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# Climate change and crop coefficients of some field crops in Egypt

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## ABSTRACT
Matching water supply and demand are essential for productivity and sustainability in an irrigation scheme. Because Egypt is experiencing water scarcity, knowledge of crop water requirements is crucial for water resources management and planning. Crop water requirements consist of two components, namely evapotranspiration (ETo) and crop coefficients (Kc). There are several equations exists in the literature to calculate the values of ETo in a certain region. The values of Kc for a certain crop are; however, vary from one region to another. Therefore, its values presented in the literature are not accurate enough to be used in Egypt. Basic Irrigation Scheduling model (BISm) provides an easy method to determine Kc values for a large number of crops, as affected by the weather in a certain region, irrigation method as well as planting and harvest dates. Thus, the objective of this

chapter was to calculate Kc values for 13 vegetable crops, 14 field crops, and 6 fruit crops. The calculation was done for these crops grown under the weather conditions of the five agro-climatic zones in Egypt.

**Keywords:** BISm Model, Agro-climatic zones of Egypt, Reference Evapotranspiration, Water Consumptive Use.

## 1. INTRODUCTION

In Egypt, irrigated agriculture is the prevailing system for food production. The main source of irrigation is the Nile River. Irrigation application is the way for obtaining the best level of production. Agriculture in Egypt represent the major water consumer, where about 85% of water resources is allocated to it (Ministry of Water Resources and Irrigation 2014). Agriculture is considered to be the most tangible affected sector by climate change, as any alteration in the prevailing temperature or precipitation patterns will disturb crops yields, crops water requirements, and soil fertility (El-Massah and Omran, 2014). The expected increase in temperatures under climate change could lead to a net deficit in atmospheric water content. Thus excessive evaporation from soil, water, and plant surfaces would occur (Kimball *et al*., 2002). Land ecosystems would require more water to match increased water demand, and consequently to prevent drought (Karmakar *et al*., 2016). It was reported that climate change is expected to negatively affect crops productivity (Ouda *et al*., 2013) and cause increases in water requirements for crops in Egypt (Ouda *et al*., 2015). Because water is becoming a scarce natural resource and this suitation is expected to get worst in the future,water management on-farm level should be implemented and irrigation scheduling has to be employed by the farmers to conserve this valuable resource and to reduce production cost, in addition to minimize the negative environmental consequences. Matching water supply and demand can attain sustainability of water resourcesincrease crop water productivity per unit of water. Furthermore, the proper management of water resources and planning necessitate the knowledge of crop water requirements (Katerji and Rana, 2008). Two components are needed to calculate crop water requirements namely reference evapotranspiration (ETo) and crop coefficients (Kc). ETo is the total amount of moisture lost from the field by both soil evaporation and plant transpiration (Gardner *et al.,* 1985). Many researchers worked on developing models to calculate ETo, such as temperature-based models (Thornthwaite 1948; Blaney & Criddle 1962; Hargreaves & Samani 1985) radiation models (Priestley & Taylor 1972; Makkink 1957) and the combination models, which are based on the energy balance and mass, transfer principles included the Penman (Penman 1948), modified Penman Doorenbos & Pruit (1977), and FAO Penman-Monteith equations Allen *et al.,* (1998). Of these equations, Penman-Monteith is the most accurate because of its detailed theoretical base, its accommodation of small time periods and suitability to be used in different regions Valipour (2014).

The other important factor in calculating crop water requirements is the crop Kc. The concept of Kc was first introduced by Jensen (Valipour, 2014) and further developed by other researchers Allen *et al.,* (1998) and Reddy *et al.,* (2015). It takes into account the relationship between atmosphere, crop physiology, and agricultural practices Allen *et al.,* (1998). Kc is defined as the ratio between crop evapotranspiration (ETc) and ETo, from a well-water (not limiting) reference surface Allen *et al.,* (1998). In most agricultural crops, the values of Kc increase from a minimal value at planting to a maximum value near full canopy cover or pollination Allen *et al.,* (1998). It was reported that the Kc is affected by all the factors that influence soil water status, namely, the irrigation method and frequency Wright (1982), the soil characteristics, the weather elements, and the agronomic techniques that affect crop growth Annandale & Stockle (1994). Accordingly, the reported values of Kc in the literature can vary significantly from the actualmeasured values in a location, if growing conditions differ from those where the said coefficients were experimentally obtained Tarantino and Onofrii (1991) & Ko *et al.,* (2009). Many researchers in Egypt depend on the values of Kc published by Allen *et al.,* (1998) in the FAO paper Number 56. However, these values were done in experiments implemented in countries with different weather conditions, compared to the observed weather in Egypt. The developments of Kc values for the cultivated crops in Egypt using field experiments could be time consuming and highly expensive. To overcome this problem, modeling could be used to estimate Kc values in Egypt. A very famous irrigation scheduling model called Basic Irrigation Scheduling model (BISm) Snyder *et al*., (2004) provides an easy method to determine Kc values for a large number of crops, as affected by the weather in a certain region, irrigation method, as well as planting and harvest dates.

Previous research in Egypt on the effect of climate change on ETo values revealed that temperature rise by 1ºC might increase ETo rate by about 4-5%, whereas a rise by 3ºC may increase ETo rate by about 15% Eid (2001). Attaher *et al*., (2006) and Khalil (2013) concluded that the future climate change in 2100 would increase potential irrigation demands, due to the increase in ETo. Ouda *et al*., (2016) stated that the value of ETo would increase by an average of 9% in 2030 and by 13% in 2040 in Egypt. Furthermore, several studies were done in Egypt to project the expected increase in water requirements for several crops under climate change conditions Ouda and Zohry (2016)**;** Ouda *et al*., (2016a). Their results proved that water requirements for crops would increase with different percentages depending on crop type, growing season and geographic location. Although several studies discussed the role of Kc in crops water requirements calculations Reddy *et al.,* (2015) and Ko *et al.,* (2009**)**, few international studies dealt with the projected effect of climate change on Kc values of different crops. Furthermore, there is no local studies were done to tackle this subject**.**

Thus, the objective of this paper was to compare between the values of Kc for 14 field crops grown under the weather conditions of the five agro-climatic zones in Egypt in 2017 and 2030.

## 2. MATERIALS AND METHODS

### Description of the Agro-climatic Zones in Egypt

Ouda and Noreldin (2017) calculated ETo values for 10-year from 2005 to 2014 and developed five agro-climatic zones for Egypt. Table (1) and Figure (1) showed the five agro-climatic zones.

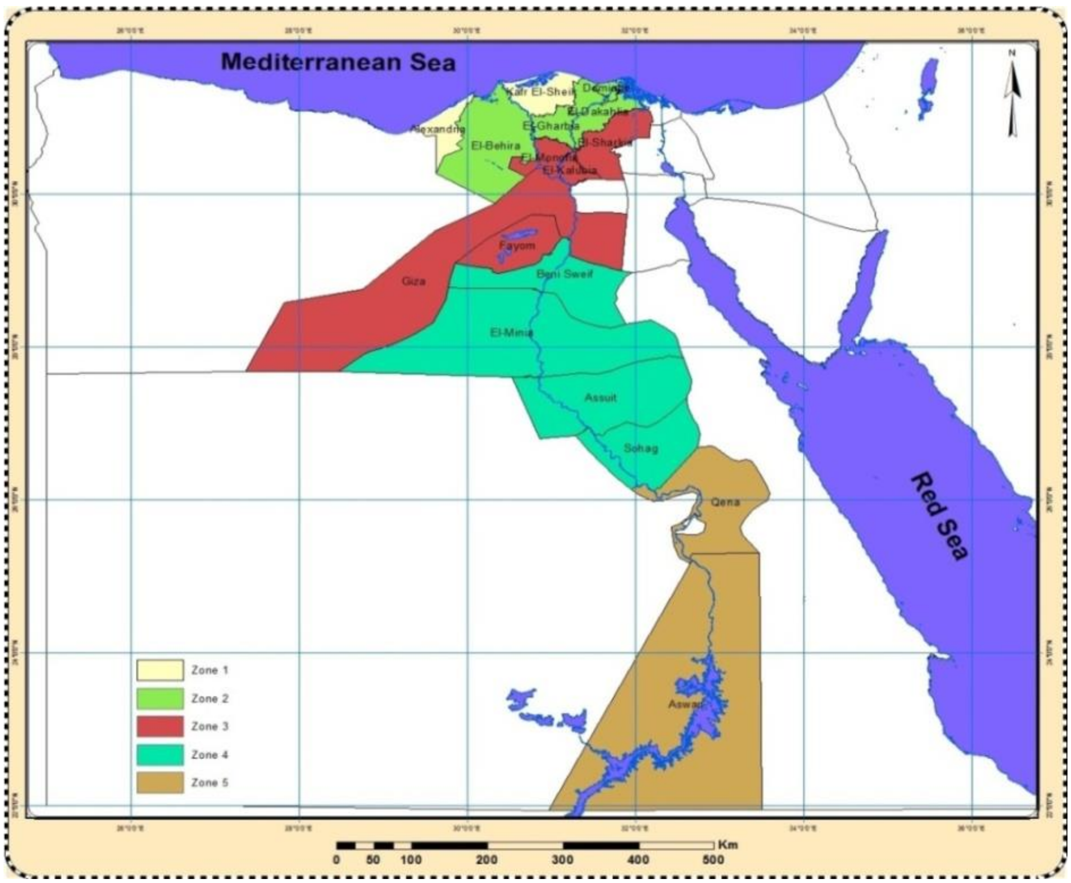


**Figure 1** Map of agro-climatic zones of Egypt using 10-year of ETo values. Source: Ouda and Noreldin (2017)

**Table 1** Agro-climatic zones of Egypt classification using 10-year time interval.

| Zone number | Governorate | ETo (mm.day$^{-1}$) |
|---|---|---|
| Zone 1 | Alexandria | 4.279 |
| | Kafr El-Sheik | 4.852 |
| Zone 2 | Demiatte | 5.123 |
| | El-Dakahlia | 5.344 |
| | El-Behira | 5.192 |
| | El-Gharbia | 5.125 |
| Zone 3 | El-Monofia | 5.800 |
| | El-Sharkia | 5.869 |
| | El-Kalubia | 5.964 |

| | | |
|---|---|---|
| | Giza | 5.701 |
| | Fayom | 5.587 |
| Zone 4 | BeniSweif | 6.139 |
| | El-Minia | 6.140 |
| | Assuit | 6.122 |
| | Sohag | 6.127 |
| Zone 5 | Qena | 6.480 |
| | Aswan | 6.600 |
| Average | | 5.673 |
| Rang | | 2.321 |
| $LSD_{0.05}$ | | 0.217 |

Source: Ouda and Noreldin (2017)

Figure 1 illustrated the five agro-climatic zones developed by Ouda and Noreldin (2017).

**ETo Calculation under current climate and in 2030**

The BISm model Snyder et *al.*, (2004) was used to calculate monthly values of ETo. The model calculates ETo using Penman-Monteith equation as presented in the United Nations FAO Irrigation and Drainage Paper (FAO 56) by Allen *et al.*, (1998). The model contained a database for 64 crops (field crops, vegetables, and fruit trees), relating to planting and harvesting dates and morphological characteristics for the calculation of crop Kc values in each growth stage of each crop. Thus, to calculate the values of Kc for a certain crop, planting, and harvest dates should be entered in the model to determine the Kc value as a percentage of the crop growing season. Snyder *et al.*, (2004) indicated that "the model assumed that as a crop canopy develops, the ratio of transpiration (T) to ET increases until most of the ET comes from T and evaporation (E) becomes a minor component. This occurs because the light interception by the foliage increases until the most light is interceptedbefore it reaches the soil . Thus, for field and row crops, crop coefficients generally increase until the canopy attain ground cover and reaches about 75%, and the light interception became near 80%. Regarding tree, the peak Kc is reached when the canopy has reached about 63% ground cover (http://biomet.ucdavis.edu/irrigation_scheduling/bis/BIS.pdf.).

The model used a two-stage method for estimating soil evaporation presented by Stroonsnjider (1987) to estimate bare soil crop coefficients. Thus, crop coefficient during initial growth ($Kc_{ini}$) is determinedby the ETo rate and irrigation frequency using the bare soil evaporation model previously mentioned. The values for $Kc_{mid}$ and $Kc_{end}$ depend on the difference in (1) daily net radiation (Rn) and soil heat flux density (G); (2) crop morphology effects on turbulence; and (3) physiological differences between the crop and reference crop Snyder *et al.*, (2004). Weather data for the five agro-climatic zones in 2017were collected and used to calculate ETo and Kc values for the studied crops .

Climate change scenario RCP6.0 resulted from MIROC5 model in 2030 was used to calculte Eto and crops Kc. This scenrio is available from the following website: http://www.ccafs.cgiar.org/marksimgcm#.Ujh1gj-GfMY.The MIROC5model is one on the CMIP5 GeneralCirculation Models developed by Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology. The model has a horizontal resolution equal to 1.40° x 1.40°.

The climate change scenario contained maximum and minimum temperature, as well as solar radiation data, which are suitable to calculate ETo using Hargreaves-Samani (H-S) equation Hargreaves and Samani (1985). However, the accuracy of Hargreaves-Samani (H-S) equation is lower than its counterpart of Penman-Monteith (P-M) equation Ouda *et al.*, (2016), which requiresusing solar radiation, maximum, minimum and dew point temperature, as well as wind speed. To solve this problem, a linear regression equation can be established with ETo values resulted from P-M plotted as the dependent variable and ETo values from H-S equation to be plotted as the independent variable. The intercept (a) and calibration slope (b) of the best-fit regression line can be used as regional calibration coefficients. This methodology was developed by Shahidian *et al.*, (2012) as follows:

$$\textbf{ETo (P-M)=a +b*ET(H-S)} \quad \textbf{[1]}$$

Thus, we used BISm model Snyder *et al.*, (2004). to calculate ETo(P-M) and Eto (H-S) using 2016 weather data. The agro-climatic zones developed by Ouda and Noreldin (2017) were used to ease calculations. An equation for each agro-climatic zone was developed, where different (a) and (b) values were estimated. The quality of the fit between ET (P-M) and ET (H-S) was presented in terms of the coefficient of determination ($R^2$), which is the ratio of the explained variance to the total variance and through calculation of root mean square error per observation (RMSE/obs), which gives the standard deviation of the model prediction error per observation Jamieson *et al.,* (1998). These equations were used to project ETo value similar to ET(P-M) using the data of RCP6.0 scenario andapply it to BISm model Snyder *et al.*, (2004) in 2030.The projected value of ET(P-M) was then used in BISm model Snyder *et al*., (2004) to calculate Kc values for the selected crops in each of the five agro-climatic zones of Egypt.

**Planting and Harvest Date for the Selected Crops**

Recommended planting and harvest dates for the studied field crops are presented in Table 2. It worth mentioning that there is a suitable range, where a certain crop can be planted. However, for an easy calculation, a certain planting date was assumed to suitable for each crop.

**Table 2** Planting and harvest dates for the selected field crops in 2017

| Crop | Planting date | Harvest date | Season length (days) |
|---|---|---|---|
| Barley | 15-Nov | 1-Apr | 138 |
| Bean (faba) | 25-Oct | 25-Apr | 152 |
| Clover | 15-Oct | 1-Apr | 169 |
| Cotton | 15-Apr | 15-Aug | 154 |
| Flax | 15-Nov | 13-Apr | 150 |
| Lentil | 25-Oct | 25-Mar | 152 |
| Maize | 15-Apr | 1-Sep | 110 |
| Rice | 15-May | 16-Sep | 125 |
| Sorghum | 15-May | 1-Sep | 110 |
| Soybean | 15-May | 25-Aug | 103 |
| Sugarbeet | 15-Oct | 12-Apr | 180 |
| Sugarcane | 15-Feb | 14-Feb | 365 |
| Sunflower | 15-May | 15-Aug | 93 |
| Wheat | 15-Nov | 18-Apr | 155 |

Under climate change in 2030 and as a result of the rise in air temperature, it is expected that planting date will be earlier by 5-7 days. Morsy (2015) simulated the effect of early planting for wheat and maize under climate change in 2030 and found that early planting of both crops resulted in a reduction of yield losses. Furthermore, it is also expected that season length of the cultivated crops will be reduced under climate change. Khalil *et al.,* (2009) reported that wheat season length was reduced by 5 days in 2030, as a result of acceleration in its growing season. Similar results were obtained by Ouda *et al.,* (2009) for maize under climate change in 2030.

## 3. RESULTS AND DISCUSSIONS

The Developed prediction equation for ET(P-M) for each agro-climatic zone are presented in Table 3. The results in the table showed that $R^2$ values between Eto (P-M) and Eto (H-S) was between 0.97-0.99 in the five agro-climatic zones. Furthermore, RMSE/obs values between them were between 0.22-0.35 mm/day.

**Table 3** Prediction equations, the coefficient of determination ($R^2$) and root mean square error per observation (RMSE/obs) for ET(P-M) values in the agro-climatic zones of Egypt.

| Zone | Prediction equation | $R^2$ | RMSE/obs |
|---|---|---|---|
| Zone 1 | ETo(P-M)= 0.95 +1.21*ET(H-S) | 0.97 | 0.35 |
| Zone 2 | ETo(P-M)= 0.98 +1.16*ET(H-S) | 0.97 | 0.31 |
| Zone 3 | ETo(P-M) = 0.58 +1.13 *ET(H-S) | 0.99 | 0.22 |
| Zone 4 | ETo(P-M)= 0.30 +1.40 *ET(H-S) | 0.99 | 0.35 |
| Zone 5 | ETo(P-M)= 0.04 +1.42*ET(H-S) | 0.99 | 0.34 |

**Kc for Crops Grown in the First, second and third Agro-climatic Zones**

Table 4 showed the date of Kc growth stages and its values for the selected field crops in the first, second and third agro-climatic zones. It is also shown from the table that sugarcane is not cultivated in this zone. It worth noting that, $Kc_{ini}$ starts from planting date and ends with the recorded date in the table.

**Table 4** The date of Kc growth stages and its values for the studied field crops in the first, second and third agro-climatic zones in 2016

| Crop | Data of growth stages | | | Kc value | | |
|---|---|---|---|---|---|---|
| | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ |
| Barley | 12-Dec | 16-Jan | 1-Apr | 0.31 | 1.11 | 0.21 |
| Bean (faba) | 29-Nov | 24-Dec | 25-Apr | 0.29 | 0.99 | 0.21 |
| Clover | 26-Oct | 3-Dec | 1-Apr | 0.26 | 1.13 | 0.40 |
| Cotton | 7-Apr | 23-Jul | 15-Aug | 0.30 | 0.93 | 0.46 |
| Flax | 10-Dec | 21-Jan | 13-Apr | 0.31 | 1.10 | 0.25 |
| Lentil | 10-Nov | 24-Dec | 25-Apr | 0.23 | 0.99 | 0.21 |
| Maize | 6-Jun | 3-Jul | 1-Sep | 0.24 | 1.04 | 0.58 |
| Rice | 14-Jun | 30-Jun | 16-Sep | 0.37 | 1.02 | 0.78 |
| Sorghum | 1-Jun | 30-Jun | 1-Sep | 0.20 | 1.06 | 0.50 |
| Soybean | 4-Jun | 30-Jun | 25-Aug | 0.24 | 1.11 | 0.39 |
| Sugar beet | 11-Nov | 4-Jan | 12-Apr | 0.27 | 1.15 | 0.95 |
| Sugarcane | -- | -- | -- | -- | -- | -- |
| Sunflower | 2-Jun | 25-Jun | 15-Aug | 0.24 | 1.09 | 0.37 |
| Wheat | 16-Dec | 22-Jan | 18-Apr | 0.31 | 1.06 | 0.19 |

Table 5 showed the date of Kc growth stages and its values for the selected field crops in the fourth and fifth gro-climatic zones. The table also showed that both the date of Kc stages and its value were different in the fourth agro-climatic zone, compared to the third agro-climatic zone. Furthermore, rice is not cultivated in this zone, as it prohibited by the law and sugarcane is suitable to be cultivated in this zone.

**Table 5** The date of Kc growth stages and its values for the studied field crops in the fourth and fifth agro-climatic zones in 2016

| Crop | Data of growth stages | | | Kc value | | |
|---|---|---|---|---|---|---|
| | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ |
| Barley | 13-Dec | 17-Jan | 1-Apr | 0.29 | 1.11 | 0.18 |
| Bean (faba) | 30-Nov | 25-Dec | 25-Apr | 0.26 | 0.99 | 0.18 |
| Clover | 27-Oct | 4-Dec | 1-Apr | 0.26 | 1.15 | 0.40 |
| Cotton | 8-Apr | 2-Jul | 15-Aug | 0.24 | 0.93 | 0.45 |
| Flax | 1-Dec | 2-Jan | 13-Apr | 0.29 | 1.10 | 0.25 |
| Lentil | 1-Nov | 25-Dec | 25-Apr | 0.21 | 0.99 | 0.18 |
| Maize | 7-Jun | 4-Jul | 1-Sep | 0.19 | 1.03 | 0.58 |
| Rice | -- | -- | -- | -- | -- | -- |
| Sorghum | 2-Jun | 1-Jul | 1-Sep | 0.16 | 1.06 | 0.50 |
| Soybean | 5-Jun | 1 Jul | 25-Aug | 0.19 | 1.11 | 0.39 |
| Sugar beet | 12-Nov | 5-Jan | 12-Apr | 0.23 | 1.15 | 0.95 |
| Sugarcane | 18-Apr | 21-Oct | 14-Feb | 0.4 | 1.25 | 0.75 |
| Sunflower | 3-Jun | 26-Jun | 15-Aug | 0.20 | 1.09 | 0.37 |
| Wheat | 17-Dec | 23-Jan | 18-Apr | 0.29 | 1.08 | 0.17 |

The results in Table 6 and 7 indicated that the projected values of $Kc_{ini}$ and $Kc_{end}$ were different in the three agro-climate zone, where both were decreasing in the third agro-climatic zone, compared to the first zone. Furthermore, the value of $Kc_{med}$ was similar in these three agro-climatic zones.

The value of $Kc_{in\ i}$ is affected by soil evaporation, which is determinedby the ETo rate and irrigation frequency Allen *et al.*, (1998). Thus, ETo rate is increasing from the first agro-climatic zone to the third agro-climatic zone. Furthermore, the interval between irrigation is long due to the characteristics of the prevailing clay soil in the agro-climatic zones), which results in a reduction in the value of $Kc_{ini}$. Regarding to $Kc_{mid}$ and $Kc_{end}$, both depend on the difference in daily net radiation, soil heat flux density, crop morphology effects on turbulence and physiological differences between the crop and reference crop Snyder *et al.*, (2004).

**Table 6** The projected values of Kc of the studied field crops in the first, second and third agro-climatic zones in 2030

| Crop | Kc in the first agro-climatic zone | | | Kc in the second agro-climatic zone | | | Kc in the third agro-climatic zone | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ |
| Barley | 0.29 | 1.11 | 0.20 | 0.28 | 1.11 | 0.19 | 0.27 | 1.11 | 0.18 |
| Bean (faba) | 0.29 | 1.00 | 0.21 | 0.25 | 1.00 | 0.20 | 0.25 | 1.00 | 0.19 |
| Clover | 0.24 | 1.15 | 0.39 | 0.23 | 1.15 | 0.38 | 0.22 | 1.15 | 0.37 |
| Cotton | 0.28 | 0.95 | 0.49 | 0.27 | 0.95 | 0.49 | 0.25 | 0.95 | 0.49 |
| Flax | 0.29 | 1.12 | 0.25 | 0.28 | 1.12 | 0.25 | 0.27 | 1.12 | 0.24 |
| Lentil | 0.22 | 1.00 | 0.21 | 0.21 | 1.00 | 0.20 | 0.20 | 1.00 | 0.19 |
| Maize | 0.23 | 1.06 | 0.60 | 0.22 | 1.06 | 0.60 | 0.20 | 1.06 | 0.60 |
| Rice | 0.35 | 1.00 | 0.77 | 0.33 | 1.00 | 0.77 | 0.30 | 1.00 | 0.77 |
| Sorghum | 0.19 | 1.06 | 0.50 | 0.18 | 1.06 | 0.50 | 0.17 | 1.06 | 0.50 |
| Soybean | 0.23 | 1.11 | 0.40 | 0.22 | 1.11 | 0.40 | 0.20 | 1.11 | 0.40 |
| Sugar beet | 0.25 | 1.16 | 0.96 | 0.24 | 1.16 | 0.96 | 0.23 | 1.16 | 0.96 |
| Sunflower | 0.23 | 1.08 | 0.38 | 0.22 | 1.08 | 0.36 | 0.20 | 1.08 | 0.36 |
| Wheat | 0.29 | 1.08 | 0.19 | 0.28 | 1.08 | 0.18 | 0.28 | 1.08 | 0.17 |

**Table 7** The projected values of Kc of the studied field crops in the fourth and fifth agro-climatic zones in 2030

| Crop | Kc in the fourth agro-climatic zone | | | Kc in the fifth agro-climatic zone | | |
|---|---|---|---|---|---|---|
| | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ | $Kc_{ini}$ | $Kc_{mid}$ | $Kc_{end}$ |
| Barley | 0.26 | 1.11 | 0.17 | 0.24 | 1.11 | 0.16 |
| Bean (faba) | 0.23 | 1.00 | 0.18 | 0.22 | 1.00 | 0.17 |
| Clover | 0.20 | 1.15 | 0.36 | 0.19 | 1.15 | 0.35 |
| Cotton | 0.23 | 0.95 | 0.49 | | Not cultivated | |
| Flax | 0.26 | 1.12 | 0.25 | 0.24 | 1.12 | 0.25 |
| Lentil | 0.19 | 1.00 | 0.18 | 0.18 | 1.00 | 0.17 |
| Maize | 0.19 | 1.06 | 0.60 | 0.17 | 1.06 | 0.60 |
| Sorghum | 0.16 | 1.06 | 0.50 | 0.15 | 1.06 | 0.50 |
| Soybean | 0.19 | 1.11 | 0.40 | 0.17 | 1.11 | 0.40 |
| Sugar beet | 0.21 | 1.16 | 0.96 | | Not cultivated | |
| Sugarcane | 0.40 | 1.25 | 0.75 | 0.40 | 1.25 | 0.75 |
| Sunflower | 0.19 | 1.08 | 0.38 | 0.17 | 1.08 | 0.36 |
| Wheat | 0.26 | 1.08 | 0.16 | 0.24 | 1.08 | 0.16 |

**Comparison between Kc values for field crops in 2016 and 2030**

The values of Kc for the studied field crops in 2016 were obtained from Ouda (2019) to conduct a comparison between Kc values in 2016 and the projected Kc values in 2030. Figure 2 showed that in the first, second and third agro-climatic zones, the values of $Kc_{ini}$ were lower in 2030, compared to its counterpart values in 2016, except for faba bean. The values of $Kc_{med}$ were higher in 2030, compared to its counterpart values in 2016 and the values of $Kc_{end}$ were higher or similar in 2030, compared to its counterpart values in 2016.

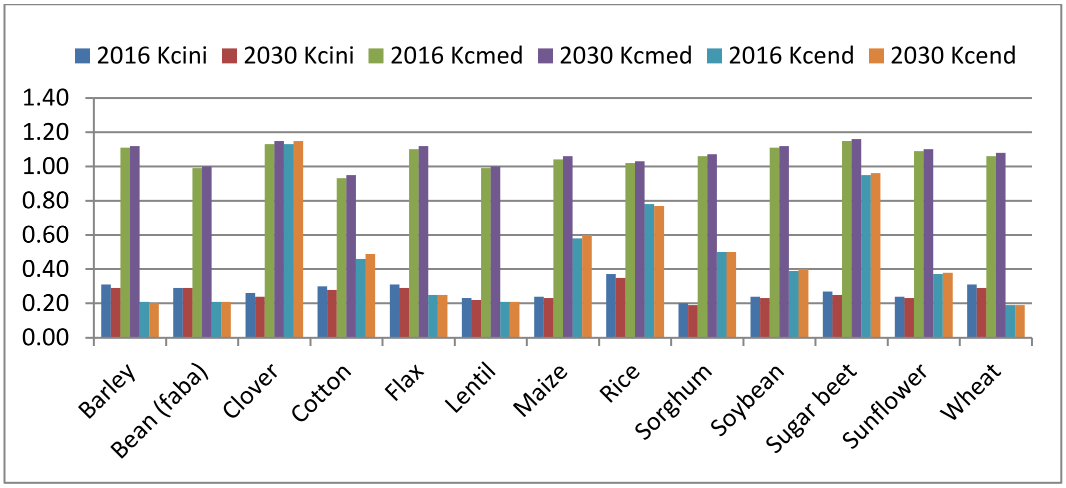


**Figure 2** Comparison between Kc values in 2016 and 2030 for studied field crops in the first, second and third agro-climatic zones

Similar trend was found in the fourth and fifth agro-climatic zones, where the values of $Kc_{ini}$ were lower in 2030, compared to its counterpart values in 2016, except for maize, sorghum and soybean. The values of $Kc_{med}$ were higher in 2030, compared to its counterpart values in 2016 and the values of $Kc_{end}$ were higher or similar in 2030, compared to its counterpart values in 2016. This increase in the Kc values, especially in the middle of the growing season, where maximum growth existed, could result in increases in the required irrigation amounts to satisfy the needs of these crops (Figure 3).

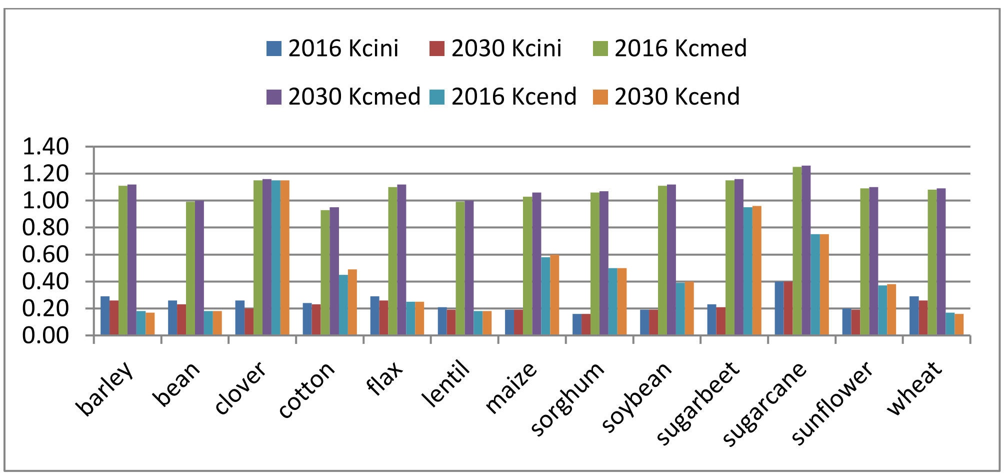


**Figure 3** Comparison between Kc values in 2016 and 2030 for studied field crops in the fourth and fifth agro-climatic zones

## 4. CONCLUSION

Proper irrigation water management under the prevailing conditions of water scarcity in Egypt required the knowledge of exact values of water consumptive use of the cultivated crops. This can be attained by the accurate estimation of the values of ETo and crop Kc. Although the calculation of ETo can be easily implemented, the calculation of Kc required more efforts to be calculated. This chapter provided the date and the values of the Kc for 33 crops (field crops, fruit trees, and vegetable crops) to contribute to irrigation water management in Egypt.

Quantification of the impact of climate change on Kc values for several crops is very important for policymakers when developing their future water management plans. This requires an accurate equation to calculate ETo values. Because only monthly air temperature and solar radiation are available in the RCP6.0 climate change scenario, it is impossible to use P-M equation. Instead, monthly ETo can be calculated using H-S equation, and the developed prediction equations for ET(P-M) can be used to calculatethe values of monthly ETo using the developed calibration coefficients for each agro-climatic zone. Our results showed that this method was accurate and the predicted ETo values were close to the calculated ETo values by the P-M equation. Thus, it is recommended to use this procedure in case of unavailability of wind speed and dew point temperature values.

The BISm model was used to project Kc values in 2030. The results indicated that $Kc_{ini}$ values for field and vegetable crops were lower in 2030, compared to its counterpart values in 2016. The values of $Kc_{med}$ were higher in 2030, and the value of $Kc_{end}$was similar or higher in 2030, compared to its counterpart values in 2016. This increase in the Kc values, especially in the middle of the growing season, where maximum growth existed, results in increases in the required irrigation amounts to satisfy the needs of these crops. Whereas, there was no change in the values of Kc for fruit crops between 2016 and 2030. This could be attributed to that fact that fruit trees established ground cover all year long, which makes it less responsive to weather variation between growing seasons. However, the projected values of ETc will increase. This increase can be attributed to the expected rise in weather elements that could lead to a net deficit inatmospheric water content, consequently excessive evaporation from soil, water, and plant surfaces. It is recommended to establish field experiments to measure Kc values for the studied crops and verify the estimated values by the BISm model. The policymakers should take into account the expected consequences of climate change in their future plans, regulate the amount of available water for agriculture and distribute it on the basis of crops needs in each agro-climatic zone. The policymakers should make efforts to improve irrigation water transport, distribution, and application efficiency to reduce water losses through evaporation and deep percolation. The prevailing irrigation system in Egypt is surface irrigation, which endures high water losses; therefore policy makers should change this type of system to more efficient one.

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