Development of Recent Information and Data on Irrigation Technology and Management

S. A. Abd El-Hafez, M. A. Mahmoud and A. Z. El-Bably

1 Introduction

In Egypt, expert systems in the agriculture field apply the application of agro-climate in agriculture that was mainly utilizing data in a set of models, including water management, planting dates of major field crops, etc., there was another technique depend on information-based, instead of a database. This led to the emergence of agriculture expert systems (www.claes.sci.eg). This required an intelligent assessment and through an understanding of all the climatic and hydrological as well as agricultural foundation and community conditions where such updated information is purposed to exercise in irrigation so that it could be widely applied [1]. Today, agriculture based on irrigation consumes the largest part of the water resources of the nation. Water consumption occurs via transpiration, evaporation, incorporation into products or crops, consumed by humans or livestock, or otherwise extracted from the water environment. Development of recent information on on-farm irrigation technique and management is very significant to improve irrigation technologies and advanced farm management practices that offer an opportunity for agriculture to utilize irrigation water more efficiently. Ongoing updated information for farmers is vital to adopt advanced water management practices to rationalize water without sacrificing crop yields [2]. Vanino et al. [3] revealed the suitability of the MultiSpectral Instrument

S. A. Abd El-Hafez · M. A. Mahmoud · A. Z. El-Bably (✉)
Water Requirements and Field Irrigation Research Department, Soil, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), 9th Cairo Univ. Street, Giza, Egypt
e-mail: elbabli@gmail.com

S. A. Abd El-Hafez
e-mail: s.a.abdelhafez@gmail.com

M. A. Mahmoud
e-mail: mahmoud_abdalla96@yahoo.com

E.-S. E. Omran and A. M. Negm (eds.), *Technological and Modern Irrigation Environment in Egypt*, Springer Water,
https://doi.org/10.1007/978-3-030-30375-4_6

sensor on-board Sentinel-2A to estimate water requirements of tomatoes is providing useful information for optimizing the irrigation over extended farmland, at field level. The hypothesized positive links between Information and Communications Technologies (ICTs) and development [4–6].

Irrigated agriculture surely faces an increased water scarcity and drought. Irrigation technology improvement and related developments in water management depending on offer an opportunity for agriculture to mitigate water shortage more efficiently for the allocated water. Increasing water supplies from surface or groundwater sources are not the solution for meeting water shortage that they were in the past. Today, decreasing chances to develop new surface supplies, deficits in the Government budget and increasing concern for tourism, industry and environment make large-scale water projects, i.e., reservoirs and dams unlikely. Concurrently, users of groundwater in many areas are facing dwindling groundwater, low yields, and higher energy costs.

A question of considerable importance to policymakers concerns how farmers will adjust production to rationalize irrigation water in response to less information and data. Updating information to farmers will assist them to adopt more efficient irrigation techniques, convert irrigated land to dry-land farming, shift to crops that use less water, and apply less water per acre for a given technology and crop [7]. Irrigation improvement schemes require data collection and evaluation, planning and design of the scheme, and implementation. Collection data and its evaluation involve collecting information from soil surveys, water analyses, and topographic surveys [8]. The scale of the topographic map depends upon the type of irrigation improvement schemes that are proposed. For example, a surface irrigation scheme requires a more detailed scale due to the precision required for preparing the land. When the surveys and analyses concerning acceptable water quality and suitable soil characteristics are completed, the team can begin the planning and design stage. The cost of the surface irrigation scheme will largely depend on the results of the surveys. Based on the detailed data collected from the surveys, the engineers can begin to plan and design the pumping stations and the layout of the irrigation scheme. Upon completion of the detailed design, the team will begin the implementation of the irrigation scheme [9].

The aim of this chapter is to develop and manage the recent information and data on irrigation technology to promote intensive and sustainable irrigated agriculture and improve food security in Egypt.

2 Data Records

2.1 Data and Records of Irrigator

Taking a sample of irrigators' agricultural and financial records (or a census if the population is small), will allow for conclusions about scheme-level performance.

When comparing the enterprise records kept by the individual irrigators, conclusions about seed rates, fertilizer levels per acre for various crops (i.e., adoption rates) can be executed about irrigators and so can conclusions be made about yields and incomes. Analysis of the scheme level can be done by the agricultural extension worker (AEW) for the scheme and/or by an external evaluation team [10].

2.2 Data and Records of Irrigation Management Advisor (IMA)

In a scheme where irrigators have the responsibility of managing scheme affairs, the IMA will keep records of scheme-level costs and responsibilities. Scheme-level costs kept by the IMA include:

- Energy bills
- Costs of servicing and repair
- Security guard cost
- Replacement costs
- Levies (e.g., subscription fees to irrigation associations, etc.).

These scheme records (fixed costs) will allow for the budgeting of scheme costs per acre. Individual farmers may keep a record of their contributions to these costs in addition repairs and other costs relating to their plots. This will allow for irrigation profit estimating per plot.

The IMA should also keep other records, like the frequency of breakdown of equipment. Monitoring the breakdown frequency, for example, engine breakdown will allow decisions to be made on whether, for example, a new engine should be bought.

The IMA also needs to keep records on the consumption rate of energy. A sudden rise in consumption of the energy rate may indicate that the equipment needs servicing. Servicing equipment in time may prevent costly repairs following equipment breakdown. Records of power failure, where national electricity supply is available, should also be kept.

The IMA may also keep other non-financial records such as, for example:

- List of plot holders
- Gender disaggregation of plot holders
- List of IMA post bearers
- Gender disaggregation of IMA post bearers. These data can be updated as and when the need arises.

They will be useful in monitoring issues, i.e., advancement of women, for example, whether, over time, women access irrigation plots in their own right or hold leadership positions.

2.3 Data and Records of Agricultural Extension Worker (AEW)

The AEW assigned to the scheme may keep the same data as the IMA. This is because the AEW is well placed to communicate the data (should the need arise) to various stakeholders such as the scheme engineer, planners, and other researchers in the scheme [9].

Over and above these data, the AEW will keep records of:

- Crops cultivated in the scheme
- Total area per crop
- Cropping program
- Recommended agronomic practices
- Irrigation infrastructure condition
- Irrigation scheduling
- Details of courses run for committees and farmers and attendance
- Courses attended by the AEW
- Problems encountered, such as disease outbreaks and conflicts.

2.4 Data and Records of Experts

Some data and records of expert, which may have financial implications, must be collected by experts since they are impossible or difficult for farmers to collect. Such data include technical performance such as discharge rate, the assessment of equipment condition, and irrigation infrastructure.

The discharge rate can be taken at the scheme working. Monitoring the discharge rate on a regular basis, for example, yearly, will allow decisions to be made on whether equipment should be kept as it is, or whether it should be serviced or replaced altogether. Estimating the water used volumes can be the means for estimating the scheme efficiency.

Some of the environmental performance data, i.e., soil pH and water pollution, will also need regularly measuring, for example, yearly, throughout the life of the project in order to detect whether there are any changes in quality of water and soil as a result of the project [11].

2.5 Data and Records of the External Evaluators

A team of outsiders working closely with the stakeholders in the scheme can survey irrigators just before they start irrigating their new plots (baseline study).

After that, mid-term evaluation, ex-post evaluation (at the project completion), and impact evaluation (some years after completion) missions should be undertaken.

The missions do not need to be executed by the same team. For example, a mid-term and ex-post evaluation may be commissioned by a donor agency using its staff [9, 10].

Issues to be known in a formal survey include:

- Asset ownership by irrigators
- Family nutritional status
- Ability to pay school fees
- Employment creation
- Food security status
- Disease incidence among irrigating households and the surrounding community.

Farmer organization and management ability, and also the external evaluating team may have informal discussions with various stakeholders and make observations to cover issues such as:

- Advancement of women
- Different linkages with the scheme food security situation of the area
- Appropriateness of the technology, for example, treadle pumps to women
- Erosion
- Waterlogging/drainage problems.

The external evaluating team may also use agricultural and financial data from a sample of farmers and scheme-level data from IMA to cover issues such as:

- Financial viability of the scheme
- Change in irrigators' yields and/or incomes.

3 Data and Information Required for Irrigation

3.1 Crop Evapotranspiration (ET_c)

The main data for crop evapotranspiration which sometimes called crop water consumption or crop water requirement are climatic factors, crop characteristics, management practices, and environmental aspects. The main climatic factors that affect evapotranspiration or water consumptive use are wind speed, solar radiation, air temperature, and air humidity. There are many factors affect crop water consumptive use such as the type of crop, variety and development stages. Moreover, crop resistance differences to transpiration, the height of crop, canopy and characteristics of the crop root system lead to different evapotranspiration in different crops types under normal environmental circumstances.

There are some factors such as fertility lack, the salinity of soil, limited use of fertilizers and chemicals, lack of disease and pest control, poor soil management and finite water availability at the root zone may limit the crop development and reduce evapotranspiration or water consumption. Other factors that affect evapotranspiration or water used are crop population and groundcover. Agricultural practices and the irrigation system type used can change the microclimate, affect the crop attributes or affect the moistening of the soil and crop surface [11, 12]. All these affect crop water consumption or crop evapotranspiration.

3.2 Crop Coefficients

Crop coefficients values over the growing period are represented on the curve of crop coefficient. Only three values of crop coefficients (K_c) are desired to construct and describe the K_c curve: those during the initial stage ($K_{c\text{ini}}$), the mid-season stage ($K_{c\text{mid}}$), and at the season stage end ($K_{c\ \text{end}}$).

The values of $K_{c\text{ini}}$, $K_{c\text{mid}}$, and $K_{c\text{end}}$ for different crops were listed in [13]. The coefficients are organized by group type similar to the way it was done for the growth stages length. There is a close similarity in coefficients among crops that belong to the same crop group because they have similar crop characteristics, i.e., plant height, etc., and water management is normally similar [14].

3.3 Crop Types

The large variation in crop coefficients values between prime groups of crops is due to the lower transpiration of different crops due to close stomata during the day in pineapple crop and waxy leaves in citrus. Also, the differences in ground cover, the height of crop, the roughness of the crop, and produce various crop coefficients values [13].

3.4 Climate

Wind and humidity factors affect crop coefficients where the wind speed changes the crop aerodynamic resistance and their crop coefficients, in particular, for those crops that are taller compared to the grass reference crop. Crop aerodynamic resistance is changing with climate, in particular, relative humidity. Crop coefficient increases when wind speed rises and relative humidity decreases. Higher crop coefficient values produce from more arid conditions and climates that have greater wind speed. However, lower crop coefficient values produce from more humid conditions and climates that have lower wind speed.

Average climatic data were used in estimating the ET_o. Since the weather condition differs from year to year, ET_c will change from year to another and from period to period. Monthly ET_c values can vary from one year to another year by 50% or more. For irrigation projects establishment, the variations with time become very important. When sufficient climatic data are available for 10 years or less, ET_c could be calculated for each year, and a probability analysis could be done. The value of ET_c then selected for design is commonly depend on a probability of 75–80%, which could be similar to the probability of water availability.

Changes in the microclimatic environment should be considered because of the cultivated area. Climatic data are gathered before irrigation progress has taken place and normally the agro-meteorological stations, from which data are taken, are located where there is irrigation development. Irrigation fields will produce a different microclimate and ET_c may not accurate to the predicted values, depend on agro-meteorological data that used. This is more clear for large the cultivated area in arid windy climates [14, 15].

Agro-meteorological elements determining crop water used or evapotranspiration are weather parameters, which give energy for evaporation. The main weather factors to be considered are wind speed, solar radiation, air humidity, and air temperature. Agro-meteorological data are registered at various weather stations. Agro-meteorological stations are sited in cropped areas where instruments are exposed to atmospheric conditions similar to those for the surrounding crops. In these stations, air temperature, sunshine duration, wind speed, and air relative humidity at each site were measured at the height of two meters above the ground surface. The gathered data at stations other than agro-meteorological stations require careful analysis of their validity before use.

In most regions in Egypt, a national agro-meteorological society commonly lists processed climatic data from the different stations and issues agro-meteorological bulletins as a service for the stakeholders. This service should be extended for information on the collected climatic data at various weather stations in Egypt to be used as input data in the FAO Penman-Monteith equation.

The databases can be checked in order to confirm the matching of the existing database. They should be used for preliminary studies as they contain, in general, mean monthly data only and some stations have incomplete data. The information found from the databases should never replace actual long-term data.

3.5 *Data and Records of Water and Soil*

Water used by crop or evapotranspiration of the crop (ET_c) is a combination of transpiration by the crop and evaporation from the soil surface. Crop coefficient is integrated within the variation of soil evaporation and crop transpiration among field crops.

According to FAO [16], if plants are sufficiently established and there are favorable growing conditions, i.e., available nutrients and water, soil aeration, etc., the ET_c is not affected, even when rooting depth is severely restricted. However, the following conditions must be considered:

Table 1 General soil data of heavy texture (clayey soil)

Parameters	
Total available soil moisture (FC-WP)	200.0 mm/m
Maximum rain infiltration rate	40 mm/day
Initial soil moisture depletion	0%
Initial available soil moisture	200.0 mm/m

Available soil water: The soil water content effect on crop water used or evapotranspiration varies with the crop and is conditioned primarily by the soils type and characteristics of water retention, characteristics of crop root and the agro-meteorological factors determining the transpiration. When evaporative conditions are lower, the crop may transpire at the predicted evapotranspiration rate even though available soil water depletion is greater. Evapotranspiration of crop or water used by the crop will be reduced if the rate of water supply to the roots zone is unable to commensurate with transpiration losses. This is more clear in heavy textured compared with light textured soils.
Groundwater: Because crop growth is influenced by a shallow water table, the ET_c is also affected.
Salinity: evapotranspiration of the crop or water consumption is affected by soil salinity, as the absorption of the crop to the added irrigation water into the soil salinity is reduced due to the higher osmotic potential of saline soil water.
Water and crop yield: Various crops have different critical periods for soil water stress. Therefore, the timing and duration of the shortage are important and associated with the yield.

General soil data of heavy texture such as total available soil moisture (field capacity (FC), welting point (WP), maximum rain infiltration rate, initial soil moisture depletion, and initially available soil moisture are presented in Table 1.

3.6 Stages of Crop Growth

The crop coefficient for a given crop changes during the growing period as the groundcover, crop height, and leaf area changes. Four growth stages are recognized for the selection of crop coefficient: an initial stage, crop development stage, mid-season stage, and stage of the late season [10].
Crop coefficient and the calculation of ET_c:

- Crop growth stages identification, determination of their lengths, and selection of the corresponding K_c values
- Adjustment of the selected K_c values for moistening frequency or climatic conditions during each stage

- Crop coefficient curve creation that allows one to determine K_c values for any period during the growing period
- Calculation of ET_c from reference evapotranspiration and crop coefficient.

4 Evapotranspiration Concepts

4.1 Crop Evapotranspiration and Irrigation Requirements

Evapotranspiration of crop, which called crop water requirement (CWR) or water consumption of crop, describes the gross water used by crop or evapotranspiration [14]. Defined crop water requirements as 'the depth of water required to meet the water loss resulted from evapotranspiration of crop or water consumptive use, being disease-free, growing in the fields under normal conditions, comprising soil fertility, soil water content, and achieving full production potential under the growing environment. The use of computer software for the estimation of ET_c or CWR will be explained later.

Irrigation requirements (IR) refer to the water that must be supplied through the irrigation system to guarantee that full evapotranspiration of the crop or water consumption of the crop was received. If some other water sources are used by crops such as rainfall, lateral and underground seepage, and water stored in the soil, and then the irrigation requirement can be considerably less than the evapotranspiration of the crop or water consumption of the crop.

4.2 Irrigation Scheduling

When evapotranspiration of crop and irrigation requirements have been calculated, the coming process is the preparation of field irrigation schedules. There are three parameters have to be taken into consideration in preparing an irrigation schedule:

- The daily evapotranspiration of the crop or water consumption of the crop.
- The soil, in particular, total available moisture content or water-holding capacity.
- Depth of the efficacious root zone. Response crop to irrigation is affected by the soil fertility, soil biological status, and chemical and physical condition of soil. Soil conditions having depth, organic matter, texture, structure, bulk density, salinity, sodicity, drainage, topography, fertility, and chemical characteristics all affect the extent to which a crop root system penetrates into the soil and uses available moisture and nutrients. These factors affect the water movement, the ability of soil to retain water, and the ability of the crops to use the water. The irrigation system should be commensurate with most of these conditions.

The estimated values for available soil water content and intake have wide ranges. The soil database values need to be constantly refined to appropriate the field conditions. In the field, the actual value may differ from location to another, season-to-season, and even within the season. Within the season, it varies based on the farm type and equipment tillage type, tillage operations a number, management of the residue, and crop type and water quality. Adequate surface drainage is necessary for the irrigated soil. Internal drainage in the crop root zone can be natural or from an installed mole drainage system.

4.3 Reference Evapotranspiration (ET_o)

After all the parameters of the FAO Penman-Monteith equation have been determined, it is now possible to calculate ET_o. For Sakha Agricultural Research Station, these calculated values are shown in Table 2 in Chap. 8. From this table, it can be seen that the peak ET_o at north delta area is 5.69 mm per day and it occurs in June, if calculated manually through an equation of the FAO Penman-Monteith [17, 18].

The manual calculation of ET_o is a long and tedious procedure, and the risk of making arithmetical errors is fairly high. A computer program has been developed to accelerate the calculations and make them less tedious to perform. One such software is the FAO CROPWAT computer program for estimating reference evapotranspiration (ET_o) and evapotranspiration of the crop. At this stage, it is only important to compare the monthly reference evapotranspiration values obtained through manual calculations with those obtained using CROPWAT. From the climatic data in Table 2 for Sakha Agricultural Research Station, ET_o was estimated with CROPWAT Version 8.0.

5 Calculation of Crop Water and Irrigation Requirements Using Computer Software

5.1 Model of the FAO CROPWAT

CROPWAT is a program that can calculate evapotranspiration of crop or water consumption of crop and irrigation requirement from data of crop and climatic. The program is interactive. Besides, the model allows the irrigation schedules development for various management conditions and the project water supply estimation for varying cropping patterns.

Model of the CROPWAT is depending on a model of water balance where the soil moisture level is determined on a daily basis from calculated evapotranspiration and inputs of rainfall and irrigation. Methodologies for water consumption of crop

Table 2 Monthly ET_o Penman-Monteith data

Country: Egypt				Station: North Delta (SAKHA)			
Altitude: 20 m				Latitude: 31.11° N Longitude: 30.95			
Months	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (m/s)	Sun (h)	Rad (MJ/m^2/day)	ET_o (mm/day)
January	6.0	19.3	84	1.30	6.2	11.4	1.54
February	6.2	20.5	82	1.40	6.9	14.2	2.03
March	7.8	23.0	73	1.70	7.8	18.1	3.04
April	10.3	27.0	62	1.51	8.7	21.6	4.15
May	14.1	31.1	54	1.51	9.6	24.1	5.23
June	17.0	32.0	58	1.51	10.8	26.1	5.69
July	19.0	34.0	63	1.30	10.5	25.5	5.66
August	18.3	33.5	67	1.30	10.2	24.2	5.27
September	17.6	32.0	71	1.10	9.5	21.0	4.31
October	15.5	29.8	73	1.00	8.5	16.9	3.24
November	12.5	25.8	77	1.10	7.3	12.9	2.25
December	8.2	21.5	84	1.10	5.9	10.4	1.54

or evapotranspiration of crop and yield response to irrigation water are used, while the actual evapotranspiration is determined from the available soil water status.

Monthly climatic data use in the program. Data of monthly climatic variables are temperature, wind speed, sunshine hours, relative humidity, and rainfall for the calculation of reference evapotranspiration. It also has four different methods to calculate effective rainfall but to be capable of doing this it requires dependable rainfall as input.

Through the input of crop data, i.e., growth stages, K_c factors, depth of root zone, and admissible soil moisture deficit factor, the program calculates the crop evapotranspiration on a decade basis (10 days).

The application of CROPWAT in calculating crop evapotranspiration and irrigation requirement is best illustrated by using an example of irrigated areas for smallholder in Egypt, as is shown later. In typical smallholder irrigation schemes in Egypt, each farmer is allocated on average a plot of between 0.5 and 1.5 acres. Smallholder farmers normally prefer to grow from two to four crops per season to obtain crops variety for home consumption, to allow agronomic considerations (rotations) and to spread their risk when it concerned with marketing.

5.2 Program of Crops Sequence or Rotation

This program is the initial step in calculating crop evapotranspiration, depend on the system capacity or the area to be completed by irrigation is determined. With the full participation of farmers, a selection of what crops to grow in summer and winter, respectively, is made. Factors to be taken in our consideration in crop selection include farmers' wishes and aspirations, financial considerations, climate and soils, water availability, labor requirements, marketing aspects, availability of inputs, rotational considerations, and susceptibility to diseases. These factors are normally sited specific.

Once the crops are selected, a cropping program showing the seasonal cropping patterns and indicating the place and the occupying area for each crop is made. Of importance are the sowing or transplanting dates, the growing season length and the needed time for crop harvest and soil preparation for the coming crop. It must be noted that the needed time for harvest and preparation of soil ought not to be included when estimating the evapotranspiration of the crop. It is, therefore, useful to indicate on the cropping program diagram the needed time to harvest.

In order to decrease the risk of pests and diseases and to avoid elimination of certain nutrients through plant uptake, the cropping program should allow the sequence of the crops among the subplots. Vegetables such as cabbages, carrots, onion, and field crops like wheat, maize, groundnuts, cotton, and beans could safely be planted on the same subplot every two years.

Cropping programs are not fixed, and they belong to the farmers. This should be considered when planning the system of irrigation. For design purposes, a cropping pattern should be made in such a condition that the water requirements for other crops that the farmer intends to grow could be satisfied. This includes a careful study of all points mentioned above and detailed discussions with the farmers.

5.3 The Efficacious Rainfall and the Reference Crop Evapotranspiration (ET_o) Calculation

The next stage is to input data on climatic variables, which are wind speed, temperature, relative humidity, sunshine hours, and rainfall into CROPWAT, to calculate the effective rainfall and the reference crop evapotranspiration. The required data concerning climatic variables for input into CROPWAT are normally contained in climatic handbooks issued by a national meteorological institution in Egypt. Alternatively, different climatic data files on disk saved after earlier sessions or from the CLIMWAT database [18] can be applied for calculating ET_o and effective rainfall. The input of relevant climatic data and dependable rainfall for Sakha climatic station result in computer printouts such as presented in Table 3. Method of the USDA Soil Conservation is used for the estimating of the efficacious rainfall from the gross rainfall.

Table 3 Effective rainfall method: USDA S.C. method

Months	Rainfall (mm)	Effective rainfall (mm)
January	17.0	16.5
February	13.0	12.7
March	5.0	5.0
April	5.0	5.0
May	2.0	2.0
June	0.0	0.0
July	0.0	0.0
August	0.0	0.0
September	0.0	0.0
October	3.0	3.0
November	8.0	7.9
December	12.0	11.8
Total	65.0	63.8

Not all the dependable rainfall is effective because it may be lost through evaporation, deep percolation or surface runoff. Only a portion of the rainfall can be effectively used by the crop, depending on the depth of root zone and the capacity of soil storage. Different methods exist to estimate the effective rainfall and the reader is referred to [16] for details.

One of the most commonly used methods is the method of the USDA Soil Conservation Service. The relationship between mean monthly effective rainfall and mean monthly rainfall is shown for different average monthly ET_c.

Depending on the cropping program adopted, the coming step is to enter the crop data into CROPWAT to enable the program to estimate crop water consumption or evapotranspiration of crop for the various crops. The crop data required is the crop planting dates, values of the crop coefficient at the various growth stages, growth stages length, depth of the crop roots at the different growth stages are given in Table 4, the allowable soil moisture deficit or depletion levels and the yield response factors (K_y). K_y is a factor to estimate yield reductions because of water stress condition [19].

This information should be based on local data, obtained through surveys or recommendations of agriculture research stations and extension service in each site. The agro-methodologies for estimating the above crop data should be accomplished. CROPWAT also contains data files for 30 different crops, based on global values, which can be recovered and adjusted for local conditions.

After the input of the crop data, CROPWAT proceeds to calculate the evapotranspiration of crops and irrigation requirement of the given cropping pattern, using the entered crop data and the ET_o and values of effective rainfall calculated earlier. The calculation of evapotranspiration of crop or consumption is done on a decade (10 days

Table 4 Maize crop data

Stage	Initial	Develop	Mid	Late	Total
Length (days)	15	35	40	30	120
Kc Values	0.30	→	0.20	0.35	
Rooting depth (m)	0.30	→	1.00	1.00	
Critical depletion	0.55	→	0.55	0.80	
Yield response f.	0.40	0.40	1.30	0.50	1.25
Crop height (m)			2.00		
Planting date: 06/06					
Harvest: 30/10					

period) basis. For reasons of simplicity, all months are taken to have 30 days, subdivided into three decades of ten-day each. The mistake caused by this assumption is negligible.

After setting up the crop coefficient curve, the next process is the calculation of evapotranspiration of crop or consumption. The crop coefficient value can be determined for any period during the growing period of the crop coefficient curve. Once the crop coefficient values have been defined, the evapotranspiration of the crop can be calculated by multiplying the crop coefficient values for the corresponding reference evapotranspiration values are shown in Table 5

Table 5 Crop water requirements

ETo station: SAKHA (North Delta)				Crop: Maize (Grain)			
Rain station: SAKHA				Planting date: 06/06			
Month	Decade	Stage	Kc coeff	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. req. mm/dec
Jun	1	Init	0.30	1.66	8.3	0.1	8.2
Jun	2	Init	0.30	1.71	17.1	0.0	17.1
Jun	3	Deve	0.44	2.50	25.0	0.0	25.0
Jul	1	Deve	0.69	3.93	39.3	0.0	39.3
Jul	2	Deve	0.95	5.36	53.6	0.0	53.6
Jul	3	Mid	1.17	6.45	70.9	0.0	70.9
Aug	1	Mid	1.19	6.42	64.2	0.0	64.2
Aug	2	Mid	1.19	6.27	62.7	0.0	62.7
Aug	3	Mid	1.19	5.89	64.8	0.0	64.8
Sep	1	Late	1.11	5.15	51.5	0.0	51.5
Sep	2	Late	0.84	3.62	36.2	0.0	36.2
Sep	3	Late	0.56	2.21	22.1	0.1	22.0
Oct	1	Late	0.38	1.36	4.1	0.2	3.8

Monthly, ten-day or weekly values for crop coefficient are necessary when ET_c calculations are prepared on a monthly, ten-day, or weekly time basis, respectively. A general procedure is to establish the K_c curve, overlay the curve with the length of the weeks, decades or months and to obtain graphically from the curve the K_c value for the time under consideration.

The CROPWAT computer outputs, showing the irrigation needs or requirements for the various crops in the cropping program, have to be combined to get the irrigation requirements of all crops together, and which are irrigated at the same time. In addition, the corrected water consumption of crop for the months of peak demand must be calculated in order to present the crop and irrigation needs or irrigation requirement in a comprehensive way and allow the correction for peak demand, a summary table should be composed showing on a monthly basis the ET_o, the effective rainfall, the corrected ET_c, the irrigation requirements, expressed in mm, as well as the total requirements, expressed in m^3.

A properly designed, constructed and operated irrigation system shall not have effect on ET_c, with the exception of localized irrigation. Hence, the variation in the amount of water that applied for irrigation under the one or the other method was not attributed to the effect of the method on ET_c, but to the corresponding efficiency being achieved under the one or the other method localized irrigation (drip, spray jet, etc.) only moisten part of the soil and since evapotranspiration includes plant transpiration and the evaporation from the soil, the overall ET_c should be expected to be less under localized irrigation systems. However, ET_c is not affected by the method when the crop is near or at full groundcover. For the period before 70% groundcover reduced ET_c should be expected, since evaporation is limited to the wet areas of the soil only.

As for cultural practices, the used fertilizers have only a slight effect on ET_c, as long as the nutrient requirements for most favorable growth and yield are provided. The crop density will affect ET_c in the same way as percentage groundcover. For low plant populations, when the soil in the area in-between the rows is kept dry, the evaporation will be less, and thus ET_c will be less to a higher crop population. Tillage produces little, if any, the effect on ET_c. Rough tillage will accelerate evaporation from the plow layer, and deep tillage increases water losses when the land is fallow or when the crop cover is sparse. As far as mulching is concerned, while polyethylene and asphalt mulches are effective in reducing ET_c, residues of the crop are often considered of little net benefit in reducing ET_c. Crop residues as a barrier to soil evaporation are ineffective in irrigated agriculture. According to FAO [13, 14], the lower temperature of the covered soil and the higher reflective capacity of the organic matter are easily outweighed by evaporation of the often re-wetted residue layer. Windbreaks, relying on the distance covered and the height of the windbreak can reduce ET_c by 5–30% in windy, warm, and dry climate because of their effect on wind velocity. Anti-transpirants have been used in research for the reduction of ET_c. Their use has so far been limited to research and pilot projects.

5.4 Net Irrigation and Irrigation Requirements

A properly designed, constructed and operated irrigation system will not have any effect on ET_c, with the exception of localized irrigation. Hence, the variation in the water amount that used for irrigation under the one or the other method was not attributed to the effect of the method on ET_c, but to the corresponding efficiency being achieved under the one or the other method localized irrigation such as drip, spray jet, etc., only wets part of the soil and since evapotranspiration includes plant transpiration and the evaporation from the soil, the overall ET_c should be expected to be less under localized irrigation systems. However, ET_c is not affected by the method when the crop is near or at full groundcover. For the period before 70% groundcover reduced ET_c should be expected, since evaporation is limited to the wet areas of the soil only. Predicted values, depend on agro-meteorological data. This is more pronounced for large cropped areas in arid and windy climates. As for water requirements versus irrigation requirements, it is important to make a distinction between crop water requirement (CWR) which called evapotranspiration of the crop or water consumption of crop and irrigation requirement (IR). Whereas CWR refers to the water used by crops for the construction of cells and transpiration, the irrigation requirement is the irrigation water that has to be applied through the irrigation system to ensure that the crop receives its full water requirement. If the source of water supply is sole irrigation for the crop, then the irrigation requirement will be at least equivalent to the crop water requirement and is generally greater to allow for inefficiencies in the irrigation system. If the crop receives other sources of water, i.e., rainfall, lateral and underground seepage, water stored in the soil, etc., and then the irrigation requirements can be less than the crop water requirement.

The net irrigation requirement (IR_n) does not have losses that are occurring during the irrigation process. IR_n and losses consist of the gross irrigation requirement (IR_g). It is significant to realize that the estimation of crop evapotranspiration or water consumption is the initial process in the estimation of irrigation requirements of a given cropping program. Importance of calculating irrigation requirements and the crop evapotranspiration or water consumption for a proposed cropping pattern is a necessary portion of an irrigation system establishment.

The irrigation requirement (IR) is one of the main parameters for the operation of irrigation and water resources systems. Detailed information of the irrigation requirement quantity and its temporal and spatial variability is essential for evaluating the adequacy of water resources, for assessing the need of reservoirs of storage, and for the determining the capacity of irrigation systems. It is of prime importance in the policy formulation for the optimal water resources allocation as well as in decision making concerning operation and management of irrigation systems.

Incorrect estimation of the irrigation requirement causes serious problems in the performance and to the waste of valuable water resources. It leads to disadvantageous control concerning the soil moisture deficit in the root zone; it causes water logging due to the shallow water table, salinity or leaching of nutrients from the soil. It may lead to the inappropriate ability of the irrigation network or reservoirs of storage, to reduce field water use efficiency or water productivity and to a reduction in the irrigated area. Overestimating irrigation requirement at peak demand may also lead to increasing development costs.

The net irrigation requirement is derived from the field balance equation:

$$\mathrm{IR}_n = \mathrm{ET_c} - (P_e + G_e + W_b) + \mathrm{LR\,mm} \quad (1)$$

where:

IR_n Net irrigation requirement in mm
ET_c Crop evapotranspiration in mm
P_e Effective dependable rainfall in mm
G_e Groundwater contribution from water table in mm
W_b Water stored in the soil at the beginning of each period in mm
LR Leaching requirement in mm

In most situations encountered in the planning of smallholder irrigation schemes at Nubaria site in the summer season, the project sites are located in dry areas with no rainfall. Hence, for planning purposes, the contribution of water stored in the soil is not considered in such schemes.

Crop evapotranspiration or water consumption can be partially covered by rainfall in the winter season. However, while the rainfall contribution may be substantial in a few years, in other years, it may be limited. Therefore, in establishing irrigation projects, the average values of rainfall that used should be avoided if more than 10 years of annual rainfall data are available, as is the case for Sakha Agriculture Research Station as presented in Table 3. In such cases, by using these data, a probability analysis can carry out so that a dependable level of rainfall is selected. The reliable rainfall is the rain that can be accounted for with a certain statistical probability, determined from a historical rainfall records. Before one carries out statistical analysis, it is always important to check with the meteorological station.

In most situations encountered in the planning of small-scale irrigation projects in winter season at North Delta, the cropped area sites that are located in dry areas with very low rainfall. Hence, for planning purposes, the water stored contribution in the soil is considered negligible in such areas.

It should be realized that the calculation of evapotranspiration of the crop or water consumption for crop and irrigation requirement is a theoretical exercise, based on statistical analysis of climatic parameters. However, climatic variables are unsteady. Consequently, the calculation of irrigation water requirements at the planning level can only be an approximation and it is not appropriate or recommended to attempt detailed accuracy.

Crop irrigation schedule is tabulated in Table 6 and Fig. 1, where for each maize crop data input is presented together with the corresponding water consumption for a crop called evapotranspiration of crops and irrigation requirements as calculated by CROPWAT.

The result of the totals is shown in Table 7 where maize crop is shown together

Table 6 Crop irrigation schedule

Date	Day	Stage	Rain (mm)	K_s fraction	ET_a (%)	Depl. (%)	Net Irr. (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
9 Jul	34	Dev	0.0	1.00	100	55	85.7	0.0	0.0	107.1	0.36
29 Jul	54	Mid	0.0	1.00	100	58	115.6	0.0	0.0	144.5	0.84
16 Aug	72	Mid	0.0	1.00	100	57	114.7	0.0	0.0	143.4	0.92
5 Sep	92	End	0.0	1.00	100	58	115.6	0.0	0.0	144.5	0.84
3 Oct	End	End	0.3	1.00	100	43					

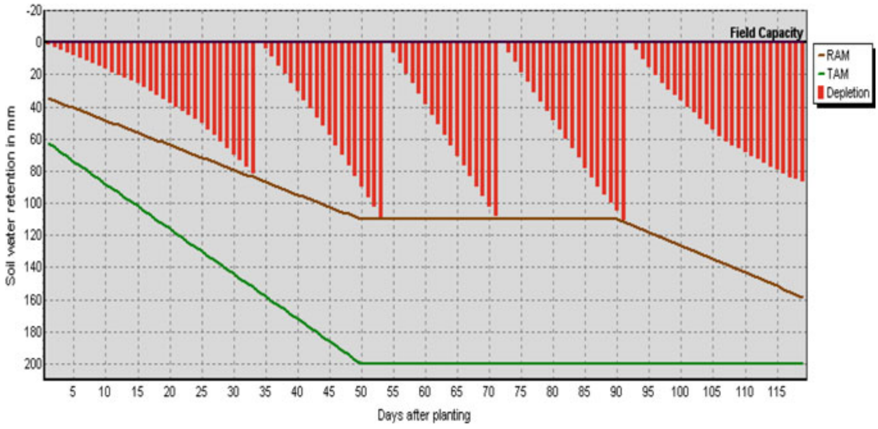

Fig. 1 Crop irrigation schedule

Table 7 Totals

Total gross irrigation	539.4 mm
Total rainfall	0.5 mm
Total net irrigation	431.6 mm
Effective rainfall	0.5 mm
Total irrigation losses	0.0 mm
Total rain loss	0.0 mm
Actual water use by crop	518.4 mm
Moist deficit at harvest	86.4 mm
Potential water use by crop	518.4 mm
Actual irrigation requirement	517.9 mm
Efficiency irrigation schedule	100.0%
Efficiency rain	100.0%
Deficiency irrigation schedule	0.0%

with the corresponding crop evapotranspiration or water consumption and irrigation requirements as calculated by CROPWAT 8.0.

The CROPWAT 8.0 model can be used for scheduling a single crop or multiple crops in the same scheme, thereby estimating water requirements for the same irrigation management. The combination of climatic analysis, soils types, and water use modeling provides an excellent opportunity for matching water needs to appropriate crops in different regions.

6 Detailed Assessment and Specific Data for the Pilot Areas

A detailed assessment of the irrigation, drainage, and soil conditions in the tertiary irrigation canal (mesqa) will be completed and the data analyzed at representative sites within each mesqa. This information is needed to identify specified problems within the area. The following activities are considered.

6.1 Soil Sampling

- At selected sites within each pilot area, soil samples will be taken at the following depths; 0–15 cm; 15–30 cm; 30–60 cm; and 60–120 cm.

6.2 Soil Analysis

Each soil sample will be analyzed for the following:

- Physical properties
- Electrical conductivity (EC)
- SAR (calculated)
- pH
- Nitrate-Nitrogen (NO_3)
- Phosphorus (P) (0–15 cm layer only)
- Organic matter (0–15 cm layer only)
- Trace elements (Ni, Pb, Cd, Cr, and Co) (0–15 cm layer only), and
- Heavy metals (Zn, Mn, Fe, Hg) (0–15 cm, layer only).

6.3 Water Balance Calculation

- Measure the amount of irrigation water pumped from the mesqa to the pilot area and selected farms;
- Measure the amount of surface drainage water from the pilot area and the selected farms;
- Measure the subsurface drainage discharge from the pilot area and the selected farms; and
- Calculate the current water balance for the pilot area.

6.4 Groundwater Monitoring

– Water table observation wells will be installed at selected sites, and located midway between two subsurface drainage laterals. These observation wells are needed to measure groundwater fluctuations in each field. Each well will be 2.0 m in length, with 0.25 m above ground level. The bottom of each well will be plugged, and a tight-fitting cap installed on the top. Each well will be slotted from the bottom to within 0.25 m of the ground surface. Each well will be sealed at ground surface to stop surface water from flowing down the side of the well.

6.5 Irrigation and Groundwater Analysis

The irrigation water at the inlet to the pilot area plus groundwater samples from the observation wells will be analyzed for the following:

– EC
– SAR (calculated)
– pH
– Nitrate-Nitrogen (NO_3)
– Fecal Coliform bacteria
– Selected pesticides commonly applied in the region
– Trace elements (Ni, Pb, Cd, Cr, and Co), and
– Heavy metals (Zn, Mn, Fe, Hg).

6.6 Analysis of Surface and Subsurface Drainage

Surface drain water will be sampled at the site where the surface drainage system leaves the pilot area. Subsurface drainage water will be sampled at the collector drain manhole located closest to the downstream end of the mesqa. All water samples will be analyzed for the following:

– EC
– SAR (calculated)
– pH
– Nitrate-Nitrogen (NO_3)
– Fecal Conform bacteria
– Selected pesticides commonly used in the region
– Trace elements (Ni, Pb, Cd, Cr, and Co), and
– Heavy metals (Zn, Mn, Fe, Hg).

Based on an assessment of data from; the existing information; Environmental and Soil Baseline Survey and the detailed pilot area analysis; the specific irrigation; drainage; soil, environmental, and groundwater problems within each irrigation canal (mesqa) will be identified. This will be executed in close consultation with the farmers.

7 Conclusions

The required new knowledge, data and information for irrigation, evapotranspiration concepts, and computer software is vital to calculate evapotranspiration of crop and irrigation requirements. Furthermore, a detailed assessment and specific information for the experimental areas for irrigation schemes to update information and data on irrigation technology to promote intensive and sustainable irrigated agriculture and improve food security and support decision making in Egypt.

8 Recommendations

Development and recent data provide Egypt with a planning tool for rational exploitation of developing and manage recent information and data concerning soil, crops and water resources. This planning is intended to lead to an increase in crop production for local consumption, as well as promote the production of high-value crops. The planning tool will support decision making with direct regard to:

- Establishing agro-ecological zones (AEZ) maps
- Identifying water availability and selection of potential irrigation areas
- Identifying criteria for crop selection and estimated water requirements
- Identification of the most favorable regions to develop irrigation management practices
- Giving priority to irrigation water distribution
- Organization and control of irrigation supply management
- Developing irrigated agriculture in small, medium and large-scale projects on old and new lands. Further, decision making will be made with regard to:
  - Supporting the national policy options for irrigation water distribution.
  - Upgrading the Egyptian agricultural production.
  - Recommending options for water harvesting and storage in the coastal regions.
  - Suggesting solutions for mismanagement.
  - Identifying energy requirements for irrigation systems.

References

1. El-Bably A (2015) Advanced irrigation technology for enhancing field water use efficiency and precision irrigation for rice (a case study-Egypt). In: 26th ICID Euro mediterranean regional conference innovate to improve irrigation performance, at the occasion of the 66th international executive council of the international commission of irrigations and drainage (ICID) Montpellier, France, 11–16 Oct 2015
2. Abd El-Hafez SA, El-Bably AZ (2006) Irrigation improvement project (IIP). On-farm water management (ofwm), Kafr El-Sheikh and El-Behira Directorates, Final report
3. Vanino S, Nino P, De Michele C, Falanga Bolognesi S, D'Urso G, Di Bene C, Pennelli B, Vuolo F, Farina R, Pulighe G, Napoli R (2018) Capability of sentinel-2 data for estimating maximum evapotranspiration and irrigation requirements for tomato crop in central Italy. Remote Sens Environ 215:452–470. https://doi.org/10.1016/j.rse.2018.06.035
4. Njoh AJ (2018) The relationship between modern information and communications technologies (ICTs) and development in Africa. Util Policy 50:83–90. https://doi.org/10.1016/j.jup.2017.10.005
5. Car NJ (2018) USING decision models to enable better irrigation decision support systems. Comput Electron Agric 152:290–301. https://doi.org/10.1016/j.compag.2018.07.024
6. Knapp T, Huang Q (2017) Do climate factors matter for producers' irrigation practices decisions? J Hydrol 552:81–91. https://doi.org/10.1016/j.jhydrol.2017.06.037
7. Ministry of water resources and irrigation (MWRI) (2008) Monitoring and evaluation of an irrigation improvement project-report in W10 command area in Kafr El-Shiekh, Egypt
8. National Water Research Center (2013) Designing Local Framework for Integrated Water Resources Management Project, 1st Technical Report, pp 10–15
9. Fulazzaky MA, Akil H (2009) Development of data and information centre system to improve water resources management in Indonesia. Water Resour Manag 23:1055–1066
10. FAO (2002) Crop water requirements and irrigation scheduling. Irrigation Manual 4, Harare, Zimbabwe
11. FAO (2002) Monitoring the technical and financial performance of an irrigation scheme. Irrigation Manual 14, Harare, Zimbabwe
12. Jordans E (1998) Sector guide irrigation. Socioeconomic and gender analysis programme, FAO, SEAGA: Rome, Italy
13. Richard A, Pereira L, Raes D, Smith M (1998) Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO: Rome, Italy
14. Doorenbos J, Pruitt WO (1984) Crop water requirements. FAO Irrigation and Drainage Paper 24. FAO: Rome, Italy
15. Sharma K (2009) Application of the climate information and prediction in the water sector: capabilities. National Rainfed Area Authority, New Delhi, India
16. Smith M (1992) CROPWAT: a computer programme for irrigation planning and management. FAO Irrigation and Drainage Paper No. 46. FAO: Rome, Italy
17. El-Bably AZ (2007) Irrigation scheduling of some maize cultivars using class a pan evaporation in North Delta. Egypt. Bull Fac Agric, Cairo Univ 58:222–232
18. Smith M (1993) CLIMWAT for CROPWAT: a climatic database for irrigation planning and management. FAO Irrigation and Drainage Paper 49. FAO: Rome, Italy
19. Doorenbos J, Kassam AH (1986) Yield response to water. FAO Irrigation and Drainage Paper 33. FAO: Rome, Italy