RESPONCE A CONSUMPTIVE USE PROGRAM MODEL ON WHEAT UNDER EGYPTIAN CONDITIONS

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ABSTRACT

The experiments were carried out at Moshtohor, Kalubia governorate [Latitude: 30^o 21`N, Longitude: 31$^o$ 14`E and Elevation: 14 m] during 2015/16 growing seasons to test model application of wheat under Egyptian conditions. A computer application program has been developed as Consumptive Use Program plus (CUP plus) as is an application, can estimate crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw). A monthly climate data, the program uses daily measured weather data to estimate daily soil water balances for surfaces that account for evapotranspiration losses and water contributions from rainfall, seepage, and irrigation. Soil water-holding characteristics, effective rooting depths, and irrigation frequency were measured with rainfall and ETc data to calculate a daily water balance and determine effective rainfall and ETaw, which is equal to the seasonal cumulative ETc minus the effective rainfall. The main objective of this paper research is testing a mode for determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), which provides an estimate of the net irrigation water diversion needed to produce a crop. The obtained results show that ETo arrive to the maximum in May by 188.19 mm/month but ETaw arrive to the maximum in April by 110.71 mm/month. The application outputs a wide range of tables and charts that are useful for irrigation planning and decision making.

Keywords: *Program, Climate data, Water balance, Evapotranspiration, and crop coefficient.*

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1. INTRODUCTION

A user-friendly Microsoft excel application program "Consumptive Use Program plus" (CUP plus) was developed to help growers and water agencies determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), which provides an estimate of the net irrigation water diversion needed to produce a crop **Morteza, N. et al. (2011)**. The application also can be used to study the impact of climate change on evapotranspiration and irrigation water needs. And also added, CUP plus computes reference evapotranspiration (ETo) from daily solar radiation, maximum and minimum temperature, dew point temperature, and wind speed using the daily Penman-Monteith equation. In addition, the program uses a curve fitting technique to derive one year of daily weather data from the monthly data and to estimate daily ETo. It also uses daily rainfall data to estimate bare soil evaporation as a function of mean of ETo and wetting frequency in days. A bare soil Kc value is calculated to estimate the off-season evapotranspiration and as a baseline for in-season Kc calculations. Further, the program computes and applies all ETo and Kc values on a daily basis to determine crop water requirements by month, by season, by year. The application outputs a wide range of tables and charts that are useful for irrigation planning. **Snyder, et al. (2011)** reported that, while evapotranspiration rates are known to increase with higher temperature, other factors in addition to rising temperatures also affect evapotranspiration (ET). For example, increasing humidity and higher CO_2 concentrations both tend to reduce transpiration and counteract the higher temperature effects on ET. **Ghandour, A. et al. (2006)** discussed a simple method to convert between reference evapotranspiration for short canopies (ET_o) and tall canopies (ET_r) using a modified Penman-Monteith equation and between the corresponding Kco and Kcr factors. Using weather data from 49 stations in California in a wide range of climates, a good relationship was found between the slope of monthly mean ETr versus ETo rates and the mean daily ETo rate for July. Similarly, a good relationship was found between the slope of monthly mean ETo versus ETr rates and the mean daily ETr rate for July. The slopes of regressions of daily ETr versus ETo rates and daily ETo versus ETr rates through the origin were nearly identical to slopes based on monthly calculations. The relationships can be used to estimate ETr from ETo and vice versa and to make crop coefficient conversions between the two reference evapotranspiration surfaces. **Nassar, A. et al. (2004)** setting the proper land, water and crop management under saline irrigation practices with a good yield without any deterioration in soil productivity. **Ghandour, A. (2016)** used model for simulation of evapotranspiration of applied water (SIMETAW) to determines effective rainfall and evapotranspiration of applied water (ETaw) for crop and land-use categories, which include similar agricultural crops and other surfaces, by different regions having similar ETo rates within California and Egypt Delta. The model uses daily observed or simulated climate data to account for ET losses and water contributions from seepage of groundwater, rainfall, and irrigation on a daily basis over the period of record to simulate a daily water balance. The model can use daily climate data or daily climate data simulated from monthly data to estimate daily ETo. **Bandyopadhyay, P. K. and Mallick, S. (2002)** indicated a constant decrease in soil water flux with increasing irrigation frequencies or rainfall with a concomitant increase in the actual evapotranspiration; by using water balance method, the seasonal evapotranspiration with four post sowing irrigations amounted 250 mm with zero ground water contribution; the crop coefficients values estimated for wheat can be used to work out crop water requirements and also irrigation scheduling under similar climatic conditions. **French, A. N. et al. (2009)** reported from modeling the surface energy balance using observations of canopy radiometric surface temperatures, readily available meteorological data, and nadir-view photography, showed agreement within $1.1 mmd^{-1}$ of independently obtained ET observations based on soil water depletions. This shows that energy balance modeling is a feasible and potentially valuable method for scheduling irrigations in arid environments. The experiment also showed that seed and oil yield were weakly correlated with ET for seasonal water supplied between 250 and 290mm. **Pereira, L. S. et al. (2015)** said that crop coefficient reference ET method is a robust method that provides for straightforward, visually-based derivation and application of the Kc curves over a wide range of climates and locations. The dual Kc method of FAO56 enables the estimation of impacts of surface wetting by precipitation and irrigation on evaporation from soil and the total ET rate, especially during vegetation development and also during periods of dormant vegetation growth such as during winter in extreme latitudes. Although simple in design and construction, the Kc method successfully incorporates a number of consistent and compensating factors that distinguish the ET of any unique crop from that of the reference ET. This characteristic has attracted a broad range and large number of users, whose backgrounds range from non-scientific commercial and operations-oriented users to relatively sophisticated research users who require high accuracy in estimates. **Anderson, R. G. et al. (2016)** analyzed three eddy covariance (EC) sites in two contrasting agricultural systems to demonstrate how a flux-variance based partitioning algorithm can be used to partition evapotranspiration into basal, soil evaporation, and stress coefficients for determination of agricultural water consumption. The objectives of this study were:

Use of the widely adopted daily Penman-Monteith equation for reference evapotranspiration (ETo) and improved methodology to apply crop coefficients for estimating crop evapotranspiration to improve ETc accuracy. Improve the dissemination of Kc and crop evapotranspiration (ETc) information to growers and water purveyors. Computes and applies all ETo and Kc values on a daily basis to determine crop water requirements by day, by month, by season, and by year. So using a free model (CUPplus) for determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), which provides an estimate of the net irrigation water diversion needed to produce a crop.

2. MATEREALS AND METHODS

The experiments were carried out at Moshtohor, Kalubia governorate [Latitude: 30^{o} 21`N, Longitude: 31$^{o}$ 14`E and Elevation: 14 m] during 2015/16 growing seasons to test CUPplus model application of wheat under Egyptian conditions.

This worksheet CUPplus program has developed and created by California Department of Water Resources and Land Air and Water Resources Department, University of California, USA.

Reference evapotranspiration (ETo) is estimated from daily weather data using a modified version of the Penman-Monteith (PM) equation as in [**Allen, et al. (1998)** and **Allen, et al. (2005)]**. The equation is:

$$ET_{ref} = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

Where Δ is the slope of the saturation vapor pressure as a function of the mean daily air temperature curve (kPa $^oC^{-1}$), R_n and G are the net radiation and soil heat flux density in MJ $m^{-2}d^{-1}$, γ is the psychometric constant (kPa $^oC^{-1}$), T is the daily mean temperature (^oC), u_2 is the mean wind speed in m s^{-1}, e_s is the saturation vapor pressure (kPa) calculated from the mean air temperature (^oC) for the day, and e_a is the actual vapor pressure (kPa) calculated from the mean dew point temperature (^oC) for the day. The coefficient 0.408 converts the R_n – G term from MJ $m^{-2}d^{-1}$ to mm d^{-1} and the coefficient C_n = 900 combine together several constants and coverts units of the aerodynamic component to mm d^{-1}. The product 0.34 u_2, in the denominator, is an estimate of the ratio of the 0.12-m tall canopy surface resistance (r_c =70 s m^{-1}) to the aerodynamic resistance (r_a =205/u_2 sm^{-1}). It is assumed that the temperature, humidity and wind speed are measured between 1.5 and 2.0 m above the grass-covered soil surface.

If only temperature data are available, then CUPplus calculates ETo using the Hargreaves-Samani (HS) equation **[Hargreaves** and **Samani (1982); Hargreaves** and **Samani (1985)]**:

$$ETo = 0.0023\ (Tc+17.8)\ R_a\ (Td)^{1/2} \qquad (2)$$

Where Tc is the monthly mean temperature (^oC), R_a is the extraterrestrial solar radiation expressed in mm/month, and Td is the difference between the mean minimum and mean maximum temperatures for the month (^oC). The calculation of extraterrestrial radiation and other parameters in the

Penman-Monteith and Hargreaves-Samani equations are described in **Allen et al. (1998)** and **Allen et al. (2005)**.

If pan data are used in CUPplus, then the application automatically estimates daily ETo rates using a fetch value (i.e., upwind distance of grass around the pan). The new method in the CUP plus estimates ETo from Epan data without the need for wind speed and relative humidity data.

Crop Coefficients and Evapotranspiration:

Field and row crop Kc values are calculated using a method similar to that described by **Doorenbos and Pruitt (1977)**, and **Allen et al. (2005)**. A generalized curve is shown in (Fig.1). In their method, the season is separated into initial (date A-B), rapid (date B-C), midseason (date C-D), and late season (date D-E) growth periods. Kc values are denoted KcA, KcB, KcC, KcD and KcE at the ends of the A, B, C, D, and E growth dates, respectively. During initial growth, the Kc values are at a constant value, so KcA = KcB.

During the rapid growth period, when the canopy increases from about 10% to 75% ground cover, the Kc value increases linearly from KcB to KcC. The Kc values are also at a constant value during midseason, so KcC = KcD. During late-season, the Kc values decrease linearly from KcD to KcE at the end of the season.

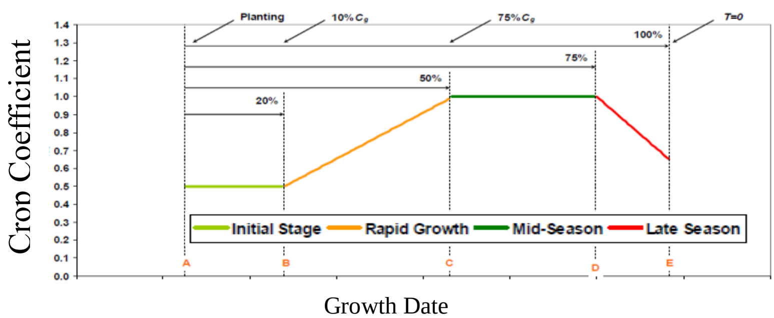


Fig. 1: Hypothetical crop coefficient (Kc) curve for typical field and row crops showing growth stages and percentages of the season from planting to critical growth dates. After Snyder, et al. (2011).

Description of Analytical Tools:

Estimation of daily crop coefficients and crop evapotranspiration main features and capabilities:

- CUPplus is written with Excel software.
- Calculate of daily ETo from daily Penman-Monteith equation.
- May be used to fill in missing data points where only monthly mean weather and ETo data exist.
- Employ the latest methodology to determine crop coefficients for a wide variety of crops.
- Calculations daily crop coefficients and crop evapotranspiration for currently entered weather and crop information.
- Adjust crop coefficients for wetting frequency from rainfall or irrigation during the off season.
- Output one year of daily weather and ETo data for the current weather information.
- Output one year of daily calculated crop coefficients and ETc data by crop.
- Provide monthly total values of ETo, ETc, and rainfall during the growing season and off-season.
- Plot daily calculated crop coefficients during the growing season with different colored lines for each growth period for the current crop information.
- Provide a bar graph of monthly total values of ETo and ETc during the growing season for the entered crop information.
- After the data entry, the calculated Kc, ETo, and ETc can be written as a row of data in the summary worksheets of Kc, ETo, and ETc.
- The input data are crop name, planting date, ending date and initial growth wetting frequency are considered.
- The weather data consist of R_s, Tmax, Tmin, wind speed, Tdew, and rainfall.
- There are 5 possible ways to input weather data as weather sheet, crop sheet, crop Ref. sheet, YTD sheet and sheet make schedule (Fig. 2).

Month	R_s (MJ m^{-2}d^{-1})	T_{max} (°C)	T_{min} (°C)	U_2 (m s^{-1})	T_d (°C)	Pcp (mm)	NRD (#)	ET_o (mm day^{-1})	E_{pan} (mm day^{-1})	PM (mm day^{-1})	HS (mm day^{-1})
1	6.5	12.7	3.6	2.6	5.4	102.6	8.6			1.01	1.17
2	10.4	16.0	5.0	2.7	6.6	107.3	6.5			1.70	1.87
3	15.9	19.0	6.0	2.7	7.2	69.6	5.8			2.74	2.92
4	21.5	22.8	7.8	3.0	6.9	17.8	1.7			4.40	4.27
5	25.5	26.3	10.4	3.0	9.2	19.0	1.5			5.54	5.42
6	28.8	30.1	12.7	3.0	10.8	6.0	0.6			6.80	6.42
7	29.0	32.9	13.7	2.7	12.7	3.3	0.3			7.11	6.87
8	26.0	32.5	13.2	2.5	11.5	2.3	0.1			6.51	6.13
9	20.9	30.8	12.1	2.4	10.2	7.4	0.7			5.36	4.82
10	14.8	26.3	9.6	2.4	7.6	17.6	1.5			3.86	3.13
11	9.4	18.4	5.4	2.4	5.3	35.7	3.5			2.10	1.71
12	6.5	12.8	2.7	2.7	4.3	60.8	4.9			1.15	1.10

Fig. 2: Interface of monthly climate input worksheet.

3. RESULTS AND DISCUSSION

3.1. Reference evapotranspiration (ETo) curve during wheat growing season:

After data entry, the CUPplus program also plots daily calculated reference evapotranspiration (ETo) with different colored lines for each growth period during the season (Fig. 3).

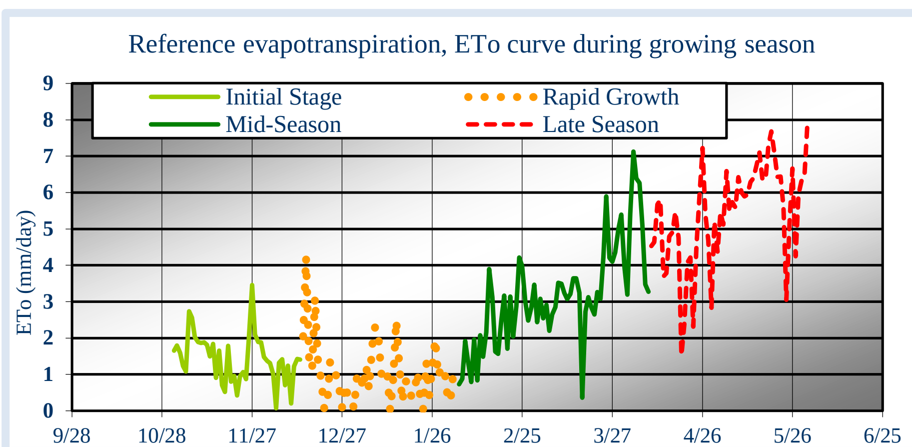


Fig. 3: Reference evapotranspiration (ETo) curve during wheat growing season.

Reference evapotranspiration (ETo) curve during wheat growing season of daily weather data including calculated reference evapotranspiration (ETo) from weather data.

The reference evapotranspiration (ETo) curve start fluctuates increasing from initial stage, rapid growth and mid-season to arrive to the maximum in late season (May).

3.2. Evapotranspiration of Applied Water (ETaw) and crop evapotranspiration (ETc):

One year of daily calculated crop coefficients and crop evapotranspiration by crop for the current crop information. The crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw) values are shown in (Fig. 4).

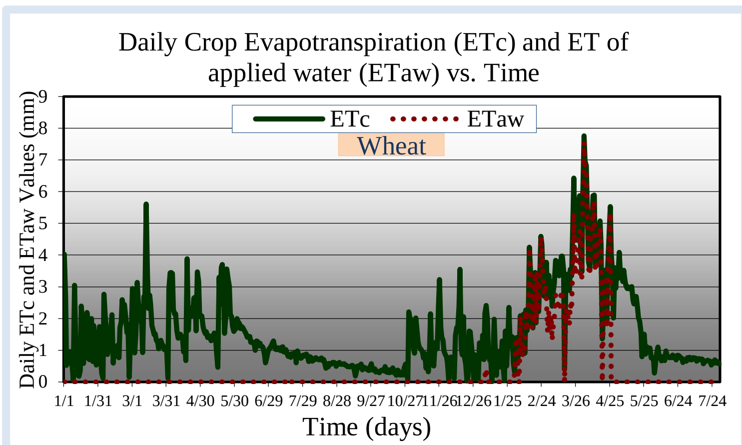


Fig. 4: Daily ETc and ETaw versus time.

The crop evapotranspiration (ETc) curve fluctuates until arrive to the maximum between March and April. Evapotranspiration of applied water (ETaw) curve starts increasing from December to arrive the maximum between March and April.

3.3. Daily calculated bare soil and crop coefficient (Kc) values:

The CUPplus program plots daily calculated bare soil and crop coefficient (Kc) values with different colored lines for each growth period for currently entered daily weather and crop - soil information during the growing season and off-season. Then it uses the baseline to determine crop coefficients (Kc) during the initial growth periods. During the off-season and initial growth period, soil evaporation is the main component of evapotranspiration ET. Therefore, CUPplus uses a two stage soil evaporation model for estimating bare soil coefficients as a function of mean reference evapotranspiration (ETo) and wetting frequency in days from rainfall or irrigation.

The colored line in (Fig. 5) shows a crop coefficient (Kc) curve for a crop that had frequent irrigation between planting that increased the Kc value during initial growth, an example where the bare-soil Kc (dark line) was higher than the crop Kc (dot colored line) during part of the season. In all cases, the higher of the bare-soil and crop Kc is used to determine the crop evapotranspiration (ETc) on each day. The Kc values for the wheat have been adjusted for wetting frequency from irrigation and rainfall during that period.

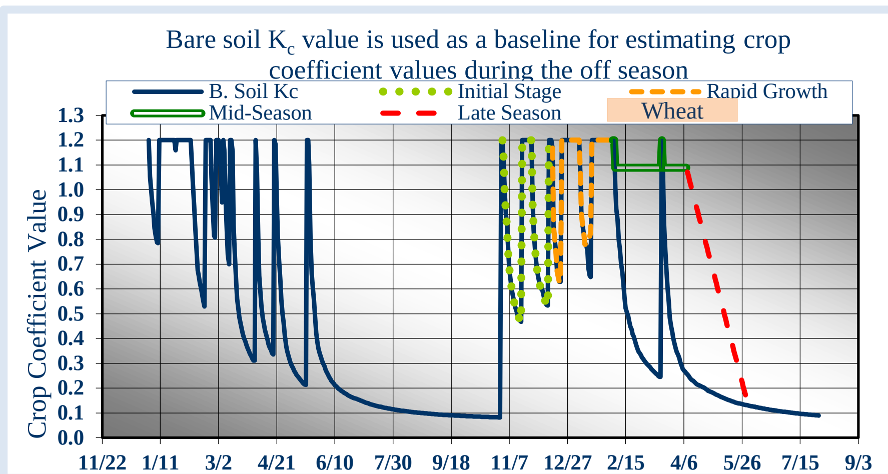


Fig. 5: Daily calculated bare soil and crop coefficient values with different colored lines for each growth period for currently entered daily weather and crop/soil information during the growing season and off-season.

3.4. Cumulative daily evapotranspiration of applied water (ETaw) values with the cumulative net application (NA):

Evapotranspiration of applied water (ETaw) is the sum of the net irrigation applications to a crop during its growing season, where each net irrigation application (NA) is equal to the product of the gross application (GA) and an application efficiency fraction (AE), (NA = GA × AE). The gross application is equivalent to the applied water, and the application efficiency is the fraction of GA that contributes to crop evapotranspiration (ETc).

Evapotranspiration of applied water (ETaw) can be calculated as the daily evapotranspiration (DETc) minus the estimated daily effective seepage contribution (DEspg) minus the daily estimated effective rainfall contribution (DEr) minus the difference in soil water content (DWC) from the beginning to the end of the season. The figure below shows the comparison of the cumulative daily evapotranspiration of applied water (ETaw) values with the cumulative net application (Cum. NA) for wheat over the period as shown in (Fig. 6).

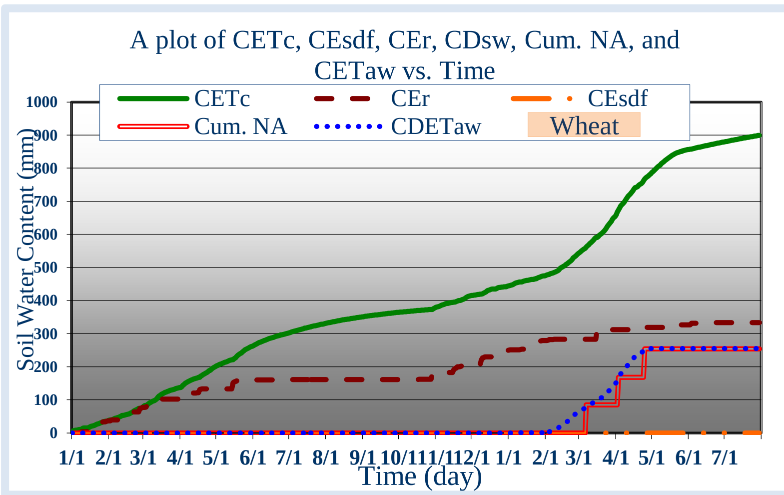


Fig. 6: A plot of CETc, CEsdf, CEr, CDsw, Cum. NA, and CETaw Vs time.

3.5. Soil water balance (WB):

The CUP plus program also plots daily calculated water balance (WB) for crops using daily weather data. The plot shows fluctuations in soil water content between field capacity and the maximum depletion during the off-season and between field capacity and maximum soil water content during the growing season. The plot also shows the daily values for crop evapotranspiration (ETc) and rainfall. Irrigation events are given when the maximum soil water depletion exceeds the maximum soil water content as shown in (Fig. 7).

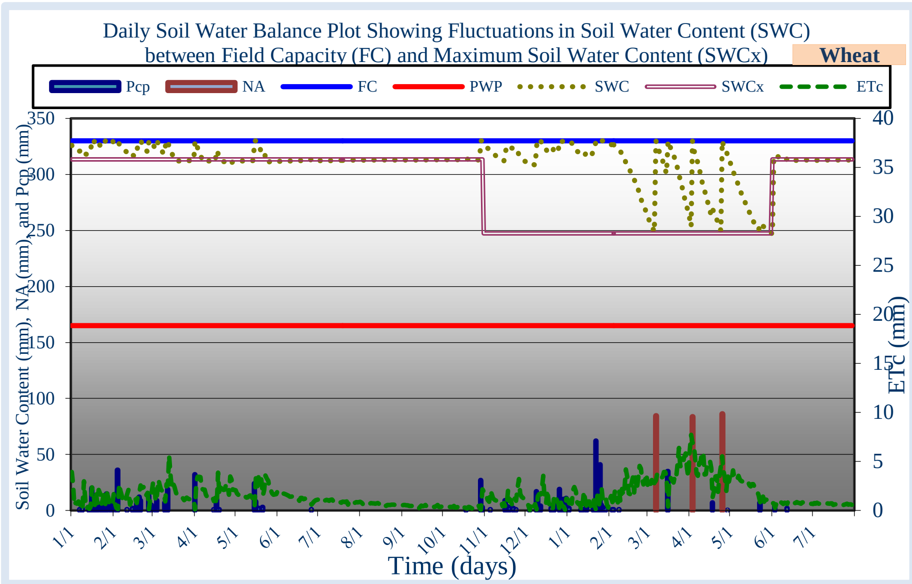
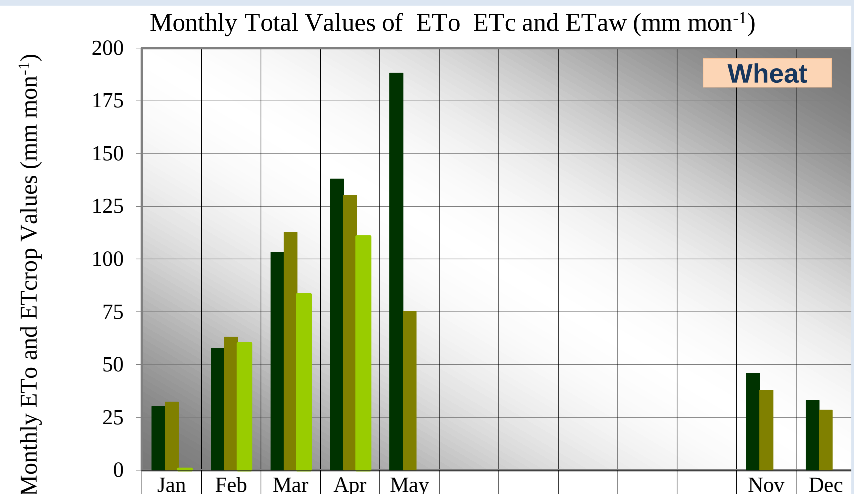


Fig. 7: Fluctuations in soil water content (SWC) between field capacity (FC) and maximum soil water content (SWCx) over the period.

3.6. Total monthly values of reference evapotranspiration (ETo), crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw):

CUPplus provides a bar graph as a summary of reference evapotranspiration (ETo), crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw) totals by month during the growing season for the current crop and soil information. The following (Fig. 8) shows the total monthly values of ETo ETc and ETaw (mm mon^{-1}). Where ETo arrives to the maximum in May by 188.19 mm/month because of increasing the temperature to the maximum at May but ETaw arrive to the maximum in April by 110.71 mm $month^{-1}$ because of stopping adding water after April. And the monthly total reference evapotranspiration (ETo) values over the period of one year are 596.12 mm, monthly total crop evapotranspiration (ETc) values over the period of one year are 479.85 mm and monthly total evapotranspiration of applied water (ETaw) values over the period of one year are 254.56 mm.

The obtained data agree with **Bandyopadhyay, P.K. and Mallick, S. (2002)** and **French, A.N. et al. (2009)**.



	Jan	Feb	Mar	Apr	May						Nov	Dec
ETo (mm)	30.21	57.56	103.21	138.00	188.19	0	0	0	0	0	45.86	33.09
ETc (mm)	32.36	63.13	112.70	130.01	75.23	0.0	0.0	0.0	0.0	0.0	37.89	28.53
ETaw (mm)	0.59	60.08	83.18	110.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fig. 8: Monthly total values of ETo ETc and ETaw (mm mon^{-1})

4. CONCLUSION

The Kc values for the wheat have been adjusted for wetting frequency from irrigation and rainfall during the search period. Total monthly values of ETo ETc and ETaw (mm mon^{-1}) can be calculated. As ETo arrives to the maximum in May by 188.19 mm/month because of increasing the temperature to the maximum at May but ETaw arrive to the maximum in April by 110.71. ETo Monthly total reference evapotranspiration values over the period of one year are 596.12 mm. ETc Monthly total crop evapotranspiration values over the period of one year are 479.85 mm. ETaw Monthly total evapotranspiration of applied water values over the period of one year are 254.56 mm. The research examined CUP plus as an efficient tool to evaluate the actual crop coefficient of major field crop (wheat). CUP plus shows high accuracy of initial weather parameters needed for calculating ETo ETc and ETaw for a long time series.

CUP plus could be used efficiently to evaluate different irrigation strategies, which support irrigation planning and improvement under Egyptian conditions.

5. ACKNOWLEDGEMENTS

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الملخص العربى

استجابة برنامج (CUPplus) الاستخدام الاستهلاكى لمحصول القمح تحت الظروف المصرية

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يهدف البحث الى امكانية استخدام برنامج CUPplus لايجاد الاحتياجات المائية ومتطلبات الرى ببعض البيانات الحقلية لمحصول القمح تحت الظروف المصرية. حيث اجريت التجربة بمزرعة مركز البحوث الزراعية بمشتهر – محافظة القليوبية. وذلك فى موسم الزراعة ٢٠١٥/ ٢٠١٦ م تحت الظروف التقليدية لزراعة القمح وتم اعداد البرنامج واعداد المدخلات التالية:

- حيث تم استخدام أقل البيانات من الارصاد الجوية (الاشعاع الشمسى – درجة الحرارة العظمى والصغرى- سرعة الرياح – الرطوبة الجوية – معدلات الامطار). تم استخدام بيانات إحداثيات الموقع – مع تاريخ الزراعة وتاريخ الحصاد ونوع التربة.

فهذا البرنامج يتيح امكانية ايجاد الاحتياجات المائية بطريقة سهلة وميسرة وسريعة وبالتالى تحسين كفائة استخدام المياه. وامكانية استخدام بيانات اقل من الارصاد الجوية الزراعية حيث ان البرامج الاخرى تحتاج الى بيانات كثيرة وفى اغلب الاحيان غير متاحة مع صعوبة تطبيق البرامج الاخرى هذا البرنامج تم عمله فى جامعة UC DAVIS بالولايات المتحده الامريكيه. ويستخدم هذا البرنامج فى تقدير الاحتياجات المائيه لعدد كبير من المحاصيل الحقليه ومحاصيل الخضر والمحاصيل البستانيه تحت نظم الرى المختلفه. و يعتبرهذا البرنامج من البرامج السهلة التشغيل والتى لا تستغرق وقت لعمل جدوله للرى. يتكون البرنامج من ملف Excel يحتوى على عدد من Worksheets

وترجع أهمية إستخدام النموذج الى تقليل الفاقد من مياة الرى - زيادة كفاءة إضافة المياة - زيادة كفاءة المحصول فى استخدام المياة والاسمدة - وهذا سوف يؤدى الى نقص تكاليف الإنتاج نتيجة توفير الطاقة وكذلك زيادة المحصول نتيجه وجود ظروف نمو أحسن وبالتالى زيادة دخل المزارع.

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وكانت اهم النتائج المتحصل عليها هى:

تقدير الاحتياجات المائية لمحصول القمح (مم/فترة) كالتالى:

البخر نتح المرجعى (ETo) وصل الى ١٨٨.١٩ مم وذلك فى شهر مايو ليصل الأجمالى ٥٩٦.١٢ مم.

البخر نتح للمحصول (ETc) وصل الى ١٨٨.١٩ مم وذلك فى شهر مايو ليصل الأجمالى ٥٩٦.١٢ مم.

البخر نتح للماء المضاف (ETaw) وصل الى ١٨٨.١٩ مم وذلك فى شهر مايو ليصل الأجمالى ٥٩٦.١٢ مم.

ومن خلال البيانات المستخرجة يمكن تحديد الميعاد المناسب لاضافة مياة الرى.

ومن هنا يتضح انه يمكن الاستفدة من البرنامج (CUP plus) فى تحديد الاحتياجات المائية لمحصول القمح تحت الظروف المصرية وكذلك يمكن تجربتة للمحاصيل المختلفة.