Sprinkler Irrigation Systems and Water Saving, A Case Study from South of Iraq

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Abstract

The irrigation systems modernization is a part of water resources management improvement process which requires a decision support system, the core of such system is an automated procedure for simulating the relevant processes governing the system. Simulation models have been used in two phases in this research for two specified areas within Maysan and Wasit provinces in Iraq with an area of 480×250 meters for each province, which have been taken as a case study to redesign and replace the existing open channel network with the new sprinkler irrigation system. The first phase is to find a crop water requirement and irrigation requirements for maize, wheat and barley using CROPWAT 8.0 simulation model, while the second phase includes the irrigation network design using EPANET 2.0 simulation model to perform extended period simulation of hydraulic behavior within pressurized pipe networks, in addition to, the SPAW model which have been used to evaluate soil characteristics. This study has revealed that the designed sprinkler system capacity is 113m^3/hr with 5.04 mm/hr precipitation rate. The designed sprinkler system can be used to irrigate different crop types including maize, barley and wheat. Since, the sprinkler system has been designed to meet the maize irrigation water requirements which is the heights requiring water consumer crop the during the summer season, then it has the ability to meet the different winter cereals irrigation requirements. The designed system can be used in the different regions of Iraq generally and southern regions, especially because it has been designed to suit the soil that characterized by moderate, slow infiltration rates in addition to suit areas of relatively high wind speed which affecting the water distribution uniformity and slow infiltration rates of soils.

Keywords: Simulation Techniques, CROPWAT, Epanet, CWR, Sprinkler Irrigation Systems

أنظمة الري بالرش وتقنين المياه – حاله دراسية من جنوب العراق

الخلاصة

تعد عملية تطوير وتحديث اساليب الري من اهم الوسائل التي تساهم في تحسين ادارة مصادر المياه.
تم استخدام تقنية المحاكاة لتحديد كمية المياه المطلوبة لارواء مساحة من الاراضي الزراعية في موقعين مختلفتين (48 دونم في كل موقع)، الاول في محافظة واسط والثاني في محافظة ميسان. حيث تم في

المرحلة الاولى من الدراسة تحديد كمية مياه الري المطلوبة لتامين احتياج نباتات الذرة، الحنطة والشعير عن طريق استخدام برنامج CROPWAT8.0 وبالاستعانة ببرنامج SPAW لتحليل وتصنيف الترب باستخدام البيانات والمعلومات المتوفرة من الدراسات والبيانات الحقلية، اما المرحلة الثانية تمثلت باستخدام برنامج EPANET2.0. صُممت الشبكة بطاقة تصريف تصميمية بلغت 113 م^3/ الثانية. ان البيانات الحقلية الخاصة بكمية المياه المستهلكة لزراعة المحاصيل المشار اليها في اعلاه تشير الى ان استخدام هذه المنظومة من الممكن ان يقلل كمية المياه المستهلكة بنسبة 25 % كحد ادنى مقارنة بطريقة الري السطحي المستخدمة حاليا وهو ما سيساهم في زيادة الرقعة الزراعية بنفس هذه النسبة من خلال الاستفادة من المياه التي ستوفرها عملية استبدال اسلوب الري بالرش مقارنة بالري السطحي المستخدم حاليا. تم استخدام انابيب نوع بلاستيكية وذلك لكلفتها المناسبة وكفاءتها العالية مقارنة مع الانواع الاخرى من الانابيب.

الكلمات المرشدة: نظام المحاكاة، برنامج كروب وات، برنامج ايبي نت، نظام الري بالرش.

INTRODUCTION

Iraq is relatively well supplied with water in comparison to its Middle East neighbours. However, only 30% of the annual available irrigation water supply actually reaches the crops. Water reaching farmers' fields often does not arrive in a timely manner or in optimum amounts for all fixed farm. Water is often poorly distributed because of inadequate levelling, lack of know-how and poor water management practices; because that total managed irrigation water area in Iraq are flood irrigated [1]. Iraq's water resources are inefficiently managed in the irrigation systems field, this issue, in the short-term does not represent a real problem because of the abundance of water, depending on the Tigris and Euphrates rivers with relatively moderate rainfall levels, but recently with water scarcity crisis, low rain levels and main rivers discharge decrease there is a need to modernize irrigation systems. The irrigation system modernization process as a part of the water resources management process requires a decision support system. The core of such system is an automated procedure for simulating the relevant processes governing the system. Simulation models are used for designing an irrigation network, reconstruction or modernization and modification may be used for the existing system or maintenance of different tasks while managing them. The aim of this research is to re-design and/or replace the existing open channel network by new sprinkler irrigation system by using simulation techniques and compare the results to evaluate the possibility of applying the model in other in the south and middle of Iraq.

The Study Area

Two different sites were selected for analyzing and designing a new irrigation network with different irrigation systems, using simulation techniques and comparing the results of the design process in both regions to evaluate the possibility of applying the models in several other areas in south and middle parts of Iraq. The first site is an East Gharraf project, which located in Wasit and Thi- Qar provinces (Al-Hay) between latitudes 31°14` to 32°26`N, and longitudes 45°52` to 46°22` E, while the second area is Al-Khaeer sub district (Al-Izz) reclamation project which located in the Province of Maysan province between latitudes 31°21`to 31°30`N and longitudes 46°54` to 47°20`E. A specific area of 480×250 meters was chosen within Al-Khaeer irrigation project and North Al-Hay zone to design a proper irrigation network instead of the present traditional irrigation network by replacing the water management and irrigation water distribution system to achieve optimal use of water resources. The areas are cultivated presently by wheat and barley presently using surface irrigation manner.

Models Description

CROPWAT and EPANET software's as any other simulation models established upon set of equations and theories that will be used to calculate the outputs and results, which include, for instance; reference evapotranspiration, effective rainfall, crop water requirements (CWR), irrigation requirement and irrigation schedule, hydraulic head, pressure, flow rate and velocity. So, to find out the working mechanism of these models; the concept in addition to the methods of determination for the elements will be discussed in details below:

Reference Evapotranspiration (ET_o) Conception

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. So the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand, from the crop by transpiration is referred to as evapotranspiration (ET). The rate of evapotranspiration from the hypothetical crop with an assumed crop height (0.12 m) and fixed canopy resistance (70 sm^{-1}) and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of the green grass cover of uniform height, actively growing, completely shading the ground and not short of water is called the reference evapotranspiration and is denoted as ET_o [2].

Many equations are used to estimate reference evapotranspiration. A consultation of experts and researchers was organized by Food and Agriculture Organization of the United Nations (FAO) in May 1990, in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements and to advise on the revision and update procedures. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. CROPWAT model for windows uses the FAO (1992) Penman-Monteith method for calculation reference crop evapotranspiration where most of the equation parameters are directly measured or can be readily calculated from the weather data. The method requires air temperature, wind speed, relative humidity and shortwave radiation data. The Penman-Monteith form of the combination equation is:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma(1 + \frac{r_s}{r_a})} \quad (1)$$

Where R_n is the net radiation, G is the soil heat flux, (e_s - e_a) represents the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, C_p is the specific heat of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and rs and ra are the (bulk) surface and aerodynamic resistances. By applying the hypothetical crop characteristics and a standardized height for wind speed (2 m) to calculate the aerodynamic resistance and the 'bulk' surface resistance, the FAO Penman-Monteith method to estimate ET_o can be derived:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \quad (2)$$

Where ET_o is the reference evapotranspiration (mm/day), T mean daily air temperature at 2 m height (C°), u_2 wind speed at 2 m height (m/s), e_s the saturation vapour pressure (kPa),e_a actual vapour pressure (kPa).

Crop Water Requirement (CWR)

Crop water requirement (CWR) represents the amount of water required to compensate the evapotranspiration loss from a cropped field. Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm day^{-1}. Estimation of crop water requirement is derived from crop evapotranspiration (ET_c) which is the product of the reference evapotranspiration (ET_o) and the crop coefficient (K_c) as illustrated in the equation below [3];

$$ET_c = K_c * ET_o \quad (3)$$

Where crop coefficient is defined as the ratios of crop evapotranspiration (ET_c) to that of reference evapotranspiration (ET_o) computed over a reference grass surface of standard height with no scarcity of available water. Crop coefficient values vary during the growing season with the development of plants as fraction of ground covered by crop canopy changes. In most cases the Kc values are provided for three plant growth stages: initial, middle and end. The length of each stage can be obtained from regional tables or computed using degree days [4]. CROPWAT Model requires Kc values for the initial stage, mid-season stage and at harvest. K_c values during the development and late season stages are interpolated.

Irrigation Water Requirement (IWR)

The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigations can be planned. CROPWAT Model computes a daily water balance of the root zone in terms of root zone depletion at the end of the day by equation bellow:

$$D_{r,i} = D_{r,i-1} - (P - RO)_i - I_i - CR_i + ETc_i + DP_i \quad (4)$$

Where; $D_{r,I}$ is root zone depletion at the end of day i (mm), $D_{r,i-1}$ represent water content in the root zone at the end of the previous day,(mm), P_i is precipitation on day i (mm), RO_i runoff from the soil surface on day i (mm), I_i is net irrigation depth on day i that infiltrates the soil (mm), CR_i represent capillary rise from the groundwater table on day i (mm), ETc_i is crop evapotranspiration on day i (mm) and DP_i represent water loss out of the root zone by deep percolation on day, (mm).

Net irrigation water requirement which is represent the water depth that is used beneficially is equal to the root zone depletion. It is worth mentioning that the gross irrigation represents the water depth applied to the field [5].

Irrigation Schedule

Decisions on when and how much to irrigate are critical both to crop growth and to water use efficiency. Irrigation scheduling aims to determine the exact amount of water to irrigate and the exact timing of application. Irrigation scheduling offers an opportunity for improving water efficiency at a farm level [6]. The CROPWAT Model carries out calculations for reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules.

Hydraulic Analysis

The choice of irrigation system will be concentrated on the pressurized irrigation systems in this study instead of the traditional irrigation methods such as surface irrigation. So, EPANET software has been chosen as a simulation model to design the desired irrigation network. EPANET's hydraulic simulation model computes hydraulic heads at junctions and flow rates through links (pipes) for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of the flow equation for each junction and the head loss relationship across each link in the network [7]. The basic hydraulic equations involved in EPANET are Conservation of Mass Equation, Conservation of Energy Equation, Friction Head loss in pipes, Hazen-Williams formula, and Manning formula.

Cropwat Simulation Model Input Data

By a simple water balance model the CROPWAT software allows the user to simulate the crop water stress conditions and estimate the yield reductions based on well-established methodologies for determination of crop evapotranspiration and yield response to water. The details of the study area characteristics input data to the CROPWAT Model include:

Climatic Data of the Study Area

A climate data for the recent thirty year was gathered from Al-Hay and Al-Amara meteorological stations and listed in (Table-1), includes; mean monthly air temperature, mean relative humidity, sunshine duration, wind speed, mean monthly evaporation and monthly rainfall.

Table (1): Climate characteristics of Al-Hay and Amara areas (mean of 1980-2014)

Month	Mean air temp. C°		Relative Humidity %		Wind speed (m/s)		Sunshine (hr/day)		Evapo. (mm)		Rain (mm)	
	Hay	Ama	Hay	Ama	Hay	Ama	Hay	Ama	Hay	Ama	Hay	Ama
Jan.	11.8	11.6	71	72	2.6	2.1	6.5	6.2	100.3	62.3	27.8	32.0
Feb.	14.1	14.1	62.1	64	3	2.5	7.4	7.2	126	91.3	18.5	22.7
Mar.	18.7	18.6	54.4	56.5	3	2.8	7.9	7.3	220.4	162	20.2	32.4
Apr.	24.9	24.8	45.2	47	3.2	2.8	8.4	8.5	305.7	233.7	13.5	16.5
May	31.3	31.3	32.8	35.4	3.3	3	9.6	9.7	444.9	372.9	4.7	3.6
Jun.	35.4	35.2	25.1	25.7	4.2	4.3	11.6	11.7	608.5	522.4	0.0	0.0
Jul.	37.2	37.5	24	24	4.3	4.2	11.6	11.5	700.5	554.6	0.0	0.0
Aug.	36.9	36.7	24.8	25.8	3.8	3.8	11.4	11.5	646.3	506.2	0.0	0.0
Sep.	33.4	33.1	28.4	29.3	3.2	2.9	10.2	10.3	495.3	366.6	0.6	1.2
Oct.	20.1	27.2	39.2	41.3	2.8	2.3	8.7	8.8	321.8	238.7	3.6	7.3
Nov.	19.4	19.1	55.9	58.4	2.8	2.2	7.5	7.1	171.9	115.9	20.2	25.1
Dec.	13.8	13.5	68.2	69.7	2.5	2	6.5	6.1	117.9	66.6	20.7	31.4
Ave./∑	24.7	25.2	44.2	45.8	3.2	2.9	8.9	8.8	∑4259	∑3293	∑130	∑172

Soil Data and Spaw Model

Most of the soil in the Gharraf zone is medium to fine texture. Silt loam, silty clay loam and silty clay are predominant in surface and in the subsoil, sand content is medium to low except in some deposits while silt has been always in large quantities with variable percentage of clay while the soil of Al- Khaeer zone is medium to fine texture and mostly of sedimentary type with different sources of sediments. Silty clay loam and silty clay are predominant in surface except in some parts that affected by aeolian materials while silty clay loam, loam and silty loam predominant in the subsurface. The desirable salinity for cultivation is 4 ds/m.

The Soil-Plant-Air-Water (SPAW) Model was developed by the United States Department of Agriculture (USDA). This graphic computer program is used to estimate the hydrologic water holding and transmission characteristics of an agricultural soil profile layer [8]. Selecting soil textures on the graphical soil texture triangle of the model, provides estimates for the soil water content-tension-conductivity relationships and associated standard water contents. The texture estimates are modified by one of four additional variables: organic matter, salinity, gravel and density (compaction). Each variable change the entire solution independently. The input data for the North Al-Hay and Al-Khaeer areas were used in the software for soil classification evaluation. The results of the SPAW model (field capacity, wilting point, texture class and saturated hydraulic conductivity), will be used to determine the crop water requirement and irrigation requirement for the selected study areas by CROPWAT8.0 Model.

Cropping Pattern

There are different ways of growing crops, these different ways can be used to give maximum benefit, and they are called Cropping Patterns. Crop pattern has been defined as the proportion of area under different crops at a particular period of time. Two main crops, wheat in the winter and maize or corn in summer, will be adopted in the East Gharraf zone. Wheat is a basic foodstuff and farmers continue to plant this crop as long as soil conditions and salinity in particular, allow acceptable yields while maize is a commonly cultivated cereal crop in the world and Iraq. In Al-Khaeer zone, barley was adopted in this study to be cultivated in the winter season because of its ability of salinity resistance more than wheat in addition to the economic importance for the peasants, also barley is a tough cereal, grown in a number of environments where other grains can't grow. However, barley, maize was identified in this study to be cultivated as a summer crop in Al-Khaeer zone field.

Cropwat Model Output Data

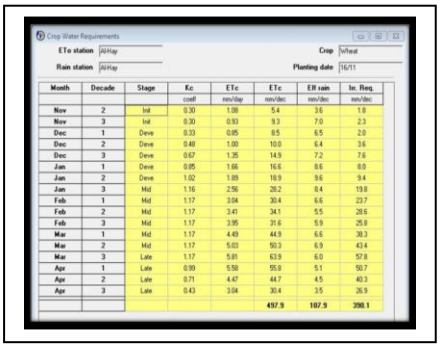
Geographical location, climatic parameters, soil type and cropping pattern data of the study areas were adopted as input data to CROPWAT Model, in addition to the other required information related to field and crop characteristics. Once all the data entered to the software, CROPWAT automatically calculate ET_{crop}, effective rainfall and total irrigation requirements of wheat, barley and maize crops that will be cultivated in the selected fields. The output data of CROPWAT Model were presented in the forms of tables and charts.

Reference Evapotranspiration Estimation

The climate data for Al-Hay and Amara regions have been obtained from the Meteorological Stations for the (1980-2014) periods then applied to the CROPWAT software. The results of reference crop evapotranspiration are obtained by the model are shown in Figure-2. It can be shown from Figures below that the values of reference evapotranspiration (ET_O) are increased during summer season and reached maximum value of 12.42 mm/day in July in the both regions, while a decline during winter season and reached a minimum value of 1.95 mm/day in Al-Hay zone and 1.8 mm/day in Amara zone during January.

Water Requirement of Wheat, Barley and Maize

Evaluation of crop water requirement (CWR) using CROPWAT Model can be carried out by calling up successively the climate, rainfall, crops and soil data sets related to the study areas. Figures 1, 2, 3 and 4 illustrate crop water requirements ET_{crop} for wheat, barley and maize calculated by CROPWAT Model application.

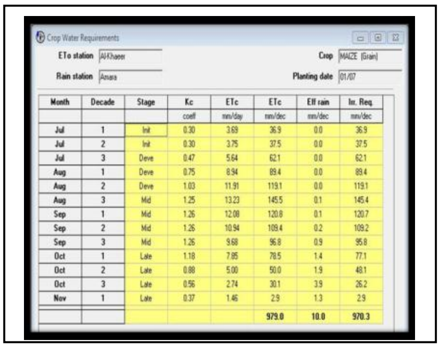


Crop Water Requirements

ETo station: Al-Hay — Crop: Wheat
Rain station: Al-Hay — Planting date: 16/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.30	1.08	5.4	3.6	1.8
Nov	3	Init	0.30	0.93	9.3	7.0	2.3
Dec	1	Deve	0.33	0.85	8.5	6.5	2.0
Dec	2	Deve	0.48	1.00	10.0	6.4	3.6
Dec	3	Deve	0.67	1.35	14.9	7.2	7.6
Jan	1	Deve	0.85	1.66	16.6	8.6	8.0
Jan	2	Deve	1.02	1.89	18.9	9.6	9.4
Jan	3	Mid	1.16	2.56	28.2	8.4	19.8
Feb	1	Mid	1.17	3.04	30.4	6.6	23.7
Feb	2	Mid	1.17	3.41	34.1	5.5	28.6
Feb	3	Mid	1.17	3.95	31.6	5.9	25.8
Mar	1	Mid	1.17	4.49	44.9	6.6	38.3
Mar	2	Mid	1.17	5.03	50.3	6.9	43.4
Mar	3	Late	1.17	5.81	63.9	6.0	57.8
Apr	1	Late	0.99	5.58	55.8	5.1	50.7
Apr	2	Late	0.71	4.47	44.7	4.5	40.3
Apr	3	Late	0.43	3.04	30.4	3.5	26.9
					497.9	107.9	390.1

Figure (1). CWR of wheat (Al-Hay, East Gharraf Field)

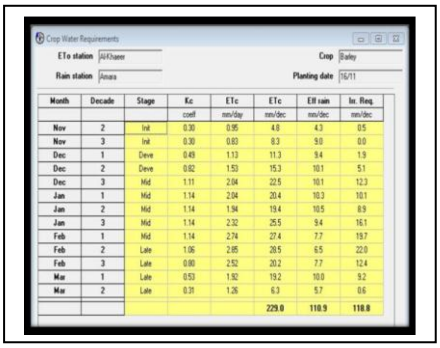


Crop Water Requirements

ETo station: Al-Khaeer — Crop: MAIZE (Grain)
Rain station: Amara — Planting date: 01/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	0.30	3.69	36.9	0.0	36.9
Jul	2	Init	0.30	3.75	37.5	0.0	37.5
Jul	3	Deve	0.47	5.64	62.1	0.0	62.1
Aug	1	Deve	0.75	8.94	89.4	0.0	89.4
Aug	2	Deve	1.03	11.91	119.1	0.0	119.1
Aug	3	Mid	1.25	13.23	145.5	0.1	145.4
Sep	1	Mid	1.26	12.08	120.8	0.1	120.7
Sep	2	Mid	1.26	10.94	109.4	0.2	109.2
Sep	3	Mid	1.26	9.68	96.8	0.9	95.8
Oct	1	Late	1.18	7.85	78.5	1.4	77.1
Oct	2	Late	0.88	5.00	50.0	1.9	48.1
Oct	3	Late	0.56	2.74	30.1	3.9	26.2
Nov	1	Late	0.37	1.46	2.9	1.3	2.9
					979.0	10.0	970.3

Figure (2). CWR of maize (Al-Hay, East Gharraf Field)

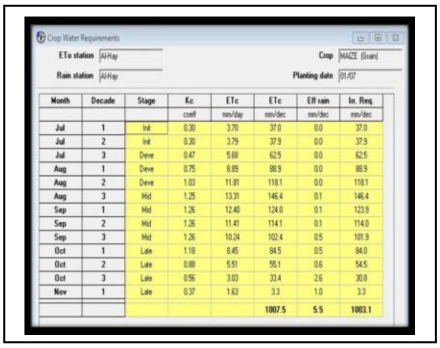


Crop Water Requirements

ETo station: Al-Khaeer — Crop: Barley
Rain station: Amara — Planting date: 16/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.30	0.95	4.8	4.3	0.5
Nov	3	Init	0.30	0.83	8.3	9.0	0.0
Dec	1	Deve	0.49	1.13	11.3	9.4	1.9
Dec	2	Deve	0.82	1.53	15.3	10.1	5.1
Dec	3	Mid	1.11	2.04	22.5	10.1	12.3
Jan	1	Mid	1.14	2.04	20.4	10.3	10.1
Jan	2	Mid	1.14	1.94	19.4	10.5	8.9
Jan	3	Mid	1.14	2.32	25.5	9.4	16.1
Feb	1	Mid	1.14	2.74	27.4	7.7	19.7
Feb	2	Late	1.06	2.85	28.5	6.5	22.0
Feb	3	Late	0.80	2.52	20.2	7.7	12.4
Mar	1	Late	0.53	1.92	19.2	10.0	9.2
Mar	2	Late	0.31	1.26	6.3	5.7	0.6
					229.0	110.9	118.8

Figure (3). CWR of barley (Amara, Al-Khaeer Field)



Crop Water Requirements

ETo station: Al-Hay — Crop: MAIZE (Grain)
Rain station: Al-Hay — Planting date: 01/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	0.30	3.70	37.0	0.0	37.0
Jul	2	Init	0.30	3.79	37.9	0.0	37.9
Jul	3	Deve	0.47	5.68	62.5	0.0	62.5
Aug	1	Deve	0.75	8.89	88.9	0.0	88.9
Aug	2	Deve	1.03	11.81	118.1	0.0	118.1
Aug	3	Mid	1.25	13.31	146.4	0.1	146.4
Sep	1	Mid	1.26	12.40	124.0	0.1	123.9
Sep	2	Mid	1.26	11.41	114.1	0.1	114.0
Sep	3	Mid	1.26	10.24	102.4	0.5	101.9
Oct	1	Late	1.18	8.45	84.5	0.5	84.0
Oct	2	Late	0.88	5.51	55.1	0.6	54.5
Oct	3	Late	0.56	3.03	33.4	2.6	30.8
Nov	1	Late	0.37	1.63	3.3	1.0	3.3
					1007.5	5.5	1003.1

Figure (4). CWR of maize (Amara, Al-Khaeer Field)

Where; K_C is the crop coefficient and it is basically the ratio of the crop ET_C to the reference ET_O, and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass include crop height, albedo (reflectance) of the crop-soil surface, canopy resistance and evaporation from soil. Kc varies predominately with the specific crop characteristics and only to a limited extent with climate. This enables the transfer of standard values for *Kc* between locations and between climates. So, as the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the K_C for a given crop will vary over the growing period. The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season [2].

Irrigation Water Requirement and Irrigation Schedule of crops

The main objective of CROPWAT Model applied in this study is to calculate irrigation water requirement and finally producing irrigation time schedule that improves irrigation water management in the study areas. Irrigation management is about controlling the rate, amount, and timing of applied irrigation water in a planned and efficient manner. With good irrigation management, wheat, barley and maize can have high yield and quality potential. Where the Total Available Moisture (TAM) is representing the total amount of water available to the crop and the Readily Available Water (RAM) is the fraction of (TAM) that a crop can extract from the root zone without suffering water stress. CROPWAT Model results (output data) will be adopted in the irrigation network design for the study areas using design simulation models.

Irrigation Systems

Any irrigation system is a composite of canals, laterals, structures, and equipment involved in the transport of water from where it is available to where it is required. There are two basic types of irrigation systems, namely open canal systems and pressurized piped systems. Experience gained from many countries in arid and semi-arid zones has shown that pressure piped irrigation techniques are replacing successfully the traditional open canal surface methods at farm level [9]. The pressurized irrigation system, specifically sprinkler irrigation, will be adopted in this research for irrigate the selected fields in the study areas to increase the irrigation efficiency, and evaluate the system performance in such south and middle regions of Iraq circumstances like climatic and soil characteristics.

In sprinkler irrigation, water is applied from the sprinkler nozzle, which produces a jet breaking up in thousands of drops of different diameters. Drops travel for a distance of two to fifteen meter (depending on their diameter) before reaching the soil surface. The main constraint for sprinkler irrigation is the wind, which severely reduces irrigation uniformity and increase evaporation water losses [10]. Irrigation systems should be designed to be efficient, distribute water uniformly, conserve water resources and meet site requirements. Site specific characteristics and incorporation of water conservation practices and technologies should be evaluated in the design. The procedure for designing sprinkler systems can be divided into two phases; preliminary design steps that comprise the procedure for synthesizing farm data in order to determine preliminary design parameters, which will be needed in the final design adjustment process and adjustment or final design steps to reconcile the preliminary design parameters obtained with the irrigation equipment performance characteristics, as well as human, physical and financial factors. In fact, the final adjustment of the design is the process of selecting the appropriate irrigation system components for the specific circumstances [11]. Both the preliminary design and adjustment or final design will be applied to design a sprinkler irrigation system for the selected areas in Gharraf and Al-Khaeer terrains.

Preliminary Sprinkler Irrigation Design Steps

The preliminary design factors that need to be established are; depth of water applied per irrigation, irrigation frequency, duration of irrigation per set and required system capacity (flow rate). All these design parameters are derived from the data on climate, water, soil and plant. According to Savva and Frenken, (2001) the following procedures and calculations should be followed to compute the preliminary design factors:

Net Depth of Water Application

The depth of water applied is the quantity of water, which should be applied during irrigation in order to replenish the water used by the crop during evapotranspiration. All SPWA model output data as well as the additional required data, was applied to CROPWAT simulation model as mentioned previously, and the net depth of water application had been computed by the model using the following equation:

$$d_{net} = (FC-PWP) * RZD * P \quad (5)$$

Where d_{net} represent the readily available moisture or net depth of water applied per irrigation for the selected crop (mm), FC is the soil moisture at field capacity (mm/m), PWP is the soil moisture at the permanent wilting point (mm/m), RZD represent the depth of soil that the roots exploit effectively (m) and P is the allowable portion of available moisture permitted for depletion by the crop before the next irrigation. The maximum computed d_{net} values for crops by CROPWAT model for both fields was 80 mm for wheat, which take place in April, and 86.1 mm for maize, which take place in October in the Gharraf field, while in the Al-Khaeer field was 76.6 mm for barley which take place in December and 82.5 mm for maize which take place in October. The convergence in d_{net} values refers to the similarity of soil characteristics in both fields while the difference in time refers to the root zone depth of the crops.

Irrigation Frequency at Peak Demand

The peak daily water use is the peak daily water requirement (Et_C) of the crop determined by subtracting the rainfall from the peak daily crop water requirements. To evaluate the peak daily water use for wheat, barley and maize in the Gharraf and Al-Khaeer selected fields, two scenarios will be applied for the crop cultivation, the possibility of field cultivation for one season throughout the year, either winter (wheat or barley) or summer crops (maize) and the possibility of field cultivation for both seasons throughout the year, winter (wheat or barley) and summer crops (maize). Simulation for both scenarios made using CROPWAT and the ET_C values for each crop was obtained and the maximum value will be adopted in the sprinkler irrigation system design process to provide the required amount of irrigation water to the crop and ensure that soil moisture depletion not exceed 50% during the peak water demand period which is often occurring throughout the summer season especially in August. It can be seen from the simulation results that the maximum water demand takes place during maize cultivation period due to air temperature rises in the summer, therefore the sprinkler irrigation system will be designed to apply the maximum water demand for maize in both selected fields, and it will be already have the capability to secure the required amount of water for wheat and barley with different irrigation schedule and less operation hours certainly.

The maximum ET_C for maize in Gharraf field is 13.31 mm/day, while in Al-Khaeer field is 13.23 mm/day and occurs when the first scenario will be chosen by the farmer. Therefore, the first scenario for maize cultivation will be adopted in the design process as the most crop require for water and has a peak daily water use. After establishing the net depth of water applied, the irrigation frequency at peak water demand should be determined. Irrigation frequency is the time it takes the crop to deplete the soil moisture at a given soil moisture depletion level. The following equation will be used to determine the irrigation frequency for maize;

$$\text{Irrigation frequency } (I_F) = d_{net} / ET_C \qquad (6)$$

Where I_F represent the irrigation frequency (days), d_{net} is the net depth of water application (mm) and ET_C is the peak daily water use (mm/day) By applying equation (6) the results will be as follows:

- *For Gharraf field*

The irrigation frequency equal to (86.1/13.31) = 6.47 days (for practical purposes fractions of days are not used for irrigation frequency purposes). So, the system should be designed to provide 86.1 mm every 6 days. Hence, the irrigation frequency should be 6 days, with a corresponding (d_{net}) of 80 mm (13.31 x 6) and a moisture depletion (p) of 0.49 (80/(164 x 1.0)). For all practical purposes and in order to accommodate the time for cultural practices, it is advisable that irrigation is completed in less than the irrigation frequency. So, 5 days irrigation and 1 day without irrigation is considered adequate.

- *For Al-Khaeer field*

The irrigation frequency equal to (82.5/13.23) = 6.24 days. So, the system should be designed to provide 82.5 mm every 6 days. Hence, the irrigation frequency should be 6 days, with a corresponding (d_{net}) of 79.4 mm (13.23 x 6) and a moisture depletion (p) of 0.48 (79.4/(165 x 1.0)).

Again for all practical purposes and in order to accommodate the time for cultural practices (spraying... etc.), it is advisable that irrigation is completed in less than the irrigation frequency. So, 5 days irrigation and 1 day without irrigation is considered adequate. The 5 days required to complete one irrigation application in the area under consideration are called the irrigation cycle.

Gross depth of water application

The gross depth of water application (d_{gross}) equals the net depth of irrigation divided by the farm irrigation efficiency (E). It should be noted that farm irrigation efficiency includes possible losses of water from pipe leaks. The following equation will be applied to compute the gross depth of water:

$$d_{gross} = d_{net} / E \qquad (7)$$

The farm irrigation efficiency of sprinkler systems varies from climate to climate. According to FAO, (1992) farm irrigation efficiencies for sprinkler irrigation in hot climate regions like the middle and south of Iraq climates are 70%. Therefore, the gross depth of irrigation will be (80/0.7) = 114.2 mm for Gharraf field and (79.4/0.7) = 113.4 mm for Al-Khaeer field. Hence, it can be seen the convergence in the gross depth of irrigation between both sites, which enhances the possibility of designing a sprinkler system can work in both locations. So, this is one of the advantages to adopt this simulation model.

Final Sprinkler Irrigation System Design Steps

The final sprinkler irrigation design steps are the selection of the sprinklers Characteristics and spacing. According to Savva and Frenken, (2001) the following procedures may be followed to reconcile the preliminary design parameters:

Sprinkler Selection and Spacing

Referring to the SPAW model results that depended on the soil characteristics of Al-Hay and Al-Khaeer zones, it can be noted that the soil basic infiltration rate in both study areas is 6.3 mm/hr, which is classified as moderate basic infiltration rate. According to Iraqi Ministry of Water Resources, (2004) the moderately slow soil basic infiltration rate are 5–20mm/hr. So, Improvement of soil structure by farming techniques may be necessary. Manufacturers' tables can be used to select the sprinklers and their spacing (Table-2).

Table (2). Performance of some sprinklers, [11]

Sprinkler Specifications				Sprinkler precipitation rate (mm/hr)						
				Sprinkler spacing (m x m)						
Nozzle Size (mm)	Pressure (kPa)	Q (m3/hr)	Wetted Diam. (m)	9x12	9x15	12x12	12x15	12x18	15x15	18x18
3.0	250	0.57	25.00	5.28	4.22	3.96				
3.0	300	0.63	25.60	5.83	4.67	4.38				
3.0	350	0.68	26.20	6.30	5.04	4.72				
3.5	250	0.75	26.85	6.94	5.56	5.21	4.17			
3.5	300	0.82	27.60	7.59	6.07	5.69	4.56			
3.5	350	0.89	28.35	8.24	6.59	6.18	4.94			
4.0	300	1.08	26.60		8.00	7.50	6.00	5.00	4.60	
4.0	350	1.16	30.50		8.59	8.06	6.44	5.37	5.16	
4.5	300	1.32	30.95			9.17	7.33	6.11	5.87	
4.5	350	1.42	32.00			9.86	7.89	6.57	6.31	
4.5	400	1.52	33.05			10.56	8.44	7.04	7.56	
5.0	300	1.70	33.00				9.44	7.87	8.18	5.25
5.0	350	1.84	34.30				10.22	8.52	8.18	5.68
5.0	400	1.96	35.60				10.89	9.07	8.71	6.05

– Nozzle size indicates the diameter of the orifice of the nozzle
– Pressure is the sprinkler operating pressure at the nozzle
– Discharge indicates the volume of water per unit time that the nozzle provides at a given pressure
– Wetted diameter shows the diameter of the circular area wetted by the sprinkler when operating at a given pressure and no wind
– The sprinkler spacing shows the pattern in which the sprinklers are laid onto the irrigated area. 12 m x 18 m spacing means that sprinklers are spaced at 12 m along the sprinkler lateral line and 18 m between sprinkler lines

In order to avoid the runoff, the sprinkler application for the both study cases should be less than 6.3 mm/hr which is compatible with the soil and crop. There are several nozzle sizes, pressure and sprinkler spacing combinations to choose from the Table (3), but another aspect to be considered in selecting a sprinkler is the uniformity of application, in addition, it should be noted that the lower pressures are preferable as long as the uniformity of application is not compromised. The Coefficient of Uniformity (CU) is a measure of the uniformity of water application. As a rule, the selected sprinkler should have a CU of 85% or more. Where locally manufactured sprinklers do not tested for CU determination, it is advisable to avoid using the low pressure since usually this is the pressure that corresponds to low CU values [11].

Referring to meteorological characteristics of the study area, the maximum mean wind speed is about 15 km/hr and takes place in June and July, generally there is not main irrigation processes to be occurred during this period. Therefore, the sprinkler spacing should be based on 45% of D for square pattern and 60% of D $*$ 40% of D for rectangular pattern. The next step is to determine whether the possible spacing’s above satisfying the wind requirements. According to Table (3), as well as the conditions in Tables (4) and (5), the 9x15 sprinkler spacing satisfies the wind speed as well as suit the nature of the soil in which the prevailing type of slow infiltration rate in both study areas. From table (3), the wetted diameter of the 3.0 mm nozzle size at a pressure of 350 kPa is 26.20 m, and from table (4), for a wind speed of 15 km/hr, 40% of D and 60% of D for the 9∗15 meter spacing are 10.48 m (> than 9 m sprinkler spacing) and 15.72 m (> than 15 m lateral spacing) respectively. Moreover, a correction of the precipitation rate is recommended in order to avoid a runoff in sloping land. But in this research cases, the land is almost flat, therefore it does not need to make precipitation reduction correction.

Sprinkler System layout

The system layout is obtained by matching the potentially acceptable spacing with the dimensions of the field such that as little land as possible is left out of the irrigated area. Sprinkler system type should be specified depending on the field dimensions and the set time (Ts), which is the time each set of sprinklers should operate at the same position in order to deliver the gross irrigation depth.

Sprinkler System Type Specification

In order to specify the type of the sprinkler system, an irrigation scheme should be established according to the crop irrigation schedule and the set time which can be calculated by:

$$Ts = d_{gross} / P_r \quad (8)$$

Where; Ts is set time (hr) and P_r is the sprinkler precipitation rate (mm/hr). By Substituting gross depth and precipitation rate values in equation (8), the set time for the Gharraf selected field will be 22.7 hr (114.2 / 5.04) and in Al-Khaeer selected field is 22.5 hr (113.4/5.04). Hence, each set of sprinklers should operate at the same position more than 22 hours in order to deliver the gross application per irrigation, which will be illogical practice and not achieve optimum utilization of the sprinkler system equipment's during the peak water demand period. So, in order to improve the system performance and make it more acceptable practically, the moisture depletion level should be reassessed and consequently the set time. According to this choice the irrigation frequency will be reduced from 6 days to 5 days, which will be also the irrigation cycle to achieve the optimum utilization of the system during the peak water demand period while the cultural practices will be synchronized with the irrigation process during this period in the both selected fields.

Then; in the Gharraf field; the corresponding (d_{net}) will be 66.5 mm (13.31*5) and a moisture depletion (p) is 0.40 (66.5/ (164*1.0)) by referring to equation (6). Consequently, the adjusted (d_{gross}) values by referring to equation (7) will be 95 mm (66.5/0.7). Since, the sprinkler precipitation rate is 5.04 mm/hr the sprinklers should operate for 18.8 hours (95/5.04) at each set during the peak demand period.

In the Al-Khaeer field; the new (d_{net}) value will be 66.2 mm (13.23 x 5) and a moisture depletion (p) is 0.40 (66.2/ (165*1.0)). Consequently, the adjusted (d_{gross}) will be 94.6 mm (66.2/0.7) and the sprinklers should operate for 18.8 hours (94.6/5.04) at each set during the peak demand period.

From the set time values it can be seen the convergence or quite similarity between the Gharraf and Al-Khaeer fields characteristic, and this convergence as possible may be reflected on most of the middle and south part of Iraq in terms of soil and climate characteristics. Even some difference in soil characteristics will be found in the other regions. So, as a result of the convergence in soil properties in both areas, an unified sprinkler irrigation system will be designed for both areas in the next steps with same irrigation management manner, as well as with the possibility of using it in the other land that's similar the study areas properties or to some extent in most areas of the central and southern Iraq.

According to the set time value (about 18.8 hr), the sprinkler system type options that suitable and fit with the required operating time will be the semi-permanent or semi-portable sprinkler irrigation system. Semipermanent system has portable lateral lines, permanent main lines and sub mains and a stationery water source and pumping plant, while the semi portable system has portable main lines, laterals and fixed location of water source and pumping plant. Choice between the two cases (permanent or portable) is the farmer decision, but it is better to adopt the first choice to maintain the main and supply pipes and used it for a longer period of time. Buried pipelines are placed deep enough to permit land preparation and crop harvesting without disturbing them.

Since, the sprinklers and laterals spacing is 9∗15 meter, then farm would require 32 (480/15) lateral positions to cover the total area, but with allocation an 4 meter width for roads around the farm a 30 lateral positions will be enough to cover the total area. A more favourable arrangement from the operational point of view can be attained by locating the main line in the middle of the farm; such a layout will permit the rotation of the laterals around the mainline and the completion of irrigation will be in 5 days using 12 laterals (60 positions / 5 days). Laterals will operate with one shift per lateral per day, 6 laterals with 14 sprinklers and another 6 laterals with 13 sprinklers, discharge of each lateral is 9.52 m^3/hr (14*0.68) and 8.84 m^3/hr (13*0.68) respectively operating at the same time in order to complete the irrigation cycle. The buried main line extends along the farm and delivers water from the buried supply pipe to the laterals. When preparing the layout of the system, it should adhere to an important principle, that for the rectangular spacing the laterals should be placed across the prevailing wind direction in order to achieve fairly uniform head losses. The capacity of such a system can be calculated using the equation:

$$Q = Nc * Ns * Q_S \qquad (9)$$

Where; Q is the system capacity (m^3/hr), and Nc represents the number of laterals operating per shift while Ns is the number of sprinklers per lateral and Q_S is the sprinkler discharge (from the manufacturer's tables). Therefore, by applying equation (9), the farm system capacity will be 110.2 m^3/hr ((6 * 14 * 0.68) + (6 * 13 * 0.68).

Allowable Pressure Variation

Pressure differences throughout the system or block or subunit should be maintained in such a range, so that a high degree of uniformity of water application is achieved. Hence, the friction losses in the lateral should be kept to a minimum and for the practical purposes, the allowable pressure variation should not exceed 20% of the sprinkler operating pressure [11]. Then, for the selected spacing and nozzle size of 3.0 mm operating at a pressure of 350 kPa, the allowable pressure variation in the system should not exceed 20% of the sprinkler operating pressure, which is 70 kPa (350 * 0.2) or 7 meters.

Final Simulated Sprinkler System Layout (Simulation Result)

A final design result including field layout configuration, pipe types and sizes and pumps, product type, topographical configuration of the area will be adopted and simulated using EPANET simulation model technique to evaluate the network performance and the conformity of results (head, velocity and irrigation demands) with the hydraulic conditions and irrigation water application requirements. The simulation output layout and network configuration after simulation process shown in Figure (5) for the farm area 0.12 km^2 with 480x250 meter dimensions; which consist of semi- permanent sprinkler irrigation system of 113 m^3/hr flow capacity for 5 day irrigation cycle (set time of 18.5hr during the peak irrigation period for maize). The system components include pipes (supply, mainlines and laterals), flow control valves and sprinklers as well as pump station. System capacity and the velocity in the pipes are briefly described below:

- *Sprinklers Distribution*

Sprinklers of 3.0 mm nozzle size, 350 kPa pressure, 26.2 m wetted diameter and 5.04 m^3/hr precipitation rates; with spacing 9*15 meter were selected. So, the number of sprinklers in the farm system will be 162 sprinklers.

Nodes in the EPANET network represent a sprinkler, and models as emitters with the equation; $Q = k\,p^{n}$ (10)

Where; Q is the discharge of each sprinkler (m^3/hr), K represents the emitter coefficient (0.115), P; is operating pressure of sprinkler (m), and n represent the emitter exponent (0.5).

- *Laterals and Main Lines Distribution Characteristic's and Distribution*

The number of lateral positions are 60 distributed each 15 meters along the mainline, and 12 laterals are working at the same time to provide irrigation water with 5 days irrigation cycle. Laterals divided into two classes; one with 14 sprinklers and the other with 13 sprinklers (Figure-5). Laterals are laid on the soil surface and connected to the main line through hydrants and an uPVC pipe (Hazen & Williams factor, C=150) of 50 mm and 63 mm diameters used with 6 meter length of each pipe segment, then the number of pipe segments in the system will be 234 pipe segments (per one farm), 18 pipe of 50 mm and 216 pipe segment of 63 mm diameter.

The mainline length is 443 meters as shown in Figure (5). An plastic irrigation pipe of difference diameters was selected as main and supply lines and buried below ground about 30 cm. The standard laying length of the selected Irrigation uPVC pipes are 6 meters (20 feet) while the selected pressure class pipes are 600 kpa, and its coefficient of flow (Hazen & Williams) is C=150. So, the pipe segment number in the main lines will be about 74 pipe segments (443/6) with different diameter. The total length of the supply line from the pump station to the farm entrance is 8 meters of 200 mm diameter uPVC buried pipe. So, the supply line pipe segment number will be two as shown in Figure (5).

Pressure And Velocity Simulation Result Of The System

As mentioned previously, the pressure in the system should not be below the sprinkler operating pressure of 35m and the allowable pressure variation between the lowest point and the highest point is within 20%, the variation then should not exceed 7m. As shown in the Figures (6 and 7), the minimum pressure in the system is 35.41m occurring at the furthest node on the system, whilst the maximum reference pressure is 38.34m, so the pressure variation is 2.93 m which is within the limit and the minimum pressure requirement satisfies the constraint sprinkler operating pressure. Velocity limits are the most important constraint in pressurized network design, the lowest velocity led to less head loss per unit length of the pipe while the high velocities tend to increase the unit head losses in the pipe stretches. The velocity simulation results indicated that the maximum velocity value in the network was 1.17 m/s. The sprinkler irrigation system design discharge that resulted from simulation is 113 m^3/hr.

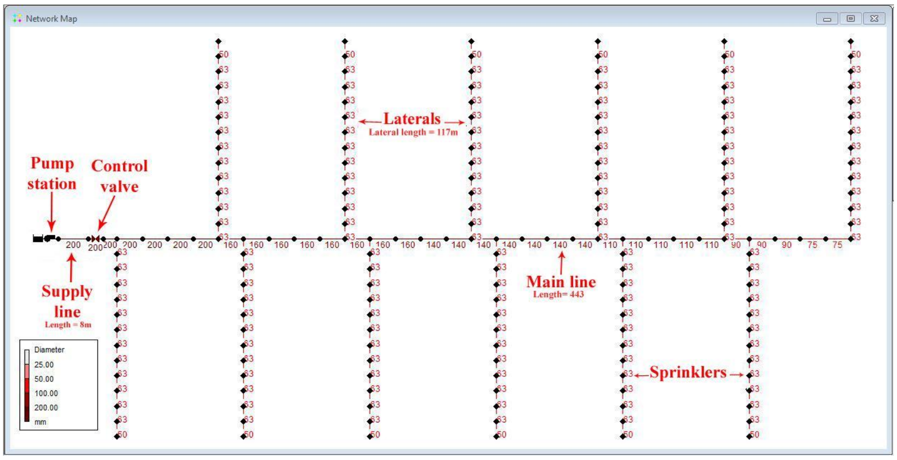
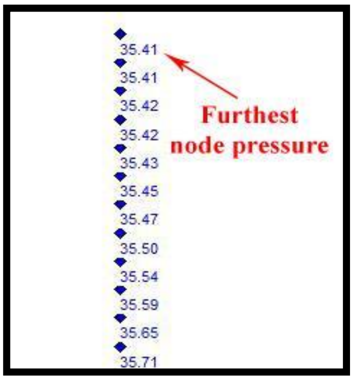
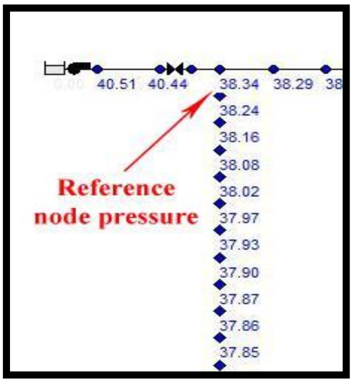


Figure (5). Farm level (separated pump stations) simulated sprinkler system layout





Figure(6). Furthest node pressure **Figure (7). Reference node pressure**

Application Of Designed System For Wheat And Barley

The sprinkler system was designed to meet the maize irrigation water requirements which is one of the most require water crops during the summer season in the both selected areas, but also it has the ability to meet the different winter cereals irrigation requirements. So, the designed system can be used for the other adopted crop type's irrigation in this research, including wheat and barley but with different operation time. The designed network operation time and manner for wheat and barley during the peak water demand period, according to the CROPWAT model resulted irrigation schedule in the both selected areas is briefly described below:

Wheat

The maximum computed d_{net} value for wheat in the Gharraf field was 80 mm which took place in April, while the maximum ETc was 5.81mm/day. Then;

- The irrigation frequency is equal to (80/5.81) = 13.8 days
- The gross depth of irrigation is (80/0.7) = 114.2 mm
- Refer to equation (8), the set time for Gharraf selected field will be 22.7 hr (114.2/5.04).

In order to improve the system performance and make it a more acceptable practically, the moisture depletion level should be reassessed and consequently the set time. Hence, each lateral in the network cover five positions and the irrigation frequency is large, then the farmer has the elasticity to specify the set time for the laterals to deliver the gross application either by one application with 10-day irrigation frequency (for instance), or by two applications during the peak water demand period (13.8 days) with less set time. So;

- Let the irrigation frequency will be 10 days, the corresponding (dnet) will be 58.1 mm (5.81* 10)
- The moisture depletion (p) is 0.35 (58.1/ (164 * 1.0))
- Consequently, the adjusted (dgross) values will be 83 mm (58.1/0.7)
- Since, the sprinkler precipitation rate is 5.04 mm/hr, the sprinklers should operate for 16.5 hours (83/5.04) at each set during the peak demand period.

Barley

The maximum computed dnet value for barley in the Al-Khaeer field was 76.6 mm which took place in December, while the maximum ET_C was 2.85 mm/day. Then;

- The irrigation frequency is equal to (76.6/2.85) = 26.8 days
- The gross depth of irrigation is (76.6/0.7) = 109.4 mm
- Refer to equation (8), the set time for Gharraf selected field will be 21.7 hr (109.4/5.04). Similar to wheat irrigation case, the farmer has the elasticity to specify the set time for the laterals in order to deliver the gross application by one application with 20-day irrigation frequency (for instance), or by two applications during the peak water demand period (26.8 days) with less set time. So;
- Let the irrigation frequency will be 20 days, the corresponding (d_{net}) will be 57 mm
- (2.85*20)
- The moisture depletion (p) is 0.34 (57/ (168 * 1.0))
- Consequently, the adjusted (dgross) values will be 81.4 mm (57/0.7). Since,

The sprinkler precipitation rate is 5.04 mm/hr the sprinklers should operate for 16 hours (81.4/5.04) at each set during the peak demand period.

Finally, as a conclusion of the system operation time to provide the maize irrigation water requirements, the final design of the system capacity is 113 m3/hr to irrigate area of 48 donums, within 5 days irrigation cycle to achieve the optimum utilization of the system during the peak water demand period and operation time of 18.5 hours per day, while the average filed information's and measurements of maize fields in the Gharraf area showed that the existing applied discharge is about 25% (as minimum) more than the system capacity value by using the surface irrigation, and spending all the month for 24 hr during the peak water demand period. This means it can increase the agricultural area at least 25 % by taking advantage of the available water as a result of using the sprinkler irrigation system.

Conclusions

The following conclusions were derived from the present study as follows;

1. The designed sprinkler system capacity in this research is 113m^3/hr, and can increase the agricultural area at least 25 % by taking advantage of the available water as a result of the use to sprinkler irrigation system instead of the surface irrigation system.

2. The maximum computed $\mathbf{d}_{net}$ value for wheat in the Gharraf field was 83 mm which took place in April, the sprinkler precipitation rate is 5.04 mm/hr, the sprinklers should operate for 16.5 hours at each set during the peak demand period.

3. The maximum computed $\mathbf{d_{net}}$ value for barley in the Al-Khaeer field was 76.6 mm which took place in December, the sprinkler precipitation rate is 5.04 mm/hr the sprinklers should operate for 16 hours at each set during the peak demand period.

4. This study has revealed that the designed sprinkler system can be used for different crop type's irrigation (maize, barley and wheat) but with difference operation time. Since, it has been designed to meet the maize irrigation water requirements which is one of the most require water crops during the summer season then it has the ability to meet the different winter cereals irrigation requirements.

5. Designs have been prepared to suit the worst conditions of the study areas of relatively high wind speed that affects the water distribution uniformity and slow infiltration rates of soils as well as high irrigation water requirements for plants during short peak demand periods.

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