Irrigation Scheduling Effect on Water Requirements

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ABSTRACT:

Irrigation scheduling techniques is one of the suggested solutions for water scarcity problem. The study aims to show the possibility of using practical and applicable irrigation scheduling program which was designed by Water Resources Department at the University of Baghdad by using Spreadsheet Formulas for Microsoft Excel program, version 2007, with some modification to generalize it and made it applicable to various climatic zone and different soil types, as a salvation for the shortage of irrigation water inside the irrigation projects. Irrigation projects which incidence of Tigris River basin will be taken as an applicable example. This program was based on water budgeting and programmed depending on scientific concepts which facilitate irrigation structures operation and ease the use by farmers. By using the abilities of this program, the monthly and annually water requirements and drainage water were estimated. Finally a comparison is made between the calculated discharges with the designers suggested ones. This comparisons showed that the use of this type of irrigation scheduling (i.e. predicted irrigation scheduling) with its applicable constrains require high attention when choosing the cropping pattern for each climate zone. Also it found that this irrigation program is a useful tool for saving water if cropping pattern has been chosen carefully.

Keywords:Irrigation scheduling, percentage of maximum root depth, water resources dept. program, water budget, Nahr Sa'd irrigation project.

اثر الجدولة الاروائية على الاحتياجات المائية

الخلاصة:

تقنيات الجدولة الاروائية هي احدى الحلول المقترحة لمشكلة شحة المياه. تهدف الدراسة الى معرفة امكانية استخدام برنامج جدولة اروائية قابل للتطبيق العملي تم اعداده في قسم هندسة الموارد المائية في جامعة بغداد باستخدام برنامج مايكروسوفت اكسل نسخة 2007، مع اجراء بعض التعديلات عليه لجعله قابلا للتطبيق في المناطق المناخية المختلفة ولأنواع مختلفة من الترب، كحل لمواجهه النقصان في مياه الري داخل المشاريع الاروائية. تم اخذ المشاريع الواقعة على حوض نهر دجلة كمثال تطبيقي. بني هذا البرنامج بالاعتماد على الموازنة المائية وعلى مفاهيم و أسس علمية تسهل تشغيل منشاءات الري وتسهل تطبيقها من قبل المزارعين. باستخدام امكانيات هذا البرنامج امكن تخمين متطلبات مياه الري الشهرية والسنوية وضائعات المياه، قورنت التصاريف المحسوبة باستخدام البرنامج مع ما اقر من قبل دوائر الدولة المعنية. اظهرت نتائج هذه المقارنة ان استخدام هكذا نوع من الجدولة الاروائية (جدولة الري المتوقع) بخصائصه التي تجعله قابلا للتطبيق يتطلب عناية شديدة عند اختيار نمط توزيع النباتات والمساحات المزروعة بهذه النباتات لكل منطقة مناخية. كما ووجد ان هذا البرنامج يمثل اداه مفيدة للحفاظ على المياه اذا ما احسن اختيار نمط توزيع النباتات.

الكلمات الرئيسيه :الجدولة الاروائية، النسبة المئوية لاطول جذر، البرنامج الخاص بقسم هندسة الموارد المائية، الموازنة المائية، مشروع نهر سعد الاروائي.

INTRODUCTION

Irrigation scheduling means how much water should be applied and when to irrigate. To make this decision, there is some steps should be followed to make right decision. First of all crop pattern and information of each crop should be known, such as growing season, growing and harvesting date, root depth, and allowable depletion, soil physical properties, climate, availability of water resources, and field water losses also should be known. Three main schedules are known, these are: constant depth; constant interval; and practical irrigation schedule.

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 unfortunately is the method adopted many farmers. This method is based on individuals decision and depends on previous observations without taking into account the need of plant to water. This method consumes a large amount of water without scientific justification, and it may cause Lack of soil aeration, Washing nutrients from the soil, and 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 depending on all these factors.

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).

Nevertheless, since 1990's there has been a wide range of proposed novel approaches to irrigation scheduling which have not yet been widely adopted; many of these are based on sensing the plant response to water deficits rather than sensing the soil moisture status directly (Jones, 1990a). Infrared sensors have been used to determine canopy temperature and scheduling irrigations (Stockle and Dugas, 1992; Alves and Pereira, 2000)

Alternative approach to irrigation scheduling has been opened up, this approach based on measurements of sap-flow rates, because sap-flow rates are expected to be sensitive to water deficits and especially to stomatal closure. Sap-flow measurement used by many workers for irrigation scheduling and control in a diverse range of crops, including grapevine (Eastham and Gray, 1998; Ginestar *et al*., 1998 a, b), fruit and olive trees (Giorio and Giorio, 2003; Remorini and Massai, 2003; and Moriana, 2007) and even greenhouse crops (Ehret *et al*., 2001).

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

- Supplied discharge would be constant in all irrigations;
- Time of application would be also be constant throughout the season;
- Starting day of all irrigation in the season or the year would be the same day in the weak 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 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.

Irrigation scheduling using pan evaporation (CPE), relies on measuring the amount of water evaporated from the container based on cumulative depth in millimeter. It is an easy way and does not require high-tech. The idea of this method depends on the farms crops lose water during the irrigation process by evapotranspiration; this quantity is a large missing depends on climatic factors, so the method give the irrigator indication when to irrigate. Several experiments have been carried out using this method in Saudi Arabia, where it became clear that this method has provided a quantity of irrigation water and up to 25% compared to traditional methods, which rely only on the period between irrigations without taking into account the climatic factors (Alderfasi, 2000).

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.

Irrigation scheduling by using the guide of the crop water stress (CWSI), takes into account the climatic factors like air temperature and relative humidity and temperature of the plant as well as the water situation of the soil and crop. This guide is divided into ten equal parts where each part refers to the situation of water for each soil, plants, and sets time limit for irrigation manner. This method is a modern and requires sophisticated technology based on the theory of remote sensing to measure the temperature of vegetation and its relation to the situation of water for soil and plants. Irrigation scheduling using this method has given good results in the case study of water plants and irrigation scheduling and is recommended for use in most agricultural crops, since they rely mainly on climatic factors, which account for most of the water consumption of plants (Alderfasi and Nielsen, 2001).

Al-Mesh'hedany (2002) investigated the effect of using a practical irrigation scheduling procedure (based upon average information about plants consumptive use rate and effective root zones) on the production and growth of each plant, for a given cropping pattern grown in a large irrigation project. The research included executing a water budgeting procedure on a daily basis considering the amounts of water moving into and out of the root zone for each plant grown in the project during its growing season. This research showed that there is a certain irrigation scheduling program, which minimize water losses, prevents water stress for all plants grown in the project, maximizes project outcomes, minimizes project requirements such as applied irrigation volume throughout the whole year, and maximizes effective irrigation water stored in the root zone.

Al-Azba *et al.* (2004) developed a computerized program by using GIS for estimating irrigation water requirements in KSA. He took into consideration easiness in use. The methodology which was provided by (Allen *et al.*, 1998) for calculating crop water requirements was followed. Noting that they considered that crop coefficient (k_c) value during development and maturity stages are constant like initial and mid-season stages. The value of (k_c) for development stage was taken as an average of (k_c) during initial and mid-season stage, and maturity stages are calculated as an average of (k_c) during mid-season and (k_c) at the end of growing season.

Fortes *et al.* (2004) presented the GISAREG scheduling model which is a Geographical Information System (GIS) based application integrating both ISAREG. It is a conceptual non-distributed water balance model for simulating crop irrigation schedules at field level and computes irrigation requirements under optimal and/or water stressed conditions, and KCISA. It was developed to create the appropriate crop data inputs for ISAREG. The model operation for different water management scenarios and the production of crop irrigation maps and time dependent irrigation depths at selected aggregation modes.

Al-Talib *et al.* (2005) proposed a computerized model with (Microsoft QuickBasic version 1.1) for simulating the effect of deficit irrigation for maize crop during spring and autumn seasons in Mosul region. The simulation was based on climatological data which is used to calculate daily reference evapotranspiration with Penman-Monteith equation. The model predicts yield reduction by changing irrigation depth for three different irrigation methods.

Vellidis *et al.* (2008) described a prototype real-time, smart sensor array for measuring soil moisture and soil temperature that uses off-the-shelf components was developed and evaluated for scheduling irrigation in cotton. The array consists of a centrally located receiver connected to a laptop computer and multiple sensor nodes installed in the field. Integration of the sensors with precision irrigation technologies provided a closed loop irrigation system where inputs from the smart sensor array determined timing and amounts for real-time site-specific irrigation applications.

Irrigation Industry Association of British Columbia's (IIABC) (2009) developed a new agriculture irrigation scheduling calculator. This calculator determines an irrigation schedule for all type of agricultural irrigation systems and a crop types, and use real time climate data. Also Harrison (2009) review the various methods available for irrigation scheduling.

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. Starting date of each irrigation during the year is the 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 be applied along 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:

1. For heavy soils, the starting day of each 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.

2. 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.

Additional constrains shall be used and these are:

1. Soil is homogenous and isotropic;

2. Initial soil water content at the beginning of irrigation scheduling is known; and

3. Soil water content at field capacity and wilting point are constant throughout the root zone of the whole project.

DESCRIPTION OF THE STUDY AREA

Soil-physical properties of Iraqi soils vary from one site to another. The General Scheme of Water Resource and Land Development in Iraq divided Iraqi territory to four zones (General scheme of water resources and land development in Iraq, 1982) they are: mountain-valley soil, Jazeera desert (its northern part), piedmont gently sloping–undulating plain, and lower Mesopotamian plain.

The climate of Iraqi is subtropical, continental, summer is long, hot and dry, and winter is short with mean monthly temperatures above zero, 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 summer no rainfall occurs in the country. Temperature, air humidity, and evaporation increase from north to south (General scheme of water resources and land development in Iraq, 1982). The general scheme of water resource and land development in Iraq divided Iraqi territory into zones according to the natural humidity, which characterizes identity of crops irrigation regimes. Three natural-climatic zone and four subzones where singled out within the territory of the country (see: Appendix (1)). From the measurement of these climatic descriptions, reference evapotranspiration was calculated by using modified Penman-Monteith equation, and a rainfall rate was measured. In this research, these values are adopted.

CONCEPTUAL FORMULATION

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:

$$ET_{cij} = K_{cij} * ET_{oi} \quad \text{……………………………… (1)}$$

where:

$ET_{c\,ij}$: 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:

$$WET_{ci} = \frac{\sum_{j=1}^{n}(ET_{cij} * NA_j)}{\sum_{j=1}^{n} NA_j} \quad \text{………………………..(2)}$$

where:

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

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

NAj: Net area planted with the j^{th} crop, it is equal to NA * PAj (don.),

don.: 2500 (m^2),

PAj: 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 from monthly crop consumptive use rate and multiplying by the area as follows:

$$NIi\ req. = \sum_{j=1}^{n} C * NAj * (WETci - ERi) \quad \text{…... (3)}$$

where:

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

ERi: Monthly effective rainfall during the i^{th} month (mm/month), and

C: Conversion for units (dimensionless).

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

$$NQ\ i\ req. = C * \frac{NI.i\ req}{NDi} \quad \text{……………………………...(4)}$$

where:

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

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

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

$$GQ\ i\ req. = \frac{NQ\ i\ req}{IEi} \quad \text{………………………………...(5)}$$

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 can be calculated from:

$$WDi = C * \frac{NQi}{NAi} \quad \text{.....(6)}$$

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, it can be calculated from:

$$URDi = \max RDij * \% RD \quad \text{..... (7)}$$

where:

URDi: Used root depth during the i^{th} month (mm),

RDij: Root depth of the the j^{th} crop during the i^{th} month (mm), and

% RD: Percentage of the root depth.

The total available water is calculated as:

$$TAWi = (FC - PWP) * URDi \quad \text{..... (8)}$$

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:

$$RAWi = TAWi * AD \quad \text{..... (9)}$$

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 ET_c=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:

$$ADj = \text{Allen } et\ al. \text{ (1998) } AD + 0.04 * (5 - ETc) \quad \text{..... (10)}$$

where:

AD_j: Allowable depletion of the the j^{th} crop expressed as a percentage, and

Allen *et al*. (1998) AD: 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 project irrigation will be adopted, and is calculated as follows:

$$AD = \frac{\sum_{j=1}^{n} ADj * PAj}{\sum_{j=1}^{n} PAj} \quad \text{..... (11)}$$

The initial soil water deficit at the first day of irrigation scheduling may either be measured or assumed. Therefore, the soil water deficit at the second day of schedule can be calculated as:

$$SWDB_{k\,i} = SWDA_{(k-1)\,i} + WET_{cki} - ER_{ki} \quad \text{..... (12)}$$

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), 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:

$$SWDL_i = \frac{SWDAL_i}{URD_i} \quad \ldots\ldots (13)$$

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:

$$ASWD_{(i+1)} = (FC - ISWC - SWDL_i) * ARD_{(i+1)} \quad \ldots\ldots (14)$$

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

$$SWDA_{ki} = SWDB_{ki} - I_{ki} \quad \ldots\ldots (15)$$

where:

I_{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 RAWi or difference between $SMDB_i$ 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., $SWDB_{ki} \leq RAW_i$).

The net applied irrigation depth can be calculated from:

$$I_i = C^* \frac{IRRtime_i * Q_{max} * IE}{NA_i} \quad \ldots\ldots (16)$$

where:

$IRR_{time\ i}$: Irrigation time (days), and

Q_{max}: Gross maximum or design project discharge (m^3/sec).

For practical purposes, the irrigation time would be held constant during winter season (from November until the end of April) and during first month of irrigation scheduling. Since the net depth of irrigation water required during

first month of irrigation scheduling is not only to meet crop water requirements during that month, but adding to that the amount required to raise the initial soil water content in the root zone depth. In the summer season, continuous irrigation will be adopted.

For practical purposes, the irrigation time would be held constant during winter season (from November till the end of April) and during first month of irrigation scheduling. Since the net depth of irrigation water required during first month of irrigation scheduling not only to meet crop water requirements during that month, but adding on that amount required to raise the initial soil water content in the root zone depth. At the summer season, continues irrigation will be adopted. Figure (1) illustrates flowchart showed the main steps of irrigation scheduling model.

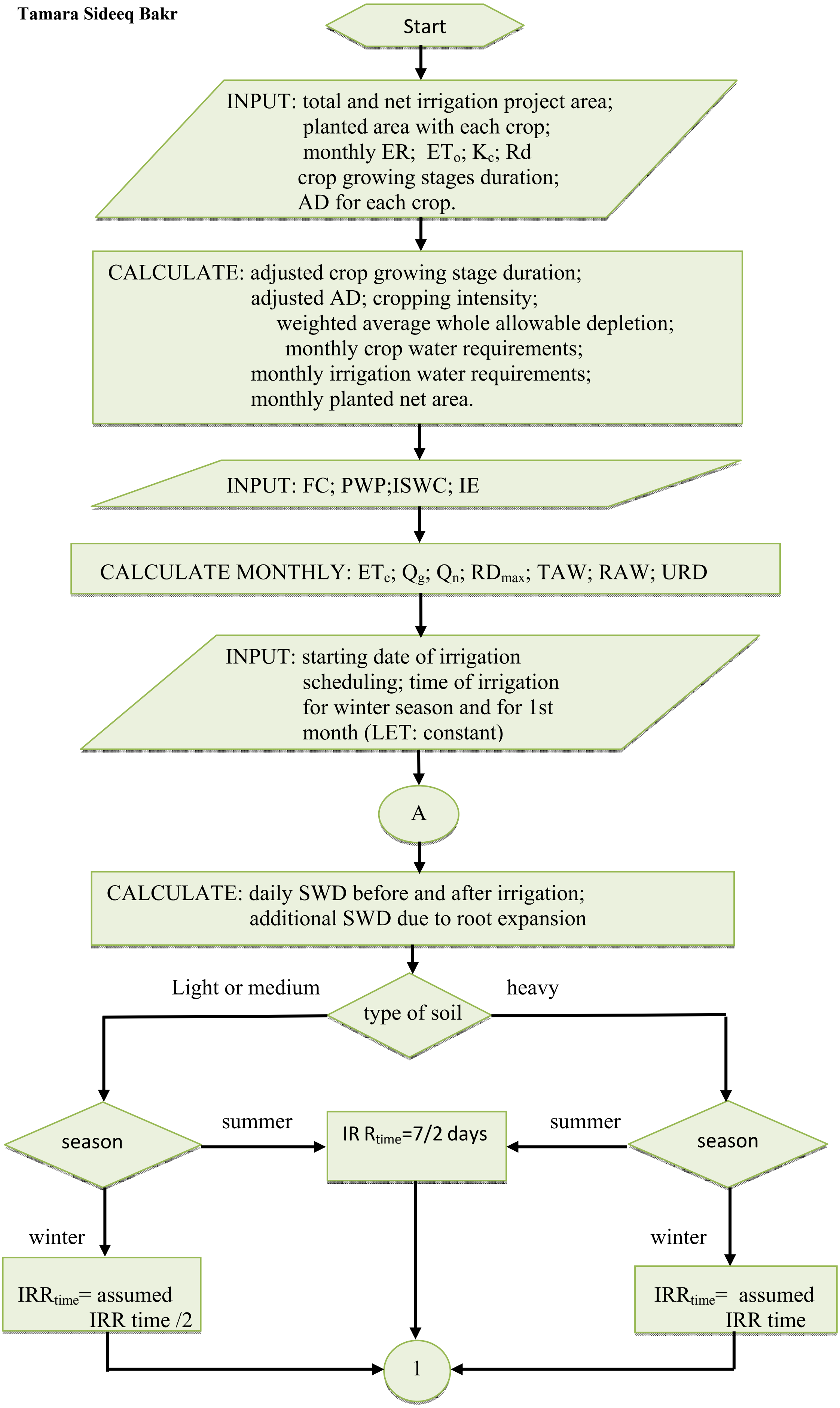


Figure (1). Flowchart illustrates the main steps of irrigation scheduling model.

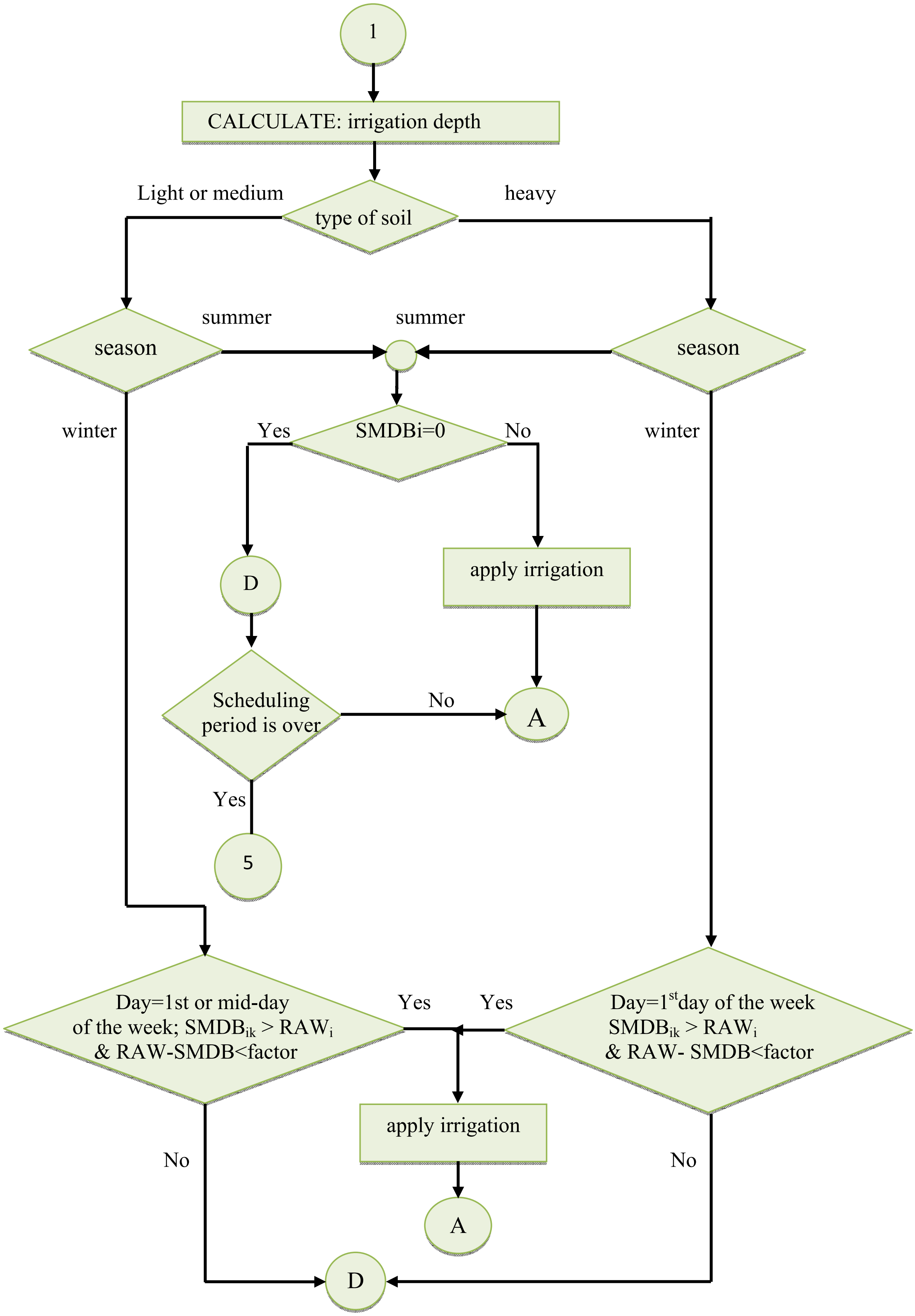


Figure (1). continued

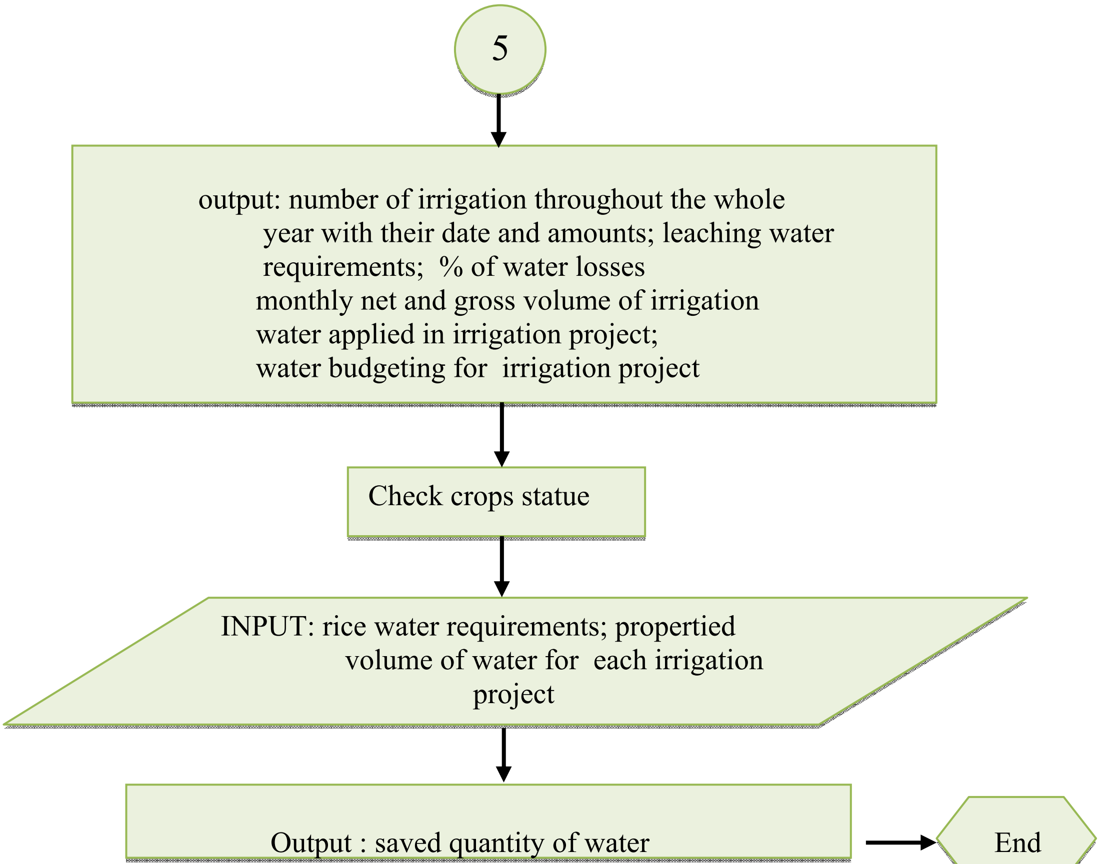


Figure (1). continued

RESULTS AND DISCUSSION

To simplify discussion, Nahr Sa'd irrigation project in Maysan Governorate was taken as an example. Nahr Sa'd irrigation project is located within the southern zone. This zone has a different textured soil refers to the ancient irrigation zone. At present, this zone has a saline soil to a variable degree, average additional leaching water requirements for southern Iraq were taken as 19-19.5% (General Scheme of Water Resource and Land Development of Iraq, 1982). 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, taking in account the irrigation interval. In summer season, continuous irrigation is used 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 and equal 3.5 (days). 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. Figure (2) shows monthly applied irrigation volumes distribution by using irrigation scheduling and by designers suggestions.

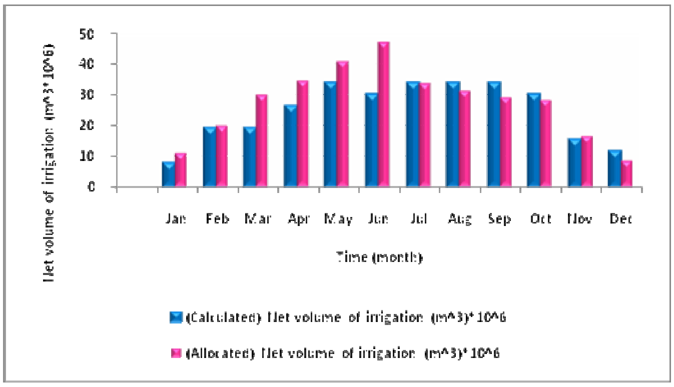


Figure (2). Variation of monthly applied irrigation volumes distribution between scheduled irrigation case (calculated) and designers suggestion case (allocated) for Nahr Sa'd irrigation project.

The monthly and annual net and gross amounts of water due to applying irrigation scheduling procedure on Nahr Sa'd irrigation project is illustrated in table (1).

Table (1). Monthly and annual net and gross amounts of water for Nahr Sa'd irrigation project.

Month	From Calculation		From General Scheme
	(Calculated) Net Volume of Irrigation 10^6 m^3	Gross Volume of Irrigation 10^6 m^3	(Allocated) Net Volume of Irrigation 10^6 m^3
1	7.51	11.92	10.95
2	18.78	29.81	19.77
3	18.78	29.81	29.93
4	26.29	41.73	34.36
5	33.80	53.65	40.59
6	30.04	47.69	47.00
7	33.80	53.65	33.60
8	33.80	53.65	31.16
9	33.80	53.65	29.06
10	30.04	47.69	28.01
11	15.02	23.85	16.50
12	11.27	17.88	8.60
Sum	292.936	464.98	329.53
Percentage of drainage water		7	
Saved volume of water 10^6 m^3		36.59	
Percentage of leaching requirements		19.5	
Percentage of water losses		…	

Figure (2) and table (1) show the difference in applied water distribution between applying irrigation scheduling procedure (calculated) case and designer suggestion (allocated) case. Applied irrigation volumes in scheduled case are less than those allocated to the project, and there is 7% of water lost as drainage water. It is known that the southern zone requires 19-19.5% of water to leach salts, so the 7% 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 36.59 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), So 50-60 (mm) 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. Winter plants statue is illustrated in the figure (3).

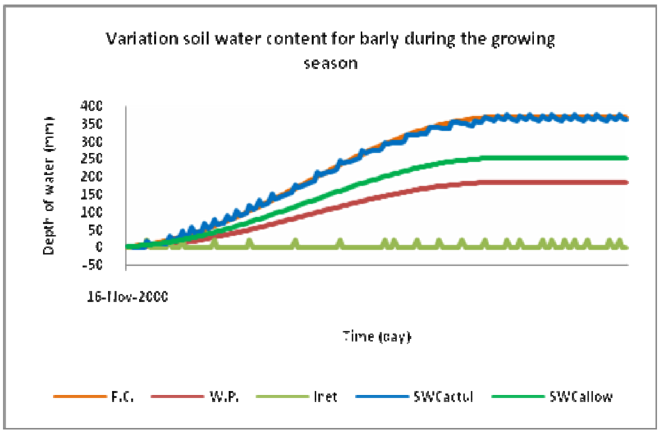


Figure (3). Variation of soil water content for barley during the growing season for Nahr Sa'd irrigation project.

Figure (3) shows a good plant statue 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. Figure (4), and (5) show these two behaviors, respectively.

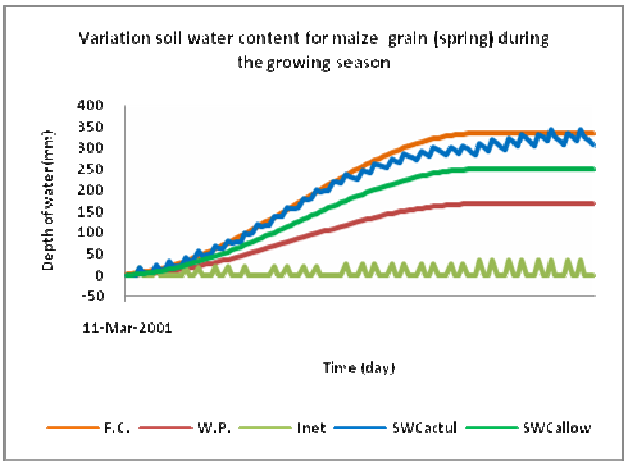
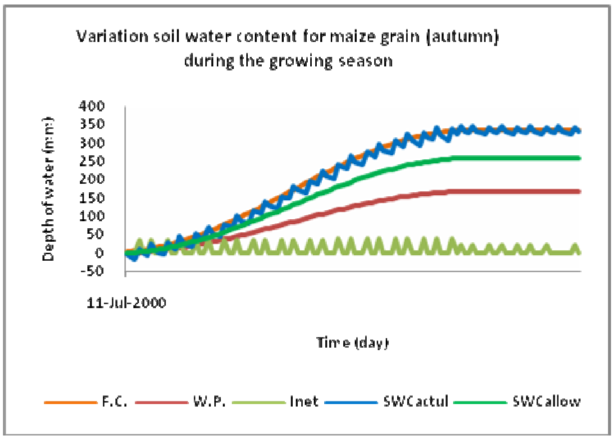


Figure (4). Variation of soil water content for maize grain (spring) during the growing season for Nahr Sa'd irrigation project.

Figure (5) shows summer crop with good statue 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.



Figure(5). Variation of soil water content for maize grain (autumn) during the growing season for Nahr Sa'd irrigation project.

Figure (5) shows stressed summers 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 statue as shown in the figure (6).

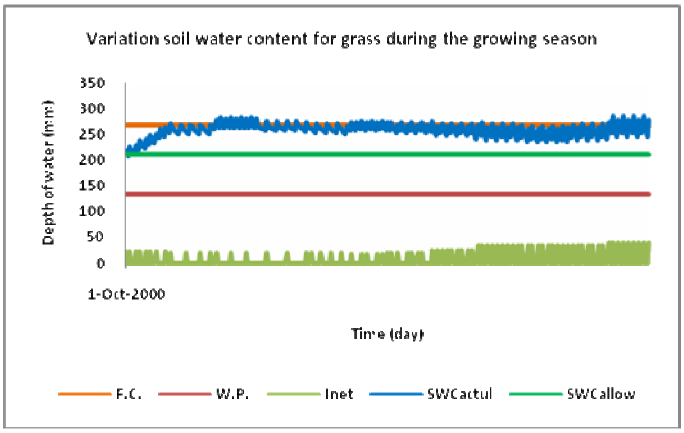


Figure (6). Variation of soil water content for palms during the growing season for Nahr Sa'd irrigation project.

During summer months, time of irrigation is at its maximum possible value and applied irrigation depth is maximum possible. In spite of that, the plants such as maize grain (autumn) do not receive enough depths to prevent stress. To know the reasons that lead to lose maize grain (autumn), several possibilities were considered, these possibilities are reviewed below and examine their impacts on the output of irrigation scheduling procedure. It should be noted that these possibilities vary in success between one irrigation project and another.

First possibility is applied discharge is not sufficient to supply crops water requirements. To study the discharge effects, assumed annual discharges are fed to irrigation scheduling program and the results are shown in table (2).

Table (2) shows that the increment in applied discharge shows no responding of Maize grain (autumn) plant statue, beside the increment in water losses and reduction in water saving. The increment in applied discharge causes increment in applied irrigation depth per irrigation. This increments in applied depth caused changing in applied irrigation frequency, but this change in frequency does not affect Maize grain (autumn) statue. This indicates that the applied discharge is enough for satisfying crops water requirements, other parameters are require some management.

Table (2). A comparison among four used annual net discharges for Nahr Sa'd irrigation project.

Second possibility is soil water reservoir

		Q (m^3/sec)			
		12.42 *	13	14	15
Applied irrigation volume (10^6 m^3)		292.94	306.63	317.52	335.66
Percentage of drainage water		7	12	16	21
Saved water (10^6 m^3)		36.59	22.9	12.01	-6.13
Percentage of water losses		...	…	…	1.5
No. of lost plants	winter	…	…	…	…
	summer	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)
	perennial	…	…	…	…

not sufficient to supply crops water requirements. Many researches used weighted average of plants root depths as a guide to choose the right depth of soil water reservoir, which minimize applied irrigation water depth without stressed plants, when more than one crop are planted. In this research, the weighted average of plants root depths was replaced by using a percentage of the longest monthly planted crops root depth as a proposed solution for stressed plant in crop pattern. By using a percentage of maximum root depth, the balance between water losses, plant statue, and applied irrigation depths be possible and be more flexible by controlling the frequency of applied irrigation depth.

To study whether used soil water reservoir depth is sufficient for storing enough water for crops, a comparison among ten used percentages of maximum root depth is shown in table (3):

It is clear from table (3) that when reservoir depth increases, water losses decreases due to the increase in reservoir capacity. Saved volume of water also increased. This is because when reservoir depth is small, it can store little quantity of water with more frequent irrigations and the rest is lost as drainage water. With the increase in soil water reservoir depth, irrigation frequency will be less, stored water volume increases and lost water decreases. Table (3) shows reduction in saved volume of water and increase in applied irrigation volume at last two percentages, this is due to the change in irrigation frequency . As shown in table (3), maize grain (autumn) does not respond due to changing the soil water reservoir depth. This indicates that the used soil water reservoir depth is enough to satisfy crops water requirements, other parameters require some management.

Third possibility is using inefficient percentage of planted area to study the effect of the percentage of planted area, assumed percentages of planted area are fed to irrigation scheduling program. In Nahr Sa'd irrigation project, same planted crops were used but with an assumed area for these crops. With many trials, the right percentages of plant area which improve water saving without losing crops could not be found.

Last possibility that used cropping pattern inefficient for applying used irrigation scheduling procedure, to improve that the used procedure is useful for saving water without harmful stress if cropping pattern are chosen carefully, Nahr Sa'd irrigation project with assumed cropping pattern will be discussed. In assumed crop pattern, 5 winter season crops, 11 summer season crops, and 6 perennial crops are planted with cropping intensity equals 137%.

The results are shown in the table (4). The table shows an acceptable percentage of water losses with more than 59 million m^3 of water saving. After checking crops statue it was found that all planted crops have no harmful stress. This result proves that if cropping pattern is chosen carefully, used program is useful for water saving.

Table (3). A comparison among ten used percentages of maximum root depth for Nahr Sa'd irrigation project.

		% RD_{max}									
		10	20	30	40	50	60	70	80	90	100
Applied irrigation volume (10^6 m^3)		394.34	360.54	338.00	307.96	300.45	300.45	296.69	292.94	296.69	300.45
Percentage of drainage water		31	26	21	14	12	12	9	7	7	7
Saved water (10^6 m^3)		-64.81	-31.01	-8.47	21.57	29.08	29.08	32.84	36.59	32.84	29.08
No. of lost plants	winter	…	…	…	…	…	…	…	…	…	…
	summer	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)	Maize grain (autumn)
	perennial	…	…	…	…	…	…	…	…	…	…

Table (4). Monthly and annual net and gross amount of water for an assumed cropping pattern/Nahr Sa'd irrigation project.

month	From Calculation		From General Scheme
	(Calculated) Net Volume of Irrigation 10^6 m^3	Gross Volume of Irrigation 10^6 m^3	(Allocated) Net Volume of Irrigation10^6 m^3
1	3.55	5.63	10.95
2	21.29	33.80	19.77
3	24.84	39.43	29.93
4	28.39	45.06	34.36
5	31.94	50.69	40.59
6	28.39	45.06	47.00
7	31.94	50.69	33.60
8	31.94	50.69	31.16
99	31.94	50.69	29.06
10	14.19	22.53	28.01
11	10.65	16.90	16.50
12	10.65	16.90	8.60
Sum	269.687	428.07	329.53
Percentage of drainage water		19	
Saved volume of water 10^6 m^3		59.84	
Percentage of leaching requirements		19.5	
Percentage of water losses		…	

Winter, summer, and perennial plants statue are illustrated in figures (7), (8), and (9), respectively.

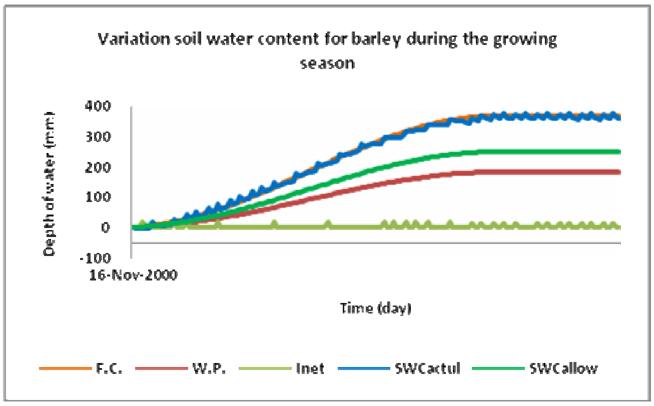


Figure (7). Variation of soil water content for barley during the growing season for assumed cropping pattern/ Nahr Sa'd irrigation project.

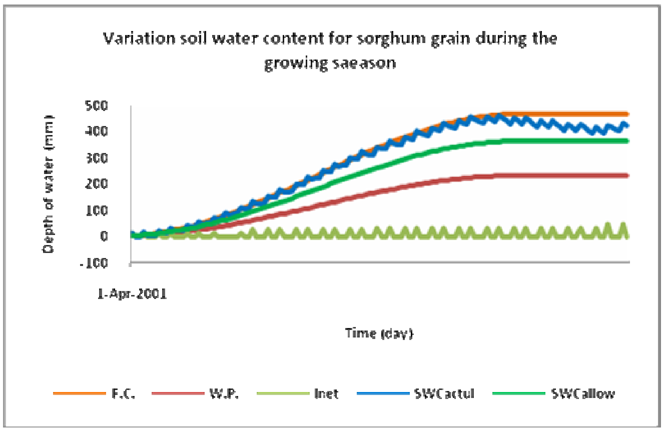


Figure (8). Variation of soil water content for sorghum during the growing season for assumed cropping pattern/ Nahr Sa'd irrigation project.

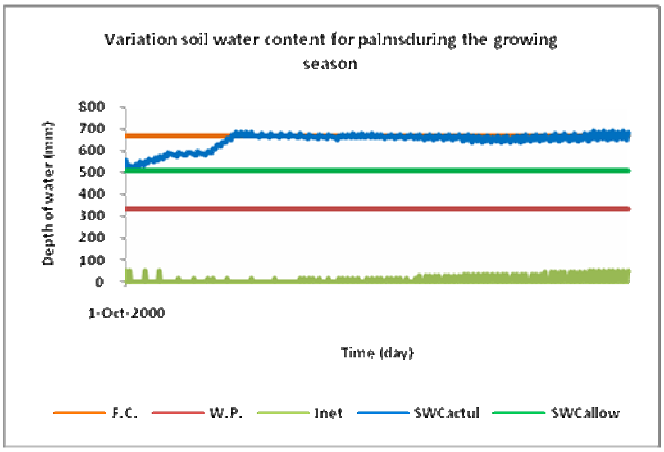


Figure (9). Variation of soil water content for palms during the growing season for assumed cropping pattern/ Nahr Sa'd irrigation project.

CONCLUSIONS

1. The comparison between applied discharges by using irrigation scheduling procedure and designers suggested discharges for the most of studied irrigation projects are impossible, because in these projects some planted crops are lost.

2. Irrigation scheduling procedure is useful if cropping patterns are chosen carefully. Some of studied irrigation projects are requires 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 giving flexibility to have a balance between applied irrigation, saved water, drainage losses, total available water, readily available water, and plant statue by control applied irrigation frequency.

4. The distribution of monthly applied irrigation volumes by irrigation scheduling procedure is unlike suggested one by designers.

5. Irrigation frequency plays an important role in saving plants, applying same quantities of water with less frequency that should be applied may suffers young plants from water shortage as their roots are not able to take up water from the lower layers of the root zone.

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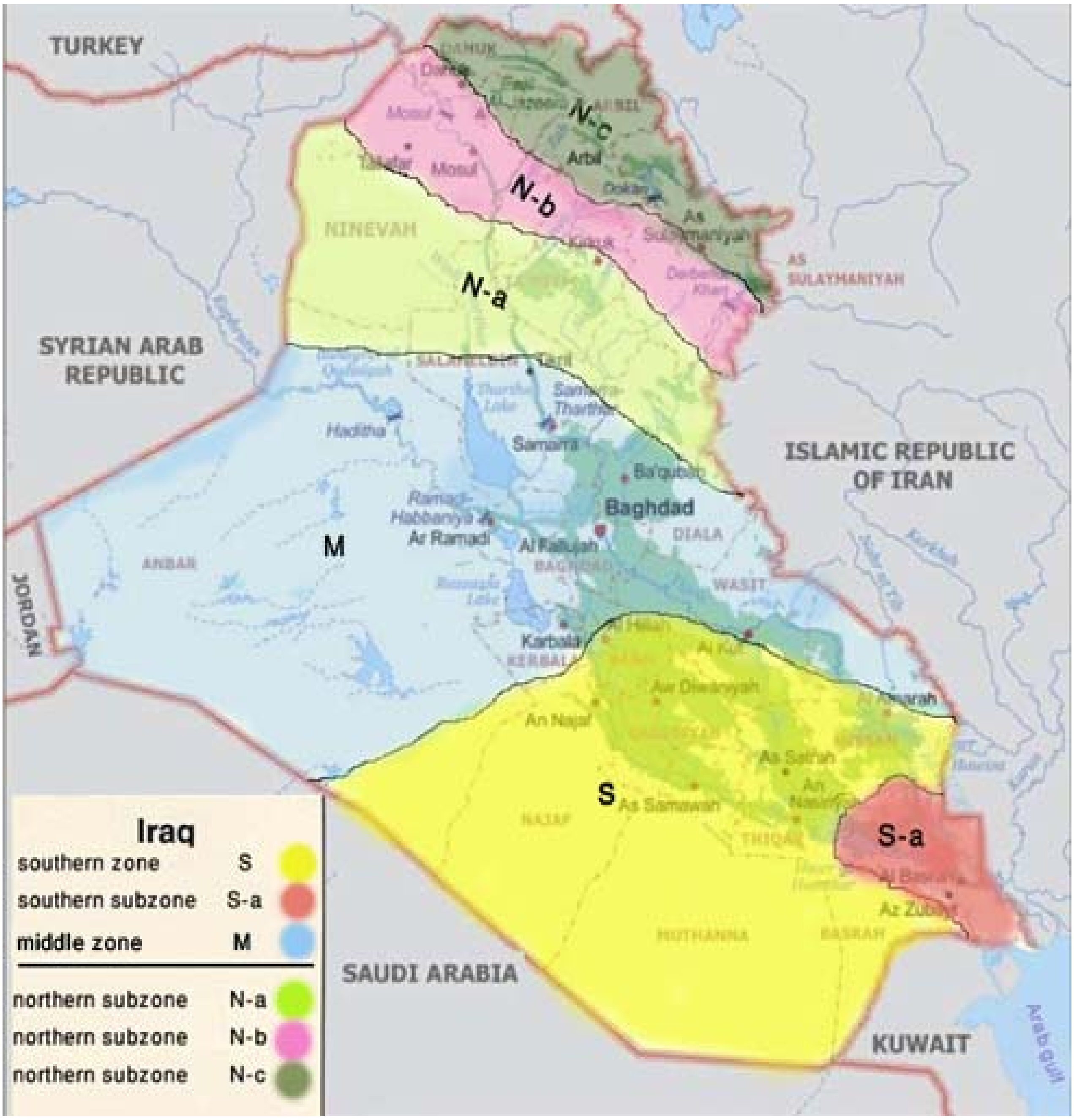
ABBREVIATIONS

Symbol	Description	Unit
% RD	Percentage of maximum root depth	%
%RAW	Percentage of depletion from readily available water	%
AD	Percentage of Allowable depletion	%
ARD	Additional used root depth	mm
ASWD	Additional soil water deficit	mm
C	Conversion for units	…
D_{wet}	Depth of wetted soil	mm
Dm	Number of days to reach maturity	day
Dp	Number of days after planting	day
DP	Deep percolation losses	mm
ER	Monthly effective rainfall	mm/month
ET_c	Actual monthly crop evapotranspiration	mm/month
ET_o	Monthly reference crop evapotranspiration	mm/month
F.C.	Soil moisture content at field capacity	mm
FC	Field capacity	%
$GQ_{req.}$	Gross continuous discharge required	m^3/sec
i	Index for time in month	month
I_{net}	Applied net irrigation 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	…
k	Index for time in days	day
K_c	Crop coefficient	%
Kc max	Maximum crop coefficient	%
Kco	Initial crop coefficient	%
n	Number of crops grown in the project	…
NA	Net irrigated project area	don.
NA_i	Net area in the project planted during the i^{th} month	don.
NA_j	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
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	Root depth at any time	mm
RDo	Initial root depth.	mm
SWC	Soil water content in the root zone	mm
$SWC_{(actual)}$	Actual soil moisture content	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	$^{l/sec}/_{ha}$
WL	Water losses	mm
W.P.	Soil moisture content at wilting point	mm

Appendix (1).



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