EFFECTIVE MANAGEMENT OF ON-FARM IRRIGATION FOR SOME MAJOR CROPS IN EGYPT USING CROPWAT MODEL

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ABSTRACT

Field experiments were carried out (2013/2014 and 2014/2015 for wheat; 2014 and 2015 for maize) at the two sites of Giza area (Giza governorate, represented to Middle Egypt) and Shandaweel area (Sohag governorate, represented to Upper Egypt). The present study aims to improve water management in on-farm using CropWat model. Fifteen irrigation scheduling scenarios in addition the control treatment have been proposed and studied. The irrigation scheduling criteria included irrigation timing (irrigation at fixed interval days) and application depths (fixed depths "net irrigation", mm). The Control treatment represented to Farmer application where the irrigation intervals are at a maximum whilst avoiding any crop stress.

Results indicated that elongate the period between irrigation with adding of a few water amounts led to save more of water but caused a substantial decrease in the productivity of the crop. On the other hand, shortening the period between irrigation with the addition of large amounts of water resulted in loss of large amounts of water without benefit. The results confirmed that the best scenarios that can be applied to get higher out of the water unit for wheat crop is 25 days + 50 mm at Giza and 20 days + 50 mm at Shandaweel. These scenarios led to saving irrigation water around 1,500 m^3/ha (yield reduction less than 2 %). At the level of the total area planted with wheat, the total amount of water that can be saved will reach around 2,121 BCM. This amount of water is sufficient to irrigate an area of wheat about 385,568 ha.

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Results added that the best scenario that can maximize the amount of water added to maize crop in the two sites under study is 12 days + 80 mm at Giza and 12 days + 90 mm at Shandaweel. The two scenarios led to saving irrigation water about 1,360 m^3/ ha at Giza (yield reduction less than 8%), and 380 m^3/ha at Shandaweel (yield reduction less than 4%). At the total area planted with maize in two regions of Middle and Upper Egypt, the total amount of water that can be saved could amount to 372,377,520 m^3 and 68,389,360 m^3 in both regions, respectively. These amounts can be sufficient to irrigate new area of maize about 34,909 and 5,699 ha in the two regions respectively.

Key words: *Irrigation scheduling, applied water, water saving, FAO-CROPWAT model, water productivity.*

INTRODUCTION

Correct timing of irrigation is even more essential when water is in short supply. Early decisions must be made regarding the times at which water can be saved and when its allocation is most essential. Savings in irrigation water may be made by optimum utilization of soil water stored from winter rains or pre-irrigation. Additional savings may be made by allowing the soil to dry to the maximum permissible degree at the end of the growing season, rather than by leaving a high level of available soil water at harvest time; possibly one or two irrigations may be saved by this practice. (FAO No. 24, 1977).

Agriculture is the major user of water, improving agricultural water management is essential. Fereres and Soriano (2007) indicated that at present and more so in the future, irrigated agriculture will take place under water scarcity. Insufficient water supply for irrigation will be the norm rather than the exception, and irrigation management will shift from emphasizing production per unit area towards maximizing the production per unit of water consumed, the water productivity.

Irrigation scheduling ensured higher water productivity is, thus, important in view of the global scale of fresh water crisis. However, ensuring sustainability is closely dependent on other inputs such as nitrogen, crop variety, agronomic practices, climate conditions etc. (Oner Cetin and Nese Uzen, 2016).

Irrigation scheduling is the water management strategy of when and how much water to apply to an irrigated crop to maximize total yield. Commonly irrigation scheduling is defined as determining the time of irrigation and the amount of water to be applied. Irrigation scheduling is one of the important management activities that are vital to the effective and efficient utilization of water. Water management strategies based on irrigation scheduling are intended to reduce the amount of water applied and to minimize yield reduction due to water stress. It will ensure that water is applied to the
crop when needed and in the amount needed. Irrigation scheduling based on weather prediction remains the most practical and common method (Elsheikh, 2015). Determination of the reference evapotranspiration (ETo) is the most common method to estimate crop water use from the local climatic data and crop coefficient for different crop stages (Allen, 1998). Irrigation scheduling is the most important factor affecting irrigation efficiencies and crop yields.

Egypt has been suffering from severe water scarcity in recent years. Uneven water distribution, misuse of water resources and inefficient irrigation techniques are some of the major factors playing havoc with water security in the country (Dakkak, 2016). In addition the rapid population increase multiplies the stress on Egypt's water supply due to more water requirements for domestic consumption and increased use of irrigation water to meet higher food demands. Ali and Talukder (2008) indicated that effective management of water for crop production in water scarce areas requires efficient approaches. Molden *et al.* (2010) clearly indicated that there is considerable scope for improving water productivity of crop, livestock and fisheries at field through to basin scale. Practices used to achieve this include water harvesting, supplemental irrigation, deficit irrigation, precision irrigation techniques and soil–water conservation practices.

Mathematical simulation of crop growth and water relations has become indispensable to agricultural science and practices (Singels *et al.*, 2010). Crop simulation models have a pivotal role to play in evaluating irrigation management strategies for improving agricultural water use (Geneille and Wang, 2016).

CROPWAT was designed as a practical tool to carry out standard calculations for design and management of irrigation schemes, and for improving irrigation practices. It may also be used for irrigation scheduling under full or deficit irrigation conditions and for this, it uses the yield response factors derived from the crop-water production functions synthesized in FAO *I&D* No. 33.

The objective of the current study is to improve water management in on-farm using CropWat model under different agro-climatic zones in Egypt. Wheat and maize are used in the present study with fifteen irrigation scheduling scenarios to identify the best scenarios that result in saving irrigation water without clear deficiency in crop productivity or more crop per drop.

MATERIALS AND METHODS

Study areas

The present study was carried out under two different micro agroclimatic conditions in Middle Egypt (Giza) and Upper Egypt (Sohag). The irrigated area in Middle Egypt zone is about 1.1 million feddans where very little area irrigated by pumping from the river (not more than 4%) and located on the eastern side of the river. Less temperature compared to Upper Egypt, and the reference crop evapotranspiration (ETo) is about 10 % less. Cotton and maize are the major dominant crops in the summer, while wheat and berseem are major crops in the winter. Drainage water returns to the river by gravity. Regarding Upper Egypt zone, the irrigated area is about 1.0 million feddans, 35% out of which is irrigated through pumping from the river. Higher temperature compared to the northern areas. Sugarcane represents the major crop. The

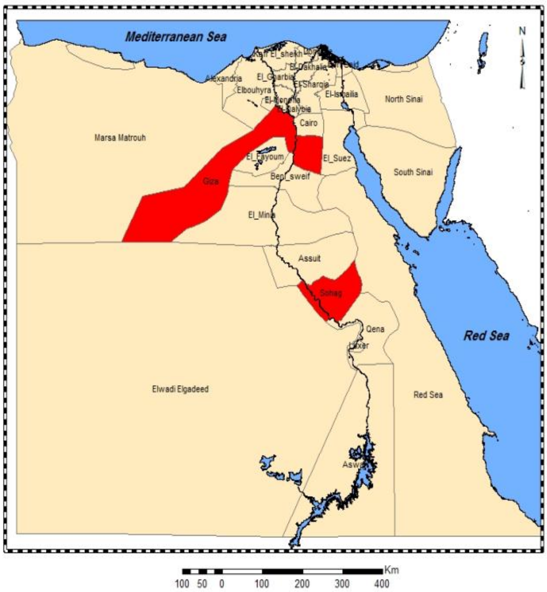


Figure (1): Geographic location of study areas

second competing crop is maize in the summer and wheat in the winter. Drainage water returns to the river by gravity (Allam et al. 2005).

The Model

In the present study, CROPWAT4 (Windows4.3, Derek et al. 1998) was used. CROPWAT for windows is a program that uses the FAO (1992) Penman-Monteith methods for calculating reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations.

This model has been used to simulate yield reduction percentage as a result of the decrease in evapotranspiration. The basic calculation procedure in this empirical model is:

$$(Ya / Ym) = Ky (1- ETa / ETm)$$

where Ya, Ym, Ky, ETa, ETm are actual harvested yield, maximum harvested yield, yield response factor, actual evapotranspiration, and maximum evapotranspiration, respectively. The relationship between crop yield and water supply can be determined when crop water requirements and crop water deficits on the one hand and maximum and actual crop yield on the other can be quantified. Where economic conditions do not restrict production, and in a constraint-free environment, Ya = Ym when full water requirements are met; when full water requirements are not met available water supply, Ya < Ym (FAO 1979).

Investigated Crops:

Wheat and maize were selected in the present study because they are major crops in the two zones under study and the national production is insufficient. Local production and import, respectively, of these two crops in 2015 reached 9.6 and 9.0 million ton of wheat; 8.1 and 6.8 million ton of maize (Ministry of Agriculture and Land Reclamation, Economic Affairs sector, Bulletin of Important indicators of the Agricultural Statistics, 2016).

Winter and summer field trials were carried out (2013/2014 and 2014/2015 for wheat; 2014 and 2015 for maize) at the two sites of Giza area (Giza governorate, represented to Middle Egypt) and Shandaweel area (Sohag governorate, represented to Upper Egypt). Wheat crop (Giza168 CV.) was sown on 26^{th} November at Giza and 28^{th} November at Shandaweel. Harvest date was on 30^{th} April in both sites.

Maize crop (SC10 CV.) was sown on 15th May in the two sites and harvest date was on 16th September at Giza and 9th September at Shandaweel.

The soil samples were collected from 0-15, 15-30, 30-45 and 45-60 cm depth for soil texture, field capacity (%), wilting point (%), available water (%) and bulk density (gm/ cm^3). The average values of all these parameters, respectively, are silty clay, 35.0, 17.4, 17.6, 1.2 at Giza; silty clay, 30.7, 12.6, 18.1, 1.22 at Shandaweel.

Data needed for the model

Climate information including name of climate stations in the two areas, with coordinates and elevation, max. and min. temperature, relative humidity, wind speed, sunshine and rainfall data. The flow chart of the FAO- CROPWAT shown in Figure 2.

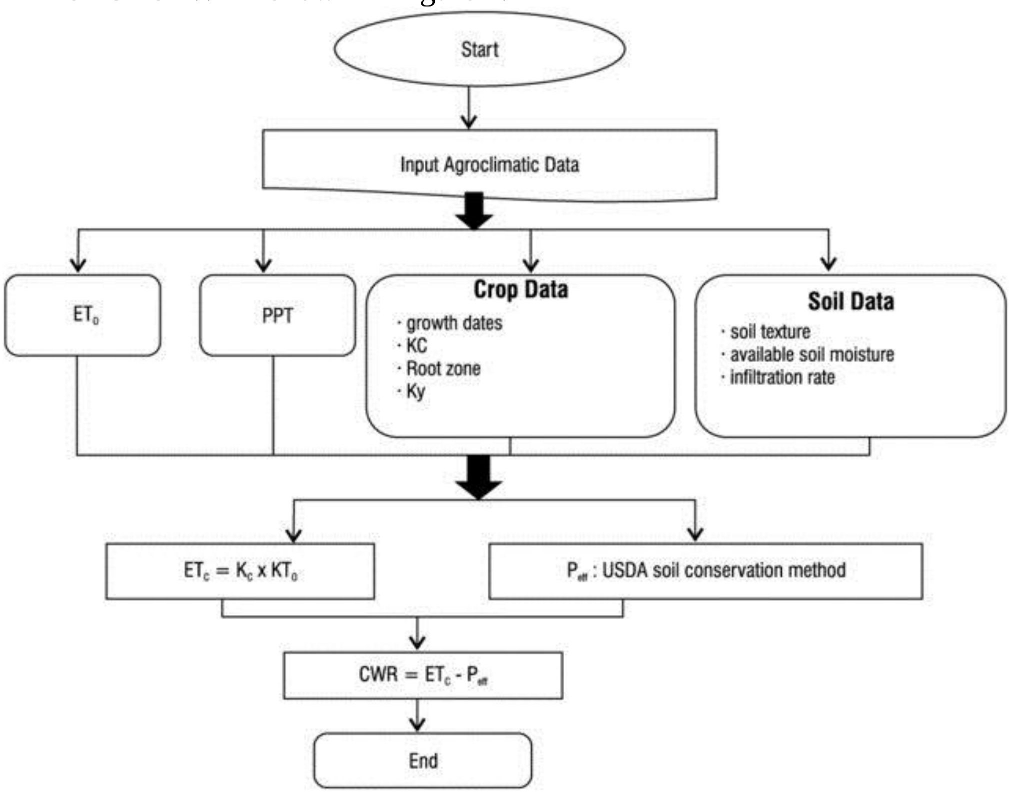


Figure 4: Flow chart of FAO-CROPWAT

Data were obtained from Egyptian Meteorological Authority “EMA” and Central Laboratory for Agricultural Climate “CLAC”. In addition, crop information including crop coefficient, growth stages, sowing and harvesting date, application timing, application depth, start of scheduling. Lastly, soil information including total available soil moisture, maximum infiltration rate, maximum rooting depth, initial available soil moisture. Data were obtained from the analysis of the soil samples, analyzed in the lab center by Soil, Water and Environment Research Institute, Agricultural Research Centre.

Treatments

To achieve the research objectives, 15 irrigation scheduling scenarios in addition the control treatment (Farmer practice) have been proposed and studied. The irrigation scheduling criteria included irrigation timing (irrigation at fixed interval days) and application depths (fixed depths “net irrigation”, mm).

- Control treatment: the irrigation intervals are at a maximum whilst avoiding any crop stress):
    - ❖ Application timing: irrigation when 100 % of readily available moisture occurs
    - ❖ Application depth: refill to 100 % of readily available moisture
- **The 15 irrigation scheduling scenarios are:**

I- For wheat crop:

1- 20 days + 40 mm
2- 20 days + 50 mm
3- 20 days + 60 mm
4- 20 days + 70 mm
5- 20 days + 80 mm
6- 25 days + 40 mm
7- 25 days + 50 mm
8- 25 days + 60 mm
9- 25 days + 70 mm
10- 25 days + 80 mm
11- 30 days + 40 mm
12- 30 days + 50 mm
13- 30 days + 60 mm
14- 30 days + 70 mm
15- 30 days + 80 mm

II- For maize crop:

1- 8 days + 50 mm
2- 8 days + 60 mm
3- 8 days + 70 mm
4- 8 days + 80 mm
5- 8 days + 90 mm
6- 12 days + 50 mm
7- 12 days + 60 mm
8- 12 days + 70 mm
9- 12 days + 80 mm
10- 12 days + 90 mm
11- 16 days + 50 mm
12- 16 days + 60 mm
13- 16 days + 70 mm
14- 16 days + 80 mm
15- 16 days + 90 mm

Reference evapotranspiration (ETo) calculated by CropWat model of the two sites are presented in Figures 3-6.

Figure 3: References evapotranspiration (ETo) during 1st winter season (2013/ 14) at Giza and Shandawee sites

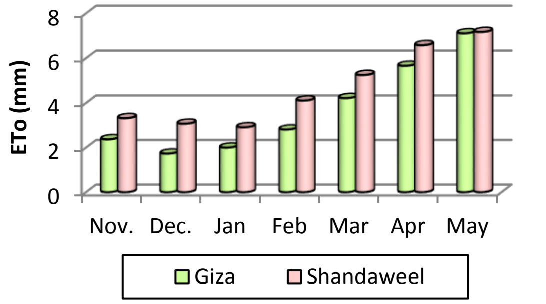


Figure 4: References evapotranspiration (ETo) during 2nd winter season (2014/ 15) at Giza and Shandawee sites

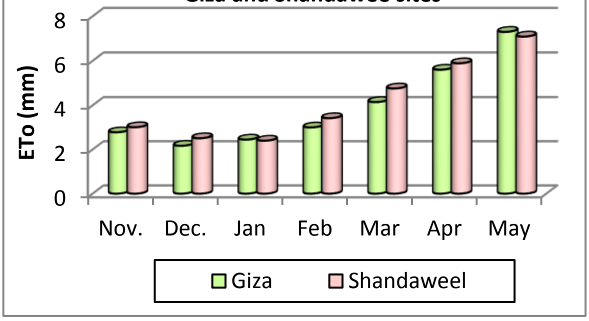


Figure 5: References evapotranspiration (ETo) during 1st summer season (2014) at Giza and Shandawee sites

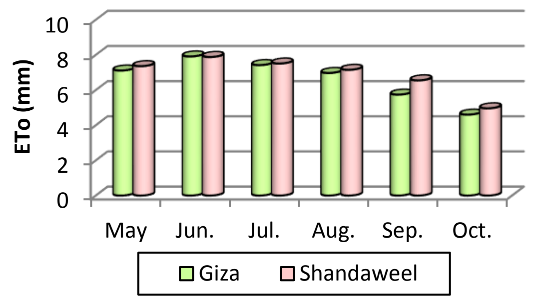
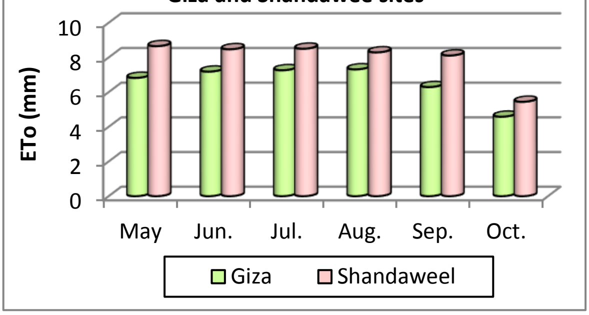


Figure 6: References evapotranspiration (ETo) during 2nd summer season (2015) at Giza and Shandawee sites



RESULTS AND DISCUSSION

I. Simulation of irrigation scheduling scenarios on wheat crop

I. 1. Water consumptive use for wheat

Results as recorded in Figures 7 and 8 indicate water consumption (ETc) for control treatment and the 15 irrigation scenarios under study. Values of ETc with the control treatment at Giza area were 3,859 m^3/ ha in the 1st season and 4,015 m^3/ha in the 2nd season. However, the respective two values at Shandaweel area were 5,018 and 4475 m^3/ ha. On the other hand, values of ETc for the 15 scenarios at Giza ranged from 3361 to 3,859 m^3/ ha in the 1st season; 3,452 to 4,015 m^3/ ha in the 2nd season. However, at Shandaweel, the values varied from 4,136 to 5,018 m^3/ ha in the 1st season; 3,941 to 4,475 m^3/ ha in the 2nd season.

I. 2. Yield reduction for wheat crop under irrigation scenarios

As a result of reducing amount of irrigation water, the water used by crop was less than actually needed, with pronounced effect on the simulated yield reduction percentage. Results as presented in Figures 9 and 10 indicated that the largest yield reduction at Giza area was 7.7 and 8.4 % occurred when the scenario 30 days + 40 mm was applied in the 1st and 2nd seasons respectively. However, at Shandaweel the same scenario resulted in yield reduction of 10.5 and 6 % in the respective two seasons. Yield reduction is caused by lower water availability or the supply of water does not match the demand.

Figure 7: Water consumption (ETc) for wheat crop under control treatment (Farmer treatment) and irrigation scheduling scenarios at Giza area in the two seasons of 2013/ 14 and 2014/ 15

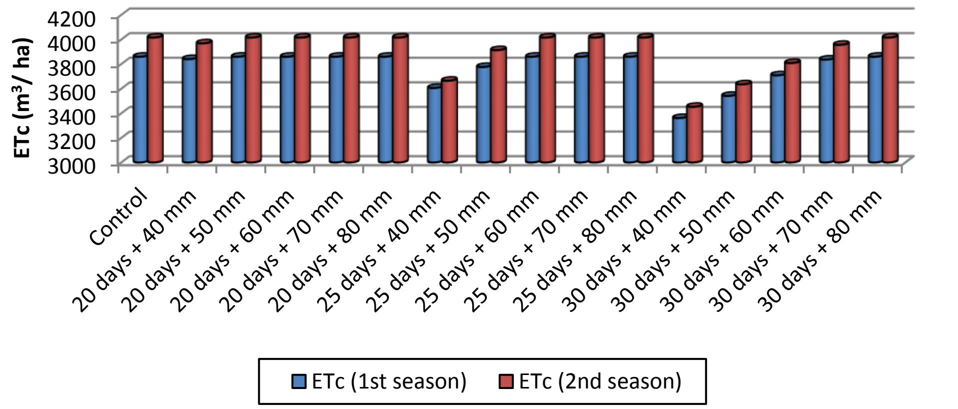


Figure 8: Water consumption (ETc) for wheat crop under control treatment (Farmer treatment) and irrigation scheduling scenarios at Shandaweel area in the two seasons of 2013/ 14 and 2014/15

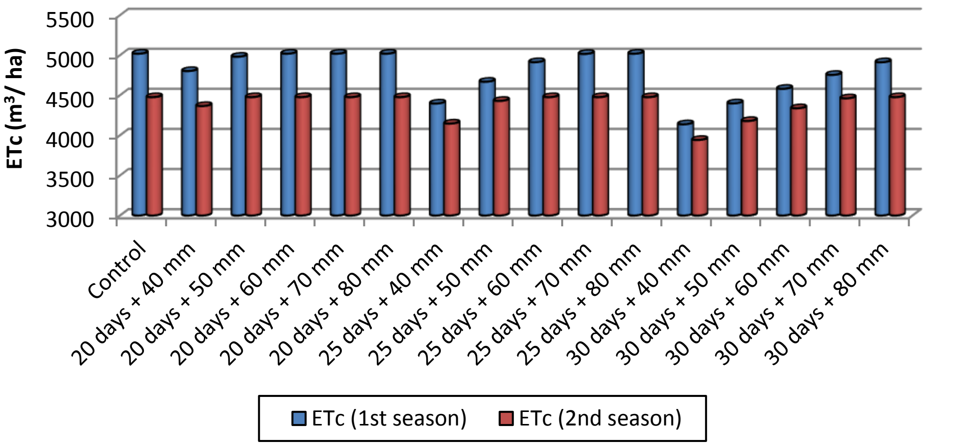


Figure 9: Wheat yield reduction (YR) under irrigation scheduling scenarios at Giza area in the two seasons of 2013/ 14 and 2014/ 15

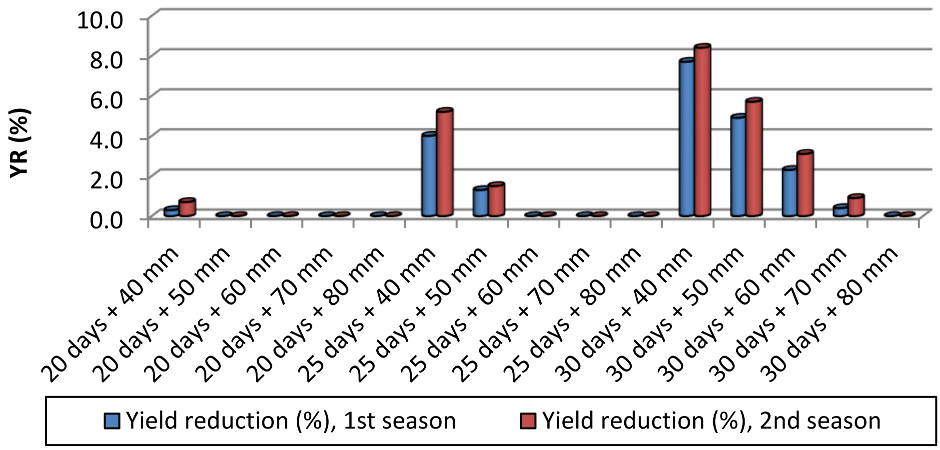
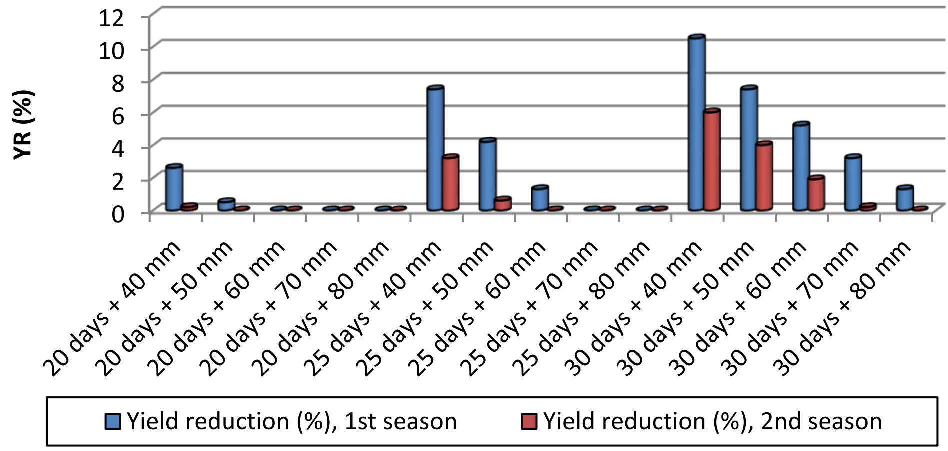


Figure 10: Wheat yield reduction (YR) under irrigation scheduling scenarios at Shandaweel area in the two seasons of 2013/ 14 and 2014/ 15



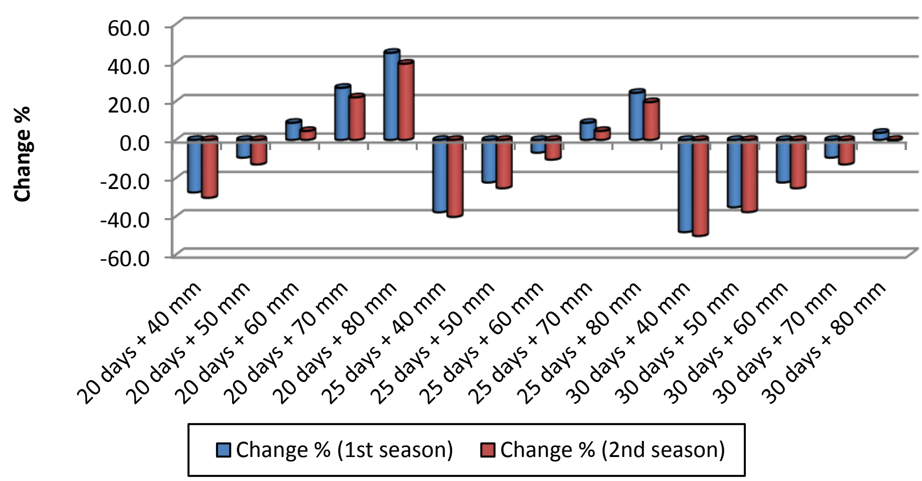
In this regards, FAO 2002 indicated that water stress affects crop growth and productivity in many ways. Most of the responses have a negative effect on production but crops have different and often complex mechanisms to react to shortages of water. Several crops and genotypes have developed different degrees of drought tolerance, drought resistance or compensatory growth to deal with periods of stress. The highest crop productivity is achieved for high-yielding varieties with optimal water supply and high soil fertility levels, but under conditions of limited water supply crops will adapt to water stress and can produce well with less water.

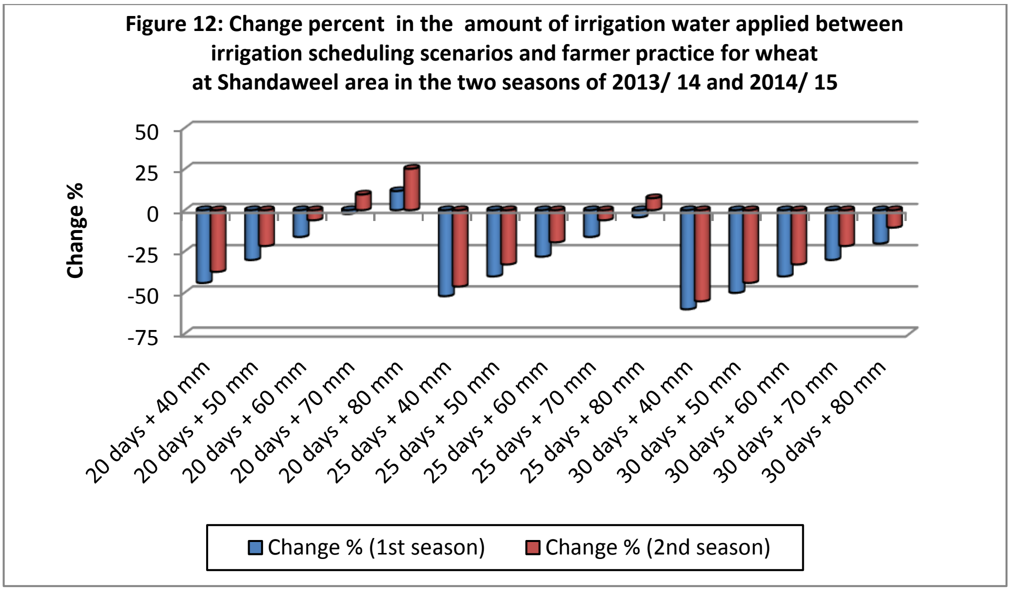
I. 3. Amount of water saving for wheat crop under irrigation scenarios

Results as recorded in Figure 11 and 12 indicated that most of the irrigation scheduling scenarios resulted in saving irrigation water. The highest saving in the amount of irrigation water was found when applying the scenarios 30 days + 40 mm, 25 days + 40 mm, 30 days + 50 mm and 20 days + 40 mm. Apply these scenarios resulted in saving irrigation water ranged from 27 to 50 % in Giza, 37 to 60 % in Shandaweel. It is worth mentioning that these scenarios are those who registered the highest shortfall in wheat productivity in the two sites under study.

Generally, it could be concluded that elongate the period between irrigation with the adding of a few water amounts led to save more of water but caused a substantial decrease in the productivity of the crop. On the other hand, shortening the period between irrigation with the addition of large amounts of water resulted in loss of large amounts of water without benefit. The best scenario can be applied to get the highest benefit from the amount of irrigation water added to wheat crop is 25 days + 50 mm at Giza; 20 days + 50 mm at Shandaweel. These scenarios can save amount of irrigation water around 1,500 m^3/ ha at Giza (yield reduction less than 2%); 2,000 m^3/ha at Shandaweel (yield reduction about 1%).

Figure 11: Change percent in the amount of irrigation water applied between irrigation scheduling scenarios and farmer practice for wheat at Giza area in the two seasons of 2013/ 14 and 2014/ 15





If the amount of water saving is about 1,500 m^3/ ha, so, the amount of water that can be saved at the level of the total area planted with wheat (1,413,750 hectares according to agricultural statistics 2013/2014) will be 2,120,625,000 m^3. This amount of water is sufficient to irrigate an area of wheat about 385,568 ha.

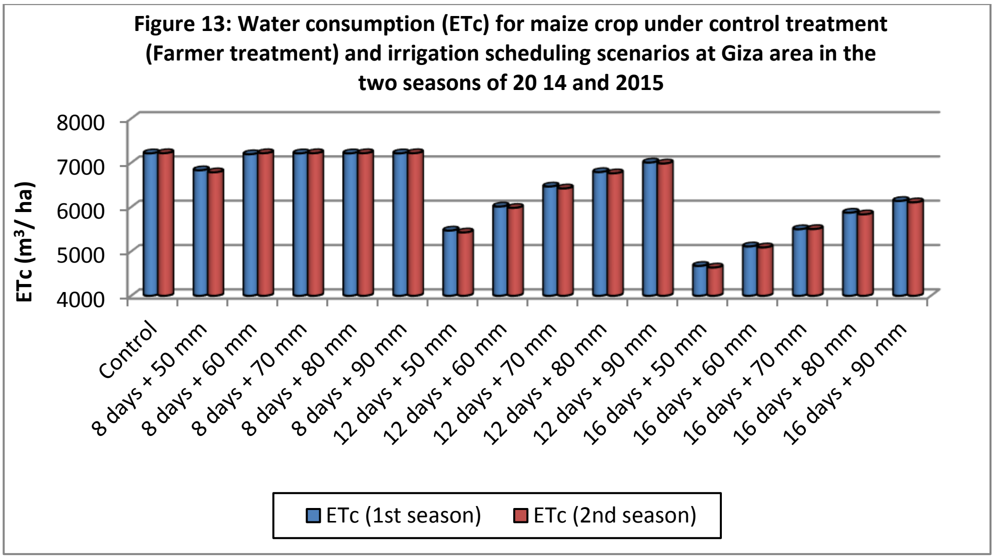
II. Simulation of irrigation scheduling scenarios on maize crop

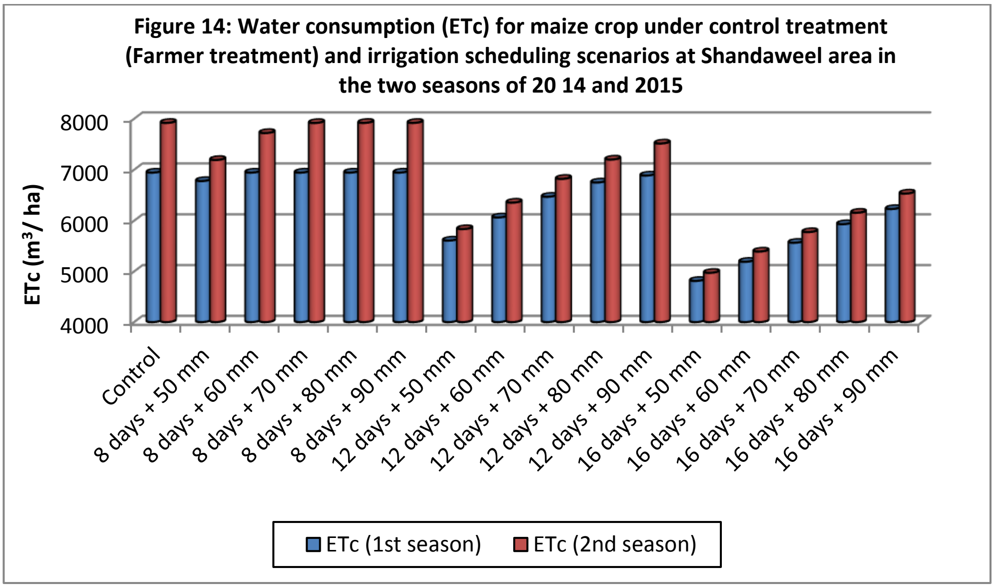
II. 1. Water consumptive use for maize

Results of ETc values for maize crop with the control treatment at Giza area were 7214 and 7218 m^3/ ha in the 1st and 2nd seasons, respectively. As for Shandaweel area, ETc values were 6943 and 7918 m^3/ ha in the respective two seasons. On the other hand, results of the 15 scenarios at Giza varied between 4673 and 7214 m^3/ ha in the 1st season; 4637 and 7218 m^3/ ha in the 2nd season. However, values of ETc for the 15 scenarios at Shandaweel ranged from 4812 up to 6943 m^3/ ha in the 1st season, 4971 up to 7918 m^3/ ha in the 2nd season (Figures 13 and 14).

II. 2. Yield reduction for maize crop under irrigation scenarios

Results as shown in Figures 15 and 16 show that the reduction of maize productivity caused by low irrigation water depth especially under long intervals conditions. Reduction in soil moisture resulted in reduction in evapotranspiration that directly influence the crop yield.





The results added that the highest yield reduction happened with the scenarios 16 days + 50 mm, 16 days + 60 mm, 16 days + 70 mm and 12 day + 50 mm, where the reduction in productivity reached up to 45 and 47 % in Giza and Shandaweel, respectively.

FDigure 15: Maize yield reduction (YR) under irrigation scheduling scenarios at Giza area in the two seasons of 20 14 and 2015

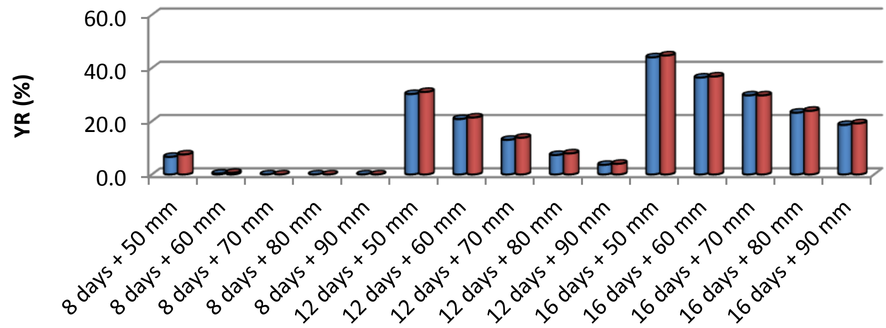
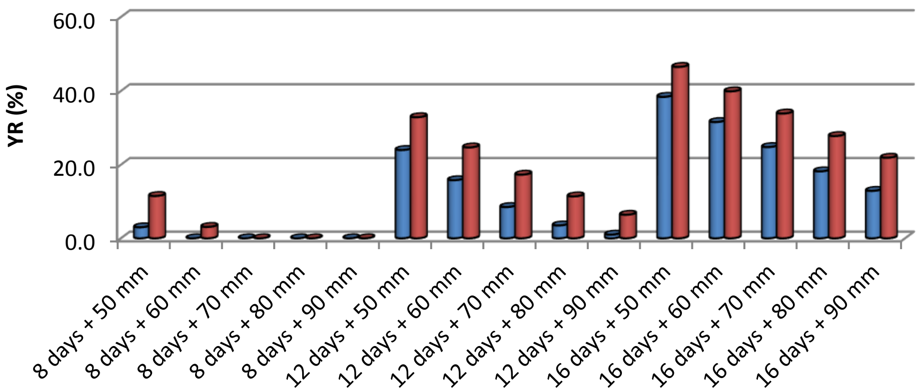


Figure 16: Maize yield reduction (YR) under irrigation scheduling scenarios at Shandaweel area in the two seasons of 20 14 and 2015



II. 3. Amount of water saving for maize crop under irrigation scenarios

Most irrigation scheduling scenarios resulted in conservation irrigation water used for maize (about 10 out of 15 scenarios). The change percent in the amount of irrigation water added under conditions of irrigation scheduling scenarios compared to Farmer practice ranged from about + 50 % to – 58 % in Giza; + 56 % to – 57 % in shandaweel (Figures. 17 and 18).

Figure 17: Change percent in the amount of irrigation water applied between irrigation scheduling scenarios and farmer practice for maize at Giza area in the two seasons of 2014 and 2015

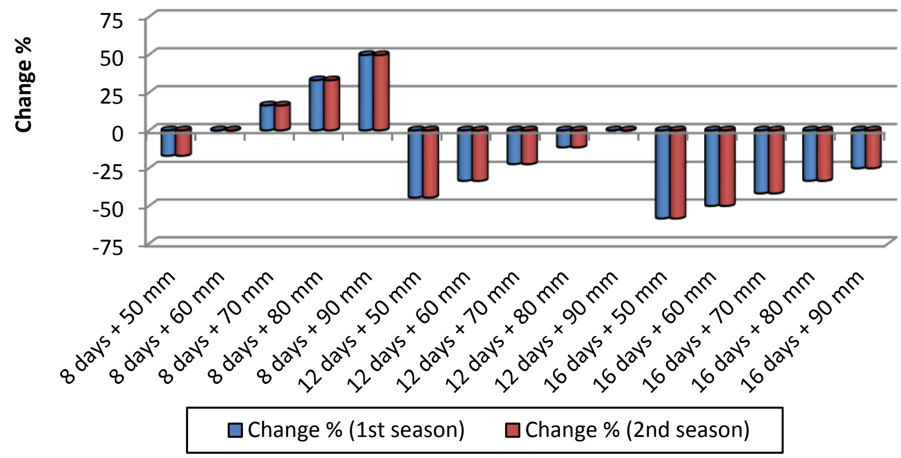
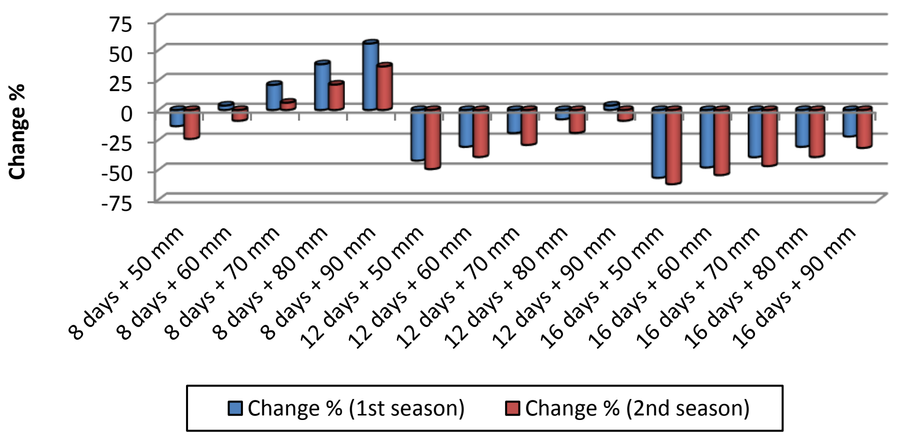


Figure 18: Change percent in the amount of irrigation water applied between irrigation scheduling scenarios and farmer practice for maize at Shandaweel area in the two seasons of 2014 and 2015



From the previous maize results it could be concluded that the best scenario that can maximize the return from water unit for maize crop in the two sites under study is 12 days + 80 mm at Giza and 12 days + 90 mm at Shandaweel. These scenarios led to saving irrigation water (average two seasons) about 1,360 m^3/ ha at Giza; 380 m^3/ ha at Shandaweel (yield reduction less than 8 and 4 % at the two sites, respectively).

If we apply these scenarios at the level of the total area planted to maize in Middle and Upper Egypt (the total area of maize in Middle and upper Egypt respectively are 273807 and 179972 ha), the total amount of water that can be saved will amount to 372,377,520 m^3 and 68,389,360 m^3 in both regions, respectively. These amounts can be sufficient to irrigate new area of maize about 34909 and 5699 ha in the two regions respectively.

CONCLUSION

- Reducing irrigation depth with the long intervals causing sever yield reduction. At the same time, reduce irrigation depth with reducing the intervals between irrigations may not significantly affect the productivity of the crop. Current research aims to study many irrigation scheduling scenarios to reach the best scenarios that maximize the use of the amount of water applied to some main crops in Egypt (wheat and maize).
- The results showed that the best scenarios for wheat are 25 days + 50 mm at Giza; 20 days + 50 mm at Shandaweel.
- Regarding maize crop, scenarios of 12 days + 80 at Giza and 12 days + 90 mm at Shandaweel are the best.
- These scenarios have led the conservation of natural resources and also saving irrigation water amounts without significant reduction in crop productivity. Such amounts of water can add new agricultural areas of these crops to reduce the gap between production and consumption.

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الملخص العربى

الادارة الفعالة للرى الحقلى لبعض المحاصيل الرئيسية فى مصر باستخدام نموذج CropWat

عاطف سويلم* ، سامية المرصفاوى و مها البنا*****

اقيمت تجارب حقلية خلال الفترة ٢٠١٣ - ٢٠١٥ فى منطقتى الجيزة وشندويل لتمثل مناطق مناخية مختلفة فى مصر وذلك بهدف تحسين ادارة الرى الحقلى لبعض المحاصيل الرئيسية فى مصر (القمح والذرة الشامية) . يهدف البحث أيضا الى اختيار أفضل السيناريوهات التى تحقق أقصى استفادة من كمية المياه المضافة للمحاصيل أو بمعنى اخر أفضل محصول بأقل كمية مياه مضافة. وقد استخدم فى البحث نموذج كروب وات واقترحت عدد من السيناريوهات (١٥ سيناريو بالإضافة الى معاملة الكنترول) لجدولة الرى من خلال فترات رى فاصلة وكميات مياه مضافة فى كل رية.

وأوضحت النتائج أن أفضل سيناريو لمحصول القمح فى منطقة الجيزة هو ٢٥ يوم فترة فاصلة بين الريات + ٥٠ مم كمية مياه فى كل رية، وفى شندويل ٢٠ يوم + ٥٠مم. هذه السيناريوهات حققت توفير فى مياه الرى حوالى ١٥٠٠ م٣/ هكتار (النقص فى المحصول أقل من ٢ %). واذا تم الحساب على اساس المساحة الكلية المنزرعة بالقمح سوف يصل التوفير فى مياه رى هذا المحصول الى ٢,١٢٠,٦٢٥,٠٠٠ م٣ (حوالى ٢ مليار م٣). هذه الكمية من المياه تكفى لزراعة مساحات جديدة من القمح تصل الى حوالى ٣٨٥٥٦٨ هكتار.

هذا وقد أضافت النتائج أن أفضل سيناريو لجدولة رى محصول الذرة الشامية هو ١٢ يوم + ٨٠ مم فى الجيزة ، ١٢ يوم + ٩٠ مم فى شندويل. هذه السيناريوهات حققت توفير فى مياه الرى حوالى ١٣٦٠ م٣/ هكتار فى الجيزة (النقص فى المحصول أقل من ٨ %) ، ٣٨٠ م٣/ هكتار فى شندويل (النقص فى المحصول أقل من ٤ %). واذا تم الحساب على اساس المساحة الكلية المنزرعة بالذرة الشامية فى اقليمى مصر الوسطى ومصر العليا فان التوفير فى مياه رى هذا المحصول سوف يصل الى حوالى ٣٧٢,٣٧٧,٥٢٠ م٣ ، ٦٨,٣٨٩,٣٦٠ م٣ فى الاقليمين على الترتيب. هذه الكمية من المياه يمكنها أن تضيف مساحة زراعية جديدة من الذرة الشامية تصل الى حوالى ٣٤٩٠٩ هكتار فى مصر الوسطى ، ٥٦٩٩ هكتار فى مصر العليا.

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