Scheduling of Leaching Requirements to Prevent the Secondary Salinisation in the Root Zone

Amer H. Al-haddad
Assist. Prof.
Water Resources Eng. Dept.
Ameralhaddad1950@yahoo.com

Kolood A. Hussien
M.Sc.
Water Resources Eng. Dept.

ABSTRACT

Leaching scheduling techniques are one of the suggested solutions for water scarcity problems .The aim of the study is to show the possibility of using leaching scheduling, when applying the irrigation scheduling program for a certain irrigation project, which was prepare by Water Resources Engineering –University of Baghdad with some modifications to generalized it and it make applicable to various climatic zone and different soil types.

The objectives of this research is to build a system that concerns the prediction of the leaching scheduling (depth and date of leaching water), illustrating the main problems (soil salinity, save the amount of leaching requirement, and to maintain crops growth).The other objective is to compare between the calculated amount of leaching water with the amount of water that is suggested by designers. The program includes, the calculating of predicted daily soil salinity ,the depth of leaching water that should be applied to remove the salt from the soil when it reaches a harmful level, and the total annual volume of leaching water.

The results showed, that the use of predicted leaching scheduling with its applicable constrains require high attention when choosing the cropping pattern for each climate zone. Also, it was found that the leaching program is a useful tool for saving irrigation water if cropping pattern has been adapted carefully. This means the leaching water depth should be added only when needed, and may not be necessary with each irrigation event.

Keywords: leaching scheduling, irrigation scheduling, maximum root depth, water resources dept. program, water budget, Amara irrigation project.

جدولة متطلبات الغسيل الإضافية لمنع التملح الثانوي في منطقة الجذور

الخلاصة

تعرف متطلبات الغسيل بانها الكمية الواجب اضافتها للتربة لغرض الحفاظ على مستوى ملحي دون المستوى المؤذي. أن استعمال اسلوب جدولة الغسيل هي أحدى الحلول المقترحة لحل مشكلة شحة المياه. تهدف الدراسة الى معرفة أمكانية أستخدام برنامج جدولة الغسيل من خلال تطبيق برنامج الجدولة الاروائية في مشروع اروائي والذي تم أعداده في قسم هندسة الموارد المائية - جامعة بغداد مع أجراء بعض التعديلات عليه لجعله قابل للتطبيق في المناطق المناخية المختلفة ولأنواع مختلفة من الترب.

اهداف البحث هي بناء نظام يهتم بحساب جدولة الغسيل (تاريخ وعمق مياه الغسل)حيث انه يوضح و يناقش المشاكل الرئيسية (ملوحة التربة, وتوفير مياه غسيل والحفاظ على نمو المحاصيل) ، أما الهدف الأخر للبحث فهو المقارنة مابين النتائج المحسوبة بأستخدام البرنامج مع ما تم أقراره من قبل المصممين ، البرنامج يتضمن حساب الملوحة اليومية ، وعمق الماء الواجب اضافته لأزالة الاملاح من مقد التربة عندما تصل الى مستوى مؤذي للنبات وتشمل الحسابات أيضا حساب حجم مياه الغسيل السنوية المضافة.

أظهرت نتائج البحث أن أستخدام هكذا نوع من جدولة مياه الغسيل المتوقعة وبخصائصه التي تجعله قابل للتطبيق، يتطلب عناية شديدة عند أستخدام نمط توزيع النباتات والمساحات المزروعة بهذه النباتات لكل منطقة مناخية، كما وجد أن البرنامج يمثل أداة مفيدة للحفاظ على المياه أذا ما أحسن أختيار الدورة الزراعية الملائمة. وهذا يعني أن عمق مياه الغسيل بالأمكان اضافته عند الحاجة فقط وليس بالضروري مع كل رية وكنسبة من عمق مياه الري.

الكلمات الرئيسة:جدولة الغسيل, جدولة الري, أقصى عمق جذور, برنامج قسم المواردالمائية, الموازنة المائية, مشروع العمارة الأروائي.

1. INTRODUCTION

Leaching scheduling , means the minimum amount of water that should be added to the irrigation requirements in order to remove the accumulated salt in the root zone due to irrigation. When it reaches a harmful effect on crop growth, the leaching scheduling will be important for saving water. Leaching is the key factor for controlling soluble salts brought by irrigation water.

2. LEACHING REQUIREMENTS

The leaching requirements (LR) concept was developed by the U.S. Salinity Laboratory, **Richard, 1954.** It was defined as "the fraction of the irrigation water that must be leached out of the bottom of the root zone in order to prevent average soil salinity from rising above some specific limit, therefore it represents the minimum amount of water that must pass through the root zone to keep salts within an acceptable range.

Leaching requirements depend on the salt concentration in the irrigation water, the amount of water extracted from the soil by the crop (transpiration), and the salt tolerance of the crop, which determines the maximum allowable concentration of the soil solution in the root zone, **Rhoades, and Merrill ,1976**.

The actual leaching requirements can only be determined by monitoring salinity control which is related to field water management. Under some conditions, however, differences in soils, drainage, and water application methods make leaching less than I00% efficient. Cracks, root holes, wormholes and other large pores can transport water quickly through the root zone when these channels are in contact with the irrigation water at or near the surface, **Rhoades, 1990b.Rhoades and Merrill, 1976**, proposed an equation to calculate leaching requirement.

If all the infiltrated water mixes completely with the soil moisture, the relation between the depth of applied water (AW) for consumptive - use and the LR as suggested by **FAO 1985b,** during a cropping season is:

$$AW=ET_c /(1-LR) = Irr.D +Pe \qquad (1)$$

Where :

ET_c: consumptive-use (L/T),

Irr.D: net irrigation water depth (L),and

Pe: effective rain-fall (L).

However, under normal conditions, a fraction of the infiltrated irrigation water equivalent to ((1–f) * Irrigation depth), where: (f) is the leaching efficiency coefficient, will percolate directly below the root zone through cracks and macro-pores without mixing with the soil moisture solution. This water does not contribute to the leaching of salts from the root zone.

In practice, the electrical conductivity of drainage water (EC_{dw}) value is not readily available, and the U.S. Salinity Laboratory recommends using the average electrical conductivity of the saturation soil solution extract, and the electrical conductivity of irrigation water (EC_{iw})to determine LR. The salt entering into the root zone from irrigation water or capillary rise from ground water remains in the root zone.

The accumulated salt in the root zone is generally leached by applying water in excess of field capacity. Field capacity can be defined as the maximum amount of moisture that can be held against gravity in the soil pores of the root zone. Results from several laboratory experiments by **Miller, et al., 1965;** and some field trials by **Oster, et al., 1972**, showed that the quantity of salts removed per unit quantity of water leached can be increased appreciably by leaching at soil moisture contents less than saturation, i.e. under unsaturated conditions.

In unsaturated field conditions leaching was obtained by adopting intermittent ponding or by intermittent sprinkling at rates less than the infiltration rate of the soil. The degree of salt removal during leaching is be markedly influenced by the method used. An experiment was carried out at Nahshala Farm, north west of Al-Ain City, U.A.E. during the 1998–2000 growing seasons, using six halophytes (Batis maritima, Distichlis spicata, Juncus roemerianus, Paspalum vaginatum, Salicornia bigelovii and Spartina alterniflora) and two levels of leaching fraction (0·25 and 0·50) under three irrigation salinity levels 10, 20, and 40 (g/l) in a randomized complete block design arranged in split plots. The results indicated that the halophyte species tested can grow with minimum reduction in the growth potential at < 20 (g/l) mean salinity of soil solution. Leaching fraction of 0·25 at the highest salinity of irrigation water 40 (g/l) was inadequate to attain the steady-state salt balance during the growing period, although drainage salinity reached more than 90 (g /l). Furthermore, if the same level of salinity is used for longer periods, soil salinity under this high salt treatment will continue to rise and plant growth may deteriorate. Leaching fraction of 0.50 is preferable if salinity of irrigation water is more than 20(g/l) and dry matter production is considered, although the amount of water used will be excessive, **El-Sayed et al., 2000**.

In the past, the means of estimating LR was based on a set of conditions, referred to as steady-state conditions, which rarely actually exist in real world. The real world is more dynamic and transient-state conditions predominate. The traditional guidelines for the calculation of the crop-specific leaching requirement of irrigated soils have fallen under the microscope of scrutiny and criticism because the commonly used traditional method is believed to over-estimate LR due to the assumption of steady-state flow and disregarding salt precipitation and preferential flow. Over-estimation of LR of detrimentally impacts the environment and reduces water supplies. Steady-state models for calculating LR based on traditional model of the U.S. Salinity Laboratory and water-production-function models were compared to transit-state models. The calculated LR was lower when determined using a transit-state approach than using a steady-state approach. Transit-state conditions and the influence of preferential flow have no significant effect on lowering the value of LR as shown in the study of the Imperial Valley using Colorado River water EC_{iw} 1.23 (ds/m) for irrigation. The LR was 0.08 for a certain crop rotation and certain area, as was calculated by transit- state model, and was found to be the most reasonable estimate for the entire Imperial Valley as compared to LR of 0.13 by using the commonly traditional method.

Letey et al., 1985,conducted a reclamation leaching experiment in a drip-irrigated pistachio orchard south of Huron, California, during the winter of 2002-2003.The study was conducted to quantify the leaching water required to remove salts from the effective root zone of trees. This experiment tested a new reclamation leaching technique by using multiple lines of low-flow drip tape to supply water to the area of salinity accumulation along a tree row. This new technique allows water to be supplied where there is salt accumulation along the tree row, instead of supplying water to the entire area of the field. Since reclamation leaching requires a relatively large depth of water, this technique offers potential for significant water savings.

Bakr, 2011, calculated monthly, and annually water requirements and calculated the leaching requirements as a percentage from the depth of irrigation water for many projects on Tigris River basin.

To make the right decision, there are some steps that should be followed, namely selecting the cropping pattern, initial salt concentration of soil, salt concentration of irrigation water, leaching efficiency coefficient, and crop characteristics properties. In addition to know growing and harvesting date, root depth, and allowable depletion.

The physical properties of the soil, climate data, availability of water resources, soil water deficit before irrigation, and field water losses should be known as well.

With the aid of the information mentioned above, monthly and annual water requirements for leaching can be calculated, and then the irrigation and leaching scheduling can be adapted. The computer simulation model developed in this research was based on the following constrains:

- The desired salt concentration of soil is 4 (ds/m), at this value the effect of salt on crop growth is negligible,**Richard,1954**, and
- The harmful level of salt concentration index on crop growth is selected as follows: if the expected conductivity of soil saturation extract after irrigation is less than or equal to crop salt tolerance at 50% yield reduction, then leaching water is added to the soil at or before reaching this value.

Some constrains are required to build the leaching scheduling model and they are as follows:

a. Assuming that the desired salt concentration of soil saturated extract is the initial salt concentration in each reservoir.

b. The soil reservoir is divided into four reservoirs, each one has constant depth of 250 mm, and therefore the soil depth is always one meter. If the depth of root zone is more than one meter, the remained depth of root zone falls within the drain zone **,Van Der Molen, 1979**, and

c. Two cases are employed, the first case is field water losses cannot be controlled as surface runoff and deep percolation to the drainage zone losses, and the second case is 33% from the field water losses can be controlled and will be considered as the depth of leaching water (deep percolation).

3. DESCRIPTION of SELECTED PROJECT AREAS

Five irrigation projects on the Tigris River basin were selected because there are tributaries on the river.

The climate of Iraq is subtropical, continental, summer is long, hot, and dry, and winter is short with mean monthly temperatures above zero, and intensive cyclonic activity in the atmosphere provoking rainfall. The mean annual amount of precipitation in the country tends to decrease from north to south and from east to west. In the summer, no rainfall occurs in the country. Temperature, air humidity, and evaporation increase from north to south.

Iraqi territory was divided into six zones according to the natural humidity, which characterizes identity of crops. Three natural-climatic zones and three subzones were identified within the territory of the country, **General Scheme of Water Resources and Land Development in Iraq, 1982.**

4. CONCEPTUAL FORMULATION

The conceptual concepts were mathematically formulated in order to obtain a workable procedure. Below is a brief description of the mathematical formulation of leaching scheduling procedure as presented by **FAO, 1985**. The first step in leaching scheduling is to determine leaching requirements, and to calculate the leaching requirements by using the salt equilibrium equation, which is based on the application of water balance, salt balance, and leaching coefficient equation.

4-1 The Water Balance Equation in the Root Zone

The basis for understanding the impact of irrigation and drainage management on the salt balance is the water balance at the root zone, and can be described by the following equation, FAO**, 1985b**:

$$\text{Irr. D} = R^{*} + ET_{c} - Pe \qquad (2)$$

Where:

Irr.D: irrigation depth (L),
R^{*}: leaching water depth (L), and
Pe: effective rainfall(L).

4-2The Salt Balance Equation in the Root Zone

In irrigation, salts are added to the root zone because all irrigation waters contain salts. A fraction of the salts is leached below the root zone by deeply percolated water. After a certain period, salt accumulation in the soil will approach an equilibrium or steady-state concentration which depends on the salinity of applied water and leaching requirements, **FAO, 1985.**

The following assumptions were made to formulate the salt balance equation:

- The exchange processes and chemical reactions which take place in the soil are not taken into consideration, and
- The amount of salts supplied by rainfall, fertilizers, and exported by crops is negligible. A zone of shallow groundwater is created with the same average salinity concentration as the percolation water.

The root zone is one meter deep, and the salts are distributed homogenously through it.

The movement of salts starts when the soil moisture content reaches field capacity level.

Under these assumptions, the salinity of the soil water is equal to the salinity of the water percolating below the root zone. The water balance the root zone can be given by the following equation, **FAO, 1985**:

$$\text{Irr. D} * C_{iw} = R^{*} * C_{R} \qquad (3)$$

Where:

C_{iw}: average salt concentration of irrigation water,(ppm), and
C_{R}: average salt concentration of leaching water, (ppm).
Other abbreviations are as described earlier.

5-LEACHING EFFICIENCY COEFFICIENT

Leaching efficiency coefficient is an essential parameter to be considered in the leaching processes. It indicates the degree of mixing between the applied water and the original soil solution, it could be defined with respect to the water percolating from the bottom of the root zone, or it can be defined as the percentage of water percolating from the original soil water, the remainder of which flows through a bypass consisting of a crack and\or a root hole. This concept of leaching efficiency for vertical water movement was originated carried out during the experimental work carried out in Dujailah Project in Iraq by **Boumans, 1963.** Also, it can be defined as the percentage of irrigation water that mixes with soil water.

The introduction of a leaching efficiency coefficient means that the full amount of water percolated through the soil profile is replaced by the effective amount of water during the leaching process.

In a related work by, **Van Der Molen, 1979**, two different expressions were introduced, each describing a different model of physical leaching process. These two expressions are:

$$f=C_{DP}\backslash C_e \tag{4}$$

$$f=C_{DP}-C_{iw}\backslash\ C_{fc}-C_{iw} \tag{5}$$

Where:

C_{DP}: average salt concentration of the water percolating below the root zone, (ppm)

C_e: average salt concentration of the reservoir solution (after leaching) at field capacity,(ppm)

Leaching efficiency coefficient variation with soil depth for many soils in pilot projects in Iraq is presented by **Hussein, 1997**.

To calculate the leaching requirements, the salt equilibrium equation presented by **Richared, 1954,** was used in this study; This equation was obtained from:

- Salt balance equation, Eq.(2), and
- Leaching efficiency coefficient equation, Eq.(4).

The salt equilibrium equation therefore is:

$$R^{*} = (ETc - Pe) * [EC_{iw} / f *(EC_{fc} - EC_{iw})] \tag{6}$$

Where:

EC_{fc}: Electrical conductivity, (ds/cm) ,and :

$$EC_{fc} = EC_{\circ} * (\theta_{vs} / \theta_{fc}) \tag{7}$$

Where:

$EC_{\circ}$: Initial electrical conductivity of soil solution at field capacity, ds/m,

θ_{fc}: Soil moisture content of soil at field capacity, fraction of unity, and

θ_{vs}: Soil moisture content of soil at saturation, fraction of unity.

θ_{vs} / θ_{fc} For moderate texture soil equal to two as showed by**, Al-Furat Center For Studies and Designs of Irrigation Project, 1992.**

To guarantee that all root zones are leached, the maximum crop root depth was adopted to prevent any crop losses during whole year. The amount of salts that can added during the first irrigation in any month equal to the amount added in the second irrigation ,and for all irrigations during that month .So, the depth of leaching water differs from month to another. The amount of salt added through any irrigation can be calculated from:

$$Z_{ki}= (EC_{iw})_k*NA*RD_j*C \tag{8}$$

Where:

Z_{ki}: amount of salts added on the k^{th} day after irrigation, during the i^{th} month,(grams),

NA_j: net area planted with j th crop, hectares,

RD_j: root depth at any time of the j th crop, mm,

k: index for time, days,

i: index for time, months, and

C: conversion factor milli equivalent per liter (meq/l) or part per million (ppm), and the unit of electrical conductivity is decisemens per meter (ds/m).

1(ds/m)=640(ppm),or (gm/m^3), **Ayers and Westcot, 1985.**

There are three possibilities of supplying irrigation water, which are: If the net depth of irrigation water is equal to the soil water deficit before irrigation (full irrigation), the soil water content after irrigation will reach the field capacity of soil, then:

$Irr.D_{ki} = SWDB_{ki}$

Where:

$SWDB_{ki}$: Soil water deficit on the k^{th} day before irrigation during the i^{th} month, (L).

Second probability**,** if the net depth of irrigation water is less than the soil water deficit before irrigation (partial irrigation).Accordingly there is an additional quantity of water that should be added to raise the water soil content to field capacity level. In this case, and if the salinity reaches a harmful level that will effect growth of crop, the leaching water must be added to remove the salt from the root zone. The additional quantity of water is calculated as extra leaching water depth.

$$(act.R^*_t)_{ki}=ASWD_{ki}+R^*_{ki} \tag{9}$$

$$SWDB_{ki}–Irr.D_{ki}=ASWD_{ki} \tag{10}$$

Where:

$ASWD_{ki}$: Additional soil water deficit in the k^{th} day during the i^{th} month, which equals to water requirement that raises the soil water content to field capacity level, (L).

Third, the net amount of irrigation water is greater than the soil water deficit before irrigation. According to the contiguity between net irrigation water and soil water deficit, the water losses may be divided into two parts:

The first is surface runoff, this amount of water losses cannot be controlled and goes as surface run off, and

The second is one third from field water losses which can be controlled and will be used as a depth of leaching water; this part is considered as deep percolation. In this case, the deep percolation must be checked if it is greater than depth of leaching water therefore, there is no need to add water for leaching purposes. If deep percolation is less than the depth of leaching water, leaching water is needed so,

If $Irr.D_{ki} > SWDB_{ki}$, there are two possibility which are:

The first is;

$Irr.D_{ki} - SWDB_{ki} > R^*_{ki}$ then

$(act.R^*_t)_{ki} =0$, and the second is;

$Irr.D_{ki} - SWDB_{ki} < R^{*}_{ki}$ then:

$(act.R^{*}_{t})_{k} = R^{*}_{ki} - [Irr.D_{ki} - SWDB_{i}]$ (11)

Where:

$(act.\ R^{*}_{t})_{ki}$: Actual depth of irrigation water on the kth irrigation during the ith month,(L).

6- SIMULATION MODEL

The above described mathematical procedure requires tedious calculations if done by hand, so it is translated into a computer simulation. Model inputs, outputs, and flow chart are presented in Fig.1 as a leaching scheduling program.

This model was applied for three different climatic zones with three different cropping patterns and different soil properties.

Spreadsheet Formulas for Microsoft Excel program, version, 2007, was used to program the procedure. The following input data were used to construct the program:

- Number of irrigations around the year together with their dates and depths of irrigation water, and link this work with the main irrigation scheduling program which was built by **Bakr, 2011**, and developed by **Al-Haddad, 1997;** and **Hamad, 1996.**
- The seasonal average of irrigation water salinity in the water source of each project.
- Initial soil salinity, leaching efficiency coefficient, **Hussein, 1997.** , and the salinity at field capacity, as averages. Daily soil water deficit after irrigation around the year, and daily field water losses.

The main outputs of the simulation model are:

The amount of added salinity, salt increase in the soil after each irrigation cycle, and daily, monthly, and annual depths of leaching water,

- Actual daily, monthly, and annual depths of leaching water that should be provided to remove salt from soil reservoir for the two cases: one third of losses is controlled, and the other is uncontrolled, and for different status of soil water content before irrigation,
- Daily percentage of leaching requirements from net irrigation depth,
- Daily, monthly, and annual depths of net irrigation water for each case; volumes of supplied irrigation water to the project, annual amount of saved water by using leaching scheduling, and
- Percentage of drainage water and actual losses of water.

7- RESULTS AND DISCUSSION

Amara Irrigation Project in Maysan Government was taken as an example. Currently, this zone has a saline soil to variable degrees; the average salt concentration is 1676.25 (ppm). Additional leaching water requirements in southern zone were taken as 19-19.5% of total irrigation requirement as average,**General Scheme of Water Resource and Land Development of Iraq, 1982.** If the net depth of irrigation water is less than the soil water deficit before irrigation (partial irrigation), additional quantity of water should be added to raise the soil water content to field capacity. In this case and, if the salinity reaches a harmful level, the leaching water must be added to remove salt from the soil.

In all irrigation cycles during autumn and winter seasons, the net depth of irrigation water is greater than the soil water deficit before irrigation (full irrigation), accordingly the contingents between net irrigation depth and soil water deficit will be taken as water losses. In some irrigation applications during summer and spring seasons an additional quantity of water should be added to raise the soil water content to field capacity.

Table 1and **Fig.1**, present the difference in applied water distribution between leaching scheduling procedure (calculated) case and designer suggestion (allocated) case. In the first case applied irrigation volumes in scheduled case are less than those allocated to the project, and there is 29.8 %of water lost as drainage water. In these cases assuming that water losses cannot be controlled, 29.8% is lost to the drains, and the real need is 683mm depth of leaching water. **Table 1**, also shows that 1767.64 million m^3 of water were saved. In the second case applied irrigation volumes in a scheduled case are less than those allocated to the project and there is 25.5% of water lost as drainage water.

In these cases assuming that water losses can be controlled and part of water losses (deep percolation) substitute part of leaching, loss of drainage water become 25.5%, and 467.7 mm of leaching water only are needed to leach salts **Table 2**. **Table.1** also shows that 1845.29 million m^3 of water are saved.

Introducing leaching scheduling procedures a proper cropping pattern should be used in order to improve water use efficiency, but without crops stress. Cropping pattern should be chosen carefully. Amara irrigation project with assumed an cropping pattern, five winter-season crops, four summer-season crops, and six perennial crops were planted with cropping intensity equal to 115%. The crops differ in degree of response to salinity; some crops can produce acceptable yields at much greater soil salinity than others. Crops are divided into four relative salinity tolerance rating, sensitive, moderately sensitive, moderately tolerant, and tolerant crops.

The wide range of salt tolerance crops allows using moderately saline water some of them were previously thought to be unusable. Therefore greatly expands the acceptable range of water salinity which is considered suitable for irrigation. In the Amara Irrigation Project, some crops were planted were but with an assumed area, with many trials, the right percentages of plant area which improves water saving without losing crops can be found, in this project it is assumed that no sensitive crops are planted.

Saving crops at 50% yield potential was considered as an index for salinity hazard; in the other words must be added depth of leaching water before the soil salinity become less than or equal to the threshold value of 50 % yield potential.

The water source of Amara irrigation project is Tigris River in Maysan Government. There were some missing monthly records of salt concentration in irrigation water at Amara during 2000 to 2001were lost, therefore in this study the mean seasonal salt concentration of irrigation water was used which is equal to the mean annual salt concentration, and equal to 1676.25 ppm.

For effective salinity control, adequate drainage to control and stabilize the water table and leaching saline ground water intrusion in the active root zone were considered to be negligible.

Table 3 and **Fig. 3**, show the differences in applied water distribution between calculated leaching scheduling and designer suggested (allocated). In the first case applied irrigation volumes are less than those allocated, and there is 33.2% of water lost as deep percolation. In this case the water losses cannot be controlled therefore 303 mm of leaching water was needed. The amount of 1891.57 million m^3 of irrigation water was saved as shown in **Table 4**. In the second case, applied irrigation water volumes are less than those allocated to the project, and there is 33.2% of water lost as deep percolation. In these cases water losses assume to be controlled, and part of water losses should be substituted, therefore drainage water losses became 30.4%, and 166 mm depth of leaching water is needed to leachout salt. **Table 4** also shows that 1942.26 million m^3 of water were saved. Salt concentration of irrigation water at Amara for 2000 to 2010 years point is used. So the mean annual salt concentration for the ten years is 1165.02 ppm as shown in **Table 5**.

8- CONCLUSIONS

1. Using the maximum planted crop root depth to leach out salts from the root zone , guarantees preventing crop damage due to salt,
2. The comparison between the monthly applied irrigation volumes using leaching scheduling procedure and the suggested by designers provides flexibility for balancing between monthly applied irrigation volumes; therefore the operation is efficient while the distribution of monthly applied irrigation water suggested by designers has a maximum value at summer season which causes problems in operating irrigation and drainage network,
3. High salinity of irrigation water means high depth of leaching water is needed ,the monthly applied leaching water of the scheduling procedure, and for the two cases are greater than monthly applied leaching water suggested by designers taken into account the crops were not suffer from salinity stress , and
4. The results show that applying leaching scheduling at Amara irrigation project is more acceptable and more economic than using suggestion of designer.

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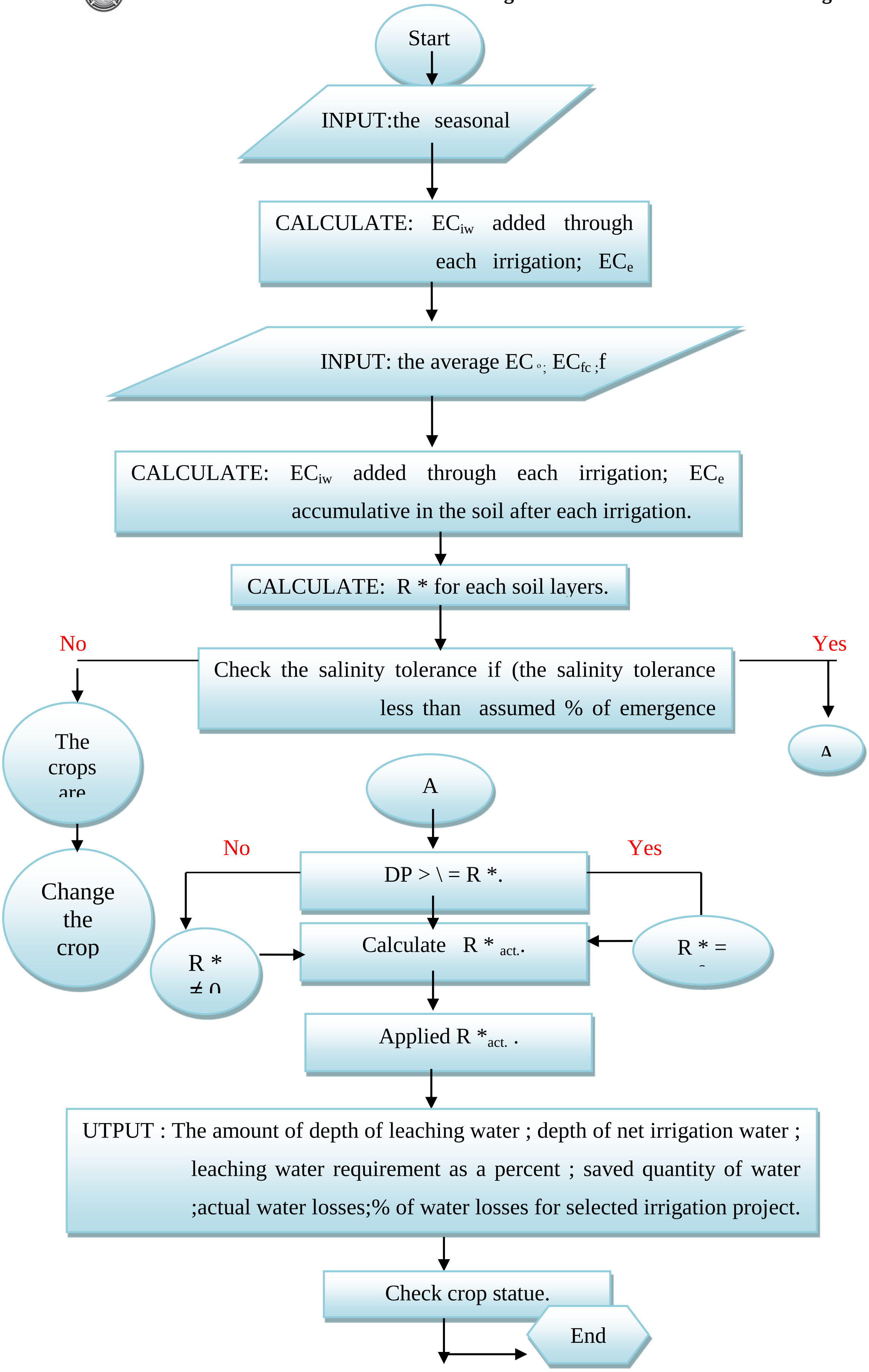

Figure 1. Flow chart illustrates the main steps of the simulation model of the leaching scheduling.

Table 1. Monthly and annual irrigation water amounts, Amara Irrigation Project, 2000-2001.

Month	**Calculation results**		**Estimated by general scheme (LR =19%)**
	Designed I: net volume of irrigation water, m^3x10^6	**Designed II: net volume of irrigation water, m^3x10^6**	**NI req. $(m^3)*10^6$**
Jan.	**113.29**	**100.42**	**36.96**
Feb .	**109.21**	**101.88**	**63.65**
Mar .	**120.71**	**116.88**	**105.37**
Apr.	**153.49**	**153.18**	**312.37**
May .	**146.49**	**136.96**	**455.33**
Jun .	**130.71**	**125.16**	**635.12**
Jul .	**144.08**	**139.18**	**631.63**
Aug .	**147.37**	**140.37**	**571.65**
Sep .	**134.37**	**126.15**	**266.49**
Oct.	**135.85**	**128.25**	**117.69**
Nov .	**66.65**	**64.91**	**62.79**
Dec.	**108.85**	**100.42**	**19.98**
Sum.	**1511.42**	**1433.76**	**3279.06**
Percentage of drainage water	**29.8**	**25.5**	
Saved volume of water 10^6 m^3	**1767.64**	**18545.29**	
Percentage of leaching requirements, %	**Av. 22.24**	**Av. 15.34**	**19.5**
Actual water losses, mm	**1111.25**	**895.61**	**……**

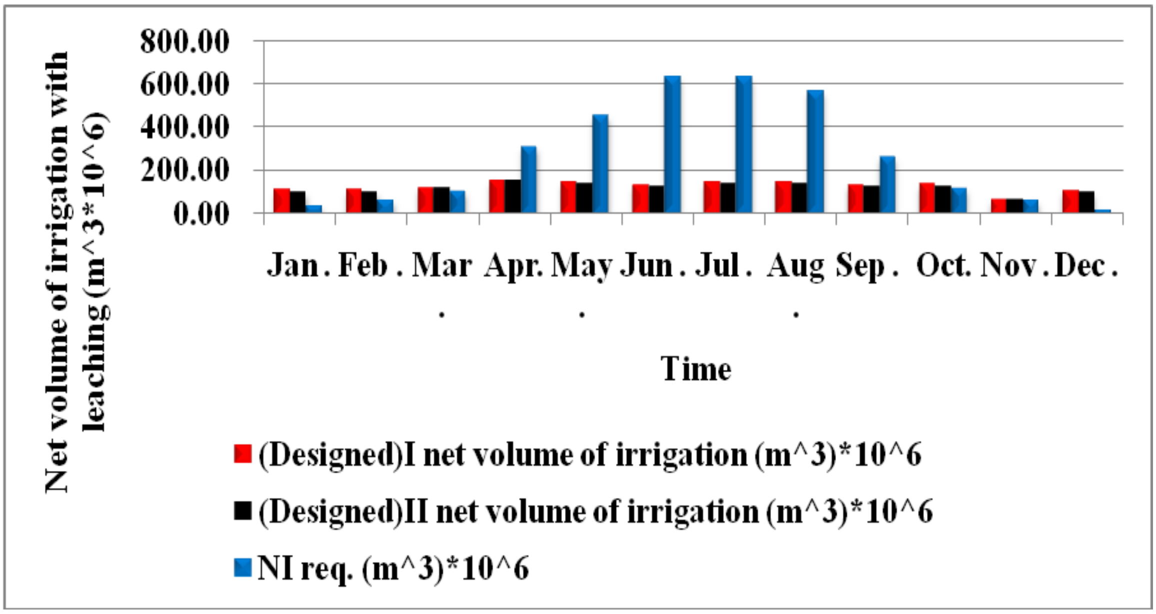

Figure 2. Monthly irrigation water amounts; distribution according to leaching scheduling, and designer suggestions if water losses uncontrolled and water losses controlled.

Table. 2 .Monthly and annual depths of leaching water, Amara Irrigation Project, 2000-2001.

Month	**From calculation**			**From general method (LR = 19.5%)**
	R^*_t (mm)	**(act . R^*_t)I (mm)**	**act . R^*_t) II (mm)**	**R^*_t (mm)**
Jan.	**17.49**	**17.49**	**0**	**26.61**
Feb .	**27.056**	**27.06**	**17.12**	**23.60**
Mar .	**41.77**	**41.776**	**36.69**	**23.12**
Apr.	**48.11**	**48.11**	**47.70**	**25.96**
May .	**92.85**	**92.85**	**57.78**	**72.02**
Jun .	**95.48**	**95.48**	**72.78**	**71.22**
Jul .	**102.06**	**102.06**	**81.99**	**80.13**
Aug .	**116.75**	**116.75**	**87.94**	**80.64**
Sep .	**71.28**	**71.28**	**34.92**	**82.99**
Oct.	**44.38**	**44.38**	**18.44**	**66.87**
Nov .	**14.6**	**14.6**	**12.29**	**14.65**
Dec.	**14.46**	**14.46**	**0.000**	**26.61**
Sum	**683.34**	**683.34**	**467.7**	**594.44**

Table 4, Monthly and annual irrigation water amounts, Amara Irrigation Project, 2000-2001.

Month	**From calculation**		**From general scheme (LR =19.5%)**
	(designed)I net volume of irrigation (m^3)*10^6	**(designed)II net volume of irrigation (m^3)*10^6**	**NIreq. (m^3)*10^6**
Jan.	**106.96**	**100.42**	**36.96**
Feb.	**109.46**	**104.34**	**63.65**
Mar.	**110.05**	**109.62**	**105.37**
Apr.	**133.68**	**131.41**	**312.37**
May.	**129.23**	**124.19**	**455.33**
Jun	**114.25**	**111.4**	**635.12**
Jul.	**129.65**	**126.8**	**631.63**
Aug.	**122.27**	**119.37**	**571.65**
Sep.	**133.57**	**126.1**	**266.49**
Oct.	**128.32**	**122.85**	**117.69**
Nov.	**61.71**	**59.24**	**62.79**
Dec.	**108.34**	**101.05**	**19.98**
Sum.	**1387.48**	**1336.79**	**3279.06**
Percentage of drainage water	**33.2**	**30.4**	
Saved volume of water 10^6 m^3	**1891.57**	**1942.26**	
Percentage of leaching requirements (%)	**Av. 9.95**	**Av. 5.47**	**19.5**
Actual water losses (mm)	**1111.25**	**977.47**	**……**

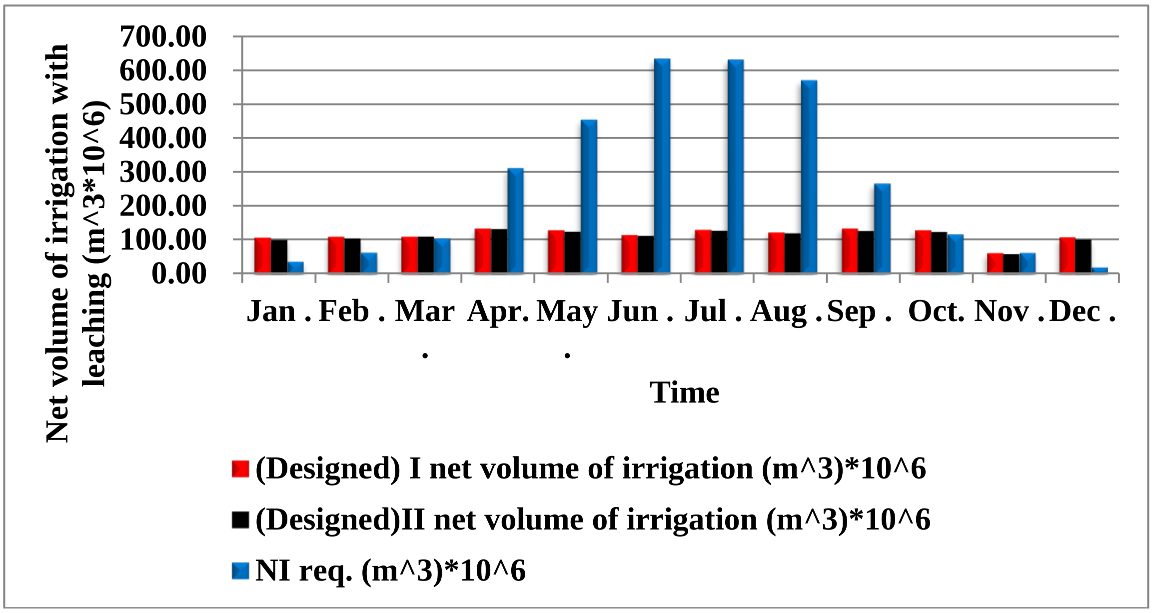

Figure 5. Monthly irrigation water amounts; distribution according to leaching scheduling, and to designer suggestions.

Table 5, Monthly and annual depths of leaching water, Amara irrigation project, 2000-2010.

Months	From calculation			From general method (LR = 19.5%)
	R^*_t(mm)	(act . R^*_t)I mm	(act . R^*_t)II (mm)	R^*_t (mm)
Jan.	8.89	8.89	0	26.61
Feb.	27.39	27.39	20.45	23.60
Mar.	27.61	27.61	27.05	23.12
Apr.	18.84	21.85	18.84	25.96
May.	29.38	29.38	10.84	72.02
Jun.	28.13	28.13	16.45	71.22
Jul.	43	43	31.35	80.13
Aug.	13.39	13.39	1.43	80.64
Sep.	66.38	66.38	34.72	82.99
Oct.	18.67	18.67	0	66.87
Nov.	7.97	7.97	4.66	14.65
Dec.	10.76	10.76	0	26.61
Sum.	300.43	303.44	165.79	594.44

ABREVIATIONS

Symbol	Description	Units
$act.R^*_t$	Actual depth of leaching water.	L
$ASWD_{ki}$	Additional soil water deficit on the k^{th}day during the i^{th} month.	L
AW	Available water.	L
C	Conversion for units.	…
C_{DP}	The average salt concentration of the water percolating below the root zone.	ppm
C_e	The average salt concentration of the soil saturation extract.	ppm
C_{fc}	The average salt concentration of the soil solution at field capacity.	ppm
C_{iw}	The average salt concentration of irrigation water.	ppm
C_R^*	The average salt concentration of leaching water.	ppm
EC_e	Electrical conductivity tolerated by the crop as measured in the soil saturation extract.	ds/m
EC_{fc}	Electrical conductivity of soil extract at field capacity.	ds/m
EC_{iw}	Electrical conductivity of irrigation water.	ds/m
$EC_\circ$	Electrical conductivity of soil before leaching (initial value).	ds/m
Etc	Monthly crop evapotranspiration rate.	L/Time
f	Leaching efficiency coefficient.	%
f_c	Specific moisture of soil at field capacity.	
I	Index for time.	Month
Irr.D	Applied net irrigation water depth infiltrated, which is the total applied irrigation water minus evaporation losses and surface runoff.	L
J	Index for crop grown in the project.	…
K	Index for time.	Day
LR	The leaching requirements.	%
NA_j	Net area planted with the j^{th} crop.	Don.
P_e	Effective rain-fall.	L
RD_j	Root depth at any time of the j^{th} crop.	L
R^*	Depth of leaching water.	L
R^*_t	Total depth of leaching water.	L
SWDB	Soil water deficit before irrigation.	L
Z	The amount of salt added after irrigation.	Gram