Comparison among Different Irrigation Systems for Deficit-Irrigated Corn in the Nile Valley

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ABSTRACT

Waterlogging, salinization, and low application efficiency are the main problems inherent with surface irrigation in the Nile Valley. Replacing the surface irrigation method with precise irrigation systems became the main interest of the decision makers and policy planners in Egypt. A field experiment was carried out at Bahteem Experiment Station near Cairo to compare surface, subsurface drip irrigation and furrow irrigation using gated pipes for irrigating corn. Three levels of irrigation 100, 80, and 60% of potential evapotranspiration (ETp) were compared. The results revealed that the highest amount of water applied for corn was with furrow irrigation using gated pipes (474.4 mm at 100% of ETp), and the lowest amount was with a subsurface drip irrigation system (352 mm at 60% of ETp). The distribution of salts in the soil profile using a subsurface drip irrigation system was not satisfactory compared with surface drip irrigation. Hence, the accumulation of salts around the root zone is considered a disadvantage of using subsurface drip irrigation. Furrow irrigation using gated pipes achieved the best distribution of salts compared with both surface and subsurface drip irrigation systems. Deficit irrigation had significant effect on the plant height, leaf area, plant circumference and the number of ears per plant. Nevertheless, its effect on the number of steps per plant and the number of leaves per plant is not highly significant. The highest value of water use efficiency (2.44 kg/m^3) was obtained with furrow irrigation at 100% of ETp followed by the surface drip irrigation system (1.77 kg/m^3) at 80% of ETp. The lowest value of water use efficiency (0.97 kg/m^3) was recorded with the subsurface drip irrigation system at 60% of water application rate. The highest value of gross margin including fixed cost (925.84 US$/ha/season) was obtained with furrow irrigation using gated pipes, which was 166.3% and 156.3% higher than subsurface drip and surface drip irrigation systems, respectively. Using a higher efficiency subsurface drip irrigation system is recommended for irrigating corn under deficit irrigation in case of water scarcity from a water-saving viewpoint. On the other hand, surface drip is strongly recommended in the areas that have waterlogging problems, but furrow irrigation using gated pipes is very suitable in the areas that have salinization problems to obtain highest yields of corn and highest growth margin in the old lands.

Keywords: Corn, deficit irrigation, Egypt, gated pipes, Nile Valley, precision irrigation, surface and subsurface drip, water stress.

1. INTRODUCTION

In the past, water resources of Egypt have been adequate to meet the existing and emerging demand for water by the various sectors. Gradually, Egypt has passed from a state of water abundance to a state of water scarcity. However, agriculture remains the backbone of Egypt's economy and the largest consumer of fresh water where it consumes more than 80% of Egypt's water resources. Egypt has plans to use its limited water resources efficiently and overcome the gap between supply and demand. In the old lands of the Nile Valley and Delta, most farmers still use primitive methods of irrigation, fertilization, and weed and pest control practices. The application of fertilizers is usually by hand with low efficiency, resulting in higher costs and environmental problems, (Abou Kheira, 2005). Irrigation is typically practiced in short furrows surrounded by small basins. This method is inefficient in the following respects: (1) Water is used excessively because flowrates are not uniform; (2) Labor is wasted in construction of checks, furrows and water manipulation; (3) 10 - 20% of land is wasted in borders, furrow ends and small canals; and (4) Poor uniformity and distribution of irrigation water results in drainage, water logging, and consequently increasing the salinity of the soil.
Corn (Zea Mays L.,) is one of the most important cereals, both for human and animal consumption, in Egypt and is grown for both grain and forage. The questions often arise, "What is the minimum irrigation capacity for irrigated corn? And what is the suitable irrigation system for irrigating corn?" These are very difficult questions to answer because they greatly depend on the weather, yield goal, soil type, area conditions and the economic conditions necessary for profitability.

English et al. (1990) defined deficit irrigation as "an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction." They also reported that deficit irrigation strategies aim to increase water use efficiency, either by reducing irrigation adequacy or by eliminating the least productive irrigations. Increasing profits and maximizing or stabilizing regional crop production can be achieved by using a deficit irrigation strategy. For instance, in the Great Plains of the United States, Ogallala aquifer "which is being depleted" is the main source for irrigating most of this area. Therefore, farmers are motivated to find ways to produce crops, especially corn, with less irrigation water, such as using more precise irrigation systems and applying deficit irrigated cropping systems (Payero et al., 2006a). Melvin and Payero, (2007) reported that at the research level deficit irrigation strategies proved to be valuable water conserving practices and it should be applied as effective strategy at the large scale level in farmers' fields.

Corn yield is closely related to crop evapotranspiration (ET) and usually yields would be lowered if ET I s lowered (Payero et al., 2006a; Payero et al., 2006b; Payero et al., 2006c; Payero et al., 2006d). Trooien et al. (1999) defined limited irrigation as 70% of evapotranspiration. Fully irrigated corn typically receives 500 to 600 mm of irrigation water. Accurate estimate of ETc on a daily or seasonal basis can be valuable for best management of corn irrigation both in-season irrigation and for strategic irrigation planning and management (Payero et al., 2008). Using subsurface drip irrigation (SDI) for corn production on the deep silt loam soils of the semi-arid Great Plains (United States) may save 20-25% of on-farm water. This will be obtained through a combination of reducing nonbeneficial water balance components and better usage of precipitation, (Lamm, 2005). Using an SDI system for irrigating corn in the Great Plains can reduce water use by 35–55% compared with traditional irrigation systems used in the region. In the last decades, SDI systems are cost competitive for corn production with the traditional irrigation systems in the Great Plains, USA, (Lamm and Trooien, 2003). Applying irrigation water to the soil from 75 to 125% of ET (well-watered) maintained stable soil water levels above approximately 55 to 60% of field capacity through the 204 cm-soil profile, while the dryland soil (no irrigation) and the treated soil by water applied from 0% up to 50% of ET (deficit-irrigated) mined the soil water, (Lamm et al., 1995). They also concluded that there is a linear relationship between corn yield and water use. Each millimeter of water used above a threshold of 328 mm produces 0.048 Mg/ha of grain. Good management of SDI systems can achieve maintaining top yields of 12.5 Mg /ha and water savings by nearly 25%. Most of these water savings can be attributed to minimizing nonbeneficial water balance components such as soil evaporation, runoff, and deep percolation. Better management of the water balance components with SDI systems can make significant improvements in water use efficiency. SDI systems had lower returns than in-canopy center pivot sprinkler systems for corn production in western Kansas. Initial investment, system longevity, and corn yield are affecting on economic returns rather than pumping costs and application efficiencies, (Dhuyvetter et al., 1995). Good irrigation scheduling decisions and the appropriate evaluation of the economic impacts at farm level are the main constraints of the adoption of deficit irrigation strategies (El Amami et al., 2001).

Deficit irrigation creates water stress that can affect the growth and development of corn plants. It is very important to estimate yield reduction due to applying deficit irrigation strategies (Payero et al., 2006a; Payero et al., 2006b). The response of corn plants to water stress has been shown to change with hybrid (Lorens et al., 1987a; Lorens et al., 1987b) and can be affected by improving technological level (Dale and Daniels, 1995). Effects of water stress on corn include the visible symptoms of reduced growth, delayed maturity, and reduced crop yield. For instance, water stress has been shown to reduce corn canopy height (Denmead and Shaw, 1960; Gavloski et al., 1992; Traore et al., 2000), leaf area index (NeSmith and Ritchie, 1992; Traore et al., 2000), and root growth (Gavloski et al., 1992; Jama and Ottman, 1993). Denmead and Shaw, (1960), and Traore et al. (2000) studied the effect of water stress on reducing corn grain and biomass yields. They found that grain yield can be reduced by decreasing yield components like ear size, number of kernels per ear, or the kernel weight. Claassen and Shaw (1970a, b) observed that stress before or during silking and pollination resulted in reduced kernel number, while stress during or after silking reduced kernel weight. NeSmith and Ritchie (1992) attributed yield loss from water stress during pre-anthesis to a reduction in the number of well-developed kernels. Yang et al. (2007) reported that the combined settings of subsoil irrigation with deficit water supply, and improvement in other aspects of crop management and corn hybrids enhanced the crop water use efficiency of corn. Trooien et al. (1999) found water use efficiency (WUE) to be greater for limited irrigated crops, but full irrigation of corn was more profitable than limited irrigation.

This study aims to compare among different irrigation systems such as surface drip, subsurface drip, and furrow irrigation using gated pipes for irrigating corn under deficit irrigation in the old lands of the Nile Valley. Different indicators were investigated such as applied water, soil moisture and salt distribution patterns, fluctuation of the water table, plant growth parameters, ears yield of corn, water use efficiency, and cost analysis for producing corn under deficit irrigation.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was carried out at Bahteem Experiment Station, Water Management Research Institute, National Water Research Center, Ministry of Water Resources and Irrigation, Kaliobiya Governorate, Egypt (longitude 31.50 E°, latitude 30.13 N° and elevation above sea level 17 m). To investigate the suitability of different irrigation systems (surface drip, subsurface drip and furrow irrigation using gated pipes) for irrigating corn under deficit irrigation conditions in the old lands of the Nile Valley and Delta. The soil texture is loamy with water field capacity of 26%, wilting point of 13%, soil bulk density of 1.403 g/cm^3 and infiltration rate of 1.05 cm/h. The irrigation water source was surface water from the El-Sharkawiya Canal.

2.2 Experimental Procedure

Corn (Zea mays L., Varity Single Cross No. 10) was cultivated in Bahteem Experiment Station on May 23. The distance between rows was 0.75 m and 0.25 m between grains in the row. Each row was irrigated by a single lateral line in the surface and subsurface drip irrigation plots, but in the furrow irrigation plots using gated pipes, each furrow was irrigated by one gate. The total experimental area was 0.42 ha (one feddan), both the modified surface irrigation and the microirrigation plots occupied 2100 m^2 each, (30 m width with 70 m long for all the modified surface irrigation plots and 20 m width with 17.5 m long for each plot of the microirrigation systems). Each of the tested irrigation systems were installed in individual plots. Each experimental plot was divided into three sub-plots. For all systems, water was applied at three levels of irrigation (sub-plots), which were 100%, 80%, and 60% of ETp. Irrigation season of corn was ended two weeks before harvest. Corn was harvested on September 18. For all plots, fertilization and weed and pest control applications followed recommendations of the Ministry of Agriculture. A statistical analysis of the factorial experiments design has been carried out for investigating the significance of growth parameters of corn, which was irrigated by the three tested irrigation systems.

2.3 Crop Water Requirements

The first step to calculate crop water requirements is potential evapotranspiration (ETp) calculation. Two models were used to calculate ETp, and the average of these values was used to estimate crop water requirements. The first one was the Hargreaves model; is the simplest one for practical use where it requires only two easily accessible parameters, which are temperature and solar radiation (Hargreaves, 1975, Hargreaves and Sammani, 1982). The second one was the Doorenbos and Pruitt model (1977); the evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface. In a similar fashion, the plant responds to the same climatic variables but several major factors may produce significant differences in loss of water, therefore, the average of calculated ETp by both models was used to estimate corn water requirements. Irrigations were scheduled to avoid or minimize runoff and deep percolation. All treatments were irrigated at the same time until the allocation for a given treatment ran out. Irrigation intervals were followed as producers do in the region, where they usually apply water once a week under microirrigation systems and once per two weeks under furrow irrigation using gated pipes.

2.4 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 the soil profile was presented by contour maps. For each treatment, nine locations around the corn plants were considered, and spacing at 25-cm. The soil water content was using the gravimetric soil samples by soil auger. Moisture content for each location was measured at 0.15-m increments to a depth of 0.60 m shortly before and 48 hours after irrigation. Soil samples oven-dried at 105 °C and the gravimetric soil water contents (%) were measured. This procedure was carried out for all treatments two times during the agricultural season; one before irrigation and the other was 48 hours after irrigation. The contour maps were derived considering that; there is a symmetric moisture distribution pattern around the irrigation line on both the 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 three columns and four rows, and the commercial program (SURFER 8) was used for developing moisture content lines. The Kriging method was used for the calculation of the intermediate points at equal distances. Each intermediate point was estimated from adjacent two points, 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 the corn experiment.

2.5 Salt Distribution Patterns and Movements

Salt distribution and accumulation under different irrigation systems is an important factor for evaluation of each irrigation system. The accepted system produces a remarkable moisture distribution in the root zone and removes salts far from it. Electrical conductivity (EC) in dS/m for each gravimetric soil samples has been measured using EC meter. 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 the moisture distribution pattern was used in obtaining the contour maps for the salt distribution pattern for each irrigation system. The salt distribution pattern procedure was carried out at the end of the agricultural season.

2.6 Measurements of Water-Table Level

Waterlogging and a rising water table is a dilemma inherent with flooding surface irrigation in the old lands of the Nile Valley and Delta. To study the effect of tested irrigation systems on this problem, six piezometer tubes 2.25 m long and 0.25 m diameter were constructed at 100% of ETp treatment under each irrigation system. A length of 2.0 m of each piezometer was immersed in the soil and 0.25 m was above it to monitor the water table level under each irrigation system between two irrigation events. The difference in water table levels and the average of these levels between two irrigation events was measured throughout the growing season.

2.7 Corn Growth Indicators, Yield, and Irrigation Water Use Efficiency

Five growth indicators of corn such as plant height, plant circumference, leaf area, leaf number per plant, and internodes were measured. Plant height and plant circumference at 1/3 of the total length of the plant were measured by tape meter**.** Leaf area was estimated by multiplying the maximum length times the maximum width of ear leaves**.** Leaves and internodes were counted manually. Number of ears and total weight of ears in five meters of the cultivated row were measured for estimating the total yield. This procedure was carried out three times: one meter inside the row head, in the middle of the row, and one meter before the end of the row. This procedure was followed with all replications and all treatments under the tested irrigation systems. Commercial statistics software (SPSS 10) was used for statistical analysis of the growth indicators of corn. 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) was expressed as kg kernels/m^3 water applied, (Begg and Turner, 1976). Kernels moisture content was adjusted to be 15.5%.

2.8 Cost Analysis

The analysis of the irrigation system cost depends on many factors such as price of the irrigation system component, energy requirements, fuel cost, and labor cost. Simple cost analysis was carried out by using the current dealer prices of the irrigation system and installation according to 2006 price levels, and corn production costs, which was determined according to agricultural census issues of the Ministry of Agriculture in 2006. A simple cost analysis has been carried out to evaluate the gross margin of corn cultivated in the old lands under surface drip, subsurface drip and furrow irrigation using gated pipes. Both fixed and variable costs were calculated for each irrigation system in (US$/ha/season), and the gross margin of the product under the tested irrigation systems was derived to compare among these systems. The fixed costs included the treatments' share of digging the well, purchasing the pump and engine, main control unit, sub-main control unit and lateral control unit, main and sub-main lines, manifold, laterals, emitters, gathering the system, design and installation of the irrigation system costs and excluded rent of land.

3. RESULTS AND DISCUSSION

3.1 Irrigation Water Amount

Water applied for corn throughout the growing season by the three systems of irrigation was calculated (Table 1). The three irrigation systems tend to follow a similar trend at the three tested levels of water application. The applied water decreased from the first irrigation event to the third irrigation event when corn was under deficit irrigation. There was a gradual increase in the applied water from the third irrigation to other irrigation events during the growing season, and the maximum value of applied water was achieved at the last irrigation by 18 days before harvest. The highest amount of water applied was added with the furrow using gated pipes technique (474.4 mm at 100% of ETp), and the lowest value was applied with the subsurface drip irrigation system (352 mm at 60% of ETp). Therefore, the subsurface drip irrigation system is recommended when insufficient water is available because of its higher application efficiency over surface drip and furrow irrigation using gated pipes. It also noted that the differences of water applied among tested irrigation systems were small, because the application efficiencies for the tested irrigation systems were very close. The application efficiencies were ranged from 87, 92, and 95% for furrow irrigation using gated pipes, surface drip irrigation, and subsurface drip irrigation systems, respectively.

Table 1. Irrigation water amounts for surface drip, subsurface drip and gated pipes irrigation systems throughout the growing season of corn.

Days from planting	**Growing stage**	**K_c**	**Water application depth (mm)**								
			Surface drip			Subsurface drip			Furrow irrigation using gated pipes		
			100% of ETp	80% of ETp	60% of ETp	100% of ETp	80% of ETp	60% of ETp	100% of ETp	80% of ETp	60% of ETp
1-21	Initial	0.4	136.9	136.9	136.9	136.9	136.9	136.9	109.9	109.4	109.4
22-36	Develop-ment	0.8	69.4	69.4	69.4	69.4	69.4	69.4	66.7	66.7	66.7
37-56			22.2	17.8	13.3	21.8	17.5	13.1	27.6	22.1	16.6
57-66	Mid-season	1.1	22.6	18.1	13.6	22.2	17.8	13.3	42.6	34.1	25.6
67-78			40.7	32.5	24.4	39.9	31.9	24.0	56.4	45.1	33.8
79-94			63.0	50.4	37.8	61.8	49.5	37.1	67.0	53.6	40.2
95-101	Late	1.05	98.8	79.0	59.3	97.0	77.6	58.2	104.8	83.8	62.8
	Total		**453.5**	**404.1**	**354.6**	**449.1**	**400.5**	**352**	**474.4**	**414.7**	**355.1**

3.2 Soil Moisture Distribution Patterns

The contour maps of moisture distribution of corn for all treatments under surface drip, subsurface drip, and gated pipes techniques were drawn (Figs 1, 2 and 3). For each treatment, the contour maps of moisture distribution were drawn two times; one before irrigation, and the other at 48 hours after irrigation. In the surface drip irrigation system as presented in Fig. (1), the gradual distribution of soil moisture before irrigation was greater against soil depth for 100%, 80% and 60% of ETp. The soil effective depth in all treatments (20 cm) was approximately dry before irrigation while moving downward; the soil depth became moist to about 60 cm depth. For all treatments, before irrigation, the soil moisture content was approximately in equal values moving downward the soil profile. After irrigation, the contour maps represent a great difference, especially at the soil effective depth (20 cm). It became moist and the value of soil moisture content increased and ranged from 11% to 14% at the 20-cm depth of soil for 100%, 80% and 60% ETp. It can be observed that the surface drip system resulted in a good distribution of the soil profile up to 60 cm depth for all treatments (100%, 80% and 60% of ETp). The moisture distribution in this system changed from gradual distribution before irrigation to best uniformity at 48 hours after irrigation. This may be due to the high value of uniformity distribution in the surface drip irrigation system, which leads to distributing water uniformly in the root zone.

The contour maps for moisture distribution before irrigation in subsurface drip irrigation followed the similar behavior of the surface drip system (Fig. 2), but 48 hours after irrigation, the soil profile for a depth up to 60 cm was moister than in the surface drip system for all treatments. The best uniform distribution was at 60% of ETp, where the soil moisture was higher, especially at the soil effective depth (20 cm from the ground surface). The distribution of water in the soil profile for corn irrigated by the subsurface drip system was uniform for all treatments. Therefore, it can be concluded that under subsurface drip, the water available in root zone was enough for plant growth. This is because under subsurface drip, the lateral irrigation line was buried at 25 cm below the soil surface, and the soil profile below this depth became wetter because of the minimum evaporation loss with this system. Furrow irrigation wetted all the soil profile, therefore, the soil moisture is too high in the soil profile both before and after irrigation compared to the microirrigation systems that wetted only small portion of the soil profile (root zone) (Fig 3).

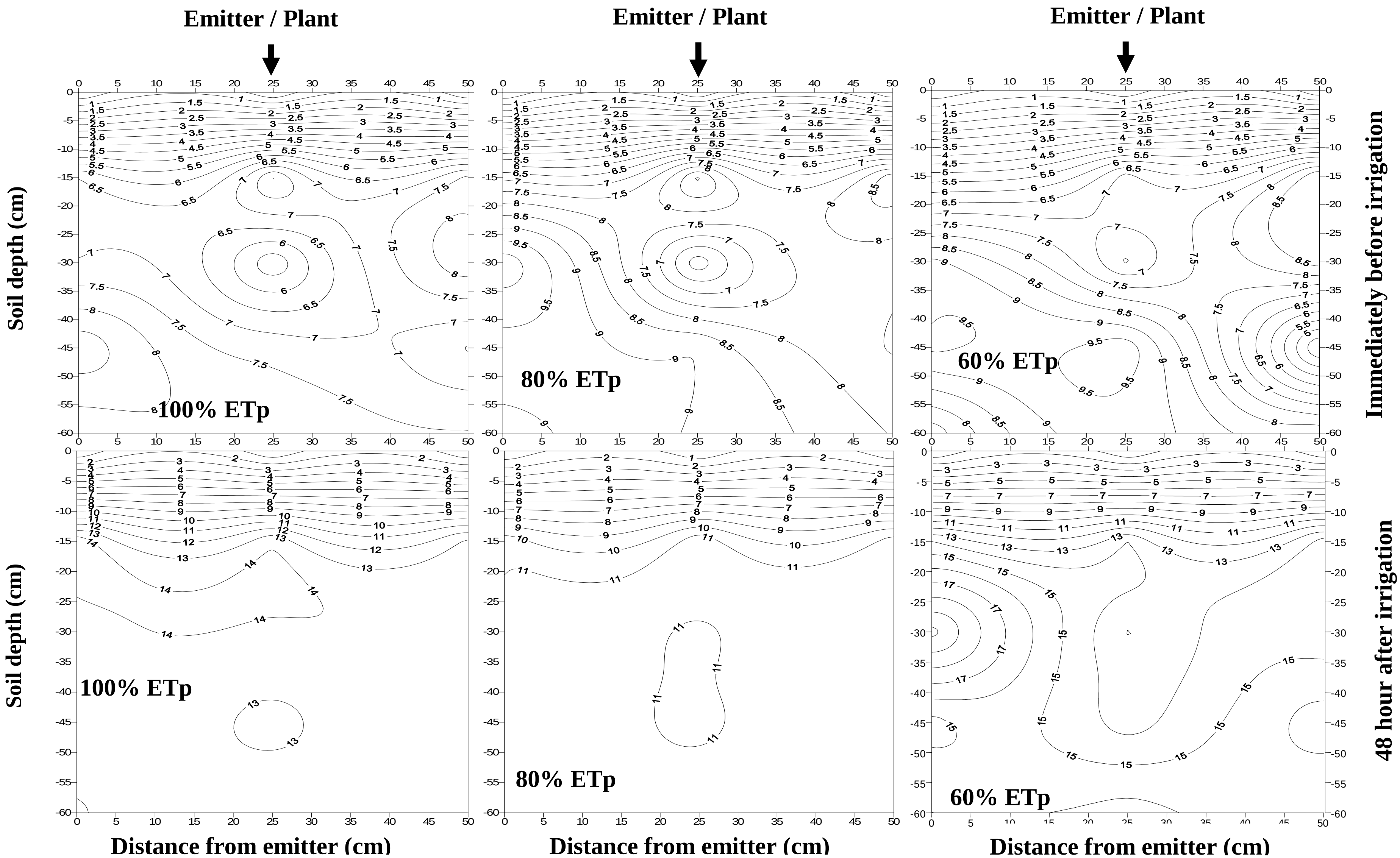

Figure 1. Contour maps of soil moisture (%) distribution around corn plants before irrigation and 48 hours after irrigation under surface drip.

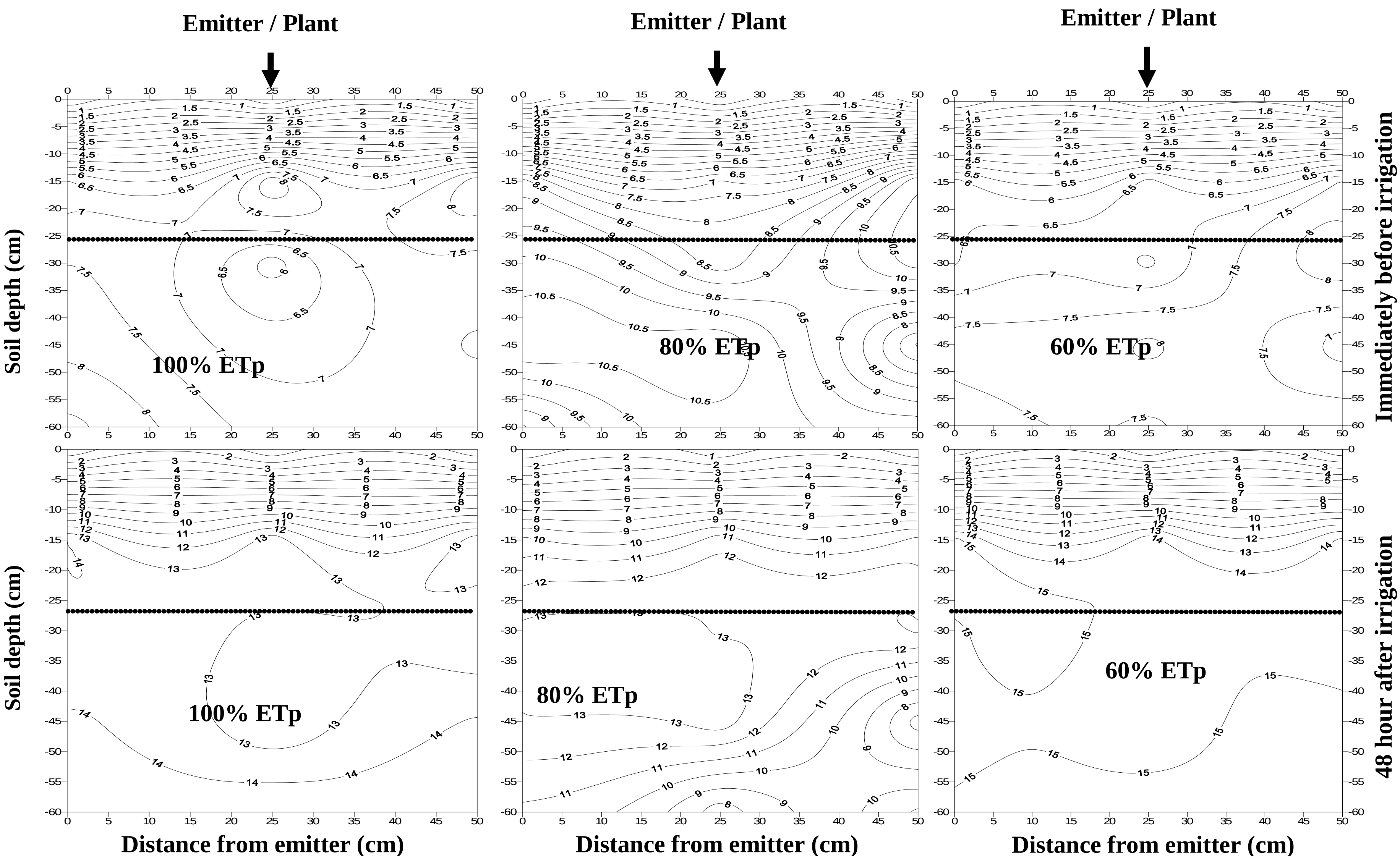

Figure 2. Contour maps of soil moisture (%) distribution around corn plants before irrigation and 48 hours after irrigation under subsurface drip

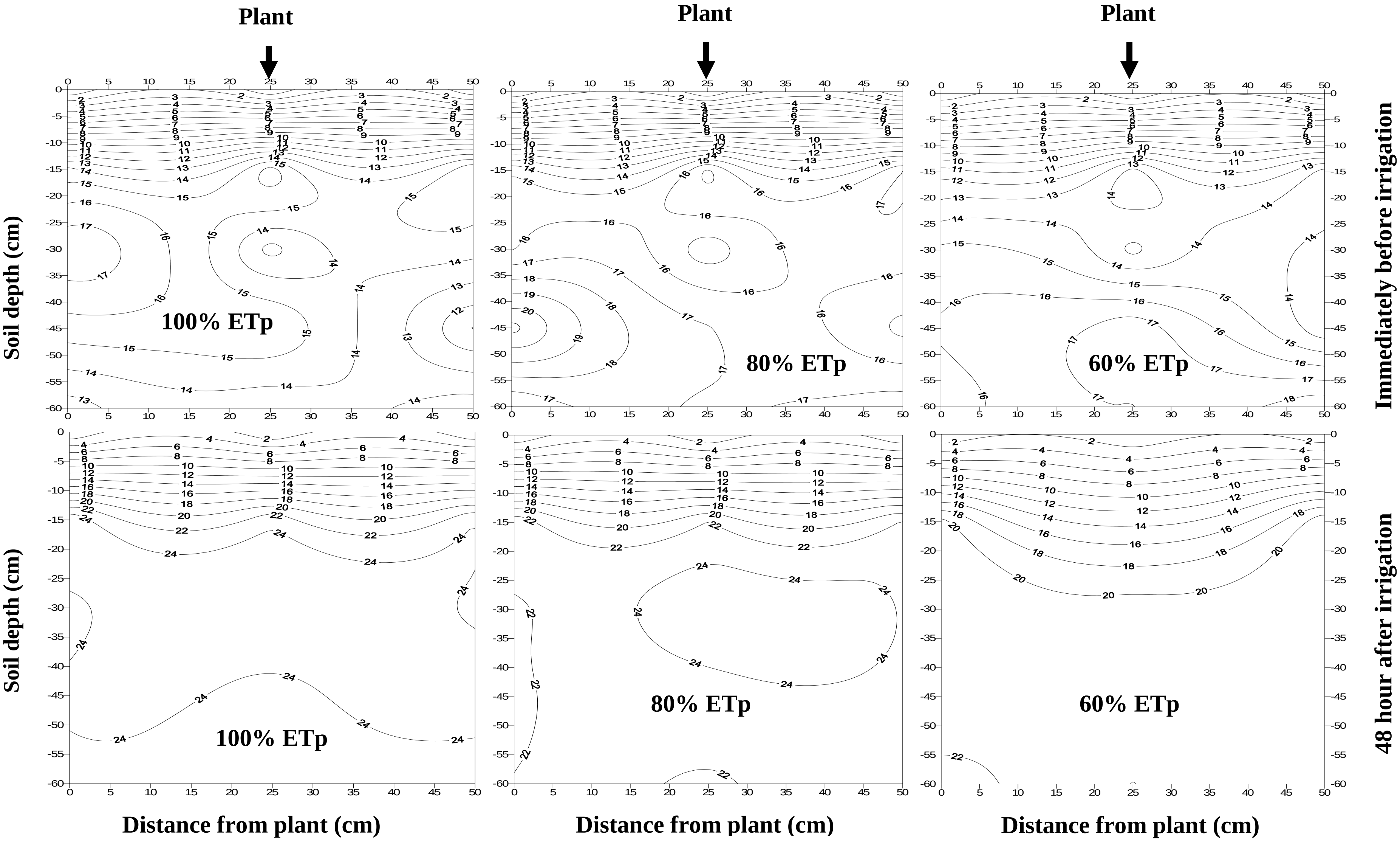

Figure 3. Contour maps of soil moisture (%) distribution around corn plants before irrigation and 48 hours after irrigation under furrow irrigation using gated pipes technique.

3.3 Salt Distribution and Movements

The contour maps of salt accumulation in the soil profile around the corn plant for all treatments under surface drip, subsurface drip, and furrow irrigation using gated pipes were drawn (Figs 4, 5 and 6). The contour maps represent the value of electrical conductivity (EC) in dS/m for all depths starting at zero depth and ending at a 60-cm depth. Under surface drip irrigation as presented in Fig. (4), for all treatments, the value of EC decreased as one moves upward from the 60-cm depth to the soil surface, and spread horizontally at both sides from the emitters. This figure also illustrated the salt accumulation before irrigation was better at 100% of ETp compared to the other two levels of water application where, at a depth of 20 cm in the soil profile, the greatest value of EC was about 0.2 dS/m at 100% of ETp, while it was about 0.45 dS/m at 60% of ETp. This may be due to insufficient application of water added at 60% with respect to that at 100% of ETp. The figure also showed that moving downward from a depth of 20 cm to a depth of 60 cm, the value of EC decreased, in addition to the great distance between contour lines for all treatments, 48 hours after irrigation. The best uniform distribution of salts in the soil profile was observed at 100% of ETp immediately before irrigation. At 80% and 60% of ETp, the salts slightly concentrated at the depths up to 20 cm, while the great amount of salts moved deeply and concentrated the greatest amount at the 30-cm and 40-cm depth of the soil profile. Therefore, with surface drip irrigation with daily irrigation the distribution of salts was satisfactory and differentiated in concentration due to the level of water application.

For the subsurface drip irrigation system, the salt accumulation as presented in Fig. (5) showed that the salts concentrated largely either vertically and horizontally for all treatments at 48 hours after irrigation. However, in the upper depths (20 cm form the soil surface) the salts spread horizontally by minimum values of EC, especially at 100% of ETp. The greatest values of EC were at a depth ranging between 40 and 60 cm, where the value of EC was about 0.8 dS/m for all treatments. The value of EC decreased immediately before irrigation with the lowest value at the upper layer up to 20 cm. The best uniformity of salt accumulation was observed at 100% of ETp of application rate because of the accumulation of salts due to rising by capillary action. The distribution of salts in the soil profile with the subsurface drip irrigation system was not satisfactory compared with that observed by the surface drip irrigation system. Hence, the accumulation of salts around the root zone is considered a disadvantage of using this system.

As for the furrow irrigation using gated pipes, the accumulation of salts at 48 hours after irrigation as presented in Fig. (6) achieved the best distribution of salts compared with both surface and subsurface drip irrigation systems. The salt accumulated with low values at the upper depth of all treatments, while the salts almost disappeared downward except at 100% of ETp. It is evident that the water added with gated pipes plays an important role in leaching salts to be lowest at the deeper depths.

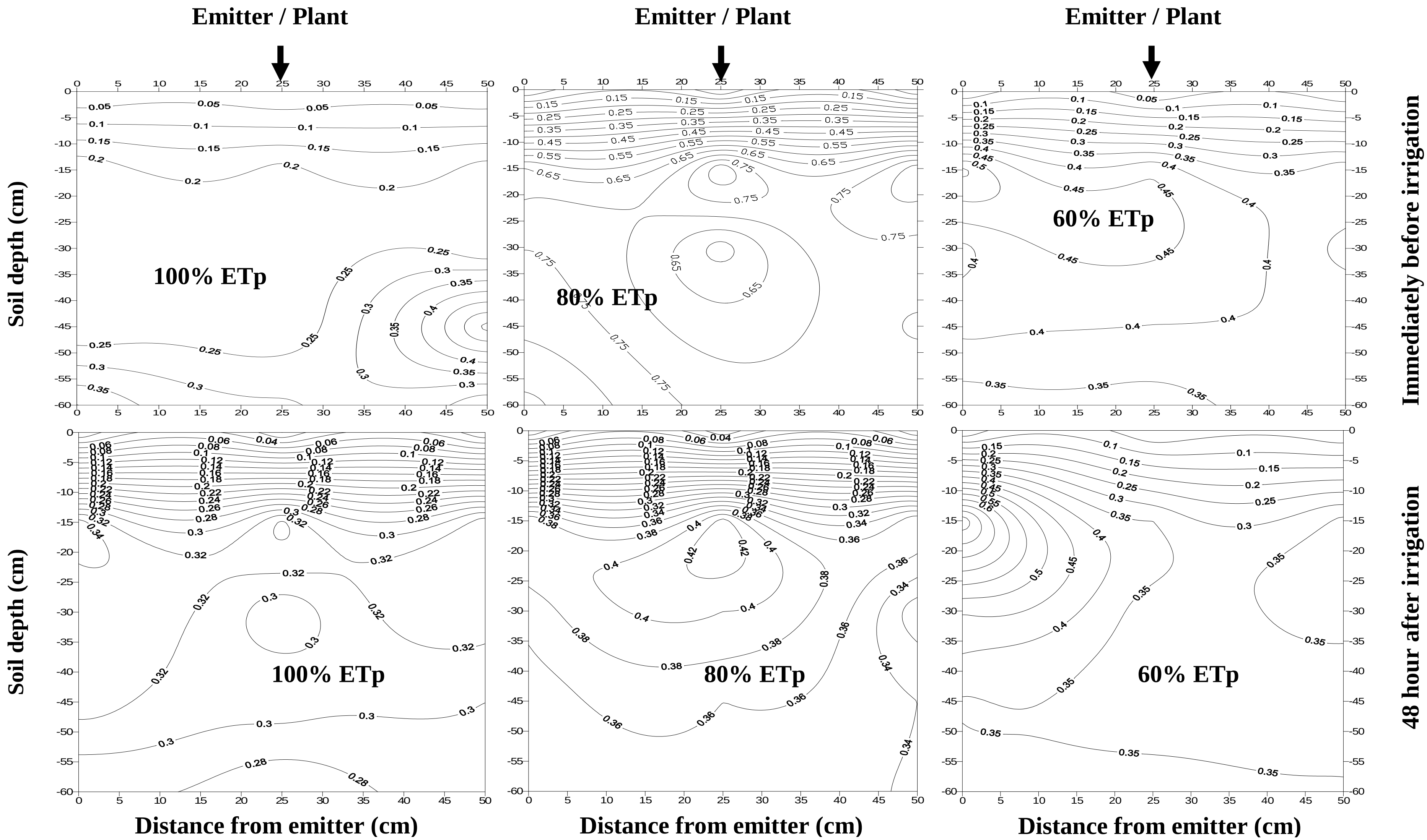

Figure 4. Salt distribution and accumulation around corn roots before and 48 hours after irrigation under surface drip.

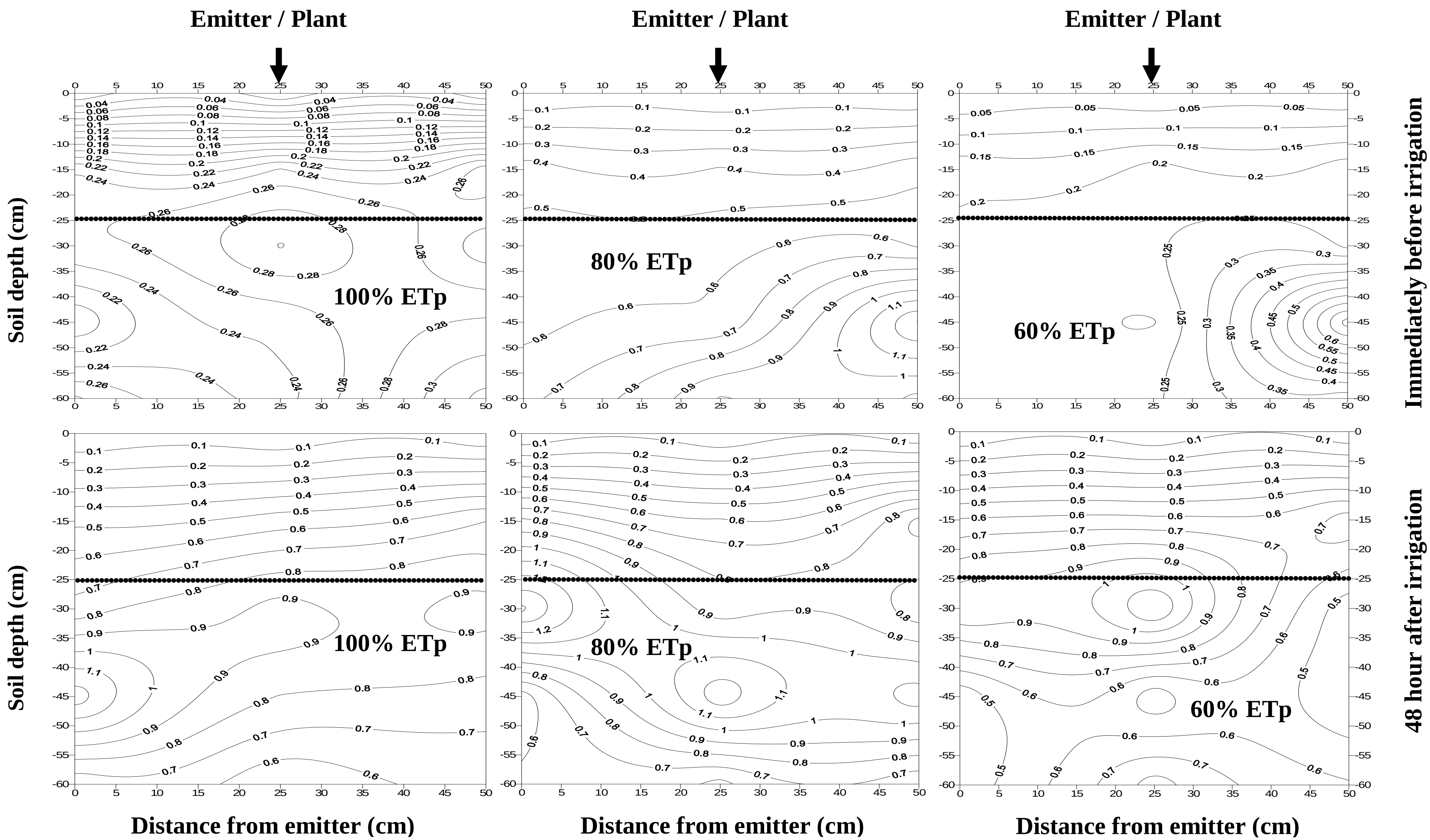

Figure 5. Salt distribution and accumulation around corn roots before and 48 hours after irrigation under subsurface drip.

•••••••••••••••• Dripper line

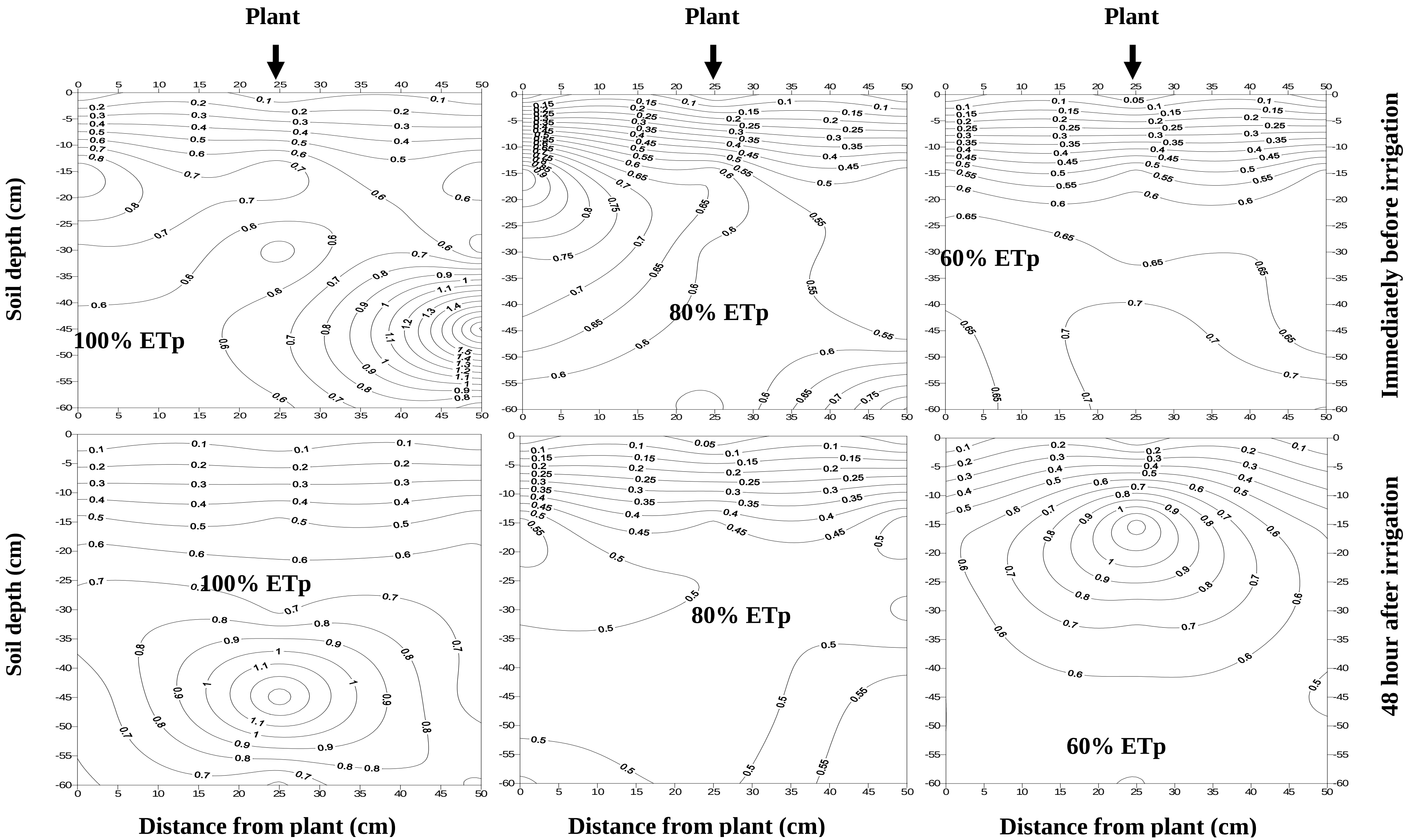

Figure 6. Salt distribution and accumulation around corn roots before and 48 hours after irrigation under furrow irrigation using gated pipes technique

3.4 Fluctuation of the Water-table Level under Surface Drip, Subsurface Drip and Gated Pipes

The water-table level throughout the growing season, which started in May and ended in September was monitored (Fig. 7). It is clear that the water-table level below the ground surface was approximately constant throughout the growing season for surface drip irrigation. This may attributed to the application of water in this treatment. It means that the applied water was sufficient for the growth of corn. Changing of the water-table level throughout the growing season occurred with both subsurface drip and furrow irrigation using gated pipes. For subsurface drip, the water-table level moved up toward the ground surface during June, July and August, while, it moved downward in September. The rate of water application was added according to the potential evapotranspiration, which was slightly lower during September than during June, July and August. As for gated pipes, the amount of water applied was larger than both surface and subsurface drip irrigation, due to the value of application efficiency, which was lower in the gated pipes technique than in both surface and subsurface drip irrigation. Part of the water applied by gated pipes was lost by evaporation, therefore, the net applied water to corn was less than required, and the level of the water-table moved downward from the ground surface.

Fig. (7) also shows that the depth of the water-table was 200 cm below the ground surface in the case of surface drip irrigation, while it was 150 and 68.6 cm for subsurface drip and gated pipes irrigation technique, respectively. Although the fluctuation of water-table level was lower in furrow irrigation using gated pipes, the level of the water-table depth was still moving towards the soil surface compared to the other two microirrigation systems. Table (2) shows the fluctuation of the water-table depth in cm/month during the growing season. It is evident that the fluctuation of the water-table depth was greater in subsurface drip irrigation, and the level moved toward the ground surface during June, July and August. The maximum increase of the water-table depth was 13.9 cm, which occurred during July with subsurface drip system.

The furrow irrigation using gated pipes system caused a decrease in the water-table depth by 11.1, 5.7, and 1.4 cm during June, July, and August, respectively. Although, in the furrow irrigation using gated pipes technique, the application of water was more than in the microirrigation systems. In the surface and subsurface drip irrigation systems, the situation of water-table was better. This was because of the large amount of water evaporated from the ground system, while the water infiltrated in the soil profile was sufficient for the plant needs, and did not cause an increase in the depth of the water-table. The results revealed that surface and subsurface drip irrigation are recommended in the Nile valley and Delta lands, especially in the areas that have waterlogging problems, because they decreased the water-table levels. The total variation in the water-table depth was 33.4 cm toward the ground surface under the subsurface drip irrigation system. It may be due to the capillary rise of water caused under the subsurface drip system, which reflects the situation of available water in the root zone in this case. However, the total variation in water-table depth in furrow irrigation using gated pipes was 15.7 cm below the soil surface.

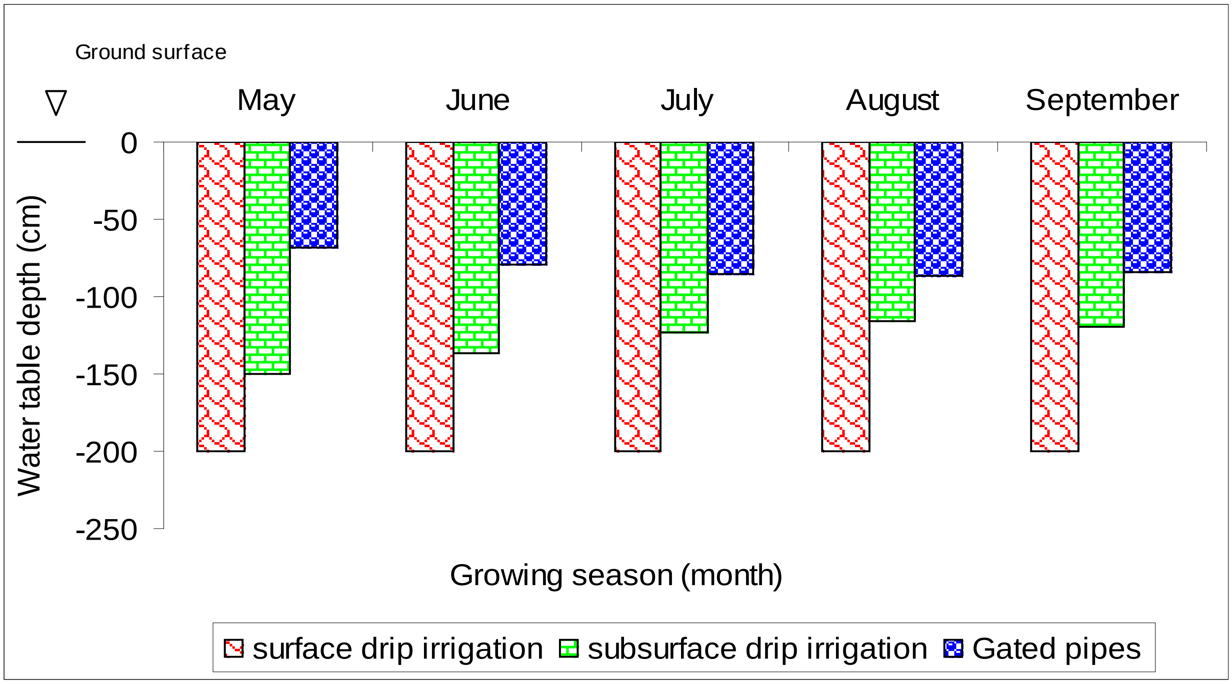

Figure 7. Fluctuation of water-table depth during the growing season of corn under three tested irrigation systems.

Table 2. Variations of the water-table depth throughout the growing season of corn under surface drip, subsurface drip and furrow irrigation using gated pipes irrigation

parameters	Surface drip					Subsurface drip					Furrow irrigation using gated pipes				
	May	**June**	**July**	**Aug.**	**Sept.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**May**	**June**	**July**	**Aug.**	**Sept.**
Depth of water-table (cm)	200	200	200	200	200	150	136.5	122.6	113	116.6	68.6	79.7	85.4	86.8	84.3
Fluctuation of water-table depth in cm/month	0	0	0	0	0	0	+13.5	+13.9	+9.6	-3.6	0	-11.1	-5.7	-1.4	+2.5
Percent of change in water-table depth per month	0	0	0	0	0	0	+9	+0.1	+0.08	-0.03	0	-0.16	-0.07	-0.02	+0.03
Total variation of water-table depth in cm/growing season	**0**					**+33.4**					**-15.7**				

+ means upward towards the soil surface
- means downward below the soil surface

3.5 Corn Growth Indictors

The growth parameters were focused upon plant height (cm), leaf area (cm^2), plant circumference (cm), number of steps per plant, and number of leaves per plant; the number of ears per plant was also measured as a yield component. Table (3) represents the statistical analysis of growth parameters of corn as affected by the three irrigation systems. It shows that the highest value of plant height was 244.3 cm achieved with the surface drip irrigation system at 100% of ETp. The lowest value of plant height was 175.2 cm with the subsurface drip irrigation system at 60% of ETp. Surface drip irrigation recorded the highest values of leaf area, number of steps per plant and number of leaves per plant, which were 862.4 cm^2, 18 steps and 18 leaves at 100% of ETp, respectively, but the highest value of plant circumference was 10.27 cm obtained at 60% of ETp. Furrow irrigation using gated pipes produced the highest number of ears per plant for each treatment, which was 2.50 ear/plant at 100% of ETp. The table also shows that the lowest values of leaf area, plant circumference, the number of steps per plant, number of ears per plant, and number of leaves per plant were 497.6 cm^2, 7.53 cm, 17 steps/plant, 1.17 ears/plant, and 17 leaves/plant, respectively, obtained at 60% of ETp with furrow irrigation using gated pipes.

The statistical analysis illustrates that there are significant differences among tested irrigation systems in affecting plant height, leaf area, and plant circumference, but its effect is not significant on the number of steps per plant, number of ears per plant, and the number of leaves per plant. Deficit irrigation has a significant effect on the plant height, leaf area, plant circumference, and the number of ears per plant. Nevertheless, its effect on the number of steps per plant and the number of leaves per plant is not highly significant. The effect of the interaction between irrigation systems and water treatments is significant only on the leaf area and plant circumference and not significant on other growth parameters. From the aforementioned results, it is recommended to use furrow irrigation using gated pipes to obtain the highest yield of corn grain but surface drip irrigation to obtain the highest yield of straw in old lands.

Table 3. Average values of growth indicators of corn with different irrigation levels under surface drip, subsurface drip and furrow irrigation using gated pipes irrigation

Growth indicators	**Surface drip**			**Subsurface drip**			**furrow irrigation using gated pipes**			**Significant degree at 5%**		
	100 % of ETp	**80 % of ETp**	**60 % of ETp**	**100 % of ETp**	**80 % of ETp**	**60 % of ETp**	**100 % of ETp**	**80 % of ETp**	**60 % of ETp**	**Irrigation systems**	**Water treatments**	**Interaction between irrigation systems and water treatments**
Plant height, (cm)	244.3	244.3	220.5	232.8	192.5	175..2	230.5	234.5	181.2	0.001	0.000	0.172
Leaf area, (cm^2)[a]	862.4	804.8	836.6	836.5	767.8	760.3	740.8	677.9	497.6	0.000	0.003	0.038
Plant circumference, (cm)	10.12	9.58	10.27	9.88	9.90	9.97	9.33	9.40	7.53	0.000	0.000	0.000
Number of steps per plant	18	17	17	17	18	17	17	18	17	0.488	0.124	0.074
Number of leaves per plant	18	17	17	17	18	17	17	18	17	0.488	0.124	0.074
Number of ears per plant	2.00	1.83	2.00	2.33	2.33	1.67	2.50	1.83	1.17	0.459	0.016	0.147

[a] Leaf area = 0.75 (Maximum width x length of the leaf of corn)

3.6 Corn Yield and Irrigation Water Use Efficiency

The relationship between irrigation levels and the yield of corn ears was similar for the used irrigation system, where the yield of corn ears decreased as the irrigation level decreased. However, the decrease in the yield differed from one system to the other. The data obtained in Table (4) illustrate that the highest value of corn ears yield at 100% of ETp was 11.59 Mg/ha obtained with furrow irrigation using gated pipes followed by 7.43 Mg/ha with surface drip irrigation and 7.33 Mg/ha with subsurface drip irrigation.

The same trend was followed at 80% of ETp and 60% of ETp where the yield of corn ears was 9.50, 7.16, and 4.05 Mg/ha at 80% of ETp and 7.95, 4.52, and 3.43 Mg/ha at 60% of ETp with furrow irrigation using gated pipes, surface drip, and subsurface drip irrigation systems, respectively. Decreasing applied water by 20% of ETp led to decreased grain yield of corn by 18.07%, 44.81%, and 3.85% with furrow irrigation using gated pipes, subsurface drip, and surface drip irrigation systems, respectively.

However, decreasing the applied water by 40% of ETp led to decreased yield of corn ears by 31.42%, 53.24%, and 39.10% under furrow irrigation using gated pipes, subsurface drip, and surface drip irrigation systems, respectively. In addition, the obtained results show that the highest decrease in corn ears with respect to furrow irrigation using gated pipes was 57.39%, which occurred at 80% of water application rate with subsurface drip irrigation, while, the lowest decrease was 24.81%, which occurred at 80% of water application rate with surface drip irrigation.

Crop water use efficiency as related to irrigation systems and irrigation levels was calculated (Table 4). They show that the highest value of irrigation water use efficiency (2.44 kg/m^3) was obtained with furrow irrigation using gated pipes at 100% of ETp followed by surface drip irrigation (1.77 kg/m^3) at 80% of ETp. The lowest value of water use efficiency was (0.97 kg/m^3) recorded with subsurface drip irrigation at 60% of water application. It is also evident that, at each irrigation system, the crop water use efficiency decreased with decreasing the water application rate except at 80% of ETp with surface drip irrigation. Decreasing the total seasonal water application negatively affected the crop water use efficiency. Comparing between surface drip and subsurface drip from the point of view of the recorded crop water use efficiency, it is clear that the surface drip system has an advantage in the beneficial use of water. This is because of higher values of crop water use efficiency recorded with surface drip than that recorded by the subsurface drip irrigation system. This may be due to the uniform distribution of moisture in the effective root zone of corn in the soil profile observed with surface drip irrigation.

Table 4. Water added, yield of corn, and water use efficiency under surface drip, subsurface drip and furrow irrigation using gated pipes

Parameters	Irrigation systems								
	Surface drip			Subsurface drip			furrow irrigation using gated pipes		
	100% of ETp	80% of ETp	60% of ETp	100% of ETp	80% of ETp	60% of ETp	100% of ETp	80% of ETp	60% of ETp
Irrigation amount (m^3/ha)	4533.19	4039.10	3544.77	4488.92	4003.40	3518.12	4742.15	4145.72	3549.29
Yield (Mg/ha)	7.43	7.16	4.52	7.33	4.05	3.43	11.59	9.50	7.95
Irrigation water use efficiency (kg/m^3)	1.64	1.77	1.28	1.63	1.01	0.97	2.44	2.29	2.24
Decreasing percent in yield due to water application (%)	0	3.53	39.10	0	44.81	53.25	0	18.07	31.42
Decreasing percent in yield due to irrigation system (%)	**35.93**	**24.81**	**43.11**	**36.76**	**57.39**	**56.89**	**0**	**0**	**0**

3.7 Cost Analysis

The variable cost included operating cost of the irrigation system and agricultural operation costs; all details are presented in Table (5).

The total costs varied gradually from irrigation system to another; from the results presented in Table (5) it can be deduced that there are significant differences in the total cost of producing corn in the old lands under tested irrigation systems. The highest value (545.43 US$/ha/season) was recorded with the subsurface drip irrigation system due to the extra cost for burying the lateral lines in the soil. The lowest value (443.02 US$/ha/season) was obtained with the furrow irrigation using gated pipes. The total cost of surface drip is higher than furrow irrigation using gated pipes irrigation system by 18.63%, and it is lower than subsurface drip irrigation system by 0.2%.

The highest value of gross margin including fixed cost (925.84 US$/ha/season) was obtained with furrow irrigation using gated pipes, which was 166.3% and 156.3% higher than subsurface drip and surface drip irrigation systems, respectively. Moreover, the lowest value (347.66 US$/ha/season) was obtained with the subsurface drip irrigation system.

Table 5. Seasonal total cost and gross margin in (US$/ha/season) of corn under the three tested irrigation systems (at 100% of ETp) of water application.

Cost items		Microirrigation systems: Surface drip	Microirrigation systems: Subsurface drip	Furrow irrigation using gated pipes
Capital cost (US$/ha)		2048.34	2072.45	1244.92
Fixed costs (US$/ha/season**, 4 month)**				
1- Depreciation		54.86	54.86	32.31
2- Interest		81.93	82.90	49.80
3- Taxes and insurance		10.24	10.36	6.22
Sub-total		**147.04**	**148.12**	**88.33**
Operating costs (US$/ha/season**, 4 month)**				
1- Fuel		35.16	34.82	1.52
2- Maintenance and Repairing		20.48	20.72	4.15
3- Labors		2.82	2.82	10.08
Sub-total		**58.47**	**58.37**	**15.75**
Total annual irrigation cost (US$/ha/season**, 4 month)**		**205.51**	**206.49**	**104.08**
Total agricultural Costs		**338.94**	**338.94**	**338.94**
Total costs (US$/ha/season**, 4 month)**		**544.45**	**545.43**	**443.02**
yield	**Main, (Mg/ha)**	7.40	7.29	11.53
	Straw,(Heap of Hay)	9.18	9.18	9.18
Price, (US$/ha**)**	**Main**	50.40	50.40	50.40
	Straw	8.40	8.40	8.40
Total revenue, (US$/ha/season**, 4 month)**		**905.69**	**893.09**	**1368.86**
Gross Margin, (US$/ha/season**, 4 month)**		**361.24**	**347.66**	**925.84**

- ✓ Interest rate, (12% and 7%) for fixed and variable costs, respectively
- ✓ Taxes and insurance, 1.5% of capital cost
- ✓ Fuel consumption of the pump, 6 l fuel/hr and irrigated area 2.5 ha per one valve
- ✓ Annual maintenance and repairing costs are expressed as a percentage, (3% and 1%) of initial cost for microirrigation and modified surface irrigation systems, respectively
- ✓ Irrigation labors required were estimated to be (0.67 and 2.38 hr/ha/event) for microirrigation and modified surface irrigation systems, respectively
- ✓ Heap of Hay =250 kg of Straw
- ✓ Total costs excluding the rent of land

4. CONCLUSION

In many areas of the Nile Valley and Delta in Egypt under scarce water conditions of the country, farmers still use primitive methods of irrigation. Agricultural irrigation consumes more than 80% of the country's water budget for cultivating approximately 3.36 million ha (8 million feddans) with an annual crop area about 6.3 ha (15 million feddans). About 2.52, ha (6 million feddans) are old lands irrigated by surface irrigation methods with low on-farm water application efficiency (40-60%). Waterlogging, salinization, and low application efficiency are the main problems inherent with surface irrigation. Replacing the surface irrigation method with precise irrigation systems became the main interest of the decision makers and policy planners in Egypt. Goals were to ration the water used for irrigating the old lands of the Nile Valley and Delta, increase the water productivity, alleviate the environmental impacts of surface irrigation such as waterlogging and salinization, and to reclaim the Egyptian desert using rationalized water. The farmers are faced with a decision on whether they should convert to higher efficiency microirrigation systems or modified surface irrigation systems. The results revealed that it is recommended to use furrow irrigation using gated pipes to obtain highest yields of corn and highest growth margin in the old lands, especially in the areas that have salinization problems. Surface drip is recommended in the areas that have waterlogging problems but subsurface drip irrigation is strongly recommended under water scarcity conditions.

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