Journal of Soil Sciences and Agricultural Engineering

Journal homepage: www.jssae.mans.edu.eg
Available online at: www.jssae.journals.ekb.eg

Irrigation Water Management for Wheat Using Aquacrop Model

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ABSTRACT

The study aimed to evaluate the performance of the Food and Agriculture Organization "AquaCrop" model (version 6.1) in simulating the productivity and biomass of wheat crops in old lands under the surface irrigation system. Field data for the period from 2013- 2016 were used to calibrate the model's through matching productivity and biomass observed using root mean square error (RMSE) 0.05 and 0.2 ton/ha and Nash coefficient values of 0.9 and 0.8, resp. A calibrated model was simulated the grain yield to generate an irrigation schedule with the aim of developing an appropriate irrigation management strategy for wheat. Results showed that the highest value of wheat water production was achieved through the application of five irrigations when applying fixed net application (80 mm) with a total of 400 mm for the season and different interval between irrigation ranges between 30-39 days depended on depilation of the 80% of Readily Available Water (RAW) threshold while taking into rainy mind. This sequence was superior to the normal used irrigation sequence conducted from 2013 to 2016 (fixed net application 80,96mm and fixed interval 27,33 days on six and five irrigations application resp. with a total of 480 mm per season). 16.7% less water use with increasing water productivity is one of the important things at the present time. The results will help determine an irrigation management option appropriate to the prevailing weather conditions and farm resources, and thus this model can be used as a decision support tool in increasing water productivity.

Keywords: AquaCrop, Irrigation schedule; Canopy cover, wheat productivity, water productivity, management.

INTRODUCTION

The impact of climate change, population growth, land depletion, and escalating demand in non-agricultural sectors deeply influence the accessibility and water sources for irrigated agriculture. Among intensifying worries that water shortage and food insufficiency were among the main problems to be confronted by several societies in the 21st century, a global challenge for the agricultural sector was to found extra food with less water,(Toumi, .2016). Irrigation policies concentrating on collective agricultural water yield attached with crop simulation modeling to check multiple replacements, have an essential task to act in sustainable water development .The FAO AquaCrop simulation model gives a sensible theoretical outline to explore crop yield response to environmental stress, (Theodore *et. al*.,2009 It was accurate, simple model therefore can be worked through water managers, economists and policy originators to planning and evaluation of irrigation scenarios, (Hsiao *et. al*., 2009).

Also, AquaCrop model expects the yield response to water of Cereal crops, (Vanuytrecht *et. al*., 2014). Elements of simulation processes were presented in irrigation and drainage paper number 66, (Steduto *et. al*., 2012). It was verified for several crops under environmental conditions, (Heng *et. al*., 2009; Todorovic *et. al*., 2009; Trombetta *et. al*., 2016). This model had well simulated to crop growth and yield as affected by variable soil moisture environments for crops like wheat, (Rezaverdinejad, *et. al*., 2014), Farahani *et. al*. and Geerts *et. al*.,(2009), suggested that this model supports a good balance between accuracy and robustness, and a significant element of the model compared to other cereal crop growth models was the simplicity it presents its users; it does not need advanced skill for its calibration or operation and does not need a large number of input parameters, (Heng, *et. al*., 2009). The relatively small number of input data explains the soil–crop–atmosphere environment in which the crop grows, most of which can be obtained by simple methods. AquaCrop simulates crop growth and yield based on the water-driven growth model that depend on the traditional behavior of biomass per unit transpiration relationship, (Todorovic, *et. al*., 2009 and Steduto, *et. al*., 2009). The shortcomings discovered in the irrigation process, (García Morillo, *et. al*., 2015) prompted the development of tools to facilitate farmers in scheduling irrigation. Stakeholders need practical decision support tools to help them assess irrigation practices and the resulting return. Simulation models provide a low-cost way to study a large range of management options. Several researchers noted that model parameterization was effectively set - limited and that important calibrated parameters needed for accurate simulation must be tested under different climate, soil, irrigation methods, and field management to improve the reliability of the simulated results, (García-Vila, *et. al*., 2009 and De Casa, *et. al*., 2013). The AquaCrop model simulates the crop's response to available water

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DOI: 10.21608/jssae.2020.114866

(soil moisture and irrigation). While it was based on simple and complex biophysical procedures, only a comparatively small number of parameters were needed to change AquaCrop to unique conditions and crops. Frequently assimilated the default input variables were satisfactory and do not require additional instruction. When additional flexibles were needed, frequently become natural and can be simply classified exploiting easy methods, (Raes, *et. al*., 2009). The aim of this study was to validate this model in simulating the appearances of irrigation scenarios on: (1) canopy cover, (2) biomass yield, (3) grain yield, and (4) water use efficiency of wheat and generate irrigation schedule for evaluating or planning a particular irrigation strategy, These data will provide some guidelines for efforts to optimize irrigation management for wheat crops.

MATERIALS AND METHODS

AquaCrop is a crop water productivity model obtained by FAO's Land and Water Division (Raes ., 2012). It simulates the yield response to herbal crop water and was especially fitting for giving conditions which water was a main restricting factor in crop production. It was considered to balance simplicity, accuracy, and stability, where was utilized version (v. 6.1) in this study. This model needs daily climate data, phenological and agronomic data, and information about soil characteristics, irrigation water and groundwater to be adept to simulate plant and soil characteristics. All this information was available and/or can be easily collected. Temperature and rainfall regime, evaporative requirement and carbon dioxide concentration as climatic characteristics, soil water balance, irrigation system and runoff as management properties, fertility stage and soil salinity as soil characteristics, and plant growth, development and yield as plant characteristics were considered in this model, (Mkhabela and Bullock, 2012). The research was divided into three parts, the first was the calibration of the canopy cover using the model in the period of three years and then used calibration file and its application on the followed irrigation system in this period to calibrated the productivity and biomass for the same period and finally the suggestion of a different irrigation system using the model so that it can be applied at a later time with a comparison of the amounts of irrigation used. The calibration process used an input data sets from the historical data records of Sakha research station (31° 5′ 34″ N, 30° 56′ 46″ E, and 2 m above mean sea level), which was following the Agriculture Research Center (ARC) of Egypt and located at Kafer El Shiekh governorate. A daily climate data set from 2013 to 2016, was presented at Fig. 1. The data set include the maximum and minimum air temperatures (°C), ETo and the daily precipitation rates(mm). The soil texture that associated with the characterization of water terrestrial relationships was one of the main inputs of the AquaCrop model. Table (1) shown soil properties at Sakha location.

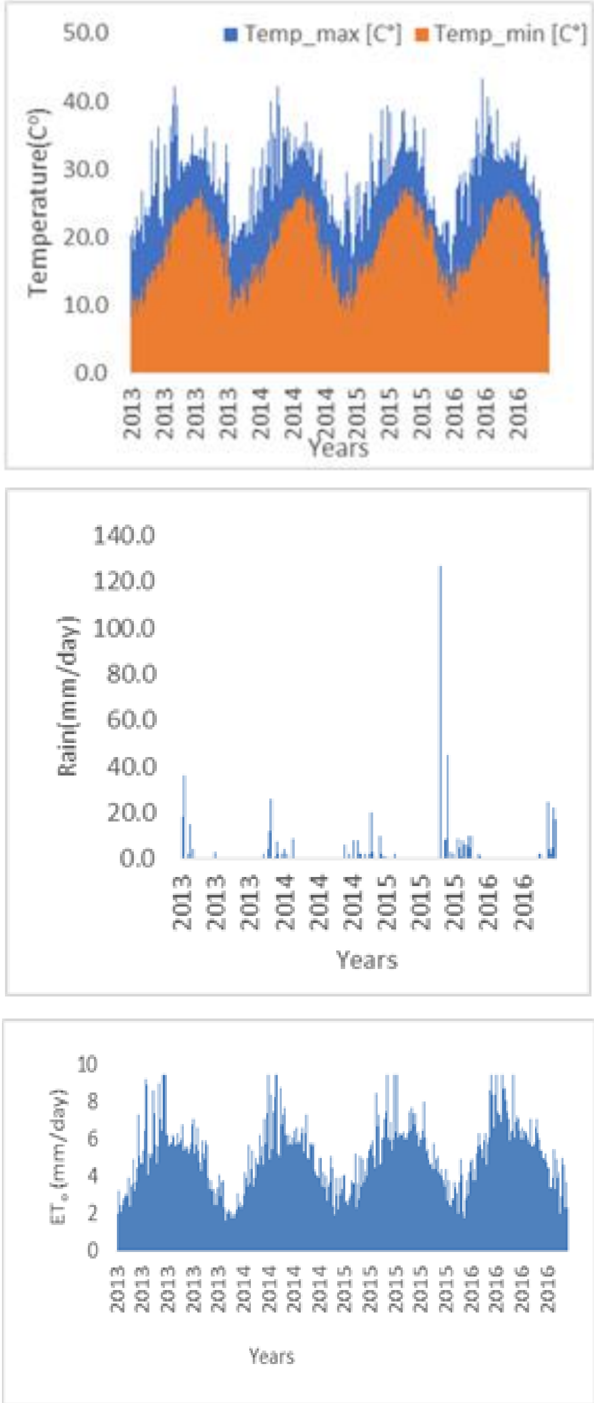

Fig. 1. Daily maximum and minimum temperature ETo and Rain values for sakha region during the growing period during 2013-2016.

Table 1. Some physical characteristics of the soil in Sakha (Kafer El Shiekh governorate).

Depth (m)	Moisture content				Bulk density ($g\ cm^{-3}$)	K_{sat} (mm day^{-1})
	FC (%, vol)	PWP (%, vol)	Sat (%, vol)	TAW		
0-20	36.9	20.0	16.9	49.5	1.36	95.8
20-40	37.9	22.3	15.6	50.0	1.33	79.2
40-60	40.8	25.1	15.7	50.9	1.29	48.7
60-80	43.1	25.5	17.6	52.2	1.27	46.3
80-100	44.5	27.1	17.4	52.9	1.25	37.9

Where: **FC is Field Capacity, PWP is Permanent Wilting Point, Sat is water content at saturation, TAW is Total Available Water, Ksat is saturated hydraulic conductivity.**

AquaCrop utilizations two different types of factors: static or traditional factors, and specific factors for the case or non-traditional. The traditional factors were individual geographical region, management performances or time. It should be established by growth conditions were unlimited but stay valid for stress conditions through integration between the functions of pressure response, (Hsiao *et. al*., 2009 and Steduto ., 2009). These parameters were mainly conservative Canopy cover growth (CGC) and decline (CDC); Crop plants for complete transpiration a canopy (Kc); Water Productivity (WP) for biomass; Thresholds for soil water depletion. These parameters It applies to a wide range of different conditions and crop varieties, (Steduto *et. al*., 2012 Some other crops Parameters were a special and non-conservative case (for example, seeding density, phenological length Phase). Table 2 refers the parameters used in calibration. Non-conservative parameters are influenced by climate, field practices, and soil conditions. The operator needs to be provided for each specific case and cannot apply Widely, (Raes *et. al*., 2009 and Raes *et. al*., 2012). After the calibration of the model by adjusting the crop parameters, irrigation practices for wheat were used based on the irrigation records of the demonstration fields at Sakha location. Those records present the commonly best irrigation practices applied by the farmers in the Nile Delta region. Table 3 refers to the irrigation practices used in the period contain the irrigation system as “border surface irrigation”, with six applications per season, 27 days’ intervals between applications and five applications per season, 33 days’ intervals between applications and the last application added before the harvesting by 20 days. The application depth was 80and 96 mm resp, with a total irrigation amount of 480 mm/ season.

Table 2. Parameters for wheat used in calibrating AquaCrop.

Parameter	Value	Unit
Date of planting	15 November to the first of December	date
Number of plants /m^2	300	plants/m^2
Time from sowing to emergence	10 :13	days
Time to reach max canopy cover	90:93	days
Maximum canopy cover (CCX)	94:96	%
Time to start senescence	103:110	days
Time to reach flowering	10:13	days
Time from sowing to reach maturity	145:150	days
Length of flowering stage	10:13	days
Maximum effective root depth	0.7: 0.8	m
Time from sowing to maximum root depth	70: 80	days
Reference harvest index (HI0)	37:39	%

Table3. Irrigation properties in the study region at period (2013–1016).

Years	Irrigation event	Applied water (mm)	Irrigation method
2013/2014	6	480	Border
2014/2015	5	480	Border
2015/2016	6	480	Border

When all data like local weather, soil, and crop data (measured, estimated, or conditioned) were available, AquaCrop can created an irrigation schedule according to specific parameters. To create an irrigation schedule to evaluate the irrigation schedule already in used or to plan a specific irrigation strategy to study the effect of the irrigation plan in simulating crop productivity, amount of irrigation, soil evaporation and water productivity under irrigation scheduling scenarios, and the goal was to obtain the best schedule that achieves the highest used of the water unit with the least amount of water used whenever possible. So, while preserving the grain yield. The time and depth standards used to create the irrigation schedules were listed in Table 4.

Table 4. Time and depth criteria used for generating irrigation schedules.

Parameter		
Time criterion	Allowable depletion (% of RAW)	60% and 80 %
Depth criterion	Back to field capacity (± extra mm water)	Extra water on top of the required dose to take the soil water content back to field capacity. Values can be zero, positive or negative.
	Fixed application depth (mm water)	80 mm

In this study, the best of fit was calculated by two model evaluation statistics such as Nash– Sutcliffe Efficiency (NSE) and the Root Mean Square Error (RMSE). The NSE establishes the relative magnitude of the remaining variance compared to the measured data variance, (Nash and Sutcliffe, 1970). NSE indicates how well the chart of observed versus suggested data fits the 1:1 line. NSE ranges between-1 and 1.0, with NSE = 1 being the optimal value. NSE was calculated with help of the following equation:

$$RMSE = \sqrt{\frac{\sum (P_i - O_i)^2}{n}}$$

$$NSE = 1 - \frac{\sum (P_i - O_i)^2}{\sum (O_i - \bar{O})^2}$$

Where: ***RMSE*** **is the Root Mean Square Error,** ***NSE*** **is the Nash–Sutcliffe Efficiency,** P_i **is the predicted,** O_i **is the observed,** ***P*** **and** $\bar{O}$ **are the average value for** P_i **and** O_i**.**

RESULTS AND DISCUSSION

Model calibration results:

Canopy cover, grain yield and final aboveground biomass have been calibrated. Maximum canopy cover, canopy growth coefficient and canopy decline coefficients were modified and re-modified to simulate the measured canopy cover. Calibrated parameters of crop growth and morphology were in Table 5.

Table 5. Calibrated crop parameters for wheat.

Parameters		Value
Growth and morphology	Initial canopy cover, %	4.5
	Maximum canopy cover, %	96
	Canopy expansion, %/day	7.5
	Canopy decline coefficient, %/GDD	0.389
	Shape factor for stress coefficient for canopy expansion	0.5
	P_ upper threshold for canopy/leaf expansion	0.20
	P_ lower threshold for canopy/leaf expansion	0.65
	P_ upper threshold for stomatal closer	0.65
	Shape factor for stomatal closure	2.5
	P_ upper threshold for canopy senescense	0.7
	Shape factor for stress coefficient for canopy senescense	2.5
	Shape factor for root expansion (-)	1.5
	Decline in crop coefficient because of mature (% per day)	0.15
Production	Normalized crop water productivity (WP), g/m^2	16

Determining the most appropriate parameters of the CC curve was a prerequisite for the model to lead to good estimates of soil evaporation, crop transpiration and biomass, and hence good predictions of yields. Also, it showed the average CC observed versus the AquaCrop simulation under the irrigation quantities and events applied by farmers for both three growing seasons. AquaCrop managed to accurately simulate CC development with various irrigation events. Fig. 2 showed that there was a good agreement between the observed and suggested canopy cover development. It was also approved by statistical values EF and RMSE,0.92 and 8.7% resp. values were close to 1 which indicates simulated canopy cover agreed well with observed.

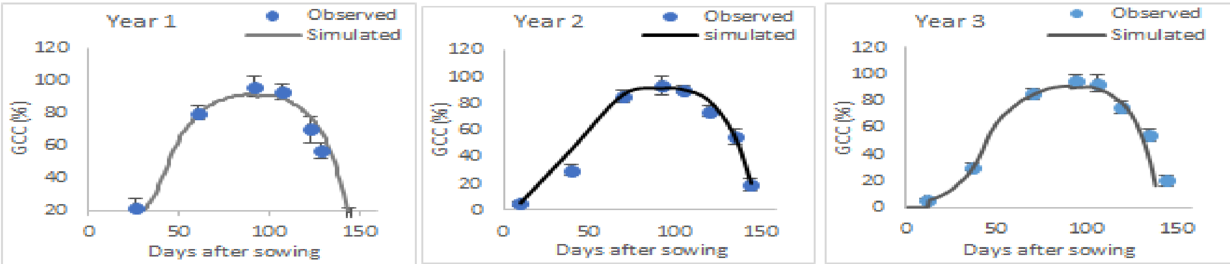

Fig .2. Simulated and observed values of wheat canopy cover (CC) during the three growing seasons from 2013-2016.

The simulated grain yield and biomass (for the year 2013-2016) were depicted in Fig. 3. The data bar indicates reasonable simulation of grain and biomass yield. The deviation of the simulated grain yield and biomass from observed data set was 0.8% and 1.1%, respectively. The statistical indicators of the simulation outputs are summarized in Table 6. which indicate that the model can simulate yield with acceptable accuracy.

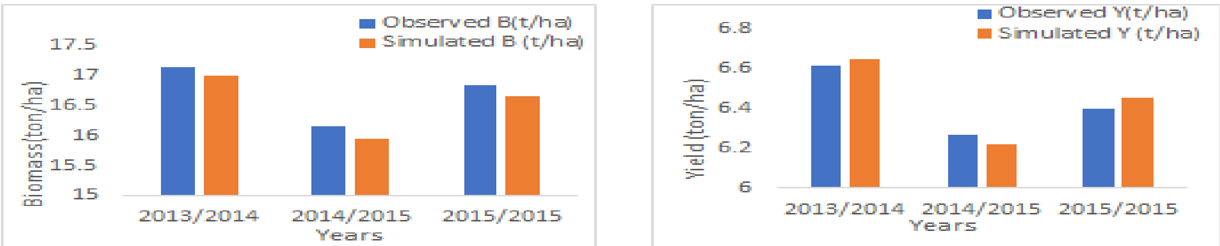

Fig. 3. Observed versus suggested grain yield and biomass during 2013:2016.

Table 6. Statistical pointers for model performance.

Statistical/performance indicators	Grain yield	Biomass yield
RMSE (ton/ha)	0.05	0.2
NSE	0.9	0.8

Generation of irrigation schedule:

By keeping the water content in the soil between the field capacity and the 80% RAW threshold, water losses because of deep percolation were limited, and crop water stress and yield loss were avoided. A 30% decrease in water use was recorded, from 480 to 334 mm, with obtaining the same yield, 6.5 ton/ha. Table 7 showed the effect of keeping the water content in the soil between the field capacity and the 80% RAW threshold in (Irri) Net application of irrigation (mm), grain yield (ton/ha) and (W_{pet})water productivity(Kg/m^3) but this schedule is difficult to implement in surface irrigation to increase the number of irrigation. Up to ten irrigation event per season with the close period between the irrigation, which is difficult to implement, especially in the shift system.

Table 7. Net application of irrigation (mm), grain yield (ton/ha) and water productivity (Kg/m^3) when the water content in the soil between the field capacity.

Years	60%RAW			80%RAW		
	Irri. (mm)	Yield (ton/ha)	W_{Pet} (kg/m^3)	Irri. (mm)	Yield (ton/ha)	W_{Pet} (kg/m^3)
2013/2014	341	6.675	1.98	317	6.657	2.04
2014/2015	398	6.351	1.67	371	6.339	1.69
2015/2016	338	6.61	1.76	316	6.6	1.78
Sum/Avg	1077	6.55	1.80	1004	6.53	1.84

Table 8. Shown a reduction of 16.7 % in water use was registered from 480 mm to 400 mm when used fixed net application (80mm) and depilation of the 80% RAW threshold. while obtaining the same yield, 6.5 ton/ha and increase water productivity 1.92 Kg/m^3 in addition to reducing both drainage and soil evaporation as in the Fig. (6). Less water was 16.7 % hence being extracted from the river and becomes available for other crops and farmers, constituting a considerable benefit.

Table 8. Net application of irrigation (mm), grain yield (ton/ha) and water productivity (Kg/m^3).

Years	60%RAW			80%RAW		
	Irri. (mm)	Yield (ton/ha)	W_{Pet} (kg/m^3)	Irri. (mm)	Yield (ton/ha)	W_{Pet} (kg/m^3)
2013/2014	480	6.67	2.09	400.00	6.67	2.05
2014/2015	480	6.30	1.80	400.00	6.32	1.82
2015/2016	400	6.61	1.85	400.00	6.60	1.88
Sum/Avg	1360	6.53	1.91	1200.00	6.53	1.92

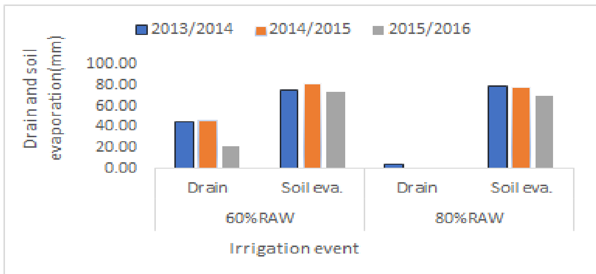

Fig. 6. Drain and soil evaporation when fixed net application (80mm) and depilation of the 60% and 80% RAW threshold.

CONCLUSION

The FAO model “AquaCrop” (version,6.1) was calibrated by matching observed yield and biomass data, and then validated with independent data sets. Subsequently, the calibrated model was treated to simulate grain yield for generation of irrigation schedule with a view to develop appropriate irrigation management strategy for wheat. The simulation study shows a clear the highest value of wheat water productivity was achieved by five event irrigations and the irrigation interval ranges between 30:39 days when fixed net application (80mm) and depilation of the 80% RAW threshold, taking into the rainy . Demonstrates this alternate sequence better than the normal/used irrigation sequence performed (fixed net application 80,96mm and fixed interval 27,33 days on six and five irrigations application resp.). The results will help to select appropriate irrigation management option for the prevailing conditions of weather and farm resources. Therefore, this model can be used as a decision support tool in increasing water productivity by project managers, consultants, irrigation engineers and farmers. In other words, this model can be worked to simulate the water management effect on yield and handle managements that increase water productivity.

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إدارة مياه الري الحقلي للقمح باستخدام نموذج AquaCrop

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تهدف الدراسة الى تقييم أداء نموذج منظمة الأغذية والزراعة "AquaCrop" (الإصدار 6.1) في محاكاة الانتاجية والكتلة الحيوية لمحصول القمح بالأراضي القديمة تحت نظام الري السطحي تم استخدام بيانات حقلية عن الفترة من سنه2013 -2016 لمعايرة قدرة النموذج على محاكاة الإنتاجية والكتلة الحيوية من خلال مطابقة الإنتاجية والكتلة الحيوية المرصودة باستخدام جذر متوسط مربع الخطأ (RMSE)0.05و0.2 طن / للهكتار وقيم معامل ناش (NSE)0.9،0.8 بالترتيب. تم استخدام النموذج المعاير لمحاكاة محصول الحبوب لتوليد جدول الري بهدف تطوير استراتيجية إدارة مياه ري مناسبة للقمح. أظهرت دراسة المحاكاة أن أعلى قيمة لإنتاج مياه القمح تم تحقيقها من خلال تطبيق خمسة ريات بصافي ثابت (80 مم/ رية) بإجمالي 400مم للموسم وفاصل زمني متغير يتراوح بين 30و39 يومًا بعد استنزاف 80 ٪ من الماء الميسر (RAW) مع الأخذ في الاعتبار الأمطار. يعتبر هذا التسلسل أفضل من تسلسل الري العادي المستخدم الذي تم إجراؤه في الفترة من 2013 الى 2016 (تطبيق صافي ثابت 96،80 مم وفاصل زمني ثابت33, 27 يوم على 5،6 ريات على التوالي بإجمالي 480 مم للموسم),حيث ان استخدام 16.7٪ مياه أقل مع زيادة الإنتاجية المائية يعد من الامور المهمة في الوقت الراهن. ستساعد النتائج في تحديد خيار إدارة الري المناسب للظروف السائدة للطقس وموارد المزرعة، وبالتالي يمكن استخدام هذا النموذج كأداة لدعم القرار في زيادة إنتاجية المياه من قبل مديري المشاريع والاستشاريين ومهندسي الري والمزارعين. بمعنى آخر، يمكن استخدام هذا النموذج لمحاكاة تأثيرات إدارة المياه على المحصول ومعالجة الإدارات التي تزيد من إنتاجية المياه.