Scheduling of Irrigation and Leaching Requirements

Amer Hassan Al-haddad
Assistant Professor
College of Engineering, University of Baghdad
E-mail: Ameralhaddad 1950@yahoo.com

Alaa Ibraheem Badi Al-Safi
College of Engineering, University of Baghdad
E-mail: alaa86wr@yahoo.com

ABSTRACT

Iraq depends mainly on Tigris and Euphrates Rivers to provide high percentage of agricultural water use for thousands years. At last years, Iraq is suffering from shortage in water resources due to global climate changes and unfair water politics of the neighboring countries, which affected the future of agriculture plans for irrigation, added to that the lack of developed systems of water management in the irrigation projects and improper allocation of irrigation water, which reduces water use efficiency and lead to losing irrigation water and decreasing in agricultural yield. This study aims at studying the usability of irrigation and leaching scheduling within the irrigating projects and putting a complete annual or seasonal irrigation program as a solution for the scarcity of irrigation water, the increase of irrigation efficiency, lessening the salinity in the projects and preparing an integral irrigation calendar through field measurements of soil physical properties and chemical for project selected and compared to the results of the irrigation scheduling and leaching with what is proposed by the designers. The process is accomplished by using a computer program which was designed by Water Resources Department at the University of Baghdad, with some modification to generalize it and made it applicable to various climatic zone and different soil types. Study area represented by large project located at the Tigris River, and this project was (Al-Amara) irrigation project. Sufficient samples of project's soil were collected so as to identify soil physical and chemical properties and the salinity of soil and water as well as identifying the agrarian cycles virtually applied to this project. Finally, a comparison was conducted between the calculated water quantities and the suggested ones by the designers. The research results showed that using this kind of scheduling (previously prepared irrigation and leaching scheduling) with its properties which made it applicable requires an intense care when using the plant distribution pattern, the agrarian cycle, its agrarian areas and agricultural intensity within all climatic regions. Also, it was found that this program was an instrumental tool for providing water if the plant distribution pattern was well-selected.

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

متطلبات جدولة الري والغسيل

د. عامر حسن حداد
كلية الهندسة / جامعة بغداد

علاء ابراهيم بادي
كلية الهندسة /جامعة بغداد

الخلاصة

يعتمد العراق على نهري دجلة والفرات في توفير نسبة كبيره من الاحتياجات المائية للإغراض الزراعية منذ آلاف السنين . إلا انه في السنوات الأخيرة أصبح يعاني من شحه في موارده المائية بسبب التغيرات المناخية العالمية والسياسات المائية الجائرة لدول الجوار مما اثر على الخطط الزراعية المستقبلية . أضافه إلى ذلك ضعف طرق إدارة المياه في المشاريع الاروائيه وتوزيع مياه الري بصورة غير فعاله مما قلل من كفاءة استخدام المياه والذي أدى إلى هدر في مياه الري ونقص في الإنتاج . تهدف هذه الدراسة إلى دراسة إمكانية استخدام جدولة الري والغسيل ضمن المشاريع الاروائيه ووضع برنامج إروائي سنوي أو موسمي متكامل كحل

لشحه مياه الري وزيادة كفاءة الري وتقليل الملوحة في المشاريع وإعداد تقويم إروائي متكامل وذلك من خلال قياسات حقلية لخواص التربة الفيزيائية والكيمائية للمشاريع المختارة ومقارنه نتائج جدولة الري والغسيل مع ما هو مقترح من المصممين. تتم هذه العملية باستخدام برنامج حاسوبي تم انشاؤة وإعداده وتتطويرة في قسم هندسة الموارد المائية في جامعه بغداد مع بعض التعديلات للارتقاء به نحو العمومية وجعله قابل للتطبيق في المناطق المناخية المختلفة ولأنواع مختلفة من الترب. تم اختيار مشروع ري العمارة كمنطقة للدراسة وتم جمع العينات الوافية للمشروع لمعرفة خواصه الفيزيائية والكيميائية ونسبة الملوحة في التربة ومياه الري أضافه إلى ذلك تم معرفة الدورة الزراعية المطبقة فعليا في المشاريع. وأخيرا تم إجراء مقارنة بين كميات المياه المحسوبة وكميات المياه المقترحة من قبل المصممين ومن خلال نتائج البحث أظهرت إن استخدام هكذا نوع من الجدولة (جدولة الري والغسيل المعدة مسبقا) بخصائصه تجعله قابل للتطبيق, والذي يتطلب عناية شديدة عند استخدام نمط توزيع النباتات والدورة الزراعية والكثافة الزراعية, كما وجد إن هذا البرنامج أداة مفيدة لتوفير المياه إذا ما أحسن اختيار النباتات ونمط توزيعها.
الكلمات الرئيسية : ألجدوله الاروائيه , جدوله الغسيل , النسبة المئوية لأطول جذر , الملوحة , البرنامج الخاص بقسم الموارد المائية , الموازنة المائية , مشروع ري العمارة.

1. INTRODUCTION

1.1 Irrigation Scheduling

Irrigation scheduling simply determines when to irrigate and how much irrigation water to apply, or it is a strategy that minimizes the supplied water with minimal impacts on yields and crop quality. An effective irrigation schedule helps to maximize profit while minimizing environmental problems, water, and energy use.

The following factors that contribute in developing a workable and efficient irrigation schedule:

- Soil properties;
- Soil-water relationships;
- Type of crop and its sensitivity to drought stress;
- Stage of crop development;
- Availability of water supply; and
- Climatic factors such as rainfall and temperature.

A range of irrigation scheduling methods have been developed to assist farmers and irrigators to apply water more efficiently taking into account crop evaporation and rainfall. Irrigation scheduling includes the following methods:

First - Traditional method which is unfortunately the method adopted by many farmers. This method is based on individuals' decision and depends on previous observations without taking into account the need of plant to water. There is a belief among many farmers that the addition of large amounts of irrigation water increases the agricultural productivity. This method consumes a large amount of water without a scientific justification, and it may cause:

1. Lack of soil aeration and accumulation of CO_2 that inhibits the ability of roots to absorb water and nutrients.
2. Leaching nutrients from the soil and removing it from the root zone.
3. Depletion of water without justification, causing a crisis in water resources.
4. Lack of productivity.

Therefore, this method must be disposed of.

Second - Modern methods which are methods based on scientific base to take into account several factors affecting water consumption, and these methods depend on climatic factors, soil factors, plant type, or depend on all these factors.

Making the very best decisions about when and where to irrigate is not easy when the irrigation water available over a season is production limiting. Each decision requires a consideration of the entire remaining irrigation season. A farmer needs to make difficult decisions about when and which crops will be subjected to water stress. Uncertain rainfall further complicates decisions. Optimal on-farm irrigation scheduling methods can provide advice in these situations. Existing optimal on-farm irrigation schedulers generally use dynamic programming for optimization. A number of authors since the late 1960s have proposed using simplistic plant models combined with dynamic programming optimization to schedule irrigation for a single crop. Made significant contributions to these single crop schedulers.

,Hamad ,1996. developed a practical and easy procedure for preparing seasonal or annual irrigation programs for an irrigation project. The developed procedure is based on some practical criteria among them are the:

- Supplied discharge would be constant in all irrigations;
- Time of application would be also constant throughout the season;
- Starting day of all irrigations in the season or the year would be the same day in the week in order to make the farmers and irrigators accustomed to the days of irrigation; and
- Irrigation intervals are selected in such a way to avoid crop stress due to insufficient soil moisture.

,Al-Hadaad, 1997, developed a model to pre-schedule irrigations in large irrigation projects based upon average weighted of root depth, physical soil properties and crop water requirements. This model also includes estimating expected annual crop production of the project for a given cropping pattern.

,Riffat, 1999, developed an optimization process to maximize total crop production from a given cropping pattern in an irrigation project by using pre-scheduled irrigations and pre-specified constraints on the volumes of applied water and cropping intensity.

,Al-Hadaad ,2001, evaluated the effect of using weighted average root depths and a certain level of depletion in building an irrigation scheduling program for large projects containing different crops on water stress of wheat crop during the growing season.

,Broner ,2005, pointed out that the irrigation scheduling offers several advantages such as:

1. It enables the farmer to schedule water rotation among the various fields to minimize crop water stress and maximize yields,
2. It reduces the farmer’s cost of water and labor through less irrigation, thereby making maximum use of soil moisture storage,
3. It lowers fertilizer costs by holding surface runoff and deep percolation (leaching) to a minimum,
4. It increases net returns by increasing crop yields and crop quality,
5. It minimizes water-logging problems and reducing the drainage requirements,
6. It assists in controlling root zone salinity problems through controlled leaching, and
7. It results in additional returns by using the saved water to irrigate non-cash crops that otherwise would not be irrigated during water-short periods.

,Bakr, 2011, pointed to effectively schedule irrigation applications, four key pieces of information need to be known:

- soil texture;
- water holding capacity of the soil;
- Initial soil moisture content; and
- crop water use at the specific development stage.

The use of computer programs to help scheduling irrigation was introduced in the 1970’s. However, only recently with the introduction of fast, personal computers have they begun to gain wider acceptance, **Martin, 2009**. Irrigation scheduling is based on three methods and tools; they are plant stress measurement, predictive models, and soil moisture measurement ,**Antosch, 2007**. Soil water measurement based on either "soil water measurement", where the soil water status is measured directly or determine the need of irrigation, or on "soil water balance calculations" where the soil water statue is estimated by calculation using a water balance approach in which the change in soil water over a period is given by the difference between the inputs and the losses.

The scheduling procedure adopted in this research is that developed by ,**Hamad ,1996.** and **, Al-Haddad, 1997.** It is a practical and applicable procedure that can be adopted in large irrigation projects since it is simple to use and easy to understand by project manager and farmers. It was based on the following constrains:

1. Applied discharge at the project head gate is constant throughout the whole year, such application would facilitate the operation of controlling and distribution structures of irrigation network.
2. Irrigation time is held constant during the year or at least during the growing season, in order to habituate the worker and farmer on irrigation time in the project.
3. Irrigation time must be chosen in a way that facilitates water distribution and project operation and should be full-days and avoiding parts of the day.
4. Irrigation interval must be selected in a way that crops will not be stressed due to decreasing soil moisture content and will not cause over-irrigation.
5. The day of starting irrigation during the year is same day of the week and the day of starting of irrigation scheduling. Such a practice would habituate the farmer to irrigation date, and the date of water distribution between farmers.

These constrains can be useful for a single large project. Since this program is intended to a number of projects located the Tigris River basin which is different in soil properties, climate, and types of planted crops; such variation should be taken in account when building a scheduling program. Some modifications on these constrains are required to make it more comprehensive, so the third and fifth constrains are modified as follows:

- For heavy soils, the day of starting irrigation during the year is the same day of the week as the day of starting the irrigation schedule or irrigation year. For light soils, there are two possible irrigation days in the week, first day has the same interiority of heavy soils irrigation day and the second is in the middle of week of the day of starting irrigation year.
- In winter season, time of irrigation will be chosen in a way that does not affect crop growth, while in summer season there is a continuous irrigation except in rainy zones.

1.2 Leaching Scheduling

Leaching scheduling means how much water should be applied to leach soil salinity and when. Leaching is often done to reclaim saline soil or to conserve a favorable salt content of the soil of irrigated lands as all irrigation water contains salts.

The Leaching Requirement concept was developed by the U.S. Salinity Laboratory **,Richards, 1954.** It has been 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 specifiable limit"; therefore, it is the minimum amount of water that must pass through the root zone to keep salts within an acceptable range.

The leaching requirement depends on the salt concentration of the irrigation water, the amount of water extracted from the soil by the crop (evapotranspiration) and the salt tolerance of the crop, which determines the maximum allowable concentration of the soil solution in the root zone , ,**Rhoades, 1974. and ,U.S. Salinity Laboratory Staff, 1954.**

The accumulated salt in the root zone is generally leached by applying water in excess of field capacity (LR). Field capacity can be defined as a 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;** some field trials by**, Nielsen et al.,1966. and Oster et al.,1972**, had shown that the quantity of salts are removed per unit quantity of water leached can be increased appreciably by leaching at soil moisture contents of less than saturation, i.e. under unsaturated conditions. In the field, unsaturated conditions during leaching were obtained by adopting intermittent pounding or by intermittent sprinkling at rates less than the infiltration rate of the soil. The degree of salt removal during leaching can be markedly influenced by the method used.

,Hussein ,2012, pointed that leaching is the key factor in controlling soluble salts brought in by the irrigation water and can be divided into two parts:

1. Fundamental (Initial) Leaching

To reclaim saline soils, leaching strategies especially continuous pounding and intermittent pounding were developed by Laboratory scientists and are universally used ,**Reeve et al., 1955**.

Hoffman, 1980, used the data obtained from the field in USA and some countries and represented in the equation below:

$$\frac{EC_{fc} - EC_e}{EC_{iw} - EC_e} = \left(\frac{0.07}{\left(\frac{D_{iw}}{D_s}\right)}\right) + 0.02 \qquad (1)$$

Where:

EC_e : Electrical conductivity of soil , ds/m,

EC_{fc}: Electrical conductivity of soil extract at field capacity, ds/m,

EC_{iw}: Electrical conductivity of irrigation water, ds/m,

D_{iw}: Depth of irrigation water, mm, and

D_s: Soil depth, mm.

Leaching curves both with respect to desalinization and of a highly saline-sodic soil, were determined experimentally using large size ring (infiltration meters). These curves were useful in knowing the amount of water of a given composition needed to reduce the harmful levels of salinity and sodicity to the lower desirable values. Different theoretical models were also tested by comparing the calculated and experimental desalinization leaching curves. It was found that there is a reasonably good agreement between theoretical and experimental results up to nearly 10% of the initial salinity.

2. Maintenance (Secondary) Leaching or Leaching Requirement

The actual LR can only be determined by monitoring salinity control which is then 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, and Merrill, 1976,** and **,Rhoades, 1990.** suggested the following equation:

$$LR = \frac{EC_{iw}}{(5 * EC_e - EC_{iw})} \qquad (2)$$

Where:

LR: Leaching Requirement, expressed as percentage.

,Hussein ,2012, pointed that the success of irrigated agriculture, in the long run, depends on maintaining the balance of salt in the root zone of crops, where whenever the salt dissolves in irrigation water added to the soil, it increases its focus as a result of evaporation-transpiration. Thus, the salt concentration becomes higher than the estimated carrying plants to it, and to maintain the crop damage must remove these excess salts by leaching zone using irrigation water, and at the expense of high irrigation water to be added by the specific scheduling program, we should take into account the salt budget for this case. The additional irrigation water used to wash the soil will also wash the nutrients in the soil.

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

If drainage is adequate, the depth of water required for leaching depends on the salt sensitivity of the crop and the salinity of the applied water. When salinity is high, the depth of leaching water needed may be too great, making it necessary to change to a more salt tolerant crop, providing that the market economics will allow this. In dealing with a major salinity problem related to water quality, a cropping change is considered a drastic step and will only be taken when less severe options have failed to maintain economic production. Leaching, on the other hand, is a basic step in production even for water of the best quality and must be practiced when necessary to avoid salt accumulation that could ultimately affect production. Leaching salt downward into the deeper layer with excess water is the most common method to lower soil salt content in the root zone **,Qadir et al., 2003.**

2. MATHEMATICAL MODEL

2.1 Irrigation Scheduling

Conceptual formulation

Irrigation scheduling means how much water should be applied and when to irrigate. To make the right decision, there are some steps that should be followed. First of all, indicate cropping pattern and information about each crop should be known, such as growing season, growing and harvesting date, root depth. Soil physical properties, climate, availability of water resources, and field water losses also should be known.

With the aid of the information above, monthly and annual water requirements can be calculated and irrigation scheduling can be adopted. Three main schedules are known, these are: constant depth; constant interval; and practical irrigation schedule. As it is known, scheduling of irrigation affects the quantity of irrigation water which is received by plants. Since each crop has its own root zone and consumptive use rate, **Al-Mesh'hedany ,2002.** investigated the effect of an irrigation scheduling scheme on each crop grown in the project by executing a water budgeting procedure for each crop on a daily basis in order to determine the actual amounts of water received from the adopted irrigation scheduling scheme for each crop during its growing season. In this research, this procedure will be adopted to investigate planted crop statue due to irrigation scheduling procedure.

The procedure described in the previous section was mathematically formulated to obtain a workable procedure .Below, a brief description of the mathematical formulation of irrigation scheduling procedure items that must be provided, **Al-Haddad, 1997.**

Crop water requirements: The first step in irrigation scheduling is to determine crop water requirements. Actual monthly crop water requirements can be estimated from reference evapotranspiration and crop coefficient as follows:

$$ET_{cij} = K_{cij} * ET_{Oi} \qquad (3)$$

where:

ET_{cij} : Actual monthly evapotranspiration rate of the j^{th} crop during the i^{th} month (mm/month),

K_{cij} : Monthly crop coefficient of the j^{th} crop during the i^{th} month (dimensionless),

ET_{Oi} : Monthly reference crop evapotranspiration rate (potential evapotranspiration rate) during the i^{th} month (mm/month),

i : Month index, and

j : Crop index.

Since a cropping pattern contains many crops, the weighted average of crop evapotranspiration rate ought to be used to estimate irrigation water requirements. The monthly weighted average of actual crop evapotranspiration for certain crop pattern can be calculated from:

$$\mathrm{WET_{ci}} = \frac{\sum_{j=1}^{n}(\mathrm{ET_{cij}} * \mathrm{NA_j})}{\sum_{j=1}^{n}\mathrm{NA_j}} \quad (4)$$

where:

$\mathrm{WET_{ci}}$: Monthly weighted average of actual crop evapotranspiration for certain cropping pattern during the i^{th} month (mm/month),

n : Number of planted crops in adopted crop pattern, and

$\mathrm{NA_j}$: Net area planted with the j^{th} crop, it is equal to $NA * PA_j$ (don.),

PA_j : Percentage of area planted with the j^{th} crop, and

NA : Net irrigated project area (don.).

Net monthly volume of irrigation water requirements can be calculated from subtracting average monthly effective rainfall (if there is) from monthly crop consumptive use rate and multiplying by the area as follows:

$$\mathrm{NI_{i\,req.}} = \sum_{j=1}^{n} \mathrm{C} * \mathrm{NA_j} * (\mathrm{WET_{ci}} - \mathrm{ER_i}) \quad (5)$$

where:

$\mathrm{NI_{i\,req.}}$: Net volume of water required during the i^{th} month (m^3),

$\mathrm{ER_i}$: Monthly effective rainfall during the i^{th} month (mm/month), and

C : Conversion factor units (dimensionless).

So, the net continuous irrigation discharge required during the i^{th} month would be:

$$NQ_{i\,req.} = C_1\left(\frac{NI_{req,}}{ND_i}\right) \quad (6)$$

where:

NQ i req.: Net continuous discharge required during the i^{th} month (m^3/sec),and

$\mathrm{ND_i}$: Number of days in i^{th} month.

C_1 : conversion factor.

The gross continuous irrigation discharge required during the i^{th} month can be calculated by:

$$\mathrm{GQ\ i\ \ req.} = \frac{\mathrm{NQ_{i\,req}}}{\mathrm{IE_i}} \quad (7)$$

where:

GQ i req : Gross continuous discharge required during the i^{th} month (m^3/sec), and

IE : Expected irrigation efficiency in the project expressed as a percentage.

The water duty which represents the irrigation capacity of unit irrigation water to irrigate unit of area, and can be calculated from:

$$\mathrm{WD_i} = \frac{\mathrm{NQ_{i\,req}}}{\mathrm{NA_i}} \quad (8)$$

where:

WD_i : Water duty during the i^{th} month ($^{l/sec}/_{ha}$), and

NA_i : Net irrigated project area during the i^{th} month (don.)

One of the main and important parameters that affects irrigation scheduling is soil water content. First step to estimate soil water content is to know the root zone depth. Adopting maximum root depth means occurrence of water losses on areas planted with crops having shallow root zones, while adopting minimum root depth means water shortage and/or water stress on areas planted with crops having deep root depth zone. Thus, in this research a percentage of maximum root depth shall represent root zone depth for a certain cropping pattern**, Bakr ,2011**, and it can be calculated from:

$$URD_i = \max(RD_{ij}) * \% RD \tag{9}$$

where:
URD_i : Used root depth during the i^{th} month (mm),
RD_{ij} : Root depth of the j^{th} crop during the i^{th} month (mm), and
$\% RD$: Percentage of the root depth.

The total available water is calculated as:

$$TAW_i = (FC - PWP)\ URD_i \tag{10}$$

where:
TAW_i : Total available water (mm),
FC : Soil water content at field capacity expressed as a percentage by volume, and
PWP : Soil water content at permanent wilting point expressed as a percentage by volume.

The readily available water is expressed as a percentage of the total available water, or:

$$RAW_i = TAW_i * AD \tag{11}$$

where:
RAW_i : Readily available water in the root zone during the i^{th} month (mm), and
AD : Allowable depletion expressed as a percentage.

The allowable depletion differs from one crop to another and it is a function of evaporation power of the atmosphere. ,**Allen et al., 1998,** gave an allowable depletion for ETc =5 mm/day. Therefore, an adjustment is required for different evapotranspiration rates and they suggested an adjustment formula. In this research, the fraction of allowable depletion and adjustment formula for each crop presented by ,**Allen et al, 1998.**,will be adopted. The adjustment formula is:

$$AD_j = app.(ii) + 0.04 * (5 - ETc) \tag{12}$$

where:
AD_j : Allowable depletion of the j^{th} crop expressed as a percentage, and
app. (ii): Soil water depletion fraction for no stress for crops.

As allowable depletion is different from one crop to another as was mentioned above, the weighted average allowable depletion for an irrigation project will be adopted, and is calculated as follows:

$$AD = \frac{\sum_{j=1}^{n} AD_j * PA_j}{\sum_{j=1}^{n} PA_j} \tag{13}$$

Initial soil water deficit in the first day of irrigation scheduling is measured or assumed. Therefore, the soil water deficit at the second day of schedule can be calculated as:

$$SWDB_{ki} = SWDA_{(k-1)i} + WET_{cki} - ER_{ki} \qquad (14)$$

where:
$SWDB_{ki}$: Soil water deficit on the k^{th} day before irrigation during the i^{th} month (mm),
$SWDA_{(k-1)i}$: Soil water deficit after irrigation on the $(k-1)^{st}$ day during the i^{th} month (mm),
ER_{ki} : Effective rainfall (mm),
and
k : Day index.

When a new month begins, root zone depth increases due to a plant growth if the soil water at the end of the previous month is greater than the soil water at the beginning of the new month, then the increase in root depth requires additional quantity of water to raise its water content. This additional quantity of water is calculated as follows:

$$SWDL_i = \frac{SWDAL_i}{URD_i} \qquad (15)$$

where:
$SWDL_i$: Soil water deficit after irrigation (if there is any) at the last day in the i^{th} month measured as a percentage, and
$SWDAL_i$: Soil water deficit after irrigation (if there is any) at the last day in the i^{th} month expressed as a depth of water (mm).

The additional soil water required to raise the soil water content due to the additional root depth calculated as follows:

$$ASWD_{(i+1)} = (FC - ISWC + SWDL_i)ARD_{(i+1)} \qquad (16)$$

where:
$ASWD_{(i+1)}$: Additional soil water deficit in the $(i+1)^{th}$ month (mm),
ISWC : Initial soil water content (mm), and
$ARD_{(i+1)}$: Additional used root depth and is equal as $URD_{(i+1)} - URD_i$ (mm).

This additional water is added to the soil water deficit on the first day of the $(i+1)^{th}$ month and it is equal to zero when root depth at i^{th} month is equal or greater than root depth at $(i+1)^{th}$ month or when the soil water content at the last day of the month is less than the initial soil water.

The daily soil water deficit after irrigation during the i^{th} month can be calculated from:

$$SWDA_{ki} = SWDB_{ki} - Irr.D_{ki} \qquad (17)$$

where:
$Irr.D_{ki}$: Applied net irrigation depth infiltrated in the soil on the k^{th} day during the i^{th} month (mm).

Irrigation water must be applied whenever soil water content reaches a pre-specified value expressed as a percentage of RAW_i or difference between ($SWDB_i$ and RAW_i) . To avoid crop water stress, irrigations should be applied before or on the day when the used readily available water is depleted (i.e., $SWDA_{ki} \le RAW_i$).

The applied net irrigation depth can be calculated from:

$$Irr.D_{ki} = \frac{IRR_{time\,i} * Q_{max} * IE}{NA_i} \qquad (18)$$

where:
$IRR_{time\,i}$: Irrigation time (days), and
Q_{max} : Gross maximum or design project discharge (m^3/sec).

2.2 Leaching Scheduling

The conceptual facts were mathematically formulated in order to obtain a workable procedure. Below, is a brief description of the mathematical formulation of leaching scheduling procedure items as presented .The basis for understanding the impact of irrigation and drainage management on the salt balance is the water balance of the root zone. The water balance of the root zone can be described in the following equation **,FAO, 1985.**

$$Irr.D = R^{*} + ET_c \tag{19}$$

where:
R* : Depth of leaching water, mm.

Salt balance equation the root zone

With each irrigation, salts are added to the root zone because certainly there is a salt in water . A fraction of the salts is leached below the root zone by the net deep percolation water. After a certain period, salt accumulation in the soil will approach an equilibrium or steady-state concentration based on the salinity of the applied water and leaching water **,FAO, 1985.**

The following assumptions are made to put 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. The zone of shallow groundwater is created with the same average salinity concentration as the percolation water.

Under these assumptions, the salinity of the soil water is equivalent to the salinity of the water percolating below the root zone. The water balance of the root zone can be described in the following equation**:**

$$Irr\,.D \, * \, C_{iw} = \, R^{*} * C_R{}^{*} \tag{20}$$

Where:

C_{iw}: The average salt concentration of irrigation water, ppm, and

$C_R{}^{*}$: The average salt concentration of depth leaching water, ppm.

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, where it could be defined in one of two ways:

- With respect to the water percolating from the bottom of the root zone. 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 or a root hole. This concept of leaching efficiency for vertical water movement was originally during the experimentation works carried out in the Dujailah Project in Iraq by ,**Boumans, 1963,** and
- With respect to the irrigation water, the leaching efficiency is defined as the percentage of irrigation water mixing 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 efficient or effective amount of water during the leaching process.

In a related work by ,**Van Der Molen, 1979,** two different expressions were formed, each describing a different model of physical leaching process. These two expressions take the following forms:

$$f = \frac{C_{Dp}}{C_e} \tag{21}$$

$$f = \frac{C_{Dp} - C_{iw}}{C_{fc} - C_{iw}} \tag{22}$$

Where:

C_{DP}: The average salt concentration of the water percolation below the root zone,
C_e: The average salt concentration of the reservoir solution (after leaching),
C_{fc}: The average salt concentration of the soil solution at field capacity, and
f : Leaching efficiency coefficient.(fraction of unity).

The salt equilibrium equation:

To calculate the leaching requirement amount, the salt equilibrium equation presented by ,**Richards, 1954.** is used in this study; this equation was obtained from:

- Salt balance equation, Eq. (20), and
- Leaching efficiency coefficient equation, Eq. (21).

The salt equilibrium equation therefore is:

$$R^* = (ET_c - ER)\left(\frac{EC_{iw}}{f(EC_{fc} - EC_{iw})}\right) \tag{23}$$

EC_{fc} calculated by the following relationship:

$$EC_{fc} = \mathrm{EC_0}\left(\frac{\theta_{vs}}{\theta_{fc}}\right) \tag{24}$$

where:

EC_o: The 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.
$\frac{\theta_{vs}}{\theta_{fc}} = 2$: For moderate texture soil as showed by, **Al-Furat Center For Studies and Designs of Irrigation Project, 1992.**

To start the leaching scheduling, using the maximum planted crop root depth to guarantee that all necessary depths of others root zone will be leached during whole year. The amount of salts could be added during the first irrigation in any month equal to the amount of salts would be added in the second irrigation for the same month because the depth of irrigation dose is constant considered to be, but the depth of leaching water differ from month to another due to root`s growth and. The amount of salt would be added by any irrigation is:

$$Z_{ki} = (EC_{iw})_{ki} * NA_j * RD_j * C_o \tag{25}$$

Where:

Z_{ki}: The amount of salts to be added on the kth day after irrigation, during the ith month, gram,
NA_j: Net area planted with jth crop, don.,
RD_j: Root depth at any time of the j th crop, mm, and
C_o: The conversion factor milli equivalent per liter (meq/l) or part per million (ppm), and the unit of electrical conductivity is dicesemen's per meter.

Through, 640 ppm=1 dS/m, **Ayers and Westcot, 1985.**

There are three probabilities of supplying irrigation water due to the status of soil moisture content, and these are;

- First probability is the net depth of irrigation water was equal to the soil water deficit before irrigation (full irrigation). Accordingly the soil water content after irrigation will reach the field capacity of soil, then:

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

- Second probability is the net depth of irrigation water was less than the soil water deficit before irrigation (partial irrigation).Accordingly there is an additional quantity of water should be added to raise the water soil content to field capacity level. In this case and, if the salinity reaches a harmful level effect on crops, the leaching water must be added to remove the salt from the soil (the additional quantity of water is calculated as depth of extra leaching water) is:

$$(act.R^*_t)_{ki} = ASWD_{ki} + R^*_{ki} \quad (26)$$

$$SWDB_{ki} - Irr.D_{ki} = ASWD_{ki} \quad (27)$$

Where:

$(act.\ R^*_t)_{ki}$: Actual depth of irrigation water on the k^{th} irrigation during the i^{th} month, mm.

- Third probability is that, the net amount of irrigation water is greater than the soil water deficit before irrigation. According to the contiguity between the net irrigation water and the soil water deficit the water losses may be divide into two parts:
  1. The first is the surface runoff and this amount of water losses cannot be controlled and goes as surface run off, and
  2. The second is the one third from the field water losses which can be controlled **,Hussein ,2012.** and will be used as a depth of leaching water, the name of this part considered as deep percolation, in this case deep percolation must be checked if it is greater than depth of leaching water therefore, there is no need to add water for purposes of leaching . If deep percolation is less than depth of leaching water therefore, adding leaching dose is needed.

If $Irr.D_{ki} > SWDB_{ki}$, then the are two possibility these are:

1. $Irr.D_{ki} - SWDB_{ki} > R^*_{ki}$ then $(act.R^*_t)_{ki} = 0$, and
2. $Irr.D\ ki - SWDB_{ki} < R^*_{ki}$ then

$$(act.\ R^*_t)_{ki} = R^*_{ki} - [Irr.D\ ki - SWDB_{ki}] \quad (28)$$

3. SAMPLE OF CALCULATION

To simplify discussion, Amara irrigation project in Maysan Governorate was taken as an example. Amara irrigation project is located within the southern zone. This zone has a different soil textured refers to the ancient irrigation zone. At present, this zone has a saline soil to a variable degree of salinity. The design average percentage of additional leaching water requirements for southern Iraq were taken as 19-19.5% from net irrigation requirement, **General Scheme of Water Resource and Land Development of Iraq, 1982**.

Irrigation scheduling

In winter season and during the first month of irrigation scheduling calendar (October), irrigation depth was applied twice a week if it is required, with a chosen time of irrigation, taken into account that this time was not exceed the irrigation interval. In summer season, continuous irrigation is adopted since there is no rainfall during the summer season period and crop water requirements become large during this season. To minimize water losses and avoid plant water stress in summer season, irrigation depth was applied twice a week with an irrigation interval equals irrigation time 3.5 . In this zone, the effective rainfall is not sufficient to supply crops water requirements. In other words, irrigation water is required even in winter season to supply crop water requirements.

Table1. and **Fig.1** show the difference in applied water distribution between applying irrigation scheduling procedure (designed) case taken in account the water leaching requirement and designer

suggestion (general scheme) case. Applied irrigation volumes in scheduled case are less than those allocated to the project, and there is 18% of water lost as drainage water. It is known that the southern zone requires 19-19.5% of water to leach salts, so the 18% of applied water which is lost as a drainage water, is used to leach salts, therefore it can be said that there are no water losses. **Table 1** also shows that 1687.13 million m^3 of water were saved. This is a good result if the plants are not suffering stress.

After checking plant statue by using a water budgeting program it was found that. All winter crops are suffering from stress and soil moisture content is below wilting point at the beginning of growing season. The maximum plant root depth under soil moisture content below the wilting point is approximately 5 (cm) long. It was supposed that this case is an acceptable, since in spite of the plant initially requires high frequent and little quantities of water, "shallow root depth can absorbs required water when it logged to full the soil water reservoir". Since planted crops root depths are between 600–2000 (mm). These root depth "which represents 10% of minimum plant root depth" was considered as little root depth, and under this depth, the plants will not be lost even the soil moisture content is under the wilting point level because the soil water reservoir filled with water at the beginning of scheduling . Winter plants statue is illustrated in the **Fig. 2.**

Fig. 2 shows a good plant status since soil water content curve approximately conforms to field capacity curve. At the beginning of growing season, the soil water content curve overreaches wilting point curve, this is done with root depth not exceeds 60 mm, so it is acceptable as mentioned previously.

Summer crops have two behaviors: the first one is soil water content exceeds wilting point at the beginning of the growing season with root depth not exceeding 60 (mm),the second one is soil water content exceeds wilting point at the beginning of the growing season with root depth exceed 60 (mm), which means losing the crops. **Figs.3** and **4** show these two behaviors, respectively.

Fig. 3 shows summer crop with good status since the soil water content curve is between field capacity curve and readily available water curve except at the beginning of growing season. At the beginning of growing season, the soil water content curve overreaches wilting point curve, this is done with root depth not exceeds 60 mm. In the practice the pre-irrigation is necessary to refill the soil with necessary moisture for seeds growth , so can assumed that there is not water stress at the beginning of crop growth because of sequence irrigation with small irrigation interval (3.5 days)

Fig. 4 shows stressed summer crop with the soil water content exceeds wilting point with root depth not exceeding 60 mm. Perennial crops have no overreaching of wilting point and showing good plant status as shown in the **Fig. 5**.

Leaching Scheduling:

The amount of leaching requirement have been applied when the concentration of soil extract is greater than or equal to critical crop tolerance to salinity (with condition that less than 50% of yield reduction). If the net depth of irrigation water is less than the soil water deficit before irrigation (partial irrigation), accordingly additional quantity of water should be added to raise the water soil content to field capacity. In this cases and, if the salinity reaches a harmful level effect on crops, the leaching water must be added to remove the salt from 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, soil water deficit will be taken as water losses. In some irrigation applications during winter, spring seasons and these needs to additional quantity of water should be added to raise the water soil content to field capacity.

The difference in applied water distribution between applying leaching scheduling procedure (designed) case and designer suggestion (general scheme) case are shown in **Table 2**. In the first case the applied irrigation volumes in scheduled case are less than those allocated to the project, and there is 13.1 %of water lost as drainage water. In these cases assuming that the water losses cannot be controlled therefore 13.1% are losses and go to the drain and the real need, is 985.24mm depth of leaching water. **Table 2**. also showed that 1658.96 million m^3 of water were saved. This is a good result, if the plants are not suffering stress. In the second case the applied irrigation volumes in a scheduled case are less than those allocated to the project, and there is 13.1% of water lost as drainage water. In these cases, assuming that the water losses can be controlled and part of water losses (deep percolation) plays a role of leaching water depth, and therefore the loss of drainage water became 11.7%, and 188.96 mm of leaching water is needed to leach salt. **Table 2**, also shows that 2134.75 million m^3 of water was saved. This is a good result if the plants are not suffering stress.

Introducing the leaching scheduling procedure a cropping pattern efficient should be used in order to improve the water use efficiency, but without harmful stress to crops. Cropping pattern should be chosen carefully, Amara Irrigation Project with assumed cropping pattern four winter season crops, five summer season crops, and six perennial crops were planted with total cropping intensity equals 114%. The crops are different in degree of response to salinity; some crops can produce acceptable yields at much greater soil salinity than others and this is because some have better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil**, Hussein , 2012.**

The wide range of salt tolerance crops allows for a greater use of moderately saline water, some of there were previously thought to be unusable. Therefore greatly expands the acceptable range of water salinity which is not effect on crop growth, and the yields, so it can considered to be a suitable water for irrigation. With many trials, the right percentages of plant area which improve water saving without losing crops could not be found, in this project it is assumed that there is no portion of plant area for sensitive crops was planted.

For saving crops a 50% yield potential was considered as an index for salinity hazard; another meaning: the depth of leaching water should be add before the soil salinity became less than or equal to the threshold value of 50 % yield potential. It was assumed that the soil salinity level for sensitive crops was 6 ds/m, for moderately sensitive crops was 7.5 ds\m, for moderately tolerant crops was 10 ds\m, and tolerant crop was 12 ds/m **,Hussein ,2012.**

The water source of Amara Irrigation Project is Tigris River in Maysan Government, the mean annual of salt concentration is 1186 ppm.

4. CONCLUSION

1. The comparison between applied discharges using irrigation and leaching scheduling procedure, and the discharge that was suggested by designers are possible; with the constraint that the harmful level of the salt concentration index does not effected on crop growth.
2. Irrigation and leaching scheduling procedure is useful if cropping patterns are chosen carefully. Some of studied of irrigation projects required selecting more suitable cropping pattern; others required only changing the percentage of planted area with each crop.
3. Using percentage of monthly maximum planted crop root depth of scheduling irrigation giving flexibility to have a balance between applied irrigation, saved water, drainage losses, total available water, readily available water, and plant status by control the applied irrigation frequency.
4. Using maximum root depth to estimate the depth of leaching water, and to guaranty that all other root zones will be leached from salt.
5. Percentage of depletion from readily available water does not affect applied depth per irrigation, but it affects applied irrigation frequency during winter season, and for first month of irrigation and leaching scheduling.
6. The salinity of irrigation water affects the depth of leaching water especially; when the salinity of irrigation water high. The monthly applied of leaching water, using scheduling procedure, and for

two cases: case I uncontrolled water losses, and case II controlled water losses are greater than monthly applied of leaching water as suggested by designers(general scheme).

7. There is a difference between the monthly distribution of irrigation water for the assumed two cases of leaching and the suggestion of the designers (general scheme) when used the scheduling of irrigation and leaching water.

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ABBREVITIONS

% RD =percentage of maximum root depth,%.
%RAW=percentage of depletion from readily available water,%.
act $R*_t$=actual depth of leaching water, mm.
AD =percentage of Allowable depletion,%.
ARD =additional used root depth, mm.
ASWD=additional soil water deficit, mm.
C =conversion factor for units, dimensionless.
C_{DP} = the average salt concentration of the percolated water below the root zone, dimensionless
C_e = the average salt concentration of the soil saturation extract, dimensionless.
C_{fc} =the average salt concentration of the soil solution at field capacity, dimensionless.
C_{iw} =the average salt concentration of irrigation water, dimensionless.
C_o =the conversion factor, dimensionless.
$C_R{}^*$ =the average salt concentration of leaching water, dimensionless.
D_{iw} =depth of irrigation water, mm.
D_s =soil depth, mm.
ER = monthly effective rainfall, mm/month.

EC_e = electrical conductivity as measured in the soil saturation extract, crop tolerant, dS/m.
EC_{fc} =electrical conductivity of soil extract at field capacity, dS/m.
EC_{iw} =electrical conductivity of irrigation water, dS/m.
EC_o =electrical conductivity of soil before leaching (initial value), dS/m.
Etc = actual monthly crop evapotranspiration, mm/month.
Eto = monthly reference crop evapotranspiration**,** mm/month**.**
ds/m = measuring unit of electrical conductivity expressed as dicesemens per meter.
F = leaching efficiency coefficient, fraction of unity.
FC = field capacity,%.
GIS = geographic Information System, dimensionless.
I =index for time in month, month.
Irr.D = infiltrated net irrigation water depth, mm.
IE = expected irrigation efficiency,%.
IRR_{time}=irrigation time, day.
ISWC=initial soil water content, mm.
J =index for crop grown in the project, dimensionless.
k = index for time in days, day.
K_c = crop coefficient, %.
LR = leaching Requirement, %.
N = number of crops grown in the project, dimensionless.
NA = net irrigated project area, don.
NA I = net area in the project planted during thei^{th} month, don.
NAj = net area planted with the j^{th}crop, don.
ND =number of days in month, day.
$NI_{req.}$=net volume of water required,m^3.
NQ req=net continuous discharge required, m^3/sec.
OP = osmotic potential, bars.
PA = percentage of area planted with each crop, %.
PWP = permanent Wilting point,%,
Q max= maximum discharge m^3/sec.
RAW= readily available water in the root zone, mm.
RD j= root depth at any time of the j th crop, mm.
R* = depth of leaching water, mm.
R*t = total depth of leaching water, mm.
SWC= soil water content in the root zone, mm.
SWC (allow)= allowable soil water content, mm.
SWD = soil water deficit, mm.
SWDA= soil water deficit after irrigation, mm.
SWDAL= soil water deficit after irrigation at the last day in the month, mm.
SWDB= soil water deficit before irrigation, mm.
SWDL= percentage of Soil water deficit after irrigation at the last day in the month, %,
TAW = total available water, mm.
URD = used root depth, mm.
WD = water duty, L/sec/ha.
$WETc_i$= monthly weighted average of crop evapotranspiration for certain cropping pattern during the i^{th} month (mm/month).
Z = the amount of salt added after each irrigation. gram.
θ_{fc} = soil moisture content at field capacity, fraction of unity.
θ_{vs} = soil moisture content at saturation, fraction of unity

Table 1. Monthly and annual net and gross amounts of water for Amara irrigation project.

Month	From irrigation scheduling (Designed)		From general scheme
	Net volume of irrigation $10^6\ m^3$	Gross volume of irrigation $10^6\ m^3$	Net volume of irrigation $10^6\ m^3$
Jan.	23.33	28.11	30.93
Feb.	58.33	70.28	53.26
Mar.	81.67	98.40	88.18
Apr.	119.96	126.60	261.40
May	125.81	126.51	381.03
Jun.	111.57	112.45	531.48
July	123.85	126.51	528.56
Aug.	123.29	126.25	478.37
Sept.	122.86	126.51	223.01
Oct.	84.34	89.23	98.49
Nov.	35.00	42.17	52.55
Dec.	46.67	56.23	16.55
Sum	1056.68	1129.25	2743.81
Percentage of drainage water		18	
Saved volume of water $10^6\ m^3$		1687.13	
Percentage of leaching requirements		19.5	
Percentage of water losses		....	

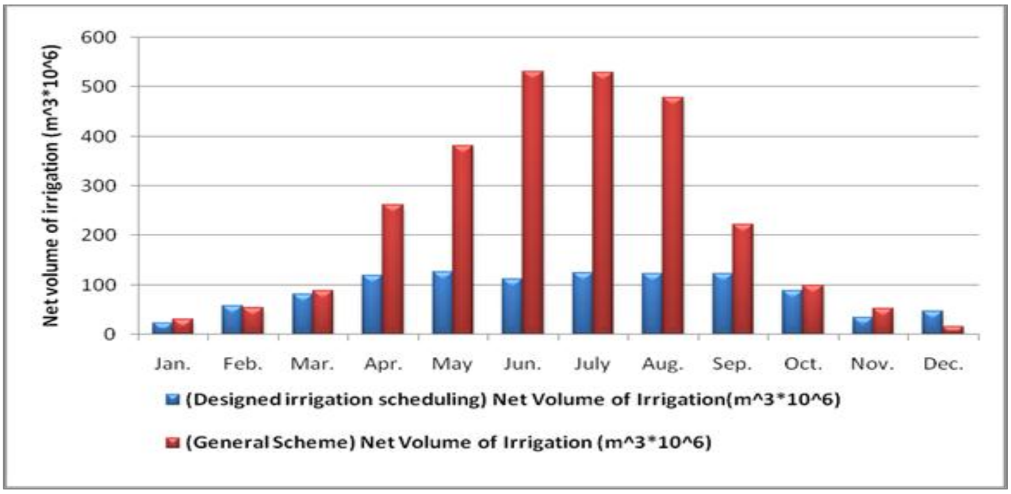

Figure 1. Variation of monthly applied irrigation volumes distribution by using irrigation scheduling and by designer suggestion.

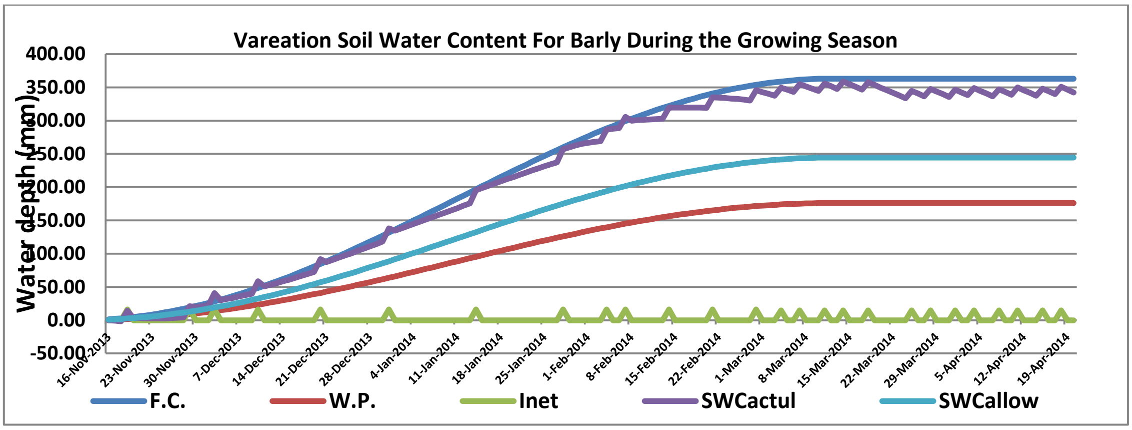

Figure 2. Variation of soil water content for Barley during the growing season for Amara irrigation project.

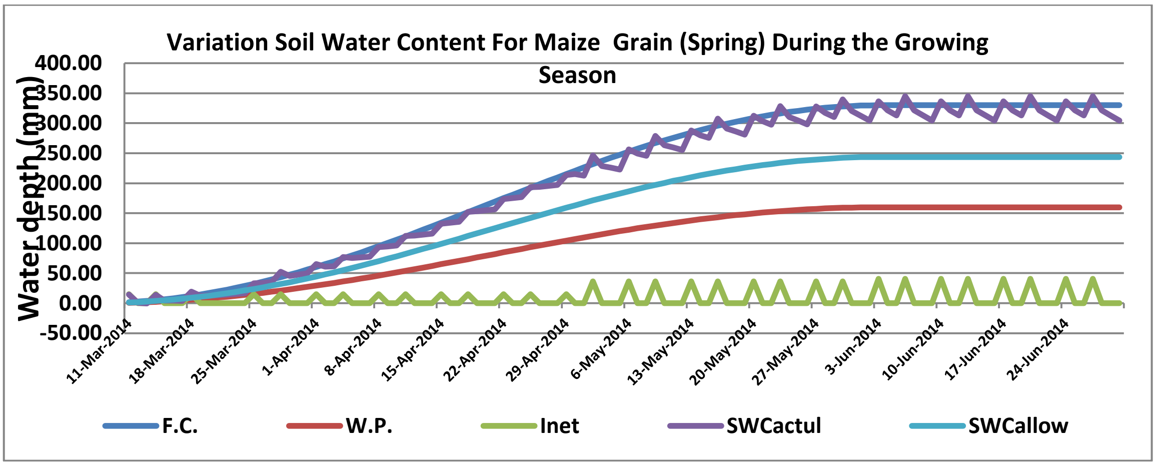

Figure 3. Variation of soil water content for maize grain (spring) during the growing season for Amara irrigation project.

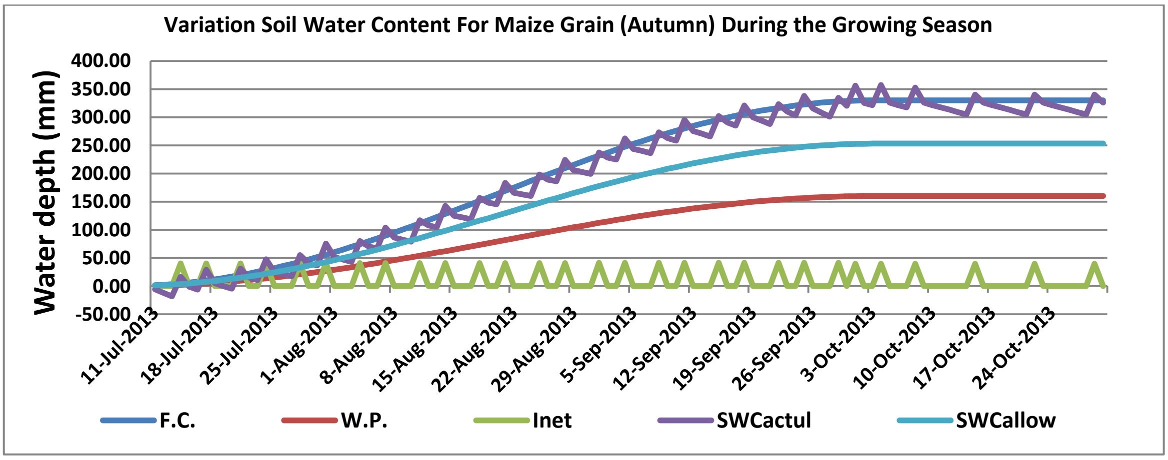

Figure4. Variation of soil water content for maize grain (autumn) during the growing season for Amara irrigation project.

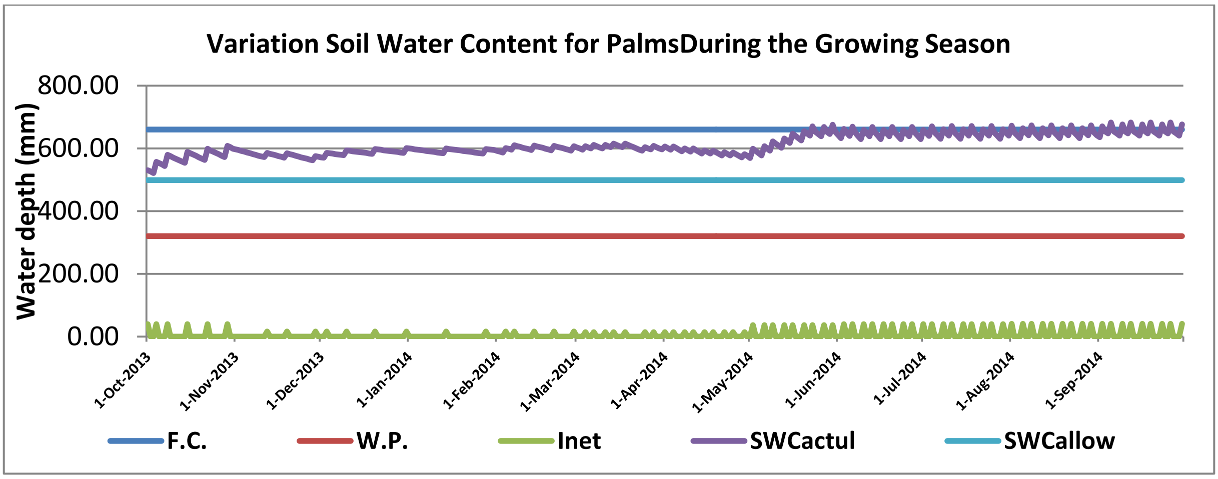

Figure 5. Variation of soil water content for palms during the growing season for Amara irrigation project.

Table 2. Monthly and annual irrigation water amounts for Amara Irrigation Project, for period 2013-2014.

Months	From leaching scheduling		Estimated by general scheme (LR =19.5%)
	Designed I net volume of irrigation water, 10^6 m^3	Designed II net volume of irrigation water, 10^6 m^3	Net volume of irrigation water, 10^6 m^3
Jan.	28.78	24.72	36.96
Feb .	111.73	64.40	63.65
Mar .	226.63	97.79	105.37
Apr.	309.85	138.09	312.37
May	149.58	129.10	455.33
Jun .	124.06	117.88	635.12
Jul .	139.03	133.74	631.63
Aug .	137.38	129.86	571.65
Sept .	144.41	131.42	266.49
Oct.	124.76	92.25	117.69
Nov .	71.46	37.89	62.79
Dec.	52.42	47.17	19.98
Sum.	1620.09	1144.31	3279.03
Percentage of drainage water %	13.1	11.7	
Saved volume of water 10^6 m^3	1658.96	2134.75	
Aver. Percentage of leaching requirements, %	40.04	7.68	19.5
Actual water losses, mm	452.06	310.67	……