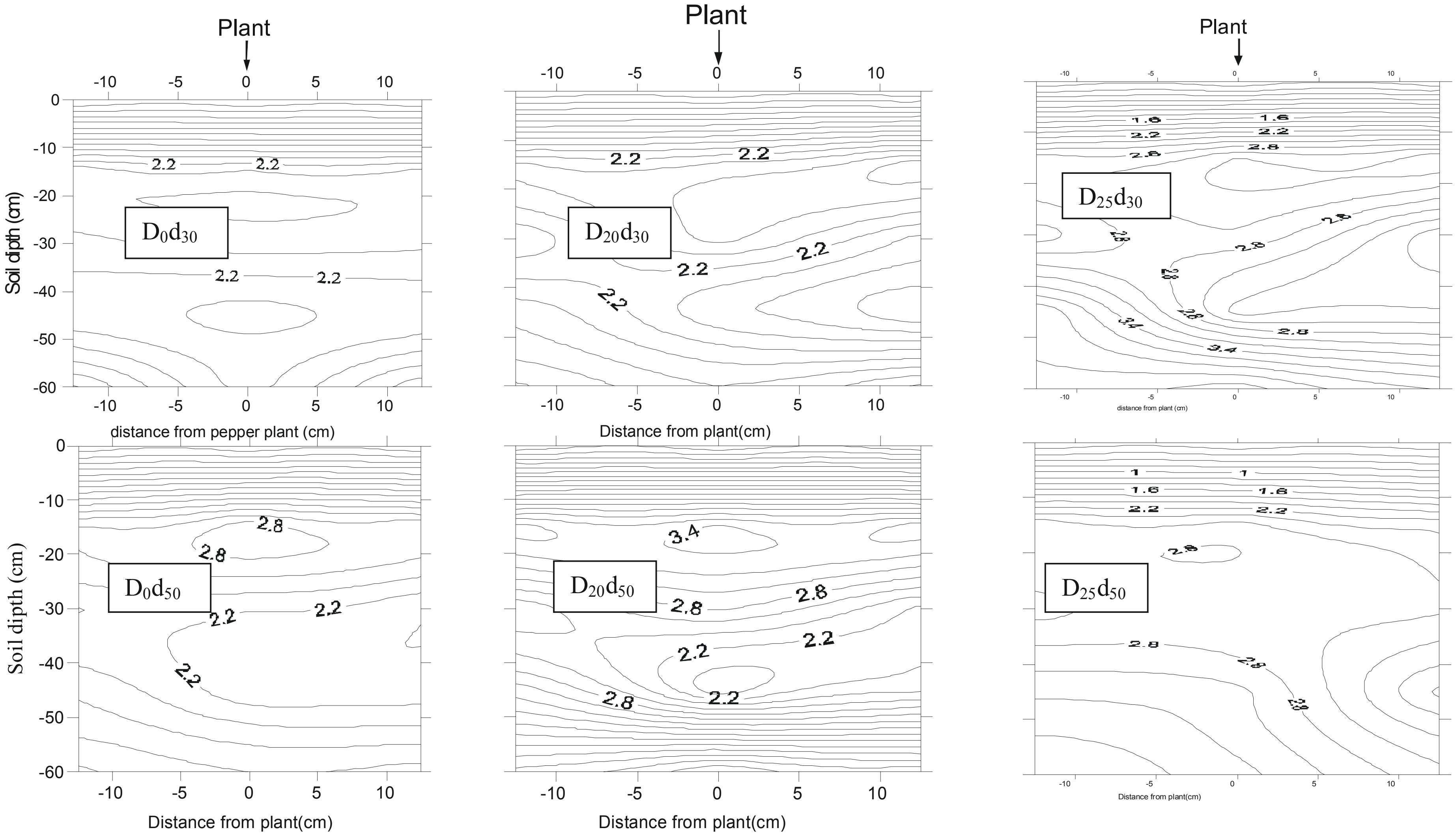

Fig. 5. Contour maps of soil salt distribution in soil profile before irrigation for all tested treatments at the end of the growing season.

Pepper plant height

For all treatments, pepper plant height was measured each month. The measurements were started after 60 days from transplanting. The data presented in Table 5 showed the average plant height each month and the average rate of growing in cm/month for all treatments. These data showed that, with surface drip lateral at 50 cm of spacing, the pepper plant was longer than that with surface drip lateral at 30 cm of spacing. In addition, the average rate of growing (13.77cm/month) at 50 cm spacing was greater than that calculated at 30 cm of spacing where it was (11.33 cm/month). For sub surface drip lateral treatment, the average rate of growing was the highest at 20 cm depth of lateral beneath the soil surface with both 30 cm and 50 cm of spacing, where it was 13.94 and 13.94cm/month respectively. The other depth of lateral beneath the soil surface (25 cm) recorded the lowest values of average rate of growing with 30 cm and 50 cm of spacing, where it was 11.92 and 12.33 cm/, respectively.

Table 5. Plant height of Hot pepper under different depths of sub-surface drip irrigation under greenhouse.

Treatments	Average plant height (cm)				Averagerate of growing cm/month
	Days from transplanting				
	60	90	120	150	
D_0d_{30}	20.38	36.54	45.60	54.36	11.33
D_0d_{50}	24.29	39.46	57.59	65.60	13.77
$D_{20}d_{30}$	19.24	32.27	50.76	61.08	13.95
$D_{20}d_{50}$	16.68	31.48	47.49	58.49	13.94
$D_{25}d_{30}$	18.54	28.86	46.60	54.29	11.92
$D_{25}d_{50}$	14.50	25.33	44.92	51.50	12.33

Root system distribution

Distribution of roots in soil profile either by weight bases or by volume bases is a considerable parameter, which can be used in comparing between treatments. Fig. 6 presented both of root weight and percent of root weight with soil depth for all treatments based on weight of both main and lateral roots in each depth. Expansion of roots horizontally or vertically depends on lateral depth beneath the soil surface and spacing between emitters. Increasing the lateral depth with 50 cm of spacing, led to increase the percent of root weight in soil surface layer up to 15 cm. Hence, the percent of root weight was 52.9%, 61.1% and 68.9% for zero, 20 and 25 cm depth of lateral beneath the soil surface. However, increasing the lateral depth with 30 cm of emitter spacing led to decrease the percent of root weight in soil surface layer up to 15 cm. Hence, the percent of root weight was 61.1%, 59.3% and 57.8% for zero, 20 and 25 cm depth of lateral beneath the soil surface. This may be due to the insufficient of moisture resulted by the wider spacing, which forced the plant to expand its lateral roots to be able to absorb the required water.

As for the other depths of soil profile, the percent of root weight in each depth, varied according to both the depth and the spacing. The best distribution of roots was recorded by surface drip lateral with 30 cm spacing (D_0d_{30}), the percent of root weight decreased gradually with soil depth and wider spacing. Percent of root weight was located at the surface layers.

Fig. 7 presented the distribution of roots in soil profile based on volume bases. The distribution of roots according to volume bases took a similar trend as in case of weight bases. The percent of root volume increased with increasing the depth of lateral beneath the soil surface and 50 cm spacing. It was 53.9 %, 62.1% and 63.4 % for zero, 20 and 25 cm depth respectively. In centrally, it decreased with increasing the lateral depth at 30 cm spacing. For all treatments, the percent of root volume decreased with soil depth. The best distribution of roots according to volume bases was observed with surface drip lateral at 30cm spacing (D_0d_{30}). The interaction of lateral depth and the spacing effected strongly the root system distribution. It can be concluded that, using a closer spacing and shallower depth produced a uniform and well distributed of roots.

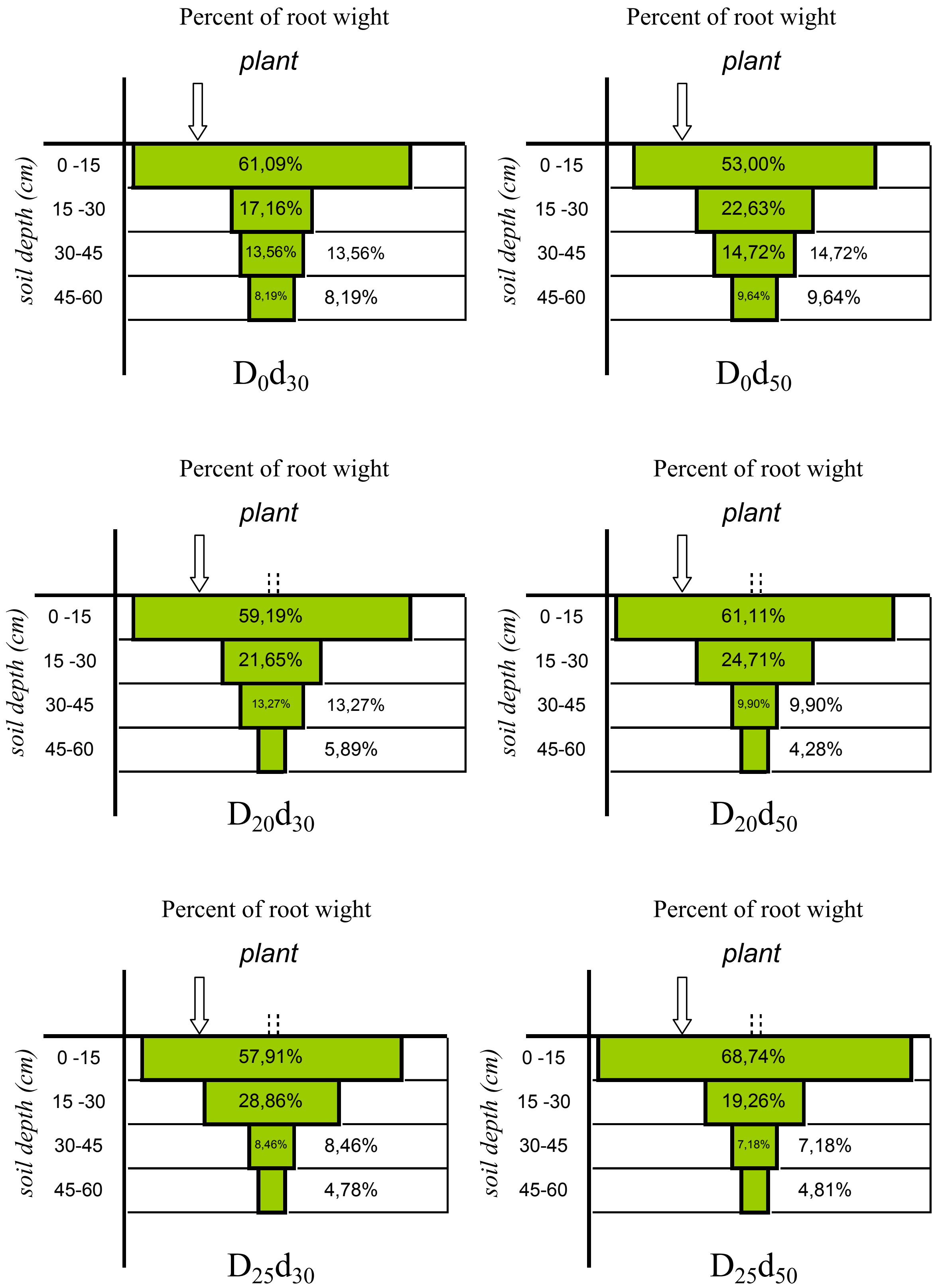

Fig. (6) : Root system distribution (weight bases) of pepper plant for all treatments.

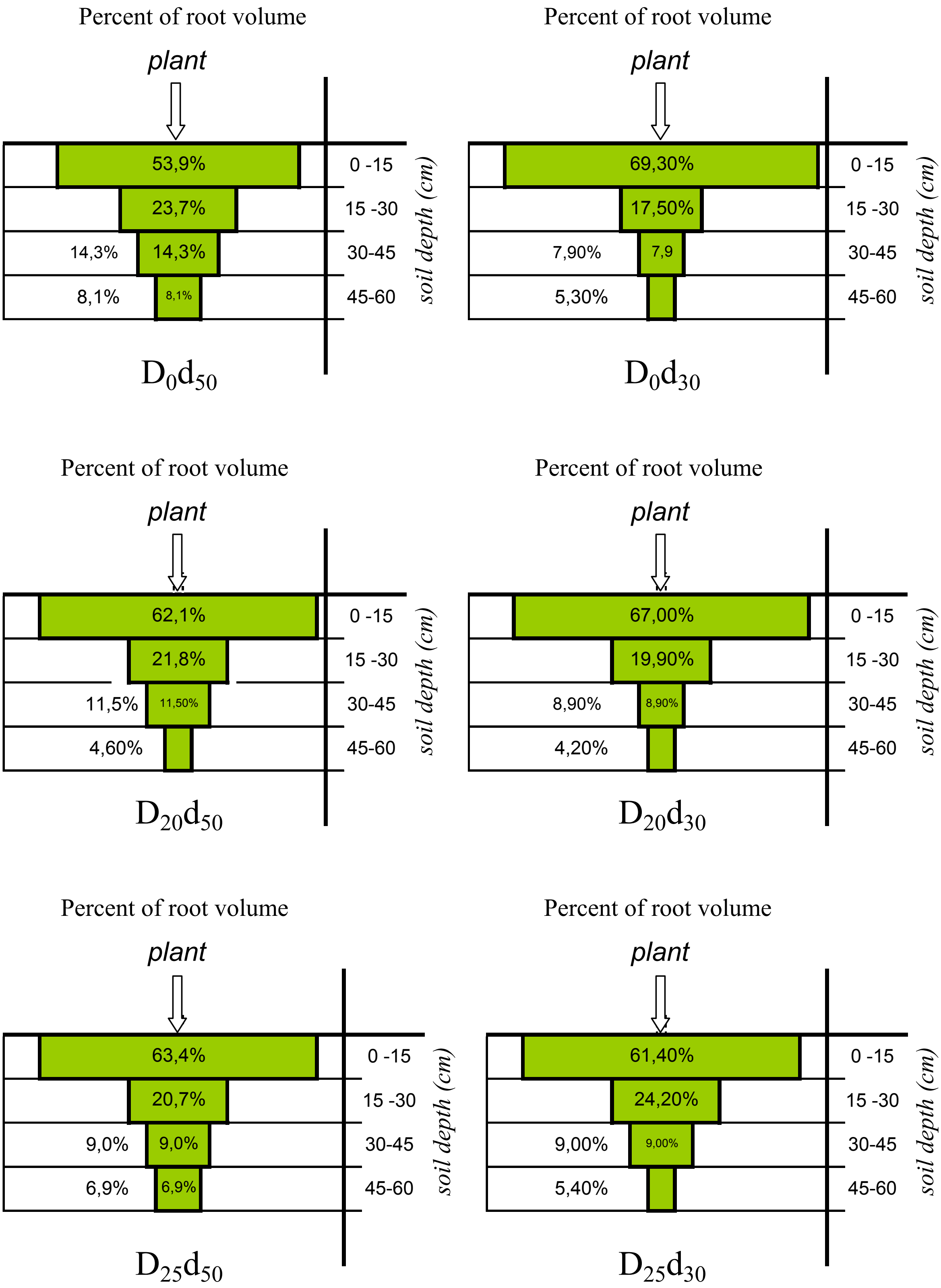

Fig. (7) : Root system distribution (volume bases) of pepper plant for all treatments.

Yield of pepper fruits and water use efficiency

Both of the obtained yield and WUE considered remarkable differentiation parameters that affected by the variation of the studied factors. *Table 6* illustrated pepper fruit yield (Mg/fed) and water use efficiency (kg/m^3) for the different treatments. It showed that, surface drip irrigation laterals resulted the highest values of fruit yield, where it was 8.36 Mg/fed and 8.26 Mg/fed at 30 and 50 cm spacing respectively. This means that, the wider the spacing in case of surface drip lateral will affect slightly in decreasing the yield, where the yield decreased by 2.42 % as the spacing increased from 30 to 50 cm. As for sub surface drip laterals, the highest value of fruit yield (7.84 Mg/fed) was achieved with 20 cm depth of lateral under the soil surface at 50 cm spacing. The lowest value of fruit yield (5.23 Mg/fed) achieved with 25 cm depth and 30 cm spacing. Table 6 also showed that, in case of sub surface drip laterals, increase the spacing from 30 cm to 50 cm led to the higher yield for both 20 and 25 cm depth of lateral. The pepper fruit yield increased by 12.4 % as the spacing increased from 30 to 50cm at 20cm depth. Also the pepper fruit yield increased by 13.79 % as the spacing increased from 30 to 50 cm at 25 cm depth of lateral. Therefore, it can be concluded that, in case of sub surface drip laterals, the wider the spacing the higher the yield at any depth. In contrary, in case of surface drip laterals, the closer the spacing the higher the yield.

Table 6. Hot-pepper fruits yield in (Mg/ fed) and water use efficiency (W.U.E) in kg/m^3 for the different tested treatments.

Treatments	Average fruit yield (kg/treatment)	Fruit yield Mg/ fed.	Seasonal water application depth (mm)	Seasonal water application m^3/ fed	Water use efficiency W.U.E (kg/m^3)
D_0d_{30}	179.10	8.36	44.84	188.33	44.38
D_0d_{50}	177.04	8.26	44.84	188.33	43.87
$D_{20}d_{30}$	151.91	7.09	41.18	172.96	40.99
$D_{20}d_{50}$	167.99	7.84	41.18	172.96	45.33
$D_{25}d_{30}$	112.10	5.23	41.18	172.96	30.25
$D_{25}d_{50}$	127.06	5.93	41.18	172.96	34.28

The value of water use efficiency reflects the best treatment, which use the applied water effectively. Table 6 showed that, the higher value of water use efficiency (45.3259 kg/m^3) was recorded with sub surface drip lateral in case of using 50cm spacing and the lateral buried at 20 cm depth beneath the soil surface. The lowest value (7.13 kg/m^3) achieved with 30 cm spacing and 25 cm depth of lateral. In case of surface drip laterals, the value of water use efficiency was also high and accepted, but it still slightly lower than sub surface with 50cm spacing at 20 cm depth. The results also recommend the 20 cm depth of lateral to be used instead of 25 cm depth. Hence, the 20cm depth of lateral resulted in higher yield and water use efficiency.

Fertilizers use efficiency

The value of fertilizer use efficiency (FUE) as well as WUE reflect the best treatment which use the applied fertilizes and water effectively. *Table 7* illustrates, the higher value of FUE (105.4 kg/kg) was recorded with surface drip lateral in case of using 50 cm spacing and a surface lateral. The lowest value (65.9 kg/kg) achieved with 30 cm spacing and 25 cm depth. In case of sub surface drip laterals, the value of FUE was also high and accepted, but it still lower than surface drip with 50 cm spacing at surface lateral. The results also recommend the surface lateral to be used instead of 20 and 25 cm depth. Hence, the surface lateral resulted in higher yield and FUE.

Table 7. Hot-pepper fruits yield in (Mg/ fed) and fertilizer use efficiency (F.U.E) in kg/kg for the different tested treatments.

Treatments	Average fruit yield (kg/treatment)	Total fertilizers Added (NPK) (kg/treatment)	Fertilizer use efficiency F.U.E (kg/kg)
D_0d_{30}	179.10	1.7	105.4
D_0d_{50}	177.04	1.7	104.1
$D_{20}d_{30}$	151.91	1.7	89.4
$D_{20}d_{50}$	167.99	1.7	98.8
$D_{25}d_{30}$	112.10	1.7	65.9
$D_{25}d_{50}$	127.06	1.7	74.7

- Average area of each treatment = 90 m^2

D_0d_{30} = zero depth and 30cm between emitters	$D_{20}d_{50}$ = 20cm depth and 50cm between emitters
D_0d_{50} = zero depth and 50cm between emitters	$D_{25}d_{30}$ = 25cm depth and 30cm between emitters
$D_{20}d_{30}$ = 20cm depth and 30cm between emitters	$D_{25}d_{50}$ = 25cm depth and 50cm between emitters

Cost analysis

A simple cost analysis has been carried out in order to derive the obtained gross margin for each depth of dripper line with different spacing (D0d30 = zero depth and 30 cm spacing, D0d50 = zero depth and 50 cm spacing, D20d30 = 20 cm depth and 30 cm spacing, D20d50 = 20 cm depth and 50 cm spacing, D25d30 = 25 cm depth and 30 cm spacing and D25d50 = 25 cm depth and 50 cm spacing) for hot pepper in greenhouse. The gross margin was calculated excluding the fixed and the rent of land costs for all treatments. Table 8 presents all the items used for carrying out the cost analysis for hot pepper under all treatments.

Total irrigation cost presented the summation of both fixed and operating costs of the irrigation system. Total variable cost represented the summation of both operating and agricultural costs. Table 8 showed that, surface drip irrigation system (zero depth) is considered the most economic system to be used for irrigating hot pepper in greenhouse.

Table 8. Seasonal total cost and gross margin in (LE/treatment/season) for hot pepper under thedrip irrigation system treatments in greenhouse.

Cost items	**D_0d_{30}**	**D_0d_{50}**	**$D_{20}d_{30}$**	**$D_{20}d_{50}$**	**$D_{25}d_{30}$**	**$D_{25}d_{50}$**
Capital cost (LE/ treatment)	100.0	1000.0	1000.0	1000.0	1000.0	1000.0
Fixed costs (LE/ treatment / season, 6 month)						
1- Depreciation	236.0	235.4	236.0	235.4	236.0	235.4
2- Interest	60.0	60.0	60.0	60.0	60.0	60.0
3- Taxes and insurance	7.5	7.5	7.5	7.5	7.5	7.5
Sub-total	**303.5**	**302.9**	**303.5**	**302.9**	**303.5**	**302.9**
Operating costs (LE/ treatment / season, 6 month)						
1- Fuel	10.0	10.0	10.0	10.0	10.0	10.0
2- Maintenance and repair	10.0	10.0	10.0	10.0	10.0	10.0
3- Labor	25.0	25.0	25.0	25.0	25.0	25.0
Sub-total	**45.0**	**45.0**	**45.0**	**45.0**	**45.0**	**45.0**
Total annual irrigation cost (LE/ treatment / season, 6 month)	348.5	347.9	348.5	347.9	348.5	347.9
Total agricultural costs (LE/ treatment / season, 6 month)	30.0	30.0	30.0	30.0	30.0	30.0
Total costs (LE/ treatment / season, 6 month)	**378.5**	**377.9**	**378.5**	**377.9**	**378.5**	**377.9**
Yield, (ton/ treatment)	177.0	179.1	168.0	151.9	127.1	112.1
Total revenue, (LE/ treatment / season, 6 month)	**354.0**	**358.2**	**336.0**	**303.8**	**254.2**	**224.2**
Gross margin (LE/ treatment / season, 6 month)	279.1	283.2	261.0	228.8	179.1	149.2

- Interest rate, (12%) for fixed cost.
- Taxes and insurance, 1.5% of capital cost.
- Annual maintenance and repair costs are expressed as a percentage, 1% of capital cost.
- Total cost (Based on variable cost only) excluding rent of land and fixed costs.

D_0d_{30} = zero depth and 30cm between emitters	$D_{20}d_{50}$ = 20cm depth and 50cm between emitters
D_0d_{50} = zero depth and 50cm between emitters	$D_{25}d_{30}$ = 25cm depth and 30cm between emitters
$D_{20}d_{30}$ = 20cm depth and 30cm between emitters	$D_{25}d_{50}$ = 25cm depth and 50cm between emitters

The highest gross margin (283.2 LE/treatment./season) was recorded by surface drip irrigation system with 50 cm spacing followed by 30 cm spacing (279.1 LE/treatment./season). This was because of; the total revenue was higher due to the highest fruits yield. The gross margin recorded with sub-surface drip irrigation system (20 cm depth of dripper line with 50 and 30 cm spacing) (228.8 and 261.0 LE/treatment/season respectively) is also considered high compared with the sub-surface drip irrigation system (25 cm depth of dripper line with 50 and 30 cm spacing). The data also showed that, there are no significant differences between the irrigation operating and total agricultural cost for both surface drip and sub-surface irrigation systems. Consequently, it can be recommended the surface drip irrigation system to be used for irrigating hot pepper cultivated in greenhouse with 50 cm spacing.

CONCLUSION

The obtained results can be summarized as follows:

1. The total depth of water added was 44.18 mm for surface drip system at both 30 and 50 cm spacing, while it was 41.81 mm for sub surface drip system.
2. The highest percent of water consumption was 66.02 % occurred during the harvesting stages for both surface and sub-surface drip irrigation systems.
3. The best uniform distribution of water was achieved with subsurface drip irrigation system when the lateral line buried at 20 cm depth beneath the soil surface and at 50 cm spacing.
4. The lowest value of EC in soil profile was 2.4 dS/m observed with both surface and sub surface drip system but when the lateral line buried at 20 cm from the soil surface with 30 cm spacing.
5. The highest fruit pepper yield was 8.36 Mg/fed achieved with both surface and sub surface drip irrigation system at 30 and 50 cm spacing.
6. The lowest fruit pepper yield was 5.23 Mg/fed achieved with sub surface drip when the lateral line buried at 25 cm beneath the soil surface with 30 cm spacing.
7. The values of CWUE were approximately equal for all treatments except in case of surface drip system when the lateral is at 25 cm depth where the value of (CWUE) was the lowest.
8. It can be concluded to use sub surface drip irrigation system to be applied in plastic green houses but with a depth not exceed the soil surface.

REFERENCES

Begg, J. E. and N. C. Turner, 1976. Crop water deficits. Advanced in Agronomy, 28 pp.

Cafe, F. A. C., and J. M. Duniway, 1996. Effect of location of drip irrigation emitters and position of Phytophthora capsici infections in roots on Phytophthora root rot of pepper. Phytopathology. 1996, 86: 12, pp: 1364-1369.

Castilla, N., 2000. Greenhouse drip irrigation management and water saving. Cahiers Options Mediterranean's Vol. 31.

Doorenbos, J. and W. O. pruitt, 1977. Crop water requirements. FAO Irrigation and Drainage paper 24, Food and Agricultural Organization of the United Nations, ROM, Italy.

El Awady, M. N., M. F. Ahd El Salam, M. M. El Nawawy, and M. A. El Farrah, 2003. Surface and subsurface irrigation effects on Spinach and sorghum. The IIth Annual Conference of Misr Society of Agr. Eng. Oct. 2003 : 118-130.

El-Gindy, A. M., A. M. El-Araby, C. R. Camp, (ed.), E. J. Sadler, (ed.), and R. E.Yoder, 1996.Vegetable crop response to surface and subsurface drip under calcareous soil. In Proceedings of the International Conference on Evapotranspiration and irrigation scheduling, San Antonio, Texas, USA, November 3-6 1996. 1996, 1021-1028.

FAO, 1980. Localized irrigation. FAO Irrigation and Drainage Paper No. 36. Food and Agriculture Organization of The United Nations, Rome, 1980.

FAO, 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29. Food and Agriculture Organization of The United Nations,Rome,1985.

FAO, 1990a. Protected cultivation in the Mediterranean climate plant production and Protection Paper pp: 90-313.

Hunt, D. 1983, Farm Power & Machinery Management, Iowa State University, Press, Ames, USA.

Phene, C. J., R. B. Hutmacher, K. R. Davis, and R. L. McCormick, 1992. Water-fertilizer management of processing tomatoes. Acta-Horticulturae, 1990, No. 277, 137-143.