IRRIGATION MANAGEMENT OF PEPPER CROP UNDER SURFACE AND SUB-SURFACE DRIP IRRIGATION SYSTEMS BY USING EXPERT SYSTEM, IRRIMET AND CROPWAT

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ABSTRACT

The scarcity of water in Egypt need for hard work to solve it. One of the best solutions is good management of limited water, therefore, this paper aims to provide farmers and decision-makers with a new accurate and cheap technique for water management. The experimental work was carried out in the farm of Faculty of Agriculture, Benha University (30^0 $21^/$ $26.24^{//}$ N and 31^0 $13^/$ $15.89^{//}$ E) during the summer seasons of 2016 and 2017. Three irrigation management tools (Expert system (ES), IRRIMET model (IM) and Cropwat model (CW)) were applied with surface and sub-surface drip irrigation systems. The results showed that the highest values of water saving were achieved by IM model followed by ES tool. Also, the estimated values of reference evapotranspiration (ET_o), single crop factor (Kc) and crop evapotranspiration (ET_C) under ES were very close to that obtained under IM model while under CW model the corresponding values were far from that under IM model especially the ETc values. Yield were achieved under subsurface drip irrigation system (SSDI). On the other hand, the IM model gave the highest values of pepper yield, water productivity (WP) and nutrient use efficiency (NUE) (6.86 ton h^{-1}, 1.59 kg m^{-3} and 21.17 kg kg^{-1}, respectively, with SSDI and 6.71 ton h^{-1} , 1.64 kg m^{-3} and 20.75 kg kg^{-1}, respectively, with SDI), followed by ES (6.02 ton h^{-1} , 1.3 kg m^{-3} and 17.28 kg kg^{-1}, respectively with SSDI and 4.31 ton h^{-1} , 1.09 kg m^{-3} and 13.76 kg kg^{-1}, respectively with SDI. However, the differences between the values resulted from using ES and IM were not significant. The lowest values of pepper yield, WP and NUE were achieved with the management based on CW model outputs.

Keywords: *Cropwat, Expert systems, IRRIMET model, surface drip irrigation, subsurface drip irrigation, WUE and NUE.*

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INTRODUCTION

Shortage of water is considered the most important problem that many countries are facing **(Gohar and Ward, 2013)**. Water management and use are a continuing problem in developing countries with semi-arid to arid climates such as Egypt. The lack of effective irrigation management is often the most limiting factor in increasing agricultural productivity in these countries **(Walters and Jha, 2016).**

The total amount of available water in Egypt is 55.5 milliard m^3/year and the sector of agriculture consumes about 85% of the total available water **(Seleym and Elshafei, 2017)**. This amount of water may be decreased by 10% and 20% annually, reducing the national income of farmers by 32% to 33% per year **(Gohar and Ward, 2013).** Many studies recommended better management of water resources as one of the most important ways for decreasing the losses of water **(Brouwer and Heibloem, 1986)**.

Due to the recognized loss of water caused by the error in predicting or calculating crop water requirements, many tools (models) are being used, nowadays **(Al-Najar, 2011)** for irrigation schedule or management, which is the most important key for succeeding any farm and to save irrigation water. Adjusting crop factors facilitates irrigation scheduling and helps achieving full yield potential without over-irrigation **(Bryla et al., 2010)**. But effective use of water and soil in complex systems, such as irrigation areas, requires the management of large amounts of information and forecasting / decision-making algorithms in an uncertain environment **(Mundo et al., 1970)** and some models have been used for this purpose. According to **Grosan and Abraham (2011)**, the rule-based systems, also known as production systems or expert systems, simulate the thinking of the human expert in solving an intensive knowledge problem. Cropwat model is used in many countries to estimate irrigation water requirements. **Al-Najar (2011)** claims that the accuracy of this model in calculating the reference evapotranspiration accounts for ± 5 mm/year.

The aim of this paper is to select the tools (models) for irrigation management of pepper crop by applying the expert system (ES) **(Farag, 2012)**, Cropwat model (CW) and IRRIMET model (IM) either using local records or historical records and comparing not only the outputs used for

irrigation scheduling in different subplots but also the resulted yields, water productivity, (*WP*) and nutrient use efficiency (NUE) as defined later. Using historical records could save costs and one of the aims is to evaluate impacts of this practice.

MATERIALS AND METHODS

The experimental site

The experimental site at Faculty of Agriculture, Moshtohor, Benha University has an iMETOS meteorological station, which is located on the faculty's farm located at latitude 30^0 $21^/$ $26.24^{//}$ and longitude 31^0 $13^/$ $15.89^{//}$, about 15 m above sea level. The experimental work was conducted at that farm, during the summer seasons of 2016 and 2017. The climate of this area is arid, and has arid climate (BWh) according to **Köppen (1936).** The investigated soil was characterized by a clayey texture with the following properties, respectively for the three layers 0-20, 20-40 and 40-60 cm: pH of 7.42, 7.19 and 77, EC of 2.59, 2.22 and 3.63 dS m^{-1}, soil water content at saturation of 0.70, 0.80 and 0.77 m^3 m^{-3}, soil water content at field capacity of 0.335, 0.385 and 0.368 , soil water content at wilting point of 0.160, 0.185 and 0.177 m^3 m^{-3} and bulk density of 1.10, 1.15 and 1.19 kg m^{-3}. The average value of saturated hydraulic conductivity of the soil was1.4 m day^{-1}.

Capsicum annuum species (pepper*)* was used for this experiment; it belongs to the Solanaceous family and is usually divided into two groups, pungent and non-pungent, also called hot and sweet pepper **(Zayed et al., 2013)**. The hot type was selected for this experiment *Capsicum annuum* 'Anaheim'. The experimental design was RCBD with three replicates.

Two irrigation systems: surface and sub-surface drip irrigation systems were used.

Irrigation models

The expert system (ES) was designed by **Farag (2012).** It can provide the user and decision maker the suitable decision in the field of fertilizers and water management. This system consists of database, user interface and rules processing unit (Fig. 1).

Cropwat model (CW) is considered the most well spread program for irrigation management of annual crops **(Smith, 1992)**; Even though FAO-CropWat model is used for many countries to estimate irrigation water

requirements **(Al-Najar, H., 2011)**. It includes three sub models to estimate reference evapotranspiration (ET_o), root depth and crop coefficients.

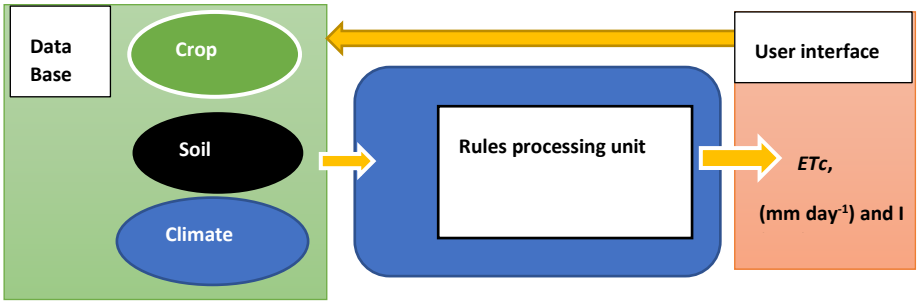

Fig (1). The expert system components

IRRIMET (IM) is a new program included in the website of FieldClimate platform (https://www.fieldclimate.com/) which works with iMETOS stations. The daily meteorological data are measured by iMETOS**,** which has sensors for air temperature, relative humidity, rain, leaf wetness, soil temperature, radiation, wind speed and wind direction. IRRIMET is a free web application associated with the FieldClimate platform, for the calculation of the daily soil water balance. For this aim, it takes into account the precipitation, irrigation depths and crop evapotranspiration for well-watered plants (ET_c) and presents the results in tables and graphics. The value of the reference evapotranspiration (ET_o) is calculated from the local microclimatic data recorded by the station **(Domínguez and Sainz-Aguirre, 2016).**

Crop water requirements

The crop water requirements were calculated by those three different tools: Expert system (ES), IRRIMET Model (IM) and CropWat model (CW), but based on different data.

The IRRIMET model has the same strategy of ES and CW, but the main difference among them was that daily required meteorological data from iMETOS were used for the IM model. Daily values for ET_o and ET_c were calculated by IRRIMET program.

All the investigated models used the same equation to estimate *ETo* but only IM used daily data. CW and ES used monthly historical records from different origins (the average of last 10 years).

ET_o was calculated with Penman-Monteith equation (eq. 1) according to **Allen *et al*., 1998.**

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} U_2\,(e_s - e_a)}{\Delta + \gamma[1 + 0.34U_2]} \qquad [1]$$

where ET_O is reference evapotranspiration [mm day^{-1}], R_n net radiation above the crop surface [MJ m^{-2}day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}], T mean daily air temperature at 2 m height [°C], U_2 wind speed at 2 m height [m s^{-1}], es saturation vapor pressure [kPa], e_a actual vapor pressure [kPa], e_s-e_a saturation vapor pressure deficit [kPa], Δ slope vapor pressure curve [kPa °C^{-1}] and γ psychometric constant [kPa °C^{-1}].

Single crop coefficients (K_c) were added to IRRIMET application taken from FAO table **(Allen et al., 1998)**. The *Kc* values taken for pepper crop were 0.6 in the initial stage, 1.05 in mid stage and 0.9 in late stage. The growth periods were 30, 35, 40 and 20 days for initial, mid and late stages, respectively (**Allen et al., 1998).**

$$ET_c = ET_o . K_c \qquad [2]$$

where ET_C is crop evapotranspiration (mm day^{-1}) and ET_O is reference evapotranspiration (mm day^{-1}).

ES tool has the same strategy as IM and CW in calculating ET_C, but there were differences among them in estimating the adjusted crop coefficients ($K_{c\,adj}$, equations 3 and 4).

$\boldsymbol{Kc_{mid\,Adj}}$ is the adjusted crop coefficient at mid growth stage calculated from equation (4) according to **Allen *et al*. (1998):**

$$Kc_{mid\,Adj} = Kc_{mid(table)} + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h_p}{3}\right)^{0.3} \qquad [3]$$

where $\boldsymbol{Kc_{mid(table)}}$ is taken from FAO 56 (**Allen *et al*., 1998)**, h_p is the maximum plant height (m), RH_{min} the mean value for minimum daily

relative humidity during the mid-season [%] and U_2 is the value of wind speed at 2 m height during the mid-season [m s^{-1}].

$\boldsymbol{Kc_{end\ Adj}}$ is the adjusted crop coefficient at the end of the growth stage, which is estimated from equation (5), according to **Allen *et al*. (1998):**

$$Kc_{\text{end Adj}}=Kc_{end(table)}+[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)](h_p/3)^{0.3} \quad [4]$$

where $\boldsymbol{Kc_{end(table)}}$ is the crop coefficient at the end of the growth stage, taken from FAO56 tables (**Allen *et al*., 1989).**

Kc_{dev} is the crop coefficient during the days of the development growth stage c, calculated by equation (5) according to **Farag (2012**):

$$Kc_{dev} = A + (B * X) \quad [5]$$

where

$$A = Kc_{int} - (B * I_S) \quad [6]$$

where I_S is the number of days of initial stage (day),

$$B = \frac{Kc_{mid\ Adj} - Kc_{int}}{Dev\ stage} \quad [7]$$

Root depth measured and modelled

The root depth was predicted by the three models: in ES model according to **Borg and Grimes (1986)** by equation (8):

$$Z_r = Z_{rm}\left[0.511 + 0.511\ Sin_{(rad)}\left[3.03\frac{DAP}{DTM} - 1.47\right]\right] \quad [8]$$

where Z_r is the root depth and *DAP* is the number of days after planting, Z_{rm}

is the maximum root depth (0.75 m) and *DTM* is the maximum days to maximum root depth (70), where the parameters Z_{rm} and *DTM* were taken from **Allen et al. (1998).**

With the model IM, the root depth was considered constant from the beginning until harvest, equal to 35 cm.
With the *CW* model, Z_{rm} was considered 0.75 m (as above) and the root depth changed linearly from 0.25 m, at the beginning of the growth season until that maximum value, at mid stage, simulated by the model as shown in Results.
Conversely, the root of pepper crop was measured six times, during the growth season, by excavation method in each of treatment (with three replications).

Irrigation scheduling

The total available soil water (*TAW*) in a layer corresponding to average *Zr* was calculated according to:

$$TAW = 1000\left(\theta_{fc} - \theta_{wp}\right)Z_r \quad [9]$$

where *TAW* is the total available soil water in the root zone (mm), θ_{fc} is the water content at field capacity ($m^3\ m^{-3}$), θ_{wp} is the water content at wilting point ($m^3\ m^{-3}$) and *Zr* is the root depth (m).
The readily available water (*RAW*) was calculated according to the following equation:

$$RAW = p * TAW \quad [10]$$

where *p* is a fraction of *TAW* which is available for the plant without reduction in *ET* it was considered as 0.3 for pepper crop according to **Allen et. al. (1998)**.
The leaching requirements (L_R) for the experimental soil under pepper crop were estimated according to **Ayers and Westcot, 1976 (FAO-29)** as:

$$L_R = EC_{iw} / (5\ EC_e - EC_{iw}) \quad [11]$$

$ECe = 1.5 \times EC_{iw}$ under conditions where leaching fraction is 15-20%, EC_{iw} is the electrical conductivity of the irrigation water (2.65 ds m^{-1}) and L_R is 15.4%.
The applied irrigation depth (I_w) in mm was calculated by the following equation:

$$I_w = \frac{RAW}{E_i(1-L_R)} \quad [12]$$

where I_w is the irrigation depth [mm] for the part of the surface that is wetted (35%) and E_i is the water application efficiency. Values for E_i were 0.9 for surface drip irrigation system (SDI) and 0.95 for subsurface drip irrigation system (SSDI).

The irrigation intervals (*II*) in days were estimated the following equation:

$$II = \frac{RAW}{ET_c} \quad [13]$$

Water productivity (*WP*) and nutrient use efficiency (*NUE*)

Water productivity (*WP*) is defined, according to **Molden et al. (2010)**, as the net benefit from the crop to the amount of water used to produce those benefits, i.e., the relationship between the marketable fruit yield (kg ha^{-1}) and the total water applied (m^3 ha^{-1}) **(Patanè et al., 2011)**.

Nutrient use efficiency (*NUE*) can be expressed several ways. **Mosier et al. (2004)** described 4 agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrient in harvested crop as % of nutrient applied) is also commonly used to explain nutrient efficiency.

According to **FAO (2005),** the pepper crop needs on average 250 kg ha^{-1} of nitrogen fertilizer, 55 kg ha^{-1} of phosphor fertilizer in form of P_2O_5 and 60 kg ha^{-1}potassium, in form of K_2O, which were applied in this experiment.

Under SDI and SSDI, the yield was measured considering all the plants under each 3 replicates of the three treatments.

RESULTS AND DISCUSSION

The relation between the estimated ET_o values

The seasonal trend of ET_o during the growth season estimated by using IM, ES and CW models, with daily data (IM) or historical records either from

local records (ES) or national records for the area (CW), is displayed in Fig. (2). The predicted ET_o values from ES was very close to the values obtained from IM especially from August to October. After October, the differences between both increases until the highest value at the end of season (November 30). The values of ET_o estimated by CW were very different from IM line and also very different from ES model, except in August. These discrepancies are due to the differences between local meteorological data used and historical records in this particular year.

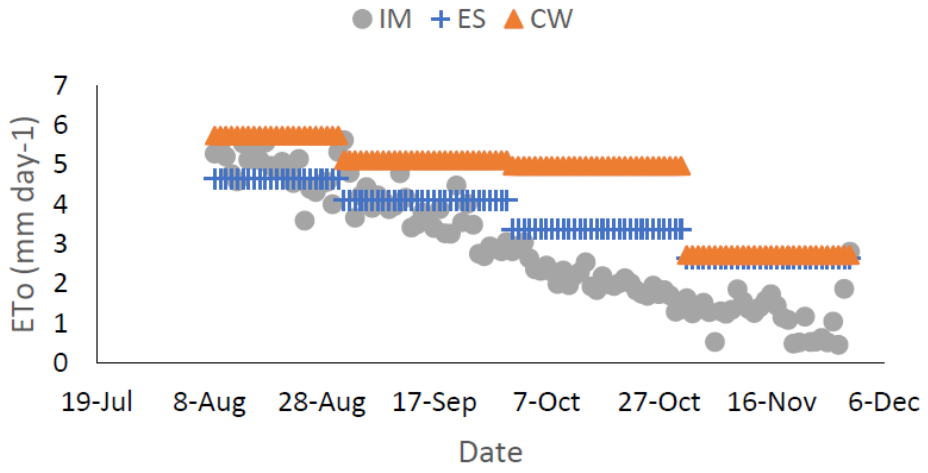

Fig (2). The relationship between estimated values of ET_o

The relationship between the estimated crop coefficient (*Kc*)

The changes of Kc estimated by the different models (IM, ES and CW) during the growth season are illustrated in Fig. (3).

The lines of *ES* and *IM* were closed to each other by the middle season, from the start of mid stage (September, 24) until the end of season, while the *CW* line was far from other lines. All lines started from the same point at the beginning of the season (initial growth stage) and crossed at the start of mid growth stage.

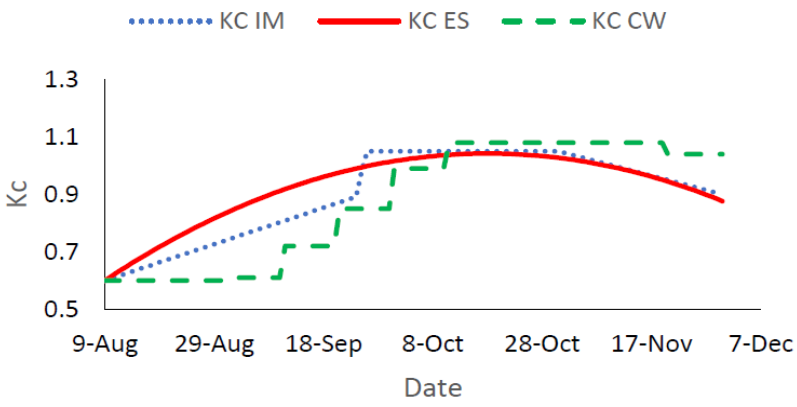

Fig (3). Relationship between estimated values of *Kc*

The relation between the estimated *ETc* by different models

The results of ET_C for the three models are illustrated in Fig. (4) and are the consequence of the deviations displayed in Figures 2 and 3. All lines in the initial stage (August, 9 until September, 20) are very close but, after that, the distance among all lines increases until October, 31. The difference between IM and CW is 3.83 mm day^{-1} and between IM and ES is 1.55 mm day^{-1}. After October, these differences decreased until 0.88 mm day^{-1} and 1.4 mm day^{-1} between IM and ES and between IM and CW, respectively.

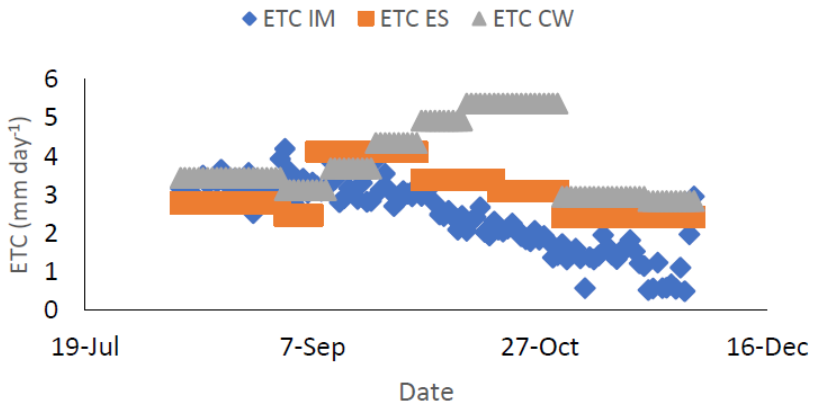

Fig (4). Relationship between the actual and estimated values of ET_C

From the previous results of ET_O, *Kc* and ET_C, it appears that the lowest differences among all estimated values were between *IM* and *ES*. Consequently, the best selection after *IM* is to select *ES* for estimating the values of ET_C with suitable accuracy, quickly, easily and with less costs (as it was estimated from historical records).

The estimated and measured root depth, Zr

The Figures 5, 6 and 7 show the estimated and measured values of root depth in each corresponding plot, during the growth season of pepper. The best predicted values were that obtained from expert system (ES) followed by that from CropWAT (CW) program while, the IRRIMET (IM) program has estimated the root depth as a constant value (35 cm) from the beginning until harvest.

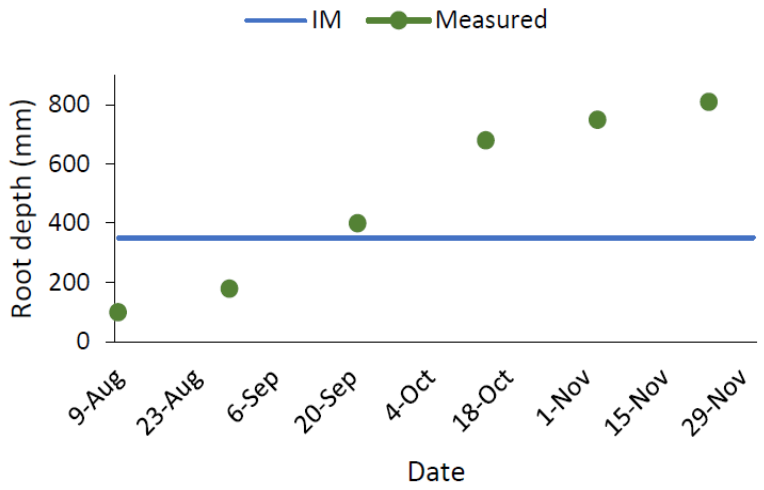

Fig (5). Estimated and measured root depth by IM in the corresponding plots (n = 3) during the growth season.

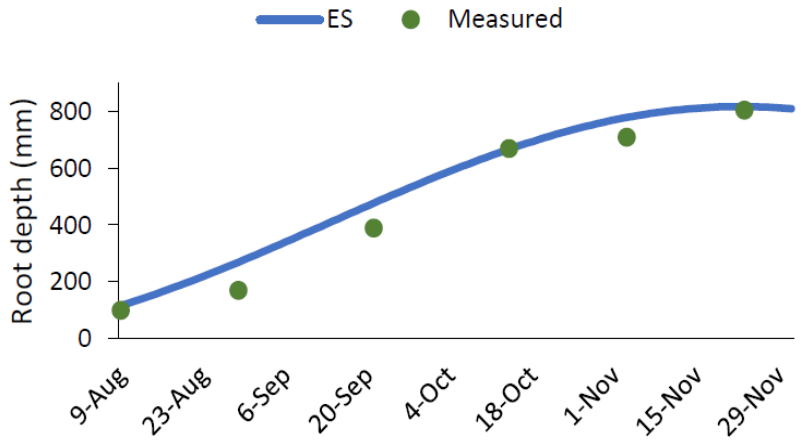

Fig (6). Estimated and measured root depth by ES in the corresponding plots (n = 3) during the growth season.

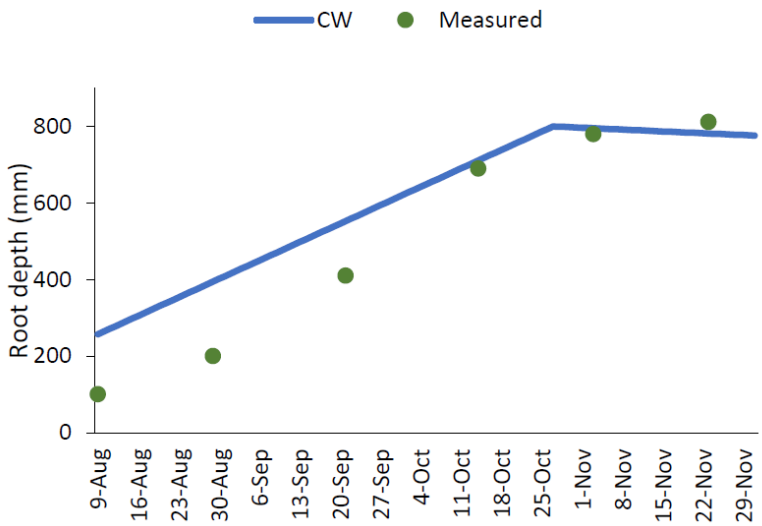

Fig (7). Estimated and measured root depth by CW in the corresponding plots (n = 3) during the growth season.

Yield and water productivity (WP)

Table (1) shows the yield and water productivity *WP* of the pepper crop by using the three irrigation management models, under surface drip irrigation (*SDI*) and sub-surface drip irrigation (SSDI) systems.

Table (1). Yield and *WP* of pepper crop

Irrigation system (IS)	Treatment (IT)	Yield (ton h^{-1})				*WP* (kg m^{-3})			
		2016	2017	Average	%	2016	2017	Average	%
SSDI	IM	16.32	13.71	15.0	100	3.78	1.05	2.4	100
	ES	13.33	13.14	13.2	88.1	3.09	1.12	2.1	87.2
	CW	11.45	11.62	11.5	76.8	2.65	0.805	1.7	71.5
SDI	IM	16	10	13.0	100	3.9	0.77	2.3	100
	ES	10.61	9.62	10.1	67.4	2.59	0.805	1.7	72.7
	CW	6.5	6.38	6.4	42.9	1.58	0.595	1.1	46.6

Data illustrated in Table (1) reveal that SDI resulted in lower yields of pepper than the corresponding ones achieved due to the SSDI; not only the yields are lower but the SDI consumed a higher quantity (by 5 %) of irrigation water (data not shown) than the SSDI irrigation, both factors contributing to higher WP with SSDI.

Table (2). *NUE* for pepper crop

Irrigation system	Treatment	*NUE* (kg kg^{-1})								
		2016				2017				Average
		N	P	K	Total (NPK)	N	P	K	Total (NPK)	Total (NPK)
SSDI	IM	65.3	679.1	327.8	50.4	54.9	570.6	275.4	42.4	46.4
	ES	53.3	554.4	267.6	41.2	52.6	546.8	263.9	40.6	40.9
	CW	45.8	476.2	229.8	35.3	46.5	483.4	233.3	35.9	35.6
SDI	IM	64.0	665.7	321.3	49.4	40.0	416.1	200.8	30.9	40.1
	ES	42.4	441.5	213.1	32.8	38.5	400.2	193.2	29.7	31.2
	CW	26.0	270.4	130.5	20.1	25.5	265.5	128.1	19.7	19.9

The highest average values of yields of season 2016 and 2017 were achieved with the IM model, i.e., 15 and 13 ton h^{-1}, under SSDI and SDI systems, respectively, followed by ES, which gave a yield not far away from those resulting from IM, i.e. 13.2 and 10.1 ton h^{-1}, under SSDI and SDI, respectively. CW resulted in the lowest yields, i.e. 11.5 and 6.4 ton h.$^{-1}$ under SSDI and SDI, respectively.

Also, the results in table (1) show *WP* under the different irrigation management models (IM, ES and CW) under surface (SDI) and subsurface drip irrigation systems (SSDI). The highest values of *WP* were obtained with IM, i.e. 2.4 and 2.3 kg m^{-3} under SDI and SSDI, respectively, followed by ES, i.e. 2.1 and 1.7 kg m^{-3} under SSDI and SDI, respectively. The lowest *WP* was with CW, i.e. 1.7 and 1.1 kg m^{-3}, respectively.

Table (2) shows the effects of the irrigation management model (IM, ES and CW) under the two investigated irrigation systems, SDI and SSDI on nutrient use efficiency (*NUE*) of pepper crop. The highest average values of *NUE* were found by using the IM model, i.e. 46.4 kg/kg and 40.1 kg/kg under SSDI and SDI systems, followed by ES method (40.9 kg/kg and 31.2 kg/kg), respectively. And the lowest values were achieved by CW (35.6 kg/kg and 19.9 kg/kg) under the SSDI and SDI, respectively.

These results show that, using the *ES* model for irrigation management of pepper resulted in *WP* and *NUE* values not very far from those achieved using the IM model. However, using the expert system (*ES*) model had less costs due to the original data required in this case so it seems to be the best compromise between costs of applying the model and benefit.

CONCLUSION

The aim of this study was to select the cheapest and most accurate management irrigation model between three irrigation management models under surface and subsurface drip irrigation systems, where differences

were mainly due to original data used. The results showed that the highest water savings were achieved by IM followed by ES model. Also, the estimated values of ET_o, Kc and ET_C under ES were very close to the corresponding values by IM, while for CW, values were far from IM values especially for ET_C. Moreover, the highest values of yield were generally achieved under subsurface drip irrigation system (SSDI). On the other hand, the IM model gave the highest values of yield, *NUE* and *WP* (15 ton ha^{-1}, 46.4 kg/kg and 2.4 kg m^{-3}, respectively under SSDI), followed by ES (13.2 ton ha^{-1}, 40.9 kg/kg and 2.3 kg m^{-3}, respectively under SSDI) while the lowest values of yield *NUE* and *WP* were achieved with the CW model. Finally, it could be recommended that the ES model to be an accepted tool for water management.

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الملخص العربى

إدارة الري لمحصول الفلفل تحت نظامي الري بالتنقيط السطحي وتحت السطحي بإستخدام نظام خبير وموديل IRRMET وبرنامجCROPWAT

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تقع مصر في المنطقة القاحلة، حيث يعتبر نهر النيل المصدر الرئيسي للمياه. حيث يمدها بحوالي ٥٥,٥ مليار متر مكعب سنوياً. وتتطلب ندرة المياه في مصر الي العمل الشاق لحلها. وواحد من افضل الحلول التي يمكن إتباعها لحل هذه المشكلة هو الإدارة الجيدة لمصادر المياه المحدودة ولذلك يهدف هذا البحث الي تذويد المزارعين وصانعي القرار بتقنية جديدة دقيقة ورخيصة لإدارة المياه. وقد تم إجراء الدراسة في مزرعة كلية الزراعة، جامعة بنها خلال الموسم الصيفي ٢٠١٦ و ٢٠١٧علي محصول الفلفل. حيث تم إختبار ثلاث طرق للإدارة المائية وهي النظام الخبير ES و الموديل IRRIMET (IM) وكذلك Cropwat (CW) حيث تم إختبارها تحت نظامي الري بالتنقيط فوق السطحي وتحت سطحي.

وقد أظهرت النتائج أن :

- أعلى كمية المياه تم توفيرها كان مع إستخدام نظام IM يليها النظام الخبير وقد أتى ال CW في المؤخرة.
- أيضاً كانت قيم البخرنتح المرجعي و المعامل المحصولي والإستهلاك المائي المحسوبة والمتوقعة بالنظام الخبير قريبة جدا من القيم المقاسة بإستخدام IM بينما كانت القيم المحسوبة والمتوقعة بإستخدام CW بعيدة عن القيم المقاسة بإستخدام IM وخاصة قيم الإستهلاك المائي.
- كانت اعلى قيم للإنتاج وكذلك كفاءة استخدام السماد وكفاءة استخدام المياه تحت نظام الري بالتنقيط تحت سطح التربة
- اعطى IM اعلي انتاج وكذلك اعلي كفاءة استخدام للمياه والسماد يليها النظام الخبير بدون اي فروق معنوية
- اقل إنتاج وكذلك اقل كفاءة استخدام للمياه والسماد كانت مع نظام CW

ومن النتائج السابق ذكرها يمكن ان نرشح هذا النظام الخبيرليكون أداة جيدة للإدارة المياه وذلك لترشيد إستخدام المياه وكذلك السماد.

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