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# IRRIGATION SCHEDULING CALCULATOR (ISC) TO IMPROVE WATER MANAGEMENT ON FIELD LEVEL IN EGYPT

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**Abstract.** The developed model is MS excel sheet called "Irrigation Scheduling Calculator, ISC". The model requires to input daily weather data to calculate daily evapotranspiration using Penman-Monteith equation. The model calculates water depletion from the root zone to determine when to irrigate and how much water should be applied. The charge from irrigation pump is used to calculate how many hours should the farmer run the pump to deliver the needed amount of water. ISC model was used to developed irrigation schedule for wheat and maize planted in El-Gharbia governorate. The developed schedules were compared to the actual schedules for both crops. Furthermore, CropSyst model was calibrated for both crops and run using the developed schedules by ISC model. The simulation results indicated that the calculated irrigation amount by ISC model for wheat was lower than actual schedule by 6.0 mm. Furthermore, the simulated wheat productivity by CropSyst was higher than measured grain and biological by 2%. Similarly, the calculated applied irrigation amount by ISC model for maize was lower than actual schedule by 79.0 mm and the productivity was not changed.

**Keywords:** *CropSyst model, evapotranspiration, maize, Penman-Monteith equation, wheat.*

## Introduction

Water resources in Egypt are becoming limited and scarce. It was reported by the Ministry of Irrigation and Water Resources in Egypt in 2014 that Egypt will reach the threshold of absolute scarcity, which account for 500 $m^3$/capita/year in 2025. Egypt received 55.5 BCM/year of Nile water. This limited share of the Nile water is not expected to increase in the future. Taking into account population growth and the expected negative effect of climate change, Egypt will face a problem to allocate water to agriculture to maintain food security. Agriculture water demand is one of the serious pressures on water sector in Egypt, since 85% of total available water is consumed in agriculture and most of the on-farm irrigation systems are low efficient coupled with poor irrigation management (Abou Zeid, 2002). Katerji and Rana (2008) indicated that excess irrigation water application causes both waste of water and negative impacts on economic, social and environmental levels. Irrigation water management becomes increasingly important in the presence of the expected low water supplies in Egypt. Thus, a correct knowledge of crop evapotranspiration allows improved water management by changing the volume and frequency of irrigation to meet crop requirements and to adapt to soil characteristics. In order to avoid the underestimation or overestimation of crop water consumption, knowledge of the exact water loss through actual evapotranspiration is necessary for sustainable development and environmentally sound water management (Irmak, A., Irmak, S., 2008).

Reference evapotranspiration (ETo) is a key component in irrigation scheduling. Various equations are available for estimating potential evapotranspiration. The Penman-Monteith equation is widely recommended because of its detailed theoretical base and its accommodation of small time periods. It was also indicated that the Penman-Monteith method exhibited excellent performance in both arid and humid climates (Shahidian *et al.*, 2012). Crop water consumptive use (WCU), it is also defines as crop evapotranspiration (ETc) consists of two components, namely ETo and crop coefficients (Kc). ETo is the total amount lost from the field by both soil evaporation and plant transpiration (Allen *et al.,* 1998). Accurate estimation of ETo is an important factor to attain prop water management. On the other hand, the Kc takes into account the relationship between atmosphere, crop-physiology and agricultural practices (Katerji, Rana, 2008). Reddy *et al.,* (2015) indicated that the values of Kc for most agricultural crops increase from a minimal value at planting to a maximum Kc value near full canopy cover or pollination. Generally speaking, Kc is defined as the ratio between crop evapotranspiration (ETc) and ETo, from a well-water (not limiting) reference surface (Katerji, Rana, 2008).

Irrigation scheduling involves making a decision on how much and when to apply irrigation water. Mohamed and Makki, (2005) indicated that the decision on when and how much water to apply is influence: water needs by the crop, water availability, and water holding capacity of the soil. Irrigation scheduling has conventionally aimed to achieve an optimum water supply for productivity, with soil water content being maintained close to field capacity (Tariq, Usman, 2009). Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level, thus saves water and energy (Pereira *et* *al.*, 2003). Irrigation scheduling minimizes water-logging problems by reducing the drainage requirements and control root zone salinity problems through controlled leaching (Laghari *et al.,* 2008).

Several models for irrigation scheduling existed in the literature, such as CROPWAT (Smith *et al*., 2002), ISM model (George *et al*., 2000), ISAREG model (Pereira *et al.,* 2003), BISm (Snyder *et al.*, 2004) and Mehran model (Lashari *et al.*, 2010). Both CROPWAT (Smith *et al*., 2002) and BISm (Snyder *et al*., 2004) are easy to be used by researchers. However, for extension workers, it requires technical education may not be acquired by the Egyptian extension workers. It is recognized, however, that the adoption of appropriate irrigation scheduling practices could lead to increased yields and greater profit for farmers, significant water savings, reduced environmental impact of irrigation and improved sustainability of irrigated agriculture. Consequently, there is a need to better identify the factors that could enhance the adoption of appropriate irrigation scheduling practices, favor the transfer of technology from research to farmer fields (Tariq, Usman, 2009). Thus, developing a model to easily calculate ETo, ETc, water depletion from root zone and schedule irrigation to be used by extension workers is very essential. Such a model can improve irrigation water management by farmers for cultivated crops and reduce water losses through deep percolation.

Crop simulation models are the dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers (Matthews *et al*., 2000). CropSyst model (Stockle *et al.*, 1994) is an example of these models. The model is a process based simulation model. It uses the same approach to simulate the growth and development of potentially all herbaceous crops. This makes CropSyst easier to be calibrated and a reduced set of crop parameters is needed. In Egypt, the model was applied on some crops, namely wheat grown in clay soil (Khalil, *et al.*, 2009) and wheat in sandy soil (Ouda *et al.*, 2014). The model was also validated for maize yield (Ouda *et al.*, 2009).

The objective of this research is to use MS Excel sheet capability to develop a program to schedule irrigation under surface irrigation. Farmers in Egypt tend to apply large amount of irrigation water. Therefore, farmers need guidance from extension workers to inform them when to irrigate and how much water they should apply. Instruction on how many hours to run the irrigation pump to apply the amount of irrigation water is also calculated.

## Materials and Methods

### *Model description*

The model is a MS Excel sheet and called "Irrigation Scheduling Calculator, ISC". The model performs water balance computations by estimating the input and output quantities of water to the soil reservoir as presented in (Allen *et al*., 1998). The model was designed to schedule irrigation for crops grown under surface irrigation. The inputs of the model by the user are:

1. Daily weather data (maximum and minimum temperature (°C), mean relative humidity (%), wind speed (m/sec) and solar radiation ($MJ/m^2/day$)).
2. Elevation above sea level (m).
3. Soil available water (m/m).
4. The depth of the root of the cultivated crop (m) at each Kc stage.

The model calculates daily values of ETo using Penman-Monteith equation (Allen *et al*., 1998). The model calculates ETc by multiplying crop Kc (provided in the data base of the model) by the calculated value of ETo. It is recommended that the farmer applied the first irrigation as appropriate. This recommendation based on the fact that the soil stayed fallow for long period of time after harvesting of the previous crop and before the following crop, This practice results in very dry soil with deep cracks and that requires the application of large amount of irrigation water. Starting from the second irrigation the model schedules irrigation.

The extension worker input the value of applied water to the model and the model calculate the depletion of the applied water from root zone area by subtracting the value of ETo because at that time, no or low ground cover exist. When the model shows that there is only 15.0 mm in the root zone, it will be the time to apply the second irrigation. This value is based on the publish value of soil water depletion fraction in FAO book number 56 (Allen *et al.*, 1998), where soil water depletion fraction equal to 0.55 for both wheat and maize.

In case of clay soil, the available soil moisture is usually between 0.19-0.22 m/m. Thus, the value of 15.0 mm to be left in the root zone area before the following irrigation is reasonably enough.

To determine the amount of the second irrigation, the model multiplies the value of soil available water by root depth (provided in the data base of the model). This amount represents the amount needed to fill the root zone with water for optimum plant growth without any water stress. Thus, the extension worker can convert the amount of water to hours according to the discharge of the irrigation pump. This procedure will continue until the last irrigation before harvest.

### *Validation of ISC model*

The ISC model was validated using field experiments for wheat in 2010-2011 growing season and for maize in 2011 growing season in El-Gharbia governorate in clay soil. Both crops were grown under surface irrigation. Weather data were collected and the value of soil available water was 0.22 m/m. Wheat was planted in 14 November 2010 and was harvested in 18 April 2011 and received five irrigations. Maize was planted in 16 June 2011 and was harvested in 5 October 2011. Maize received seven irrigations. Soil water depletion fraction is equal to 0.55 for both wheat and maize. The ISC model used the weather and the soil data of the original experiments to schedule irrigation, and then the developed schedule was compared with the actual schedule measured in the experiment.

*CropSyst model*

To determine if the developed irrigation schedule produced the same yield resulted from both the field experiments, CropSyst model (Stöckle *et al.,* 1994) was calibrated with the field data for the both crops. The model is a multi-crop and multi-year, process-oriented model with daily time step. It is serve as an analytical tool to study the effect of cropping systems management on crop productivity and the environment. For this purpose, CropSyst simulates soil water budget, crop phenology, crop canopy and root growth, biomass production and crop yield.

Weather and soil data from the studied experiments were input into the CropSyst model. The date of phenological stages and growing degree days to reach each growth stage were collected, as well as harvest index was calculated for both crops and input into the model. The model was calibrated using the field data for both crops. Then, the developed irrigation schedule by ISC model for each crop was used to run CropSyst to simulate grain and biological yields under the condition of each experiment. The predicted values of yield under the ISC schedule was compared to the predicted yield values under the measured schedule for both crops.

**Results and Discussion**

*Irrigation schedule developed by ISC model for wheat*

The developed irrigation schedule by ISC model for wheat is presented in Table 1. The ISC model was successful in determining the dates of applications, which were close to the date of irrigation done in the field. Table 1 also showed that the second irrigation was applied was applied 60 days after the first irrigation, as a result of the fall of 23.0 mm of rain in 29 December 2010, which delayed the second irrigation. Furthermore, the ISC model was successful in estimating the amount of each single irrigation event close to the amount measured in the field. The deviation between the measured values in the field and the values determined by ISC was 6.0 mm lower than the actual applied water for wheat. It was also showed from the Table 1 that the fourth and the fifth irrigations determined by the model were 4 and 3 days earlier than its counterpart in the measured schedule. To interpret that, depletion of the applied water was graphed during wheat season length.

Table 1. On-field irrigation dates and amounts versus estimated values by ISC model for wheat planted in El-Gharbia governorate.

| Irrigation | Actual irrigation schedule | | Predicted irrigation schedule | | Deviation, mm |
|---|---|---|---|---|---|
| | Date | Amount, mm | Date | Amount, mm | |
| 1 | 14 November 2010 | 73 | 14 November 2010 | 73 | 0 |
| 2 | 13 January 2011 | 62 | 12 January 2011 | 60 | 2 |
| 3 | 21 February 2011 | 61 | 21 February 2011 | 60 | 1 |
| 4 | 15 March 2011 | 63 | 11 March 2011 | 62 | 1 |
| 5 | 7 April 2011 | 64 | 4 April 2011 | 62 | 2 |
| Total | | 325 | | 318 | 6 |

Figure 1 presented the simulation of the depletion of the applied irrigation water in the experiment and the depletion using ISC model.

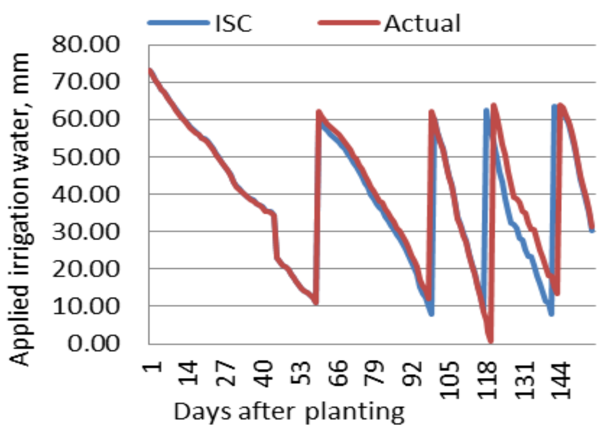


Fig. 1. Simulation of the depletion of measured irrigation amounts applied for wheat and the developed by ISC model.

The graph showed 5 hills, each one of them represents the amount of applied water in each irrigation event and the time of application in days after planting, both schedules were identical in the depletion of the applied water. The graph also showed that rain fall occurred on 29th of December, which delayed the application of the second irrigation 10 days. Regarding to the rest of the irrigations events, ISC model applied irrigation water when less than 10.0 mm was in the root zone, whereas, the measured schedule applied irrigation, when more or less than 10.0 mm existed, which could endure waste of irrigation water or stress to the growing plants.

*Irrigation schedule developed by ISC model for maize*

Table 2 revealed that the application date designated by ISC model for the second irrigation was delayed by one day, compared to the actual schedule. The date of the third and fourth irrigations was similar in ISC schedule and actual irrigation schedule. With respect of the rest of the irrigations, there was a deviation by one or two days.

The total applied irrigation water for maize in the studied experiment was 846 mm, whereas ISC model calculated irrigation amount lower than the measured by 79.0 mm. This large deviation was more pronounced in the first irrigation, where 22.0 mm was saved, followed by the fifth irrigation, where the deviation was 20.0 mm. The deviation for the rest of the irrigation was low, between 1.0-16.0 mm (Table 2).

Table 2. On-field irrigation dates and amounts versus estimated values by ISC model for maize planted in El-Gharbia governorate

| Irrigations | Actual irrigation schedule | | Predicted irrigation schedule | | Deviation, mm |
|---|---|---|---|---|---|
| | Date | Amount, mm | Date | Amount, mm | |
| 1 | 19 June 2010 | 152 | 19 June 2010 | 130 | 22 |
| 2 | 7 July 2011 | 99 | 8 July 2011 | 95 | 4 |
| 3 | 22 July 2011 | 98 | 22 July 2011 | 95 | 3 |
| 4 | 2 August 2011 | 116 | 2 August 2011 | 100 | 16 |
| 5 | 15 August 2011 | 125 | 14 August /2011 | 105 | 20 |
| 6 | 28 August 2011 | 125 | 26 August 2011 | 113 | 13 |
| 7 | 8 September 2011 | 131 | 7 September 2011 | 130 | 1 |
| Total | | 846 | | 767 | 79 |

The simulation of the measured irrigation schedule for maize revealed that all the applied water in each irrigation event did not depleted before the application of the following irrigation. Thus, there was an obvious waste in the applied irrigation water. On the contrary, the ISC schedule applied irrigation water before the depletion of last 10.0 mm to avoid such a waste (Fig. 2).

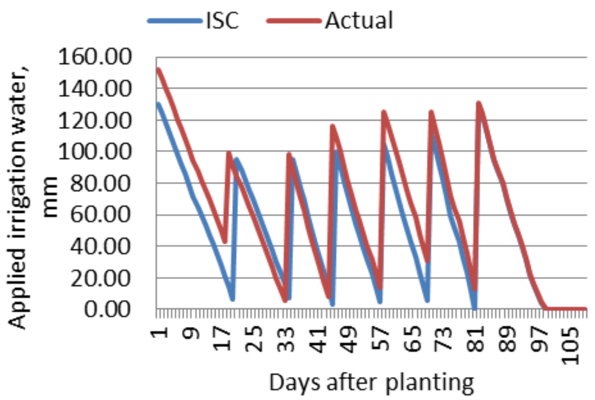


Fig. 2. Simulation of the depletion of measured irrigation amounts applied for maize and the developed by ISC model.

*Simulated wheat and maize yield using CropSyst model*

Using CropSyst model, after calibration, to simulate wheat and maize yield using ISC schedule revealed that wheat grains yield can be increased by 2% and wheat biological yield can be decreased by 1% (Table 3). This result can be attributed to proper management of the applied water by ISC schedule contributed in increasing oxygen in the root zone area and improve root growth. Consequently, it is reflected on root/shoot ratio to be in the direction to increase harvest index, i.e. the increase in grains weight is higher than above ground biomass weight (Whitmore, Whalley, 2009). The situation was different for maize, where a large amount of irrigation water was reduced, i.e. 79.0 mm. Thus, simulation of maize yield by CropSyst was important to be done to assess the effect of reducing the applied irrigation water on final yield. Table 3 indicated that maize yield was increased by low percentage, i.e. 0.4% and biological yield was decrease by 3%, which implied that these 79.0 mm, was not used in growth of maize plants and was lost to groundwater.

Table 3. Measured versus predicted seeds and biological yield wheat and maize using ISC schedule

| Crop | Grains yield, t/ha | | | Biological yield, t/ha | | |
|---|---|---|---|---|---|---|
| | Measured | Predicted | PC, % | Measured | Predicted | PC, % |
| Wheat | 6.16 | 6.31 | +2 | 14.78 | 14.63 | -1 |
| Maize | 7.86 | 7.89 | +0.4 | 18.86 | 18.36 | -3 |

PC% – percentage of change.

## Conclusion

Under the current situation of water scarcity, proper water management on field level should be enforced by the government to rationalize the use of water resources in agriculture.

1. The ISC model was validated using a winter crop and a summer crop, where the results were satisfactory. However, more testing needs to be done for different crops and locations before presenting the model to extension works in Egypt.
2. Furthermore, it is recommended that the model will tested in the governorates, where "Improved Irrigation Project" was implemented because these governorates have the facilities to test the model more intensively.
3. It is expected that the Egyptian farmers will be welling to use the advice of the extension worker regarding to the new irrigation schedule because it will reduce production cost through reduction of fuel and fertilizer amounts. Furthermore, it could optimize the applied water to crops and reduce its negative effects on soils.
4. Future modifications in the ISC model can be applied to accommodate different soil types and different crops.

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