Assessment of Different Leaching Treatments in Gated Pipe Irrigation System

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Authors' contributions

This work was carried out in collaboration between both authors. Author NBAM designed the study, wrote the protocol, performed the experimental process and analysis, and wrote the first draft of the manuscript. Author ANEH managed the literature searches, analyses of the study, and wrote the final manuscript. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The objective of this paper is to study the assessments of four leaching treatments on some soil chemical properties, irrigation efficiency and crop production. Field experiments are conducted in a study area that has gated pipes irrigation system, sandy silt loam to clay loam texture and the main crop is cotton. The study area is located at western Delta, Egypt and it covers 2.8 ha with Mediterranean semi-arid climate. Four leaching treatments are applied to the study area. They are 50%, 75%, 100% and 150% of the original leaching requirement (L.R). Total soil salinity, sodium adsorption ratio, toxic and non-toxic salts are investigated before planting, mid-season and at the end of the season for each leaching treatment. Also, additional water efficiency, irrigation efficiency, and crop production are studied for each leaching treatment. The study reveals that the 150% L.R treatment is associated with minimum increase of the total soil salinity. Sodium adsorption ratio decreased for all L.R treatments throughout the growing season. All L.R treatments increased the toxic salts, especially 150% L.R treatment. The 50% and 75% L.R treatments increased the non-toxic salts, while the 100% and 150% L.R treatments decreased them. The highest values of both

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additional water efficiency and the total irrigation efficiency are associated with 50% L.R treatment. The maximum cotton production is associated with 100% L.R treatment, followed by both 50% and 75% L.R treatments. Six equations are obtained employing regression analyses to get the percentage of the increase of total salinity, the percentage of the decrease of Sodium adsorption ratio, the percentage ratio of the change of both toxic and non-toxic salts, and both the additional water efficiency and the total irrigation efficiency with respect to the leaching treatment. It is concluded that both 50% and 75% L.R treatments produced lower values of soil salinity at the end of the growing season, and simultaneously achieved increased crop productivity.

1. INTRODUCTION

Historically, many irrigation projects had suffered reduced crop production due to excessive soil salinity. This problem had been solved by applying excess irrigation water to leach the salts from the root zone. Using more than necessary water to control salinity wastes water, while using less than necessary water decreases the soil productivity [1]. Although irrigated agriculture represents about 17% of the total cultivated land, it provides 40% of the global food production [2]. The irrigated area in developing countries needs to be expanded from 202 million ha in 1999 to 242 million ha in 2030 to meet the increasing food demand [3]. The demand for irrigation will increase in arid and semi-arid regions, where more than 90% of agriculture depends on irrigation, due to the impact of climate change that will reduce irrigation water availability. To avoid the accumulation of excessive soluble salts in irrigated soils, more water than the needs of the crops must pass through the root zone to leach excessive soluble salts. This additional irrigation water is referred to as the leaching requirement (LR). Leaching requirement was originally defined as the fraction of infiltrated water that must pass through the root zone to keep soil salinity from exceeding a level that would significantly reduce crop yield under steady state conditions associated with good management and uniformity of leaching [4] and [5].

Reclamation of inherently saline soils is not included in the determination of the LR. Root water extraction of shallow groundwater, runoff, and leaching from effective precipitation are also not considered. The relationship between crop yield and seasonal amount of water required is essential to determine the optimum irrigation management [6]. Maximum profit may not coincide at all times with maximum yield. For this reason, the economically optimum amount of water needed to prevent excessive accumulation of salts is determined employing crop- water – production functions. The traditional steady-state method for estimating LR in comparison to the transient method was evaluated [7], and the implications that these findings could have on irrigation guidelines and recommendations were discussed. A modeling study of transient conditions was carried out,[8],analyzing transient water flow and solute transport in three soil lysimeters irrigated with waters of different quality over a period of 3 years using the HYDRUS-1D model [9]. In this study, HYDRUS-1D successfully described field measurements of water content, overall salinity, concentration of individual soluble cations, as well as the sodium adsorption ratio and exchangeable sodium percentage. Stalinization and concentration in arid sodication could limit the soil's productivity, leading to fertility reduction [10].

The level of Na+ in soil is usually quantified by Exchangeable Sodium Percentage (ESP) or by its estimator, the sodium adsorption ratio SAR. The rate of the soil sodication process increases with the increase of SAR [11]. The increase of SAR caused by irrigation water had an adverse impact on water infiltration for two types of soil, clay and loam [12]. For the clay soil, an increase of SAR resulted in a significant increase in infiltration rate, while in loam soil the increase in infiltration time was significant. The effect of salinity on crop yield was estimated employing a geographical information system (GIS) and remote sensing technologies [13]. The results showed that increasing salinity above the threshold for cotton and wheat resulted in a linear decrease in crop yields, indicating that remote sensing and GIS techniques are useful tools for estimating the effects of soil salinity on crop production. Continuous decrease of the water table depth could become a major hindrance to irrigation sustainability due to secondary salinization [14]. Pepper growers must consider the salinity response function and seasonal productivity alongside an appropriate

irrigation regime [15]. An equation was obtained to predict the percentage decrease of ground water table depth according to the laterals spacing of the subsurface drainage system [16]. Authors concluded that the yields of five crops increased, some parts of saline areas were improved, and the ground water table depth was reduced.

The objective of this paper is to study the effect of four leaching treatments (50%, 75%, 100% and 150% of the LR) on some of the soil chemical properties, irrigation efficiency and crop production.

2. STUDY AREA

The field experiments are conducted in a study area that is located at western Delta, Egypt. It covers 2.8 ha, has gated pipes irrigation system, and the main crop is cotton. The study area has sandy silt loam to clay loam texture. The climate is Mediterranean semi-arid with little rainfall, which falls mostly in the winter months.

The study area is divided into lines, where each line is 240 m long and 0.75 m wide. The measured average hydraulic conductivity is 2.0 m/day. A branch canal is the source of irrigation water. The area has a subsurface drainage system. The collector drains (PVC corrugated plastic pipes) are 1.5 m deep, while all lateral drains (PVC corrugated plastic pipes covered by synthetic envelope materials) are 1.2 m deep with an average spacing of 80 m and 10% slope. The outlet of the collector has

drained to the main drain. Fig. 1 shows the study area.

A network of observation wells, 10 cm diameter and 2 m deep, were installed in the study area to measure the water table fluctuation. Irrigation water is applied to the study area from the branch canal to a tank at the beginning of the gate pipe, Fig. 1, and then flowed to all laterals and upward to the root zone by capillary flow. The water duty is given as 75% of field capacity, with additional water for leaching (50%, 75%, 100% and 150% of the LR).

3. GATED PIPES IRRIGATION SYSTEM

The pipes are 6 m in length, 0.15 m in diameter and with distance 0.75 m between holes, which can communicate with each other. The pipe holes can be changed to give the flow required using the Eq. (1). Pipe is connected with a basin to secure the appropriate pressure by counter discharge.

$$Q = 2.109d^2 * h^{0.5} \tag{1}$$

Where: Q is the flow "m^3/sec", d is the hole diameter "m", and h is the water head above the hole center "m".

The water velocity and the water slope are measured (each 20 m at the middle line), and Parshall flume with 5 cm contraction (3 m to 5 m from the start line). Class A basin (121.5 cm in diameter and 25 cm in height) resting on wooden block is used to measure the evaporation.
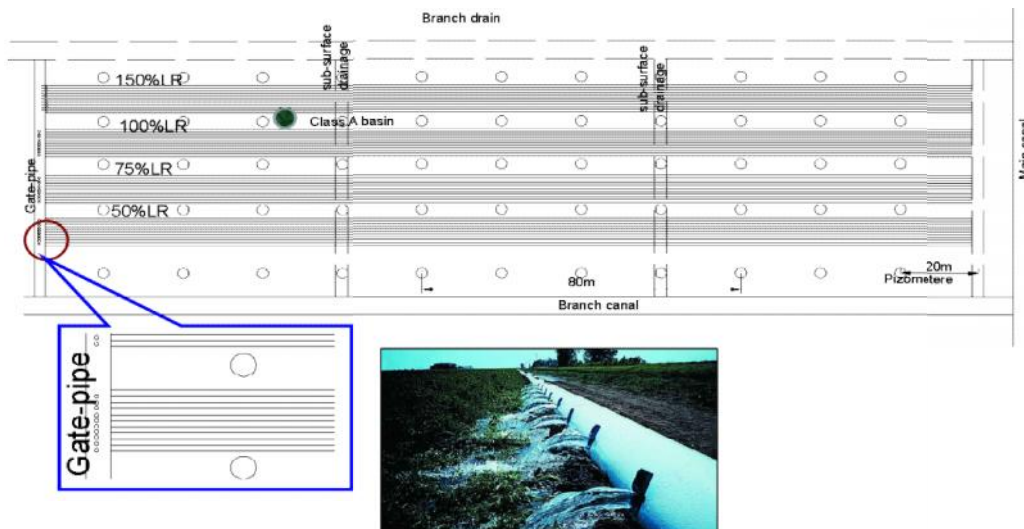

Fig. 1. Layout of study area

4. MEASUREMENTS

Measurements include water table depth, irrigation water salinity, ground water salinity, soil salinity, and crop yield.

4.1 Water Table Depth

Water table depth is measured daily employing a network of 26 wells that were installed and distributed in the study area for the different leaching treatments. A sounder and a tap are used to measure the water table depth.

4.2 Irrigation Water Salinity

It is measured before each irrigation gift by a handheld electrical conductivity meter (dS/m). Eq.(2) is used to determine the Sodium adsorption ratio (SAR).

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \qquad (2)$$

Where: SAR is sodium adsorption ratio "%", Na^+ is the sodium "meg/L", Ca^{++} is the Calcium "meg/L", Mg^{++} is the Magnesium "meg/L". The Flame Photometer model ELEX 6361 was used to measure the Na, Ca, and Mg in water.

Eq.(3) is used to determine the total salinity dissolved in water (TDS).

$$TDS = 640EC_w \qquad (3)$$

Where: TDS is the total dissolved salts in water "ppm", EC_w is the electrical conductivity "dS/m".

The average of sodium adsorption ratio was 2.96%, while the total salts dissolved in irrigation water varied from 1.052 to 0.3186 dS/m.

4.3 Ground Water Salinity

The ground water salinity is measured two times a week by an E.C apparatus (dS/m) to detect the effect of leaching treatments on the water table salinity. Electrical conductivity (E.C) was measured using a meter and probe as well. The probe consisted of two metal electrodes spaced 1 cm apart. The ground water salinity varied from 1.38 to 3.4 dS/m.

4.4 Soil Salinity

Thirty soil samples are taken before cultivation to determine the initial salinity. $CaCO_3$ was measured by addition $Ca(OH)_2$ and followed bubbling CO_2 at 1 atm. In addition, soil samples to a depth of 1.25 m are collected each two weeks for chemical analysis to follow up changes in its salinity. Table 1 shows the average soil salinity along the soil depth. It illustrates that the 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, which is considered high salinity.

Table 1. Soil salinity

Depth (cm)	E.C. (dS/m)	$CaCO_3$ (meg/L)
0-35	1.7	24.3
35-47	3.0	28.0
47-105	3.3	22.5
105-125	3.9	22.8

4.5 Crop Yield

The study area is planted in lines 75 cm apart, and 15 cm to 17 cm between the plants. Observation of cotton growth is followed and four crop samples are taken from each leaching treatment at harvest time to determine the average yield. The study area is irrigated at 75% of field capacity. Bulk density was measured by the core ring that was filled completely with soil sample, and was subjected to an oven. Mass of the soil, moisture content, dry mass and the volume were calculated. The organic fertilizers of 30 m^3/hec are added after agriculture and nitrogen fertilizers (Urea 46%) are added in three batches: 45kg before agriculture, 75kg after germination, and 30kg at flowers.

Table 2 shows the hydro physic characteristics of the soil of the study area.

Table 2. Hydro physic characteristics of the soil

Depth (cm)	Bulk density (g/cm³)	Particle density (g/cm³)	Field capacity (F.C, %)	75% of F.C (%)
0-15	2.69	1.23	39.36	29.52
15-30	2.71	1.44	40.53	30.38
30-45	2.72	1.54	40.33	30.25
45-60	2.72	1.47	40.54	30.41
60-75	2.72	1.44	40.65	30.49
75-90	2.72	1.43	40.15	30.11
90-105	2.72	1.46	39.88	29.91
105-120	2.72	1.47	40.95	30.71
120-135	2.72	1.48	41.68	31.26
135-150	2.72	1.51	41.99	31.49

5. RESULTS AND DISCUSSION

5.1 Salinity

Fig. 2 illustrates the soil salinity at different depths for all treatments. For all treatments, it can be seen that the salinity fluctuates along the depth. Comparing between the salinity values at both the surface layer and the depth of 140 cm, the following results are found:

for 50% L.R treatment, the high value of 4.8 dS/m was at the surface layer, and it decreased slightly at the depth of 140 cm;
for both 75% and 100% L.R treatments, salinity decreased from the values of 4.5 and 4.2 dS/m at the surface layer to the values of 4.25 and 3.8 dS/m at the depth of 140 cm;
while for 150% L.R treatment, salinity started with low value of 3.5 dS/m at the surface layer and increased to a value of 4.65 dS/m at the depth of 140 cm as the salt transported to the lower layer due to high leaching process.

Fig. 3 shows the development of the average total soil salinity throughout the growing season.

The total soil salinity increased for all leaching treatments until mid-season, then decreased slightly at the end of season due to the water consumption of cotton crop and the low level of the water table. For 100% and 150% L.R treatments, salinity has its maximum and minimum values respectively, while both 50% and 75% L.R treatments have lower values of soil salinity at the end of season.

Fig. 4 shows the relation between the leaching treatment and the percentage of the increase of total soil salinity. Then regression analysis is done employing micro soft excel software. Eq. (4) is obtained to get the percentage of the increase of total salinity according to the leaching treatment.

$$TPS = -0.0341 L.R^2 - 0.006 L.R + 0.1631 \quad (4)$$

Where: TPS is the percentage of the increase of total salinity "%", L.R is the leaching treatment "%".

Sodium adsorption ratio (SAR) decreased for all L.R treatments throughout the growing season, as shown in Fig. 5.
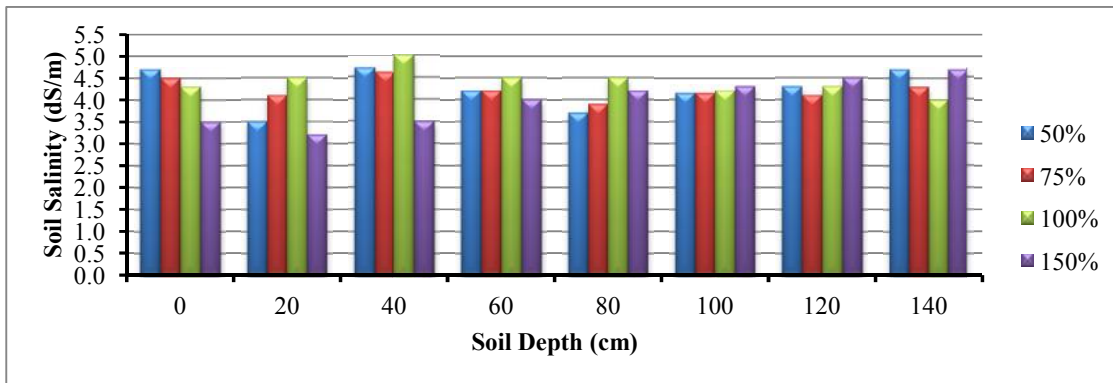

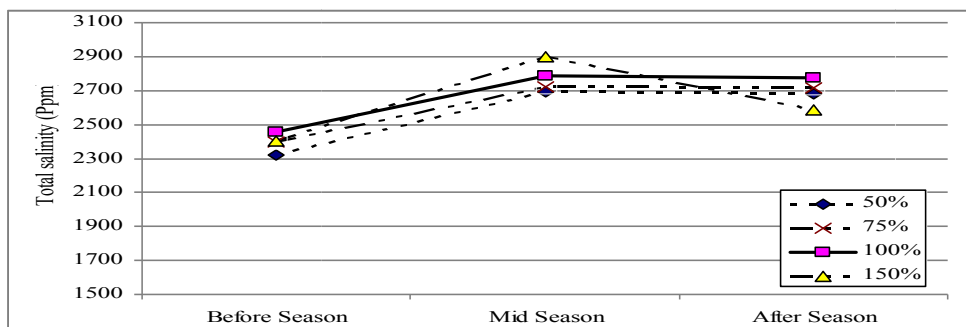**Fig. 2. Average soil salinity for different leaching treatments**

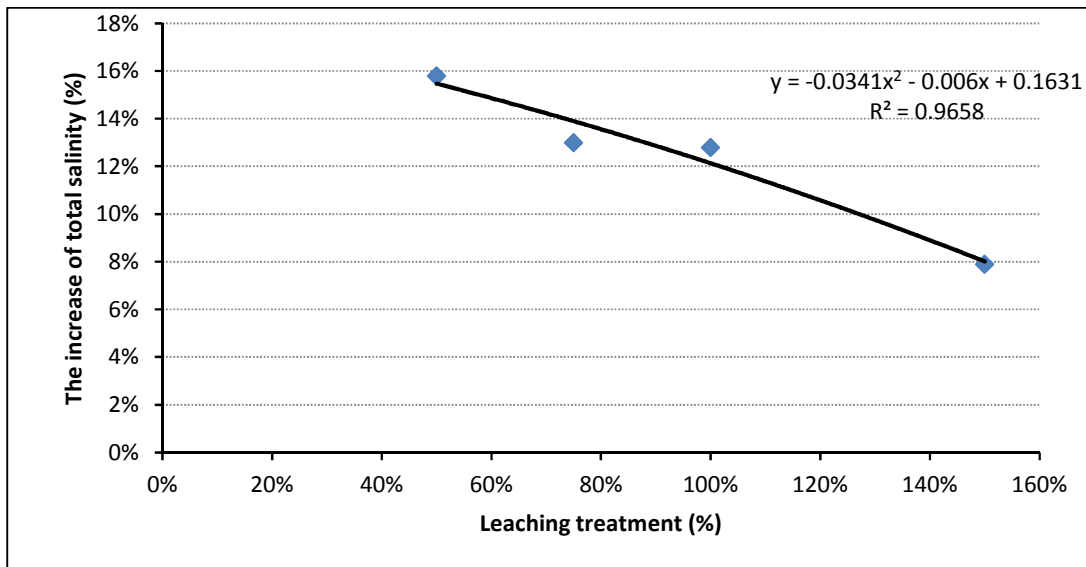**Fig. 3. The development of total salinity throughout the growing season**

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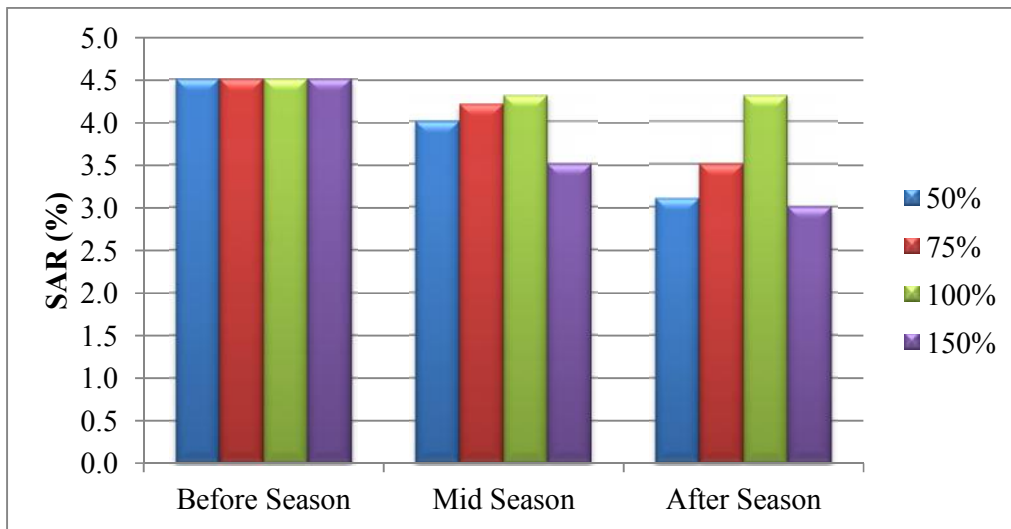**Fig. 4. The increase of total soil salinity**

Fig. 5. Sodium Adsorption Ratio (SAR) throughout the growing season

Fig. 6 shows the relation between the leaching treatment and the percentage of the decrease of Sodium adsorption ratio (SAR). Regression analysis is executed employing micro soft excel software. Eq. (5) is obtained to find the percentage of the decrease of Sodium adsorption ratio (SAR) with respect to the leaching treatment.

$$PSR = 0.1359 L.R^2 - 0.3495 L.R + 0.2887 \quad (5)$$

Where: PSR is the percentage of the decrease of Sodium adsorption ratio (SAR) "%", L.R is the leaching treatment "%".

Toxic salts (sodium sulfate, sodium chloride and magnesium chloride) are investigated before planting, mid-season and at the end of the season for each leaching treatment. Percentage changes are illustrated in Fig. 7. All L.R treatments increased the toxic salts, especially 150% L.R treatment. Regression analysis is done employing micro soft excel software. Eq. (6) is obtained to predict the percentage ratio of the change of toxic salts with respect to the leaching treatment.

Percentage change of toxic salts = 0.0291 L.R + 0.0266   (6)
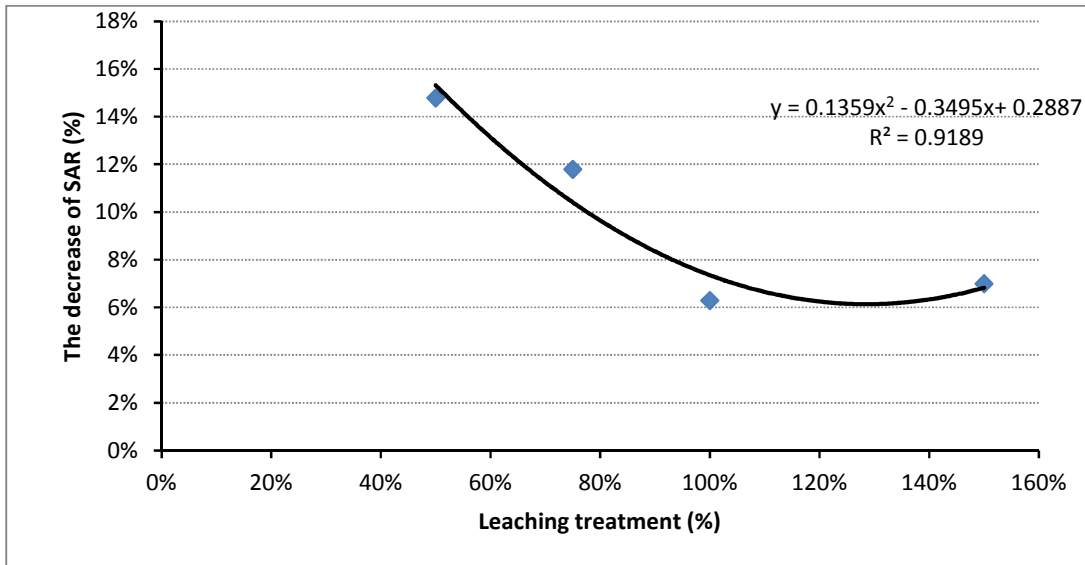
Fig. 6. The decrease of Sodium adsorption ratio (SAR)
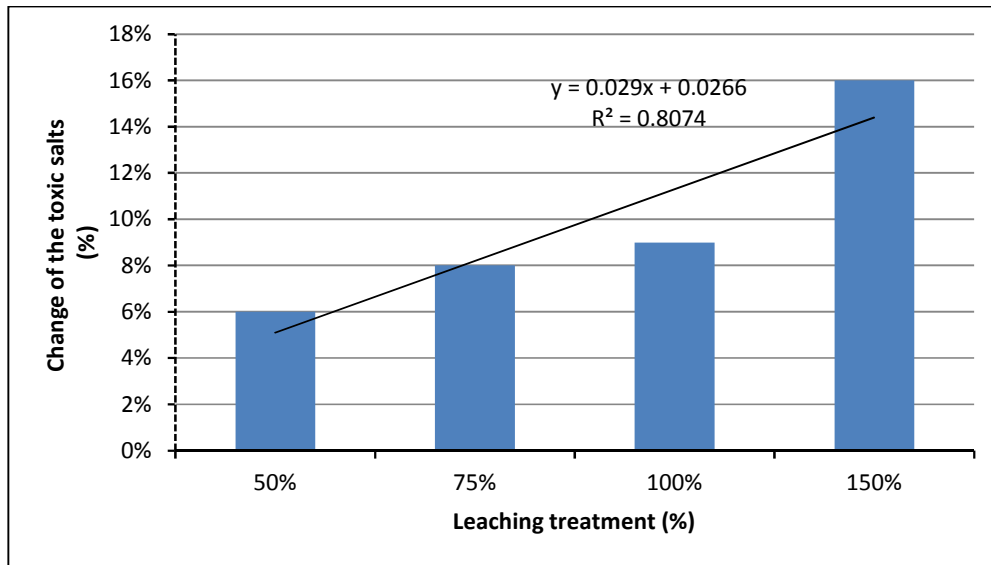

Fig. 7. Change of the toxic salts

Similarly, non-toxic salts (calcium bicarbonate and calcium sulfate) are investigated before planting, mid-season and at the end of the season for each leaching treatment. Percentage changes are illustrated in Fig. 8. The 50% and 75% L.R treatments increased the non-toxic salts, while the 100% and 150% L.R treatments decreased the non-toxic salts. Regression analysis is done also employing micro soft excel software. Eq. (7) is obtained to predict the percentage ratio of the change of non-toxic salts with respect to the leaching treatment.

Percentage change of non-toxic salts = - 0.1272 L.R + 0.2864   (7)

5.2 Irrigation Efficiency

Two types of irrigation efficiencies are considered, additional water and total irrigation efficiencies. The value of the additional water efficiency for different L.R treatments is measured using equation (8).

$$E_a = D_s / D_A \qquad (8)$$

Where: E_a is the additional water efficiency "%", D_s is the stored water in root zone + 0.8 (0.8 is the value of class A basin) "m", D_A is the additional water "m".

The highest value of additional water efficiency is associated with 50% L.R treatment, as shown in Table 3. Fig. 9 shows the relation between the leaching treatments and the additional water efficiency. Regression analysis is executed employing micro soft excel software. Eq. (9) is obtained to get the additional water efficiency with respect to the leaching treatment.

$$E_d = 1.5455\,L.R^2 - 11.432\,L.R + 64.523 \quad (9)$$

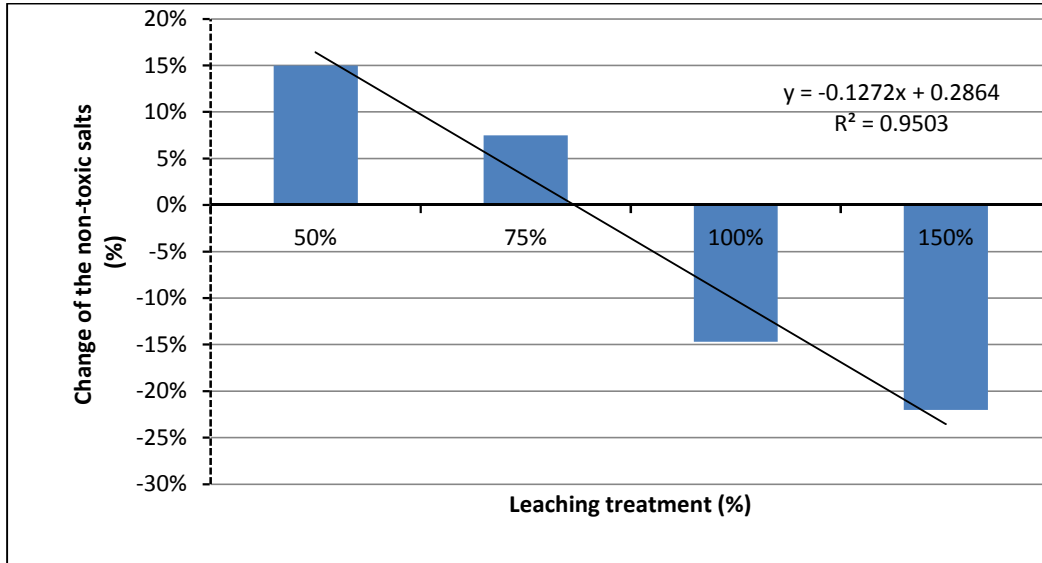Where: E_d is the additional water efficiency "%".
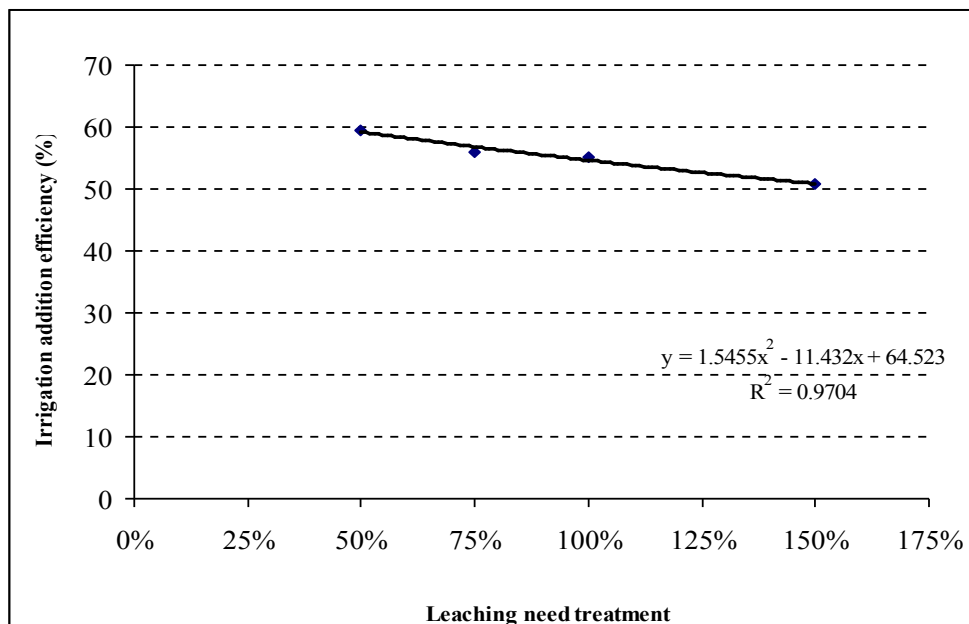

Fig. 8. Change of the non-toxic salts

Fig. 9. The additional water efficiency

8

Table 3. Additional water efficiency

Phases	50% L.R	75% L.R	100% L.R	150% L.R
Germination	61	57	56	50
Floral buds	64	60	59	54
Flowers	55	52	51	47
Maturity of the plant	58	57	55	52
Average	**60**	**57**	**55**	**51**

The value of the total irrigation efficiency for different L.R treatments is determined using equation (10).

$$TE_i = E_a \times E_C \qquad (10)$$

Where: TE_i is the total irrigation efficiency "%", E_a is the additional water efficiency "%", and E_c is the conveyance efficiency "%". Ec is the

percentage ratio of the water that enters the field to the total water from the source.

The highest value of the total irrigation efficiency is associated also with 50% L.R treatment. Fig. 10 illustrates the relation between the leaching treatments and the total irrigation efficiency. Regression analysis is done employing micro soft excel software. Eq. (11) is obtained to find the total irrigation efficiency according to the leaching treatment.

$$TE_i = -6.1714 * L.R + 45.286 \qquad (11)$$

Where: TE_i is the total irrigation efficiency "%"

5.3 Crop Production

Fig. 11 shows the average cotton yield for different L.R treatments. The maximum cotton production is associated with 100% L.R
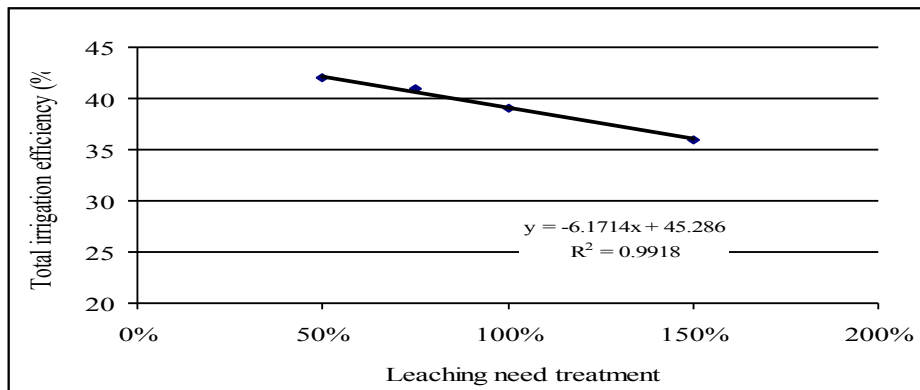

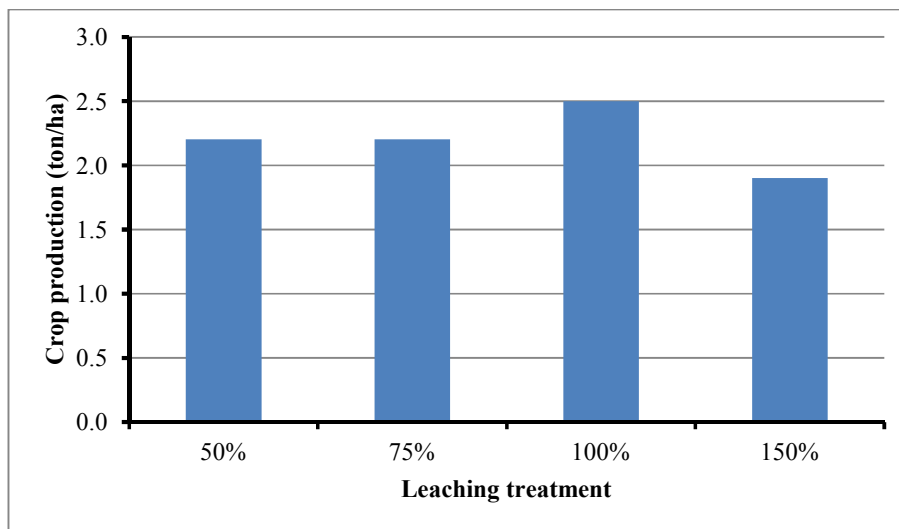**Fig. 10. The total irrigation efficiency**

Fig. 11. Crop production

treatment. Regression analysis is done employing micro soft excel software, but the accuracy of the obtained equation is low and it is excluded from consideration.

6. CONCLUSION

The total soil salinity increased for all leaching treatments until mid-season, then decreased at the end of season. The minimum increase of the total soil salinity was associated with 150% L.R treatment. An equation is obtained to get the percentage of the increase of total salinity according to the leaching treatment. Sodium adsorption ratio (SAR) decreased for all L.R treatments throughout the growing season. In addition, an equation is obtained to find the percentage of the decrease of Sodium adsorption ratio with respect to the leaching treatment. All L.R treatments increased the toxic salts (sodium sulfate, sodium chloride and magnesium chloride), especially 150% L.R treatment. An equation is obtained to predict the percentage ratio of the change of toxic salts with respect to the leaching treatment. The 50% and 75% L.R treatments increased the non-toxic salts (calcium bicarbonate and calcium sulfate), while the 100% and 150% L.R treatments decreased the non-toxic salts. An equation is obtained to get the percentage ratio of the change of non-toxic salts according to the leaching treatment. The highest value of additional water efficiency is associated with 50% L.R treatment. An equation is obtained to get the additional water efficiency with respect to the leaching treatment. The highest value of the total irrigation efficiency is associated also with 50 % L.R treatment. An equation is obtained to find the total irrigation efficiency according to the leaching treatment. The maximum cotton production is associated with 100% L.R treatment, followed by both 50% and 75% L.R treatments. It is concluded that both 50% and 75% L.R treatments showed lower values of soil salinity at the end of the growing season, and simultaneously achieved increased crop productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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