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Full Length Research Paper

Challenges of surface irrigation development, water and land productivity in Egypt

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Irrigation development is a gateway to increased agricultural, water and land productivity, increased household and national food security. However, irrigation development has been a major challenge in many developing countries, including Egypt. The overall objective of this study is to detect the influence of different irrigation systems on water-use efficiency, crop and soil salinity in highly soil salinity. Two techniques were applied in experiment, the first technique was siphon irrigation, and the second one was gated pipe. The monitored parameters were water table depth, water and soil salinity and crop yield. The study revealed that the intensive management is a very important aspect for the success of siphon technique and cotton crop yield was higher by 17% compared to gated pipe irrigation treatment. The total soil salinity increased in both treatments. The siphon method increases the average salinity by 2.7% while the gated pipe increased it by 12.9%; converging the value of the crop coefficient in all relations used in most stages of growth, except Penman relationship which gave the highest values.

Key words: Siphon irrigation method, gated pipe irrigation method, subsurface drainage, water-table management, water-table salinity, soil salinity, and crop yield.

INTRODUCTION

As water is becoming more and more a scarce resource all over the world, proper management of the available water is essential. For an optimal use of the available water resources, water management strategies have to be developed. Soil salinity problems generally occur in arid and semiarid regions and reduce crop production at different levels. Salinity is also a major limiting factor for crop yield in poorly drained soils (Mikati, 1997; Rogers, 2002; Patel et al., 2002). Nhundu et al. (2010) recommend that national governments should formulate and hold sound irrigation development strategies and encouraged to partner with public and private institutions in defining and implementing such comprehensive strategies for sustainable irrigation development. Landwirtschaftlichen et al. (2011) recommend a proper field preparation, including for instance a laser-guided land leveling is necessary before bed making to facilitate a uniform distribution of irrigation water; a suitable bed height, that is, 10 to 15 cm height, is needed for efficient salt leaching; adequate soil moisture content needs to be ensured during planting to obtain a proper plant stand; the use of appropriate herbicides for weed control is advantageous; the use of appropriate machinery to drill seed and fertilizer at the proper depth is compulsory; a reshaping of beds during planting, if necessary; the use of short-maturing crop varieties is advantageous. Abdel Ghaffer et al. (2006) studied the sub-irrigation method to manage the water table and the effect of method on wheat crop.

The beneficial and adverse effects of trace element levels in crop foods that make up major proportion of dietary intake on human health are particularly important (Grant et al., 2008). Agronomic and genetic practices can be important tools both to increase the concentration of

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desirable trace elements such as Zn and reduce that of potentially harmful trace elements such as Cd. While soil Cd concentrations are relatively low in most wheat growing areas in Iran, some agricultural lands are contaminated with Cd due to excessive application of low-quality phosphate-fertilizers containing Cd as impurities (Afyuni et al., 2007). In some cases the concentrations of Cd in wheat grains have increased to levels above the maximum permissible limit of 0.2 ppm (Codex, 2008). Bouksila et al. (2010) estimate the soil salinity over a shallow saline water table in semiarid Tunisia.

The objective of this research is studying the evolution of soil salinity after and during the use of gated pipe method and siphon method in irrigation, and study the effect of both methods on water-use efficiency, soil salinity, and their effect on the cotton.

METHODOLOGY

Experimental site

Field experiments were conducted in the irrigated area of western Delta, Egypt. The irrigated area covers 2.8 ha and the main crops are cotton. The climate is Mediterranean semiarid with little rainfall. Only 100 to 200 mm of rain falls on the delta area during an average year, and most of this falls in the winter months. The experimental area is divided into lines where each line 240 m in length and 0.75 m in width and has a sandy silt loam to clay loam texture. The field hydraulic conductivity was measured using the auger hole method and the average value is 2.0 m/day. The main source of the irrigation water is supplied from field canal, both gated pipe and siphon irrigation is used in the system. The site is served by a subsurface drainage system. The collector drains (PVC corrugated plastic pipe) have been installed at about 1.5 m depth and all laterals drains (PVC corrugated plastic pipe covered by synthetic envelope materials) have been installed at a depth of 1.2 m with an average space of 80 m. The lateral drains were sloped at 10% and exit directly to the main collector through a manhole. Figure 1 shows the experimental study. In total 77 sampling plots, spaced at about 50 by 50 m were investigated. In each plot, soil samples were collected at 0, 15, 30, 45, 60, 75, 90, 105, 120, 135, and 150 cm depth. The soil samples were analyzed to determine soil particle size and ECe. Soil particle size was measured in the laboratory using the sedimentation method (pipette and hydrometer). Five fractions were measured, clay (d<2 µm), fine silt (2<d<20 µm), coarse silt (20<d<50 µm), fine sand (50<d<200 µm), and coarse sand (200 µm<d<2 mm). Beside soil samples, the depth to groundwater table from the soil surface (Dgw) and electrical conductivity of the groundwater (ECgw) were measured at each of the 77 plots. Table 1 shows the average soil salinity along the soil depth. The table shows that the pattern of soil salinity started with low value of 1.7 dS/m at the upper layer and increases with depth to a value of 3.9 dS/m.

The gated pipe irrigation method

The pipes are 6 m in length, 150 mm in diameter and with distance holes 0.75 m which can communicate with each. The pipe holes can be changed to give the flow required by using the Equation 1. Pipe connected with the basin to secure the appropriate pressurized by counter discharge (Kemper et al., 1981).

$$Q = 0.0066 d^{2} * h^{0.5} \tag{1}$$

Where Q is the discharge "m^3/s", d is opening diameter "m", h is the water head above the opening center "m".

The siphons system

The siphons with 0.037 m in diameter and 1.5 to2.0 m are used to irrigate area. The formula used to compute the discharge from siphons is based on Wigginton (2004) formula as shown in Equation 2.

$$Q = \frac{\pi D^{2}}{4} \left[\frac{2g\Delta g}{1.9 + f \frac{L}{D}} \right]^{0.5} \tag{2}$$

Where Q is the discharge (m^3/s), g is acceleration due to gravity (9.8 m/s^2), H is the head (m). D is actual internal diameter (m), f is the friction loss coefficient of Darcy Weisbach (0.019 for example, for "small diameter pipes"), L is the length (m). The water velocity and the water slope were measured at the middle line at each 20 m and Parshall flume with 5 cm contraction at 3 to 5 m from the start line. The class A basin with 121.5 cm in diameter and 25 cm in height rested on wooden block used to measure the evaporation. Figure 1 shows the layout of the experimental site. The water drained by subsurface drainage 10 cm in diameter with spacing 80 m and depth 150 cm.

Measurements

Measurements included water table depth, irrigation and water table salinity, rainfall, temperature, evaporation, and soil salinity.

Irrigation water salinity

Saline soils are of increasing importance both in Egypt and world-wide. Richards (1954) define SAR as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \tag{3}$$

Where SAR is sodium adsorption ration "%", Na^{+} is the sodium "meg/L", Ca^{++} is the calcium ratio "meg/L", Mg^{++} is the Magnesium ratio "meg/L". It was measured before each irrigation gift by a handheld electrical conductivity meter in (dS/m). Irrigation water salinity varied from 0.83 to 2.74 with average of 1.78 dS/m and sodium adsorption ratio is 2.96% and salts total dissolved salts in water varied from 2331 to 2754 with rate of 2542 ppm.

Weather temperature

Weather has been observed daily during the study period and Figure 2 shows the temperature in the study area during the experiment.

Crop yield

The study area were planted in lines 75 cm in distance between

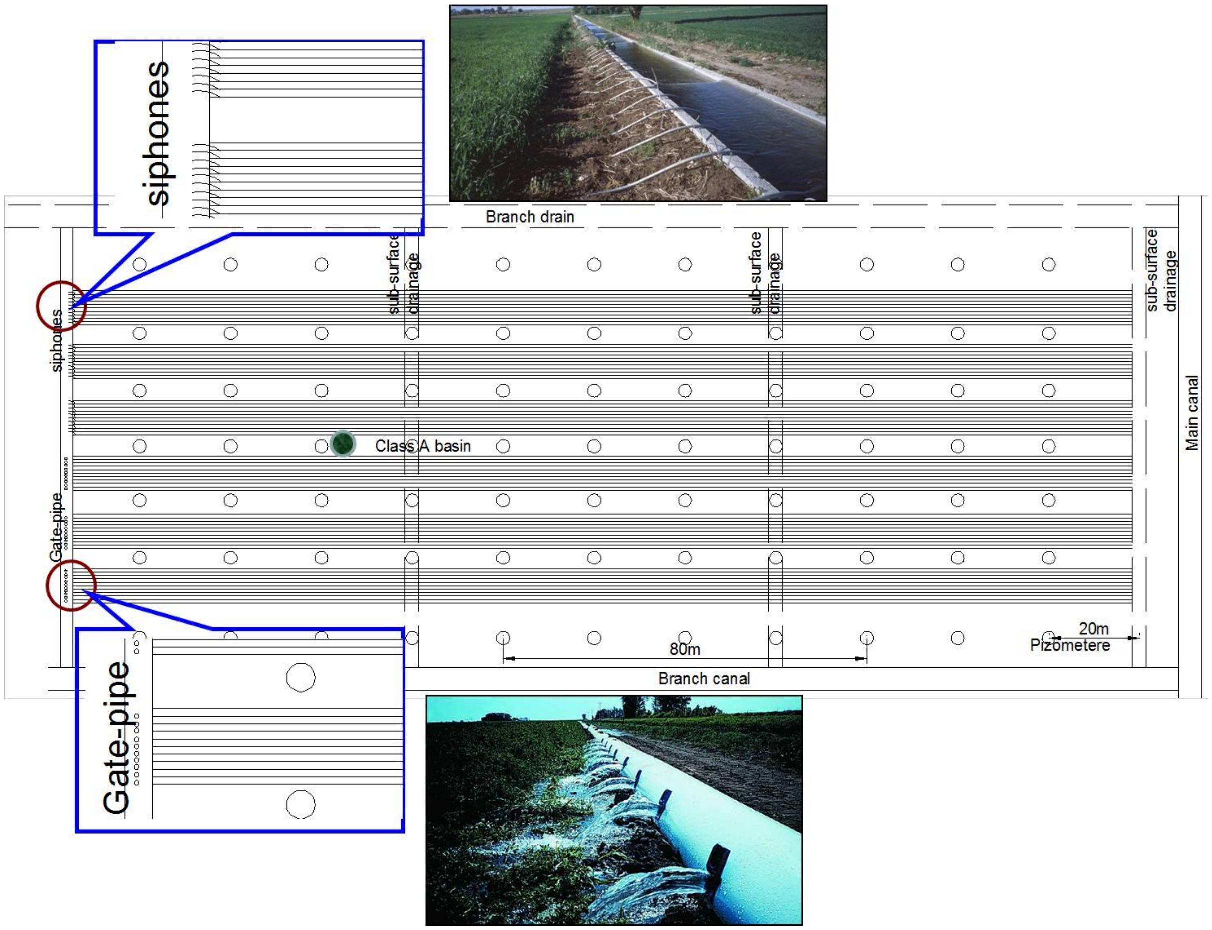

Figure 1. Experimental layout.

Table 1. Soil salinity.

Depth (cm)	E.C (dS/m)	$CaCO_3$ (meg/L)
0- 35	1.7	24.25
35 - 47	2.95	28
47- 105	3.3	22.5
105 - 125	3.9	22.75

them and 15 to 17 cm between the plants. Observation of cotton growth was followed and four crop samples were taken from each treatment at harvest time to determine the average cotton crop yield.

RESULTS AND DISCUSSION

Soil salinity

Samples were also obtained throughout the irrigation season to monitor changes in soil salinity. Figures 3 and 4 show the soil salinity profile at the before, mid and after the growing season for one sampling location. These data indicate that the soil salinity increased in both treatments at mid season then decreased after season in root zone depth due to the growth of cotton and increases in water consumption. At mid season cotton need more irrigation water for growth so the water table decreased and the soil salinity increased, after the season the crop did not need the irrigation water so the water table increased and the soil salinity decreased. In the gated pipe method, the electrical conductivity (E.C) was increased by average 13.5% at mid-season then decreased by 0.5% after the season. In siphon method, the average E.C was increased by about 6.9% at mid-season then decreased by 13.7% after the season as shown in Figure 4. This method increases the salinity at 0 to 15 cm depth at mid season then decreased it after season, and it decrease the soil salinity at 15 to 105 cm depth mid season and after season. The siphon method increases the average of total salinity by 2.7% while the gated pipe increased the salinity by 12.9%. This result is confirmed with the logical, where the irrigation water passes through the siphon system at depth lower than the ground level, so the seepage zone is lower than the ground level therefore the salinity is decreased in this zone but in gated pipe the water irrigation passes at the

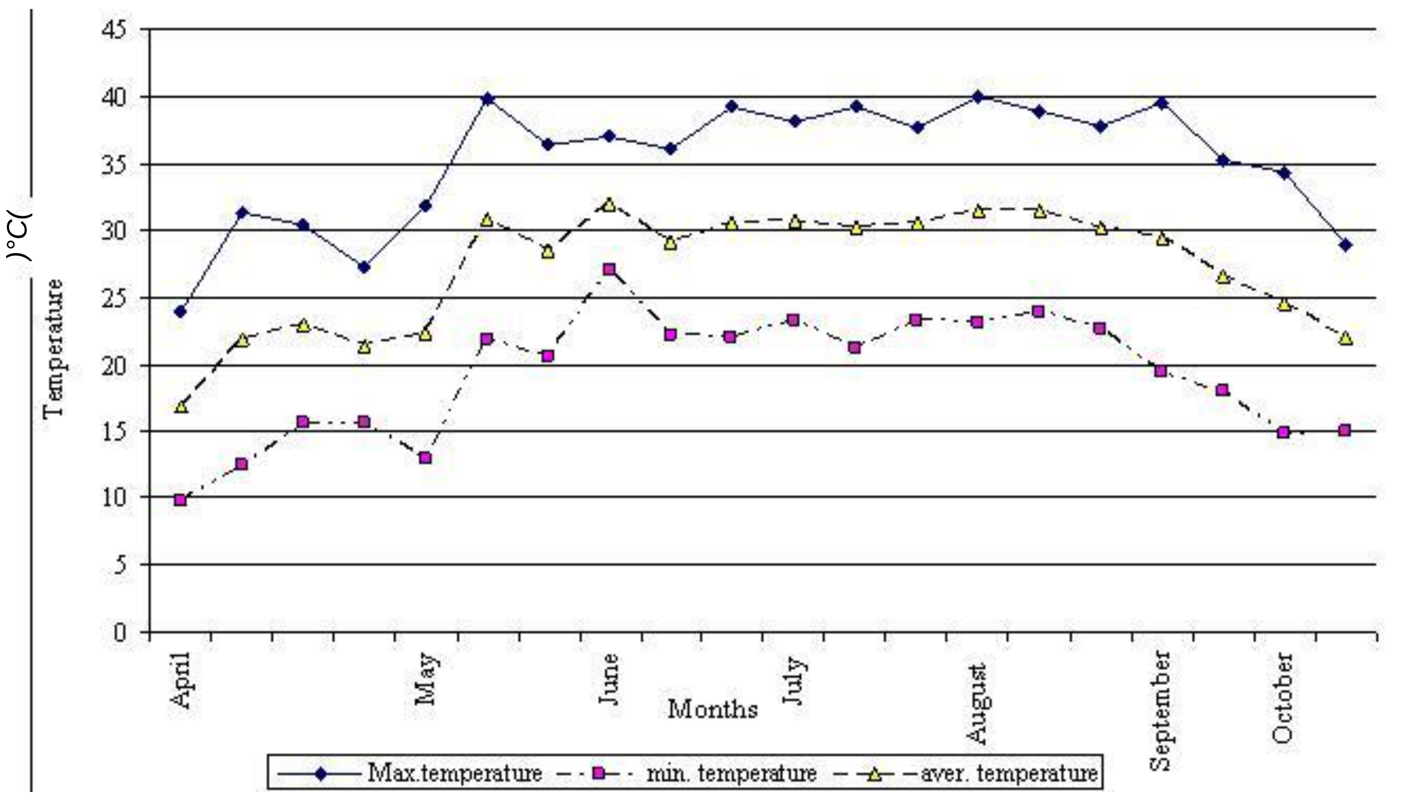

Figure 2. The weather temperature.

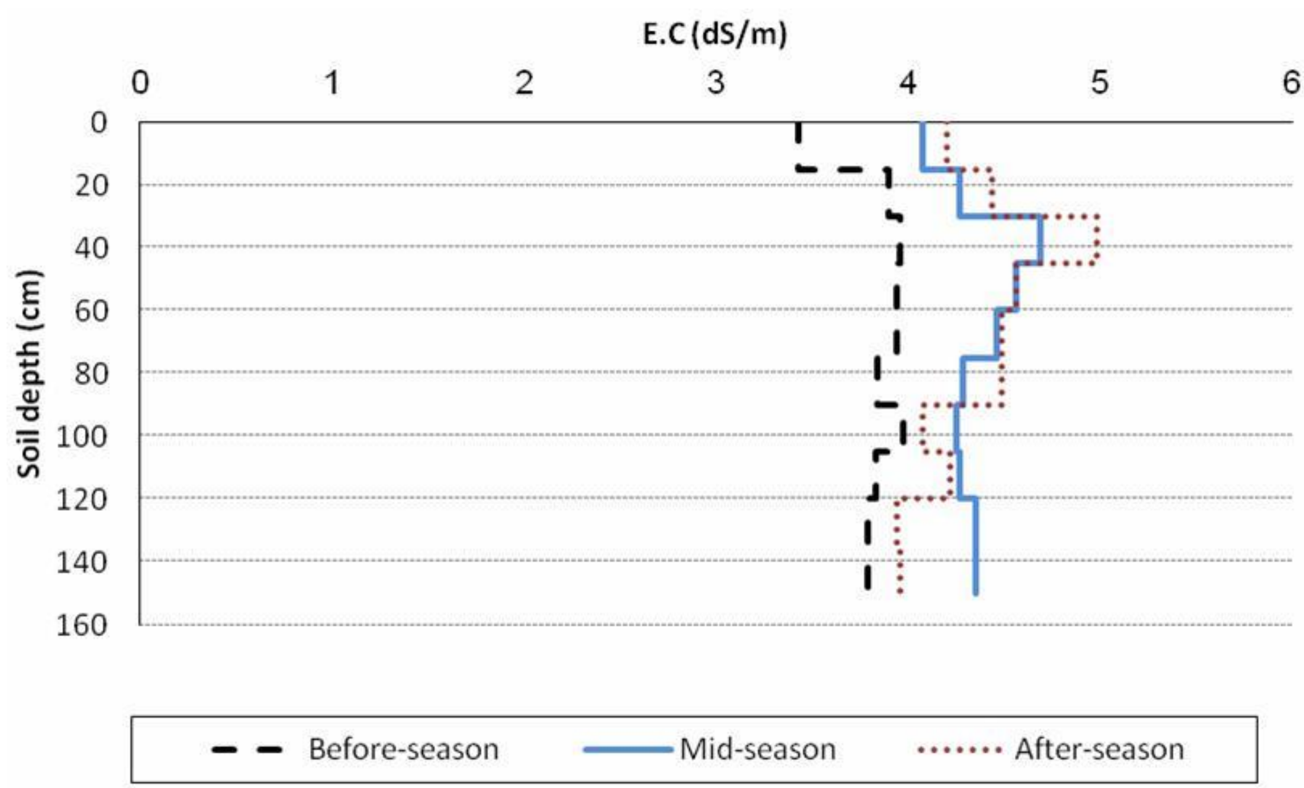

Figure 3. The electrical conductivity for gated pipe.

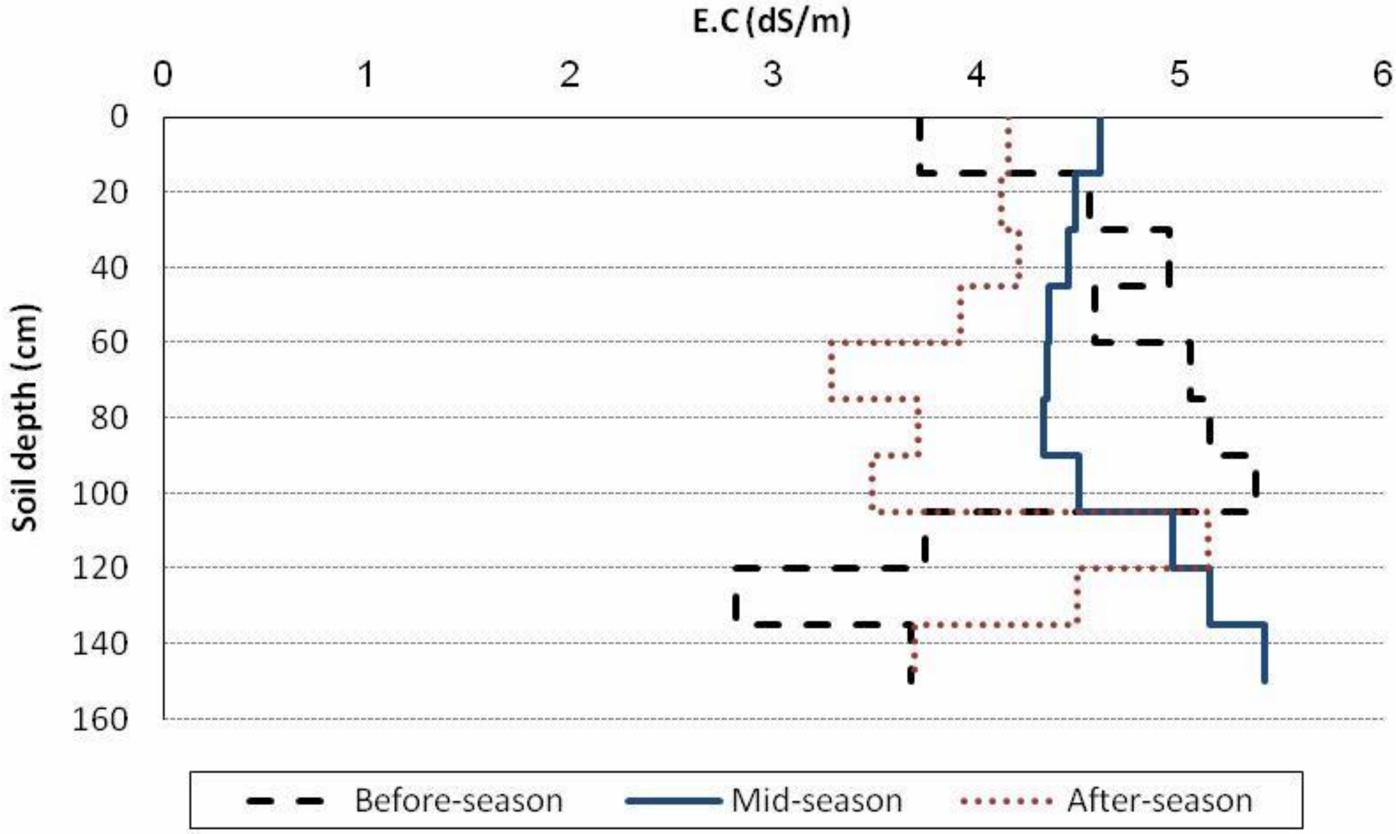

Figure 4. The electrical conductivity for siphon.

same level with the ground level. The sodium adsorption ratio (SAR) is a measure of the number of sodium ions attached to soil particles, relative to the number of calcium and magnesium ions. A large number of sodium ions (high SAR) will degrade soil particles and reduce the number of large pore spaces in the soil. Such a soil is not very permeable, and it is difficult to leach accumulated salts from such a soil by applying excess water. Sodium adsorption ratio (SAR) decreased for both methods. The siphon field average SARs in saturated soil extracts ranged from 4 to 15.83%, with an overall mean of 6.05% and a standard deviation of 1.1% before season and decrease with an overall mean 4.5% by decrease about 24% but in the gated pipe field average SARs in saturated soil extracts ranged from 4 to 12.83%, with an overall mean of 4.75% a standard deviation of 0.29% before season and decrease with an overall mean 4.05% by decrease about 11.4% as shown in Figure 5. The siphon method gives lower ECe and decrease SAR which increase the soil permeability.

The average toxic salts (sodium sulfate, sodium chloride and magnesium chloride) changed from 1.8058 mS/m before planting to 1.8376 mid agriculture then 1.9695 mS/m the end of the season for the treatment of gated pipe. And it decreased from 2.2323 mS/m before planting to 1.9113 mS/m at mid agriculture then increased to 1.9622 mS/m after season for siphon treatment. The gated pipe irrigation method increase the toxic salt by 1.8% at mid-season then it increase by 7.2% after season, but the siphon method decrease it by 14.4% at mid-season then increase it by 2.7% after season. In final the gated pipe increase the toxic salt by 9.1% where the siphon method decreases it by 12.1%. The average non-toxic salts (calcium bicarbonate and calcium Sulfate) changed from 1.0638 before planting to 1.4366 mS/m mid season then 0.9142 mS/m at the end of the season for the treatment of gated pipe. And it increased from 1.1675 mS/m before planting to 1.3758 mS/m at mid agriculture then increased to 0.8838 mS/m after season for siphon. The gated pipe irrigation method increases the non-toxic salt by 35.5% at mid-season then it decreases by 26.2% after season, but the siphon method increases it by 17.8% at mid-season then decreases it by 35.8% after season. In final the gated pipe decreases the non-toxic salt by 14.1% where the siphon method decreases it by 24.41%. The probability of producing alkaline soil in all transactions out of the question because the value of $\frac{K + N_a}{Ca + Mg}$ is less than 1 as shown in Table 2.

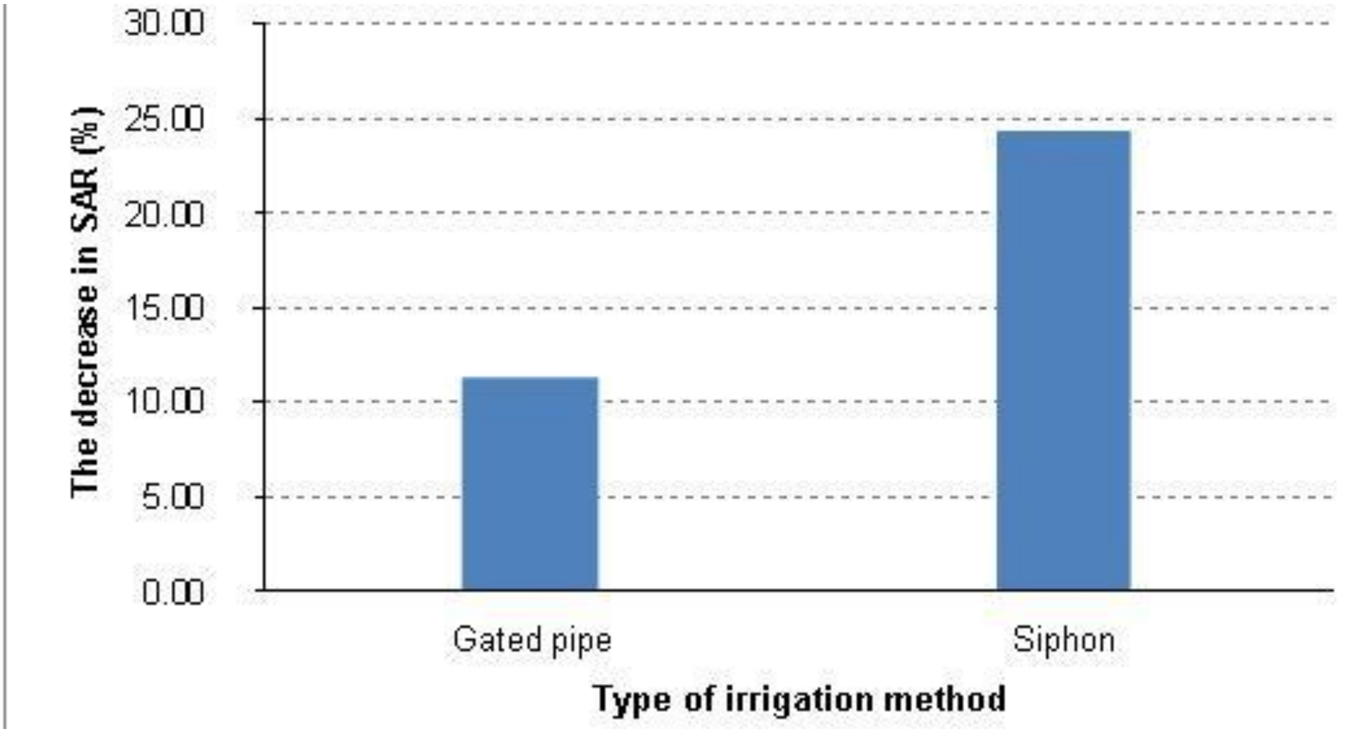

Figure 5. The sodium ratio for both treatments.

Table 2. Alkaline probability.

Season	Siphon	Gated pipe
Before season	0.761	0.61
Mid- season	0.432	0.48
After season	0.603	0.453

Water table salinity

The water table salinity for both treatments was represented in Figure 6. It ranges from 2.45 to 5.37 dS/m with an overall mean of 4 dS/m and a standard deviation of 1.17 dS/m for gated pipe treatment while the water table salinity for siphon treatment ranges from 2.3 to 5.25 dS/m with an average value of 3.9 dS/m and a standard deviation of 1.12 dS/m. It is obvious from these results that there is no difference between the water table salinity for both treatments except in flowers root phase in May due to the gated pipe method in this phase need more water as shown in Figure 8.

Water table level

The average water table levels for both treatments (Siphon and pipeline) along the cotton season are represented in Figure 7. The siphon field average water table level is ranged from 69 to 106 cm, with an overall mean of 92.5 cm and a standard deviation of 8.85 after season and in the gated pipe field it ranged from 39 to 107 cm, with an overall mean of 85.6 a standard deviation of 15.3. The gated pipe method decreases the water table level less than the siphon method by 7% so the soil salinity in gated pipe method increased than the siphon method. The soil salinity negatively correlated with the water table level.

Water consumption

For the gated pipe the water consumption during the flowering phase and form roots gives the largest amount which gives 4200 m^3/ha (42.4% from the total amount). The germination stage gives 2327 m^3/ha (23.5% from the total amount), While the water consumption during the floral buds gave the minimum amount. But for the siphon the water consumption during the flowering phase and form roots gives the largest amount which gives 3534 m^3/ha (36.61% from the total amount). The germination stage gives 2340 m^3/ha (24.2% from the total amount); while the water consumption during the floral buds gave the minimum amount equal 893 m^3/ha (9.2%) as shown in Figure 8. The total water consumption for the treatment of gated pipe is 9903 which exceed than siphon by 2.5%.

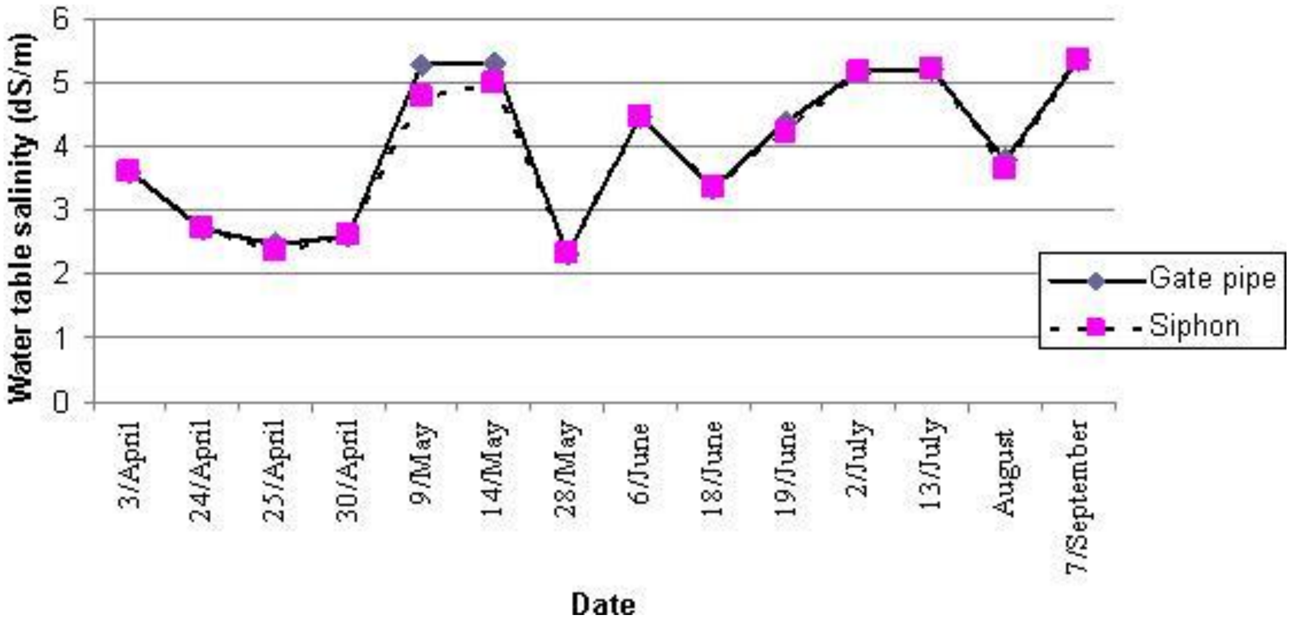

Figure 6. Water table salinity for both treatments.

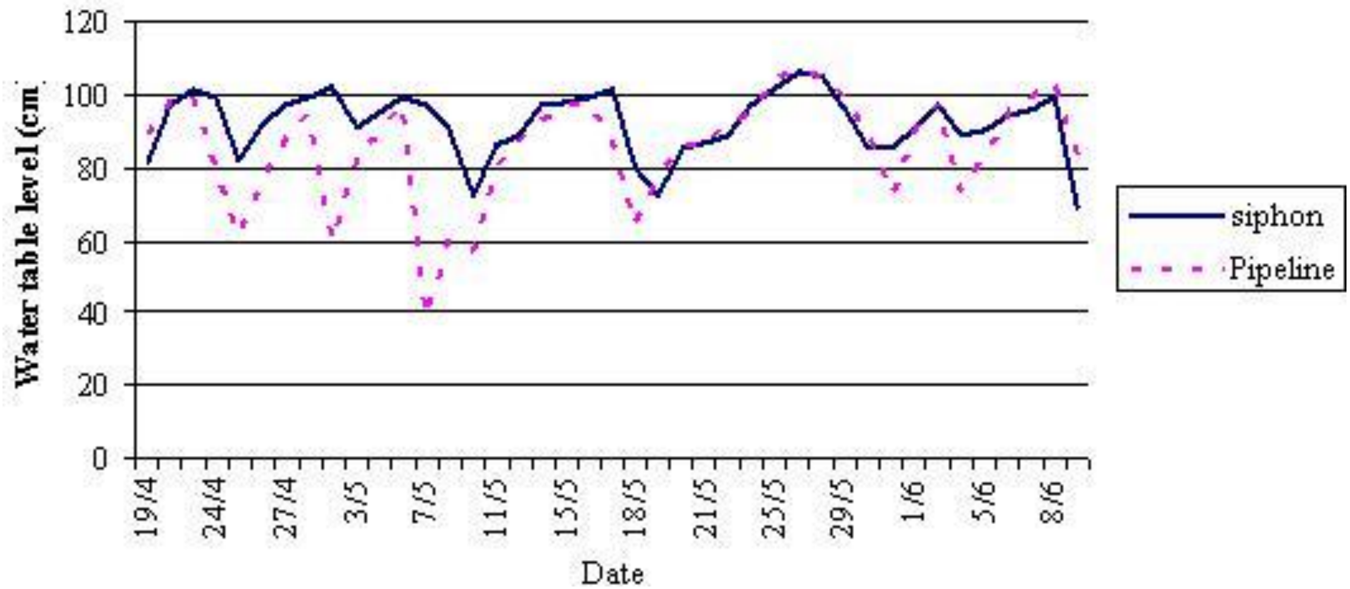

Figure 7. Water table level.

Water irrigation efficiency

The value of the additional water efficiency was measured by using Equation (4) which gives that working in siphons is higher than in the pipeline as shown in Table 3.

$$E_a = \frac{D_s}{D_A} \quad (4)$$

Where E_a is the additional water efficiency "%", D_S is the stored water depth in root zone "cm", D_A is the additional water depth "cm". The siphon method gives higher efficiency in all phases except in maturity of the plant phase; this result is due to the fact that the siphon method need more water in this phase. The irrigation efficiency is positively correlated with the soil salinity, and the permeability. The water distribution efficiency in

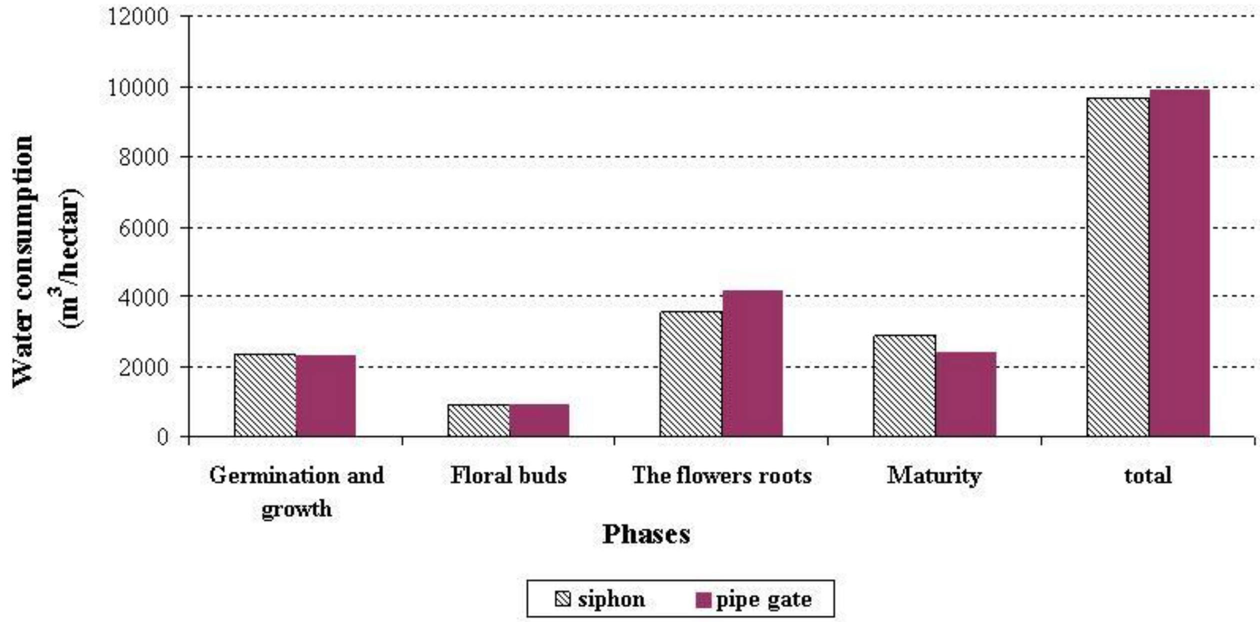

Figure 8. The water consumption for each treatment.

Table 3. The added Irrigation addition efficiency.

Phases	Pipeline	Siphon
Germination	56	66
Floral buds	59	67
Flowers	51	66
Maturity of the plant	55	52
Average	**55.25**	**62.75**

siphon is 80% where in gated pipe is 72%. The storage coefficient for pipeline is 100 and 99% for the siphon.

Time progress

Figure 9 shows the time progress inside the filed. The siphon treatment gives less time than the gated pipe by 14.3%. The applied time for the treatment of gated pipe is 223 min but in siphons is 191 min.

Crop production

The crop water need (ETP) is defined as the depth (or amount) of water needed to meet the water loss through vapor-transpiration. In other words, it is the amount of water needed by the various crops to grow optimally. Potential crop evapotranspiration under favorable growth conditions is estimated from ETP and crop coefficients (KC) and then compared with Penman, Blaney- Criddle, and Evanov formula. A standard evaporation pan exposure as used herein is defined as a Class A (Hargreaves, 1975). Class A pan evaporation, EV, has been widely used as an index for obtaining ETP. Figure 10 shows the comparison of the crop coefficient in studied area for both methods and the previous formula.

The Penman (1984) formula

$$E_{mass} = \frac{mR_n + \rho_a C_p \delta_e g_a}{\lambda_v (m + \gamma)} \quad (5)$$

Where m is slope of the saturation vapor pressure curve (Pa K^{-1}), Rn is net irradiance (W m^{-2}), ρa is density of air (kg m^{-3}), cp is heat capacity of air (J kg^{-1} K^{-1}), ga is momentum surface aerodynamic conductance (m s^{-1}), δe is vapor pressure deficit (Pa), λ_v is latent heat of vaporization (J kg^{-1}), γ is psychometric constant (Pa K^{-1}).

Blaney-Criddle (1960) formula

$$ET_o = \rho(0.46T_{mean} + 8) \quad (6)$$

Where: ETo is the reference evapotranspiration (mm day^{-1}) (monthly), T_{mean} is the mean daily temperature (°C) given as $T_{mean} = (T_{max} + T_{min})/2$, ρ is the mean daily percentage of annual daytime hours.

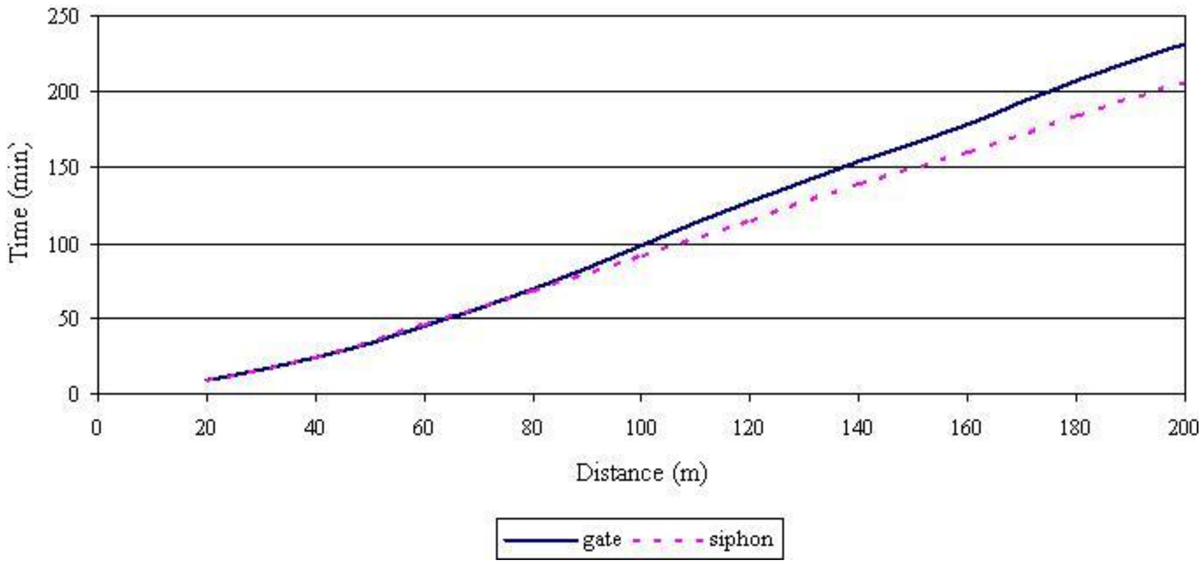

Figure 9. Time progress in both treatments.

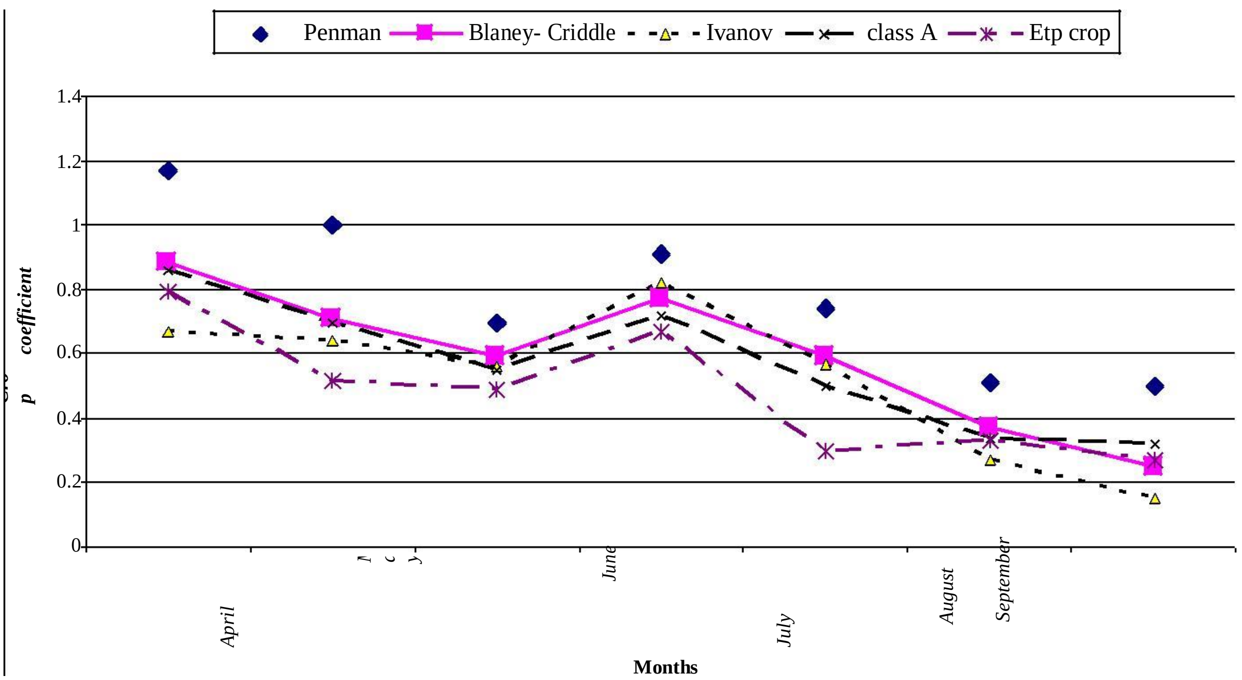

Figure 10. The comparative of crop coefficient with the previous relation.

Ivanov formula

Approach by Turc for: T > 5°C

$$ET_o = 0.0031(G + 209.4)\frac{T}{T + 15}ETPF \quad (7)$$

(Turc, 1961; Wendling and Schellin, 1986).

Where: G is global radiation in Jcm2d1, ETPF is empirical factor, T is daily mean temperature in °C.

Figure 10 shows the convergence value of the crop coefficient in all relations used in most stages of growth, except Penman relationship which gave the highest values. Figure 11 shows the average cotton yield for both siphon irrigation and gated pipe treatments. In case of siphon method, the cotton yield was 2.581 ton/ha; this

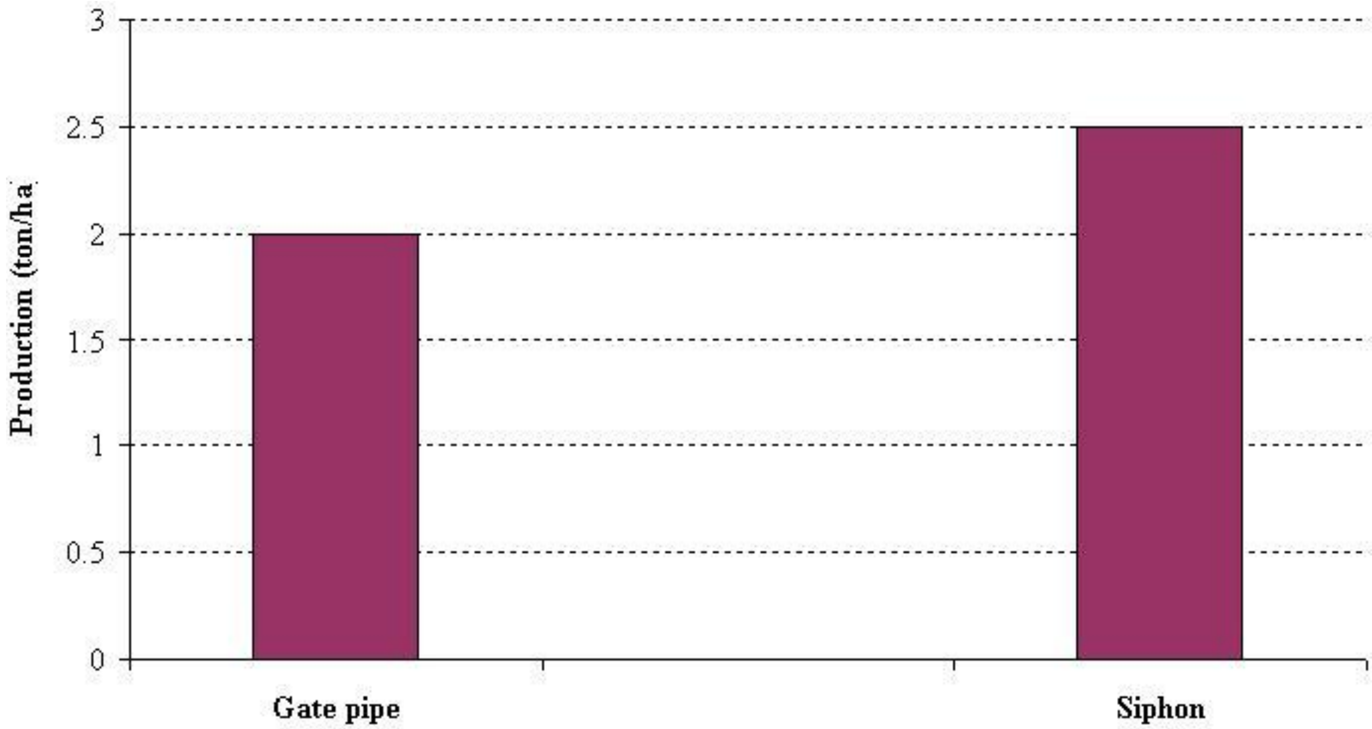

Figure 11. Crop production.

exceeds the yield of gated pipe irrigation method by 17%. Figure 12 shows the average cotton stem length for both siphon irrigation and gated pipe treatments. In case of siphon treatment, the average cotton stem length was 74 cm; this exceeds the length of gated pipe treatment by 14%. This result due to the siphon method decease the soil salinity especially in root zone so the permeability increased and the length of the crop produced increase.

Conclusion

This paper studied the effects of gated pipe, and siphon irrigation methods on cotton yield, salinity, water table, and made sense to the water-saving irrigation technique and agricultural production. The results indicate that the soil salinity increased during the irrigation season then decreased after season. In the gated pipe method, the electrical conductivity was increased by average 13.5% at mid-season then decreased by 0.5% after the season but in siphon method, the soil salinity was increased by about 6.9% at mid-season then decreased by 13.7% after the season. The siphon method increased the salinity at 0 to 15 cm depth and decreased it at 15 to 105 cm depth. The average soil salinity was increased in siphon system by 2.7% where in gated pipe it increased by 12.9%. The sodium adsorption ratio (SAR) decreased for both methods. The siphon method decreased SAR by about 24% where the gated pipe decreased it by about 11.4%. The siphon method gives lower ECe and decrease SAR which increase the soil permeability. The gated pipe irrigation method increased the toxic salt by 9.1% where the siphon method decreased it by 12.1%. The gated pipe decreased the non-toxic salt by 14.1% where the siphon method decreased it by 24.41%. The gated pipe method decreased the water table level less than the siphon method by 7%. For the gated pipe the water consumption during the flowering phase and form roots give the largest amount which gives about 42.4% from the total amount. For the siphon the water consumption during the flowering phase and form roots give the largest amount which gives about 36.61% from the total amount. The siphon treatment need water consumption less than gate pipeline by 2.5%. The water distribution efficiency is higher in siphon 80% than in gate pipeline 72%. The storage coefficient for pipeline is 100 and 99% for the siphon. The value of the crop coefficient converges in all relations used in most stages of growth, except Penman relationship which gave the highest values. The cotton production in case of siphon method was greater than gate pipeline irrigation method by 17% and equal to 2.581 ton/ha. In case of siphon treatment, the average cotton stem length was 74 cm; this exceeds the length of pipeline treatment by 14%. Cotton production, its length, the water consumption, and water distribution efficiency correlated negatively with soil salinity, while ground water

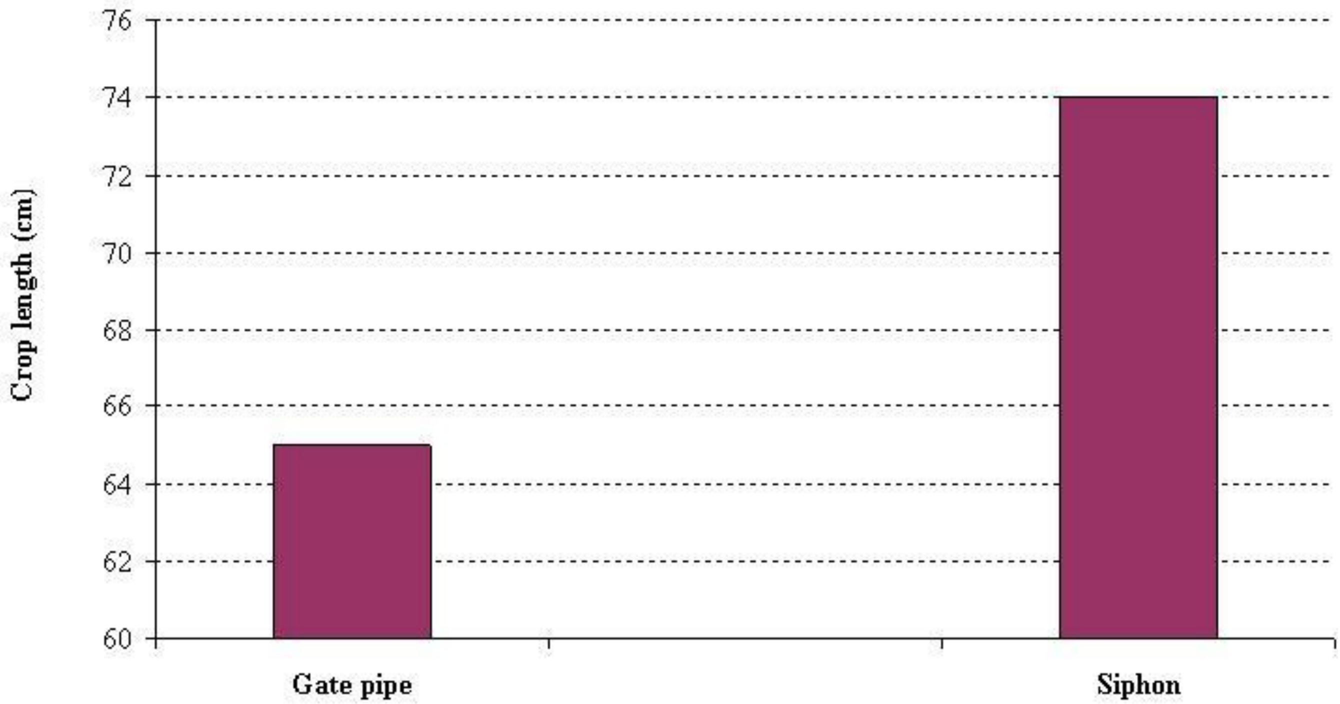

Figure 12. Stem length.

table correlated positively with the mean salinity and SAR.

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