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Effect of Drip Irrigation and Discharge Rate on Water and Solute Dynamics in Sandy Soil and Tomato Yield

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Abstract: Drip irrigation is widely regarded as the most promising irrigation system in combination with saline water. Variables affecting soil water content and soil salinity, including rates of water application and irrigation method, were investigated in the presence of active plant uptake of water and solutes. Surface and subsurface drip irrigation system with different dripper discharge rates (2, 4 and 8 l/h) were used to irrigate tomatoes with saline water (4.5 dS/m). At the same amount of water applied, increasing the rate of discharge allows more water to move in horizontal direction, while decreasing the rate allows more water to move in vertical direction. The highest discharge rate developed the highest salt concentration in the root zone and near the soil surface, because of a great fraction of applied water was lost from the soil surface. The lowest discharge rate under surface drip irrigation enables maintenance of salts at tolerable levels within the root zone and the region of highest salinity moved down towards the bottom of the root zone as a result of the vertical movement or leaching of salts. During the growing season, soil salinity build up tended to increase with the subsurface drip irrigation in the upper and lower parts of the wetted area in comparison to the surface drip irrigation. The yield reduction due to saline water use was minimal under 2 l/h, which gave better water and salt distribution in the roote zone. The growth and yield performance of tomatoes irrigated through subsurface drip was lower when compared with surface drip irrigation. The maximum tomato yield (58.25 t/ha) was obtained under surface drip irrigation applied at 2 l/h while the lowest yield (36.75 t/ha) was when water applied at 8 l/h with subsurface irrigation. Tomato production was almost 16.4% lower with the highest discharge rate than with the lowest rate while the yield reduction was more pronounced with subsurface drip irrigation and lower by 24.7% than with surface drip irrigation. The results indicate that the choice of the irrigation system appears to be of foremost importance especially when using saline irrigation water.

Keywords: Saline water, Drip irrigation, Discharge rate, Tomatoes

INTRODUCTION

Sustained irrigation agriculture is now critical for food production to support the growing human population. Because almost all accessible fresh water resources in the arid region have been already committed, it is only natural to turn to non-conventional water resources for satisfying the accelerated rates of demand for fresh water. In many countries and regions, fresh water is relatively scarce, but there are considerable resources of saline water, which could be utilized for irrigation if proper crops, soil and water management practices were established (Rhoades *et al.,* 1992; Malash *et al.,* 2005). Salinity can negatively impact plants through three major components: osmotic, nutritious, and toxic stresses (Lauchli and Epstein, 1990; Munns, 1993). When exposed to salinity, growth, development, and yield of most cultivated crops tend to decline, with consequent reduction in their economic value (Pasternak and De Malach, 1995). However, the response pattern of many crop species may substantially change due to environmental conditions (e.g., soil properties and weather) as well as by agricultural practices (Shannon and Grieve, 1999) (e.g., irrigation methods). Considerable yields were obtained using saline irrigation water (4-12 dS/m) in crops that had been previously defined as moderately sensitive to salt stress (Pasternak and De Malach, 1995; Bustan *et al.,* 2004). Furthermore, in some crops (e.g., tomato) the reduction in the fresh yield was compensated by an increase in fruit dry weight and other quality parameters (Mizrahi and Pasternak, 1985; Pasternak *et al.,* 1986).

Proper irrigation management consists of a number of practices, which when used together facilitate the efficient application of water for crop production. These practices may need to be modified and new practices

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introduced, when saline water is applied. Many factors should be considered in making management strategies, such as crops, crop cultivars, local climate, soil type, salinity levels, irrigation method and water management practices (Ferreyra *et al.,* 1997; Shannon and Grieve, 1999; Bustan *et al.,* 2004). Several brackish water irrigation experiments were carried out in open fields on loamy soil to sand dunes and the results evidently revealed that if suitable management practices were adapted, it was feasible to irrigate crops using relatively high saline water under arid conditions. When using low quality water, drip irrigation has several advantages over other irrigation methods; e.g., possible damage to the foliage is prevented and because of salts accumulation at the wetting front, soil salinity in the root zone is similar to the initial salinity in the irrigation water when the irrigation is managed properly (Aragues *et al.,* 1999). Mathematical models and laboratory experiments that describe water flow and salinity transports in soil have been available for a long time. However, the number of inclusive soil salinity transport studies at field scale is still rather limited. Field assessment of water flow and salinity transport in the soil is essential for the design, operation, and management of saline water use with drip irrigation system (Khan *et al.,* 1996; Amente *et al.,* 2000).

Drip irrigation systems generally consist of drippers that have discharge rate varying from 2.0 to 8.0 l/h. The relationships between water application rates, soil properties, and the resulting water distribution for conventional drippers are well documented (Bresler *et al.,* 1982). The wetting patterns during application generally consist of two zones: (i) a saturated zone close to the drippers and (ii) a zone where the water content decreases toward the wetting front. Increasing the discharge rate generally results in an increase in the wetted soil diameter and a decrease in the wetted depth (Ah Koon *et al.,* 1990; Assouline, 2002). Consequently, the water application rate is one of the factors, which determine the soil moisture and salt distribution around the dripper and the related root distribution and plant water uptake patterns. However, if the drippers had lower discharge rates, we hypothesize that the efficiency of salt removal out of root zone would have been greater.

The main objective of the present work was to study the effect of dripper discharge rate and irrigation method on different aspects of the water and salt distribution to establish safe salinity levels of irrigation water and maintain crop productivity under drip irrigation system.

MATERIALS AND METHODS

The experiment was conducted at El Khatatba region, Monofia province west of Nile Delta of Egypt during the summer growing season (March - June) 2007 using drip irrigation system. This area is a desert region, and the soil of the experimental site was deep, well-drained sandy composing of 85.5% sand, 10.2% silt and 4.3% clay, with an alkaline pH 8.2, EC 2.35 dS/m, $CaCO_3$ 2.5%, O.M 0.32%. The available N, P and K were 25, 8 and 47 mg/kg soil, respectively before the initiation of the experiment. The average water content at field capacity from surface soil layer down to 80 cm depth at 20 cm intervals was 12% and the water holding capacity for the corresponding depths was 25% respectively. Before cultivation, drip tubing (GR, 40 cm dripper spacing and 1.5 m apart) was either placed on soil surface or buried 10 cm deep directly under the soil beds. Twenty-five old seedlings of tomato 'Floradade' variety were transplanted to the main field in double rows (40 cm apart) on the early of March, 2007 (32 000 plants/ha). Uniform irrigation was applied to the all seedlings through the drip tubing to encourage stand establishment.

The treatments included application of equal volume of water at three different dripper discharge rates: 2, 4 and 8 liter/hour as a common dripper used in the region with surface and subsurface drip irrigation methods. The actual crop water requirement was estimated by multiplying reference evapotranspiration with crop coefficient ($ETc = ETo \times K_C$) for different months based on crop growth stages using the model suggested by Penman-Monteith's formula (Allen *et al.,* 1998). Amounts of irrigation water used after planting was 480 mm for the growing season. Irrigation frequency was running daily with well-water having EC 4.5 dS/m. The concentrations of the major ions expressed in mg/l were as follows: Na^+ 428, Ca^{2+} 284, Mg^{2+} 90, K^+ 195, Cl^- 884, SO_4^{2-} 754 and HCO_3^- 256. The experiment was arranged in randomized complete block factorial design consisting of combinations of three discharge rates with two irrigation methods (surface and subsurface drip systems) and was replicated three times in 4.5 m wide × 8 m long plots. Nitrogen was applied on weekly basis at the rate of (300 kg N/ha) through drip fertigation in a split doses and commenced after two weeks of planting. This was done along with phosphorus (160 kg P/ha), as phosphoric acid (85%) and potassium (250 kg K/ha) as K_2SO_4 respectively. All N, P and K fertilizers were injected directly into the irrigation water using venture-type injector.

To determine moisture and salt distribution for each treatment, soil samples were taken from the wetted area just after the end of irrigation periodically at 4 weeks intervals. The sampling layout was radial and

vertical intervals of 5 and 10 cm respectively, starting 0 cm from the point of application and moving outward to the edge of the wetted front, using tube auger. Soil moisture content was determined gravimetrically. All soil samples were air-dried and sieved through a 2 mm sieve. The EC were based on soil paste extracts and were determined using a conductivity meter. Tomato fruits were collected periodically and at last pick of fruits all aboveground biomass in each plot were collected and weighed to determined total yield of shoots and fruits. Average fruit weight and number of total fruits per plant were recorded for at least 10 selected plants. Water use efficiency (WUE) was also evaluated.

RESULTS AND DISCUSSIONS

Soil Wetting Patterns:

Wetting patterns are characterized by the radial distance of the wetting front and the depth of wetting from the point source (dripper) (Fig. 1). The main differences in the water content at the end of the respective water applications for the three dripper discharge rates seem to be located away from the drip line. At the same amount of water applied, the highest discharge rate produced greater radius to depth ratio while the reverse was true for the lowest discharge rate. It can therefore be concluded that increasing the application rate allows more water to distribute in the horizontal direction, while decreasing the rate allows more water to distribute in the vertical direction. A saturated zone below the drip line was obtained only for the highest discharge rate at a radius of 20-25 cm from the water source. For the two lower discharge rates, there was no saturated zone below the dripper, and the water content at that point decreased with the dripper discharge rate. The wetting front depth below the drip line was 70, 60 and 50 cm for the 2, 4, and 8 l/h, respectively.

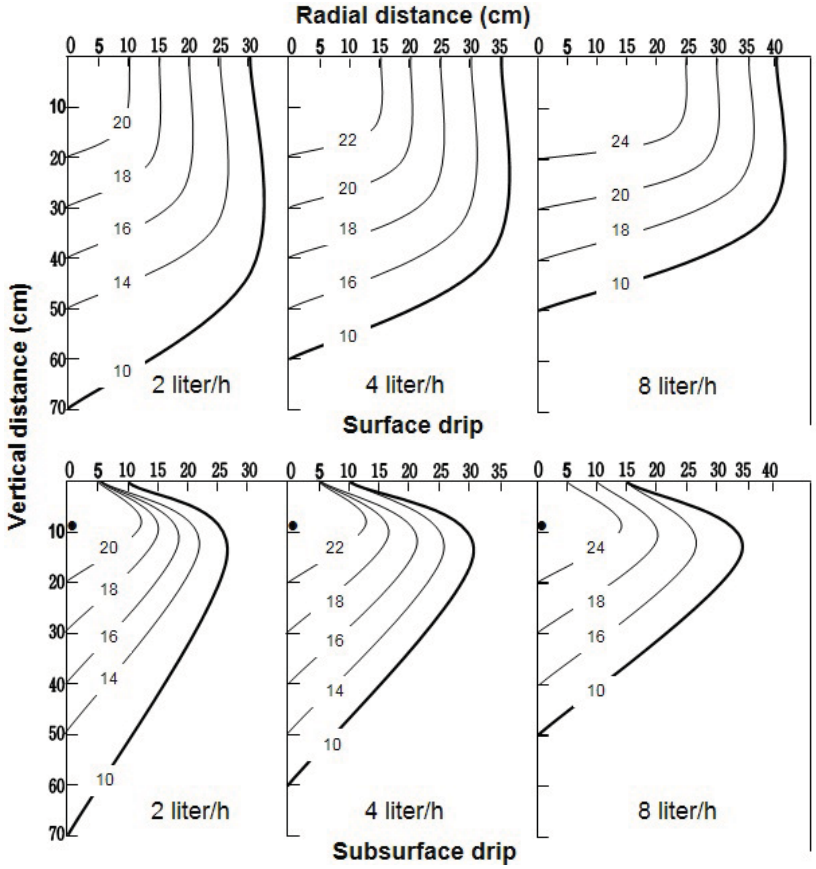

Fig. 1: Spatial distributions of water in surface and subsurface drip line for the three discharge rates. The numbers labeling curves of contour lines indicate % of moisture content. The heavy peripheral lines are the position of the wetting fronts.

Relatively, the same distribution pattern was observed in the subsurface drip irrigation (the drip line was buried at 10 cm soil depth), except that surface soil layer was not completely wetted as in the case of surface drip. However, the upward capillary movement of water was not sufficient and soil water content at the surface decreased significantly were most wetting occurred closed to the water source. Again, in the lower discharge rate, the downward movement of water was more than its lateral movement due to gravity force playing a predominant role in the sandy soil of the experimental site. The overall wetted area, delimited by the wetting front was largest for the 2 l/h dripper, and smallest for the 8 l/h practically under subsurface drip irrigation as also reported by Lubana and Narda (2001). Under both irrigation methods, the dry zone that developed in the soil profile halfway between the drip lines at 60-cm depth was largest for the 2 l/h dripper, and smallest for the 8 l/h dripper. This result indicates possible consequences for solute concentration patterns between the rows in drip irrigated crops due to fast losses of water applied through evaporation.

Ah Koon *et al.* (1990) investigated the effect of drip discharge rate on the water content distribution beneath a crop of sugar cane and they found that increasing the discharge rate resulted in an increased lateral movement of water and a decrease in the wetted depth, in agreement with the results of the laboratory experiment of Li *et al.,* (2004) for determining the geometry of the wetted volume under point source irrigation.

Compared with conventional dripper discharges, Koenig (1997) has described the water distribution resulting from micro-drip irrigation as characterized by the absence of a saturated zone and by a larger wetted zone. In the present experiment results also indicate that the absence of a saturated zone also can be obtained with conventional dripper discharges, depending on the water amount applied, the plant water uptake, and the soil hydraulic properties. This should have a direct effect on the structure of the root system and water uptake pattern (Coelho and Or, 1999).

Soil Salinity During the Season:

Generally, soil salinity in surface drip irrigation increased throughout the growing season in all treatments at certain locations with relative differences according to the rate of discharge (Fig. 2). Saline water irrigation produced three salinity zones, an upper salinity zone near the soil surface with high salt concentration, a wide intermediate zone where salinity levels are low near the drippers at the surface and a lower zone where the salinity levels increases with depth and with the distance from the water source. Soil salinity increased with increases in radius distance from the dripper and with advanced in crop growth for each discharge rate. Concentration of salts during the growing season under discharge rate of 2 l/h varied very little with time and was very close to the salinity of the irrigation water. The EC values at the radius of 40 cm ranged from (4.3 to 5.2) for 2 l/h, from (4.7 to 6.5) for 4 l/h and from (6.2 to 8.7) for 8 l/h respectively. Therefore, tomato plants grown under the lowest discharge rate were in relatively less stressed environment than any other rate indicating that relatively small changes in water movement bring about considerably changes in soil salinity. However, decreasing the discharge rate of applied water resulted in lower average salinity profiles, and led to a large reduction in the soil salinity at the end of the growing season. In addition, the increased volume of water percolated below the root zone helped in more leaching for salts as also reported by (Petersen, 1996). The highest discharge rate developed the highest salt concentration in the root zone and near the soil surface, due to shallow wetted depth, since water movement was directed horizontally rather than vertically. Capillary forces as well as the shallow wetted depth promote salt accumulation at the soil surface due to salt build up by evaporation components.

Subsurface drip resulted in higher salinity levels at the upper and lower soil layers than with surface drip irrigation and the salt concentration tended to increase around the root system for all the dripper discharge rates (Fig. 3). The EC values measured at a radius of 40 cm soil depth ranged from (4.5 to 6.7) for 2 l/h, from (4.7 to 8.8) for 4 l/h and (4.9 to 9.5) for 8 l/h respectively. Therefore, tomato plants could be grown for a considerable period without higher stress with the lowest discharge rate, because of the upper part of the root zone is relatively maintained at lower salinity level and the salinity stress might had some impact on root water uptake for both medium and high application rates. A similar pattern of salt accumulation with subsurface drip irrigation systems has been reported by Morvant *et al.,* (1997) and Cox (2001).

The higher concentrations with subsurface irrigation can be expected because the dispersion flows of saline solution inside the wetted soil volume due to capillarity force and bulk flow (Reed, 1996). Therefore, a progressive accumulation of the salts not used by the plant occurs in all the soil layers and especially in the upper portion of the soil (Molitor, 1990; Reed, 1996).

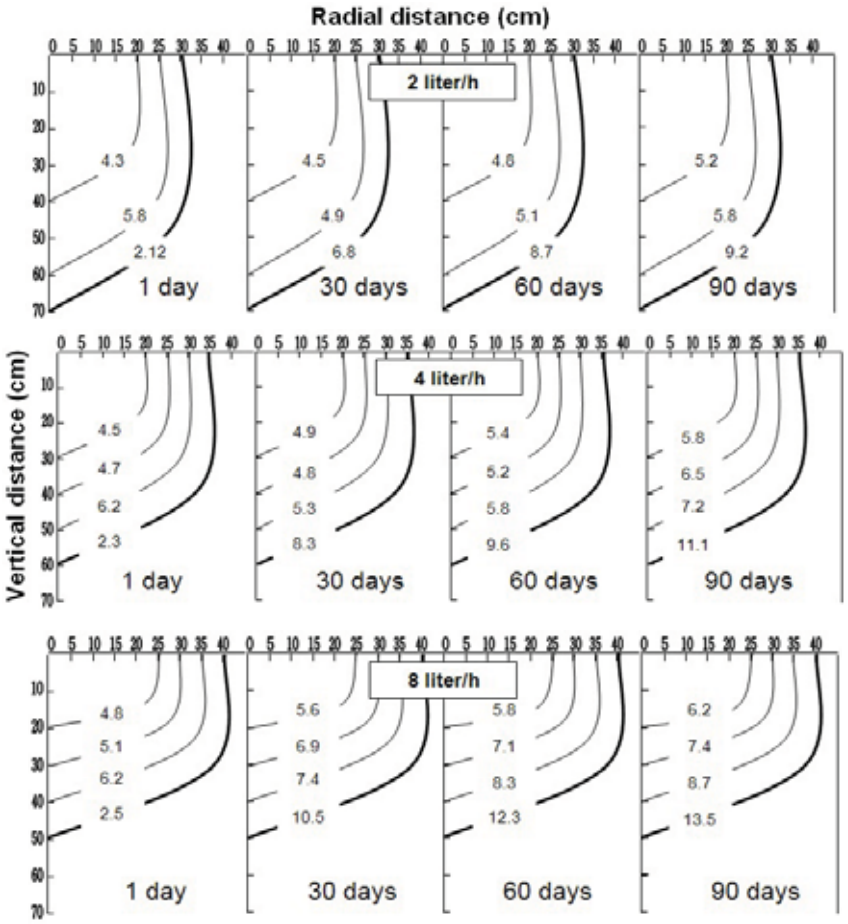

Fig. 2: Spatial distribution of salts in surface drip line during the growing season for the three discharge rates. The numbers labeling curves of contour lines indicate EC values (dS/m). The heavy peripheral lines are the position of the wetting fronts.

As indicated by the values of salt concentration in subsurface drip, the salts tended to concentrate in the upper layer where there were much less roots, which grew markedly in the lower region (as found by visual assessment). By contrast, decreasing salts from the top to the bottom of the wetted soil was found in surface drip, in which roots tended to occupy the whole wetted region. In subsurface drip, the salinity of the upper region was about two times higher than in surface drip irrigation, because a great deal of salts were directed to move upward by capillary forces. Subsurface drip, resulted in a relatively narrow vertical rang in salt concentration that showed a tendency to accumulate in the top region; the reverse phenomenon was observed in surface drip. However, drastic reductions in yield took place when the salt began to build up in the upper portion of the root zone regardless of soil depth. These results showed that the irrigation method and irrigation regime considerably affected soil salinity and salt distribution around dripper. Such results can improve our knowledge of practically using saline water under a drip irrigation system. Irrigation with saline water with salinity that exceeds the threshold salinity level of the crop would be expected to have a major impact on EC of the soil and crop yield. However, the EC of the soil may reach a limiting value in the lower portion of the root zone, which may not differ much with increasing amounts of applied water and drip-irrigation should be adopted when we are forced to use saline water (Shalhevet, 1994).

Tomato Yield:

Yield reductions occurred with saline irrigation water and the lowest reduction was under 2 l/h discharge rate in both cases of irrigation method (Table 1). Yield differences were statistically significant and the highest performance was obtained from surface drip irrigation both in terms of fruits and shoots. However, the trend was in agreement with previous observations (Minhas, 1996; Karlberg *et al.,* 2007) and also agree

Table 1: Yield and yield components of tomato plants as influenced by dripper discharge rate and irrigation method.

Discharge rate	Tomato yield (t/ha)		No. of fruits Per plant	Mean fruit weight (g)	Fruit yield kg/plant	WUE kg/mm
	Fruits	Shoots				
			Surface drip irrigation			
2 l/h	58.25	6.91	16.1	113.1	1.82	121
4 l/h	53.43	6.32	15.7	106.5	1.67	111
8 l/h	48.76	5.57	15.1	100.4	1.52	102
			Subsurface drip irrigation			
2 l/h	43.68	5.12	14.1	97.2	1.37	91
4 l/h	40.37	4.78	13.6	92.7	1.26	84
8 l/h	36.75	4.29	12.9	89.2	1.15	77

LSD (P = 0.05) for total fruit yield, discharge rate (D) = 3.24; irrigation method (I) = 5.85; D × I = 8.35.

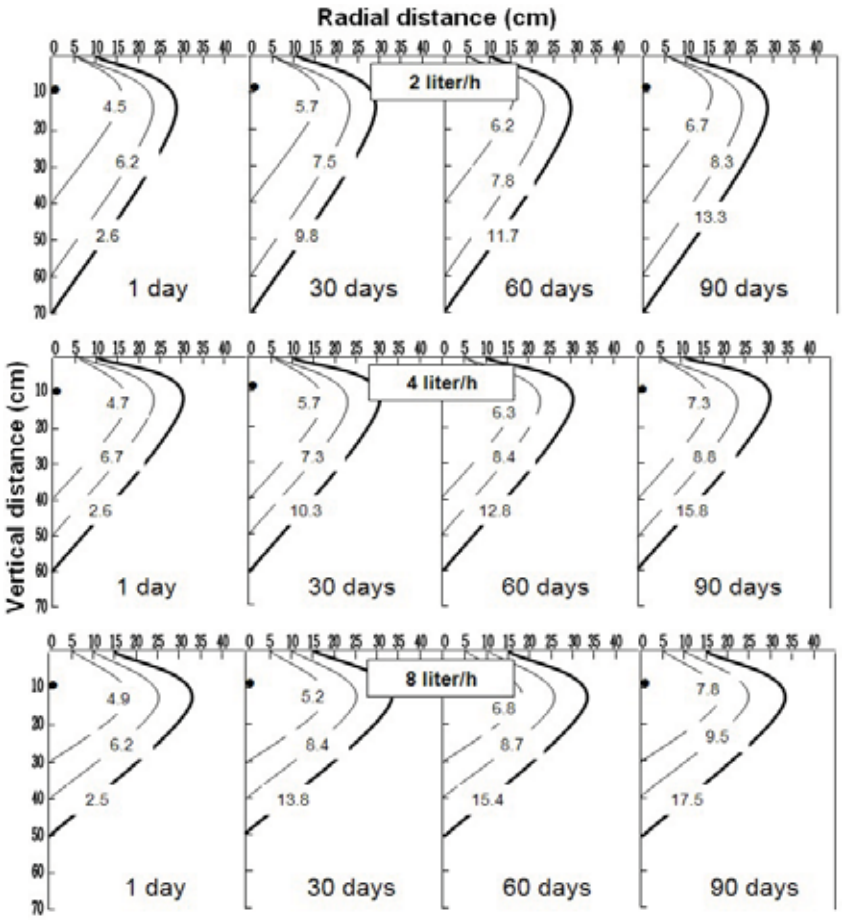

Fig. 3: Spatial distribution of salts in subsurface drip line during the growing season for the three discharge rates. The numbers labeling curves of contour lines indicate EC values (dS/m). The heavy peripheral lines are the position of the wetting fronts.

with the general trend indicating that the increase of drip irrigation frequency, which acts to reduce the gap between water application and plant needs as microdrip irrigation, improves yields (Assouline *et al.,* 2002). The maximum tomato yield (58.25 t/ha) was obtained under surface drip irrigation applied at 2 l/h while the lowest yield (36.75 t/ha) was when water applied at 8 l/h with subsurface irrigation. Tomato production was lower by 16.4% with the highest discharge rate than with the lowest rate while the yield reduction was more pronounced with subsurface drip irrigation and lower by 24.7% than with surface drip irrigation. Tomato fruit yield showed discharge rate × drip irrigation method interactions; yields were higher in surface drip than in subsurface drip irrigation with all discharge rates.

The lower tomato yield observed with subsurface drip in comparison with surface drip irrigation was due to a reduction in both the mean fruit weight and the number of fruit per plant, while at the different discharge rates, the lower total yield was mainly attributed to a reduction in the mean fruit weight. The lowest water use efficiency WUE observed in subsurface irrigation with the highest discharge rate can be expected due to a drastic reduction of yield and the increasing of evaporation losses (the average WUE was 111 kg fruit/mm for surface drip versus 84 kg fruit/mm for subsurface drip irritation).

Tomato is considered moderately sensitive to salt stress, since it can tolerate a soil salinity (EC of the saturated soil extract) of about 2.5 dS/m and fruit yield decrease by 10% with each unit of EC increasing above the threshold value (Maas, 1986). In the present study, the threshold value was similar to the value reported by Maas, (1986) where the maximum yield was depressed by about 20% than the statewide variety average yield. However, the differences that were found in tomato response can be explained by the fact that with variations of salinity in the root zone, there is an increase of crop tolerance to salinity because the root growth occurred mostly in the lower 20-30 cm layer where the EC of the soil is more favorable. Plants grown with subsurface drip irrigation gave a lower total yield than those grown with surface drip irrigation because of the higher soil salinity due to the upward flow of water and salt accumulation in the root zone leading to a moderate plant stress especially with highest discharge rate, while with surface drip irrigation, the maintenance of highly leached root zone reduces the detrimental effects of salinity on growth and yield. Similar results on the effects of the two systems under saline condition (surface drip versus subsurface drip irrigation) were also obtained by Santamaria *et al.,* (2003), who found that with drip irrigation the tomato production was almost 20% higher than with subsurface irrigation as a result of the lower soil salinity. Moreover, Scholberg and Locascio (1999) observed that the total dry weight, total fruit yield, marketable fruit yield and average fruit weight of tomato were higher with surface drip than with subsurface drip irrigation. When plants are exposed to salinity, crop performance may be adversely affected by water deficit arising from the low water potential of the nutrient solution (osmotic effect) and by salinity-induced nutritional disorders associated with the excessive ion uptake (Na^+, Cl^-) or nutrient imbalance by nutrient availability, competitive uptake, transport or partitioning within the plant (ionic effect) (Dorais *et al.,* 2001). Salinity decreased total tomato yield by reducing both mean fruit weight and the number of fruit per plant. These results are consistent with the findings reported on tomato (Scholberg and Locascio, 1999), cultivated on soil.

Finally, drip irrigation should be adopted when farmers are forced to use saline water for irrigation. The choice of the irrigation system coupled with appropriate discharge rate appears to be of foremost importance when using low quality irrigation water. Unlike subsurface irrigation, using drip irrigation with saline solution (4.5 dS/m) would be an attractive strategy in limiting yield reduction(lower salt content and higher fruit yield production),taking adavntage of the quality effect of saline water and improving the water use efficiency.

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