DETERMINATION OF EVAPOTRANSPIRATION OF SOME CROPS USING SOME EMPIRICAL EQUATIONS

Omnia S. Mahmoud*, Rushdi M. M. EL-Kilani and M. E. Shawky
Department of Soil, Faculty of Agriculture, Cairo University, Giza, Egypt.

Abstract

Two crops were used sugar beet (Beta vulgaris L.) as winter crop and maize (Zea mays L.) as summer crop. Five empirical equations were used representing the main groups in ETo calculations to determine the actual irrigation water requirements (IWR) both of maize and sugar beet and to choose the best empirical equations for predicting requirements for these crops. Also to, study the impact of different water regimes on the quantity of irrigation water, crop quantity and quality, evaluate the water use efficiency (WUE). The present investigation was optioned at the experimental Station of the faculty (Western Farm), Faculty of Agricultural, Cairo University, Giza, during two seasons (2018-2019). The obtained results showed that the maximum IWR was obtained under SMD 10% for both crops and the IWR values were decreased with the increase in water stress, so the minimum IWR value was obtained under SMD 50 %. On the meantime, satisfactory production of sugar beets and maize can be obtained by providing 30% and 25% of IWR, respectively. Using the five empirical equations data indicate that the closest equation to the actual evapotranspiration (Eta) in field is the equation Pan-evaporation for sugar beet, Turc and Hargreaves equations for maize.

Key words: Actual irrigation water requirements, soil moisture depletion, empirical equations, sugar beet, maize, water use efficiency.

Introduction

On a global scale water resources are plentiful, serious water shortages are developing especially in the arid and semi-arid regions. In this regions for example Egypt where the rainfall is infrequent and water resources are limited. Egypt is facing increasing water demands by the speedily growing population, by increased urbanization and by developed standards of living. Subsequently, increasing the productivity of obtainable water resources is essential to producing more food, fighting poverty, reducing rivalry for water.

Evapotranspiration (ET) is one of the chief components in water cycling in soil–plant–atmosphere continuum. Its dependable information is of essential importance in water connected studies and applications for example irrigation system designing, water resource planning and management, crop yield prediction (Perera et al., 2015). Though, ET can be measured by a multiplicity of methods, they are difficult, time-consuming and overpriced. So for most applications it is estimated, typically by the well known two-stage approach (Allen et al., 1998) as a product of reference crop evapotranspiration (ETo) and crop coefficient. Therefore, accurate calculation of ETo becomes a critical step in obtaining ET.

Numerous ETo models, approximately 50 according to Lu et al. (2005) have been advanced and revised so far. Based on supposition and climatological input they are approximately classified as combination, radiation, temperature and pan evaporation. The multi of models has convenience for applications, but they have also caused misunderstanding as to which one to choose under different climate and region due frequently to their restricted evaluation against measurement. Understanding the behavior of these models technique has been a key subject of anxiety under numerous climates, e.g. (Jensen et al., 1990; Kashyap and Panda, 2001; Liu et al., 2006; Perera et al., 2015; Li et al., 2016; Zheng et al., 2017) and various others. Though, a huge number of models have been advanced, their rigorous evaluation with

*Author for correspondence: E-mail: omnia.saber@agr.cu.edu.eg
measurements is still absent, leading to misperception and disarray in model selection (Liu et al., 2017).

The selection of ETo method is become more critical when modeling irrigation requirements at a short temporal scale (daily or monthly) as necessary for many applications, such as daily irrigation scheduling, than at a long chronological scale (Satti et al., 2004). Therefore, to guarantee the accuracy of results, we should either pick the sensible ones or performance domestic adjustments for the studied regions (Zheng et al., 2017).

In Egypt, some attempts were done to apply the empirical equations for estimating crop evapotranspiration (ETC) values and water requirements of crops under different climatological zones in Egypt. Amer et al. (1990) in Menofyia reported that pan evaporation was easier and best method. El-Gindy et al. (1991) found at Mariute area that the Radiation and Blaney-Cridule methods were the best empirical equations used for estimating ETO. Asker et al. (1992) reported that modified Penman, modified Blaney-Cridule, Radiation, Class A pan and Egleman methods were suitable for estimating potential evapotranspiration at Kfr-EL-Sheikh Governorate. Borham et al. (2005) reported that P.M and PE equations were the best empirical equations for predicting water requirements for maize, cowpea and intercropped cowpea/maize under similar conditions Giza.

With regards to upgrading water productivity, there is a great interest in what is known regulated deficit irrigation, an irrigation practice where by water supply is decreased below maximum levels and mild stress is allowed with insignificant impacts on yield, this methodology can prompt more prominent additions than expanding yields per unit of water (FAO, 2002).

In Egypt, sugar production depends mainly on both sugar cane and beet crops. Sugar beet contributes with about 57.61% of total sugar production. Meanwhile, Sugar cane represent 42.39% (Sugar Crop Council Report, 2017). Sugar beet (Beta vulgaris L.) is a field crop, which has tolerant to drought (Vamerali et al., 2009), however drought stress have an undesirable consequence on morpho-physiological characteristics of growth parameters ex. root, leaves and plant dry weight, leaf chlorophyll and stomatal conductance; also, root yield of sugar beet genotypes (Moosavi et al., 2017).

Maize (Zea mays L.) is a vital grain in worldwide, and more sensitive to drought stress than most of food crops (Tsonev et al., 2009). Maize is normally utilized for animals feed, ethanol production also, food production. Shortage water creates water stress that can influence the development and productivity of corn plants. Therefore, adequate water supply for maize growth and development is necessary.

The objective of this research is to determine the actual IWR of maize and sugar beet, and choose the best empirical equations for predicting IWR for these crops. Study the effect of different water regimes on the IWR, crop quality and quantity, evaluate the water use efficiency (WUE), under various conditions of water supply.

Materials and Methods

- Location and experiment

The present investigation was conducted at the Agricultural Experimental Station (Western Farm), Faculty of Agricultural, Cairo University, Giza, 30° 02 N latitude, 31° 3 E longitude). during two seasons (2018-2019) soil of the experimental station is characterized as clay loam non-alkaline non saline soil (tables 1 and 2). Two crops were used sugar beet (Beta vulgaris L.) as winter crop and maize (Zea mays L.) as summer crop. The planting date was 15, Oct. 2018 and the harvest date was 12, May 2019 for sugar beet crop. For maize The planting date was 2, Jul. 2019 and the harvest date was 20, Oct. 2019.

- Experimental design

For sugar beet the field of study area was divided into 12 equal blocks. The blocks were separated from each other by belt (1m width). The experimental unit area was 16 m² (4 × 4). Each block has five rows 0.6 m width 4m length and 17.5 cm between plants to get 40,000 plants/fed. Meanwhile, the maize crop the experimental unit area was 18 m² (4 × 4.5), each block has six rows 0.7 m width 4m length and 25 cm between plants to get 20,000 plants/fed. For sugar beet and maize crops a randomized complete blocks design with three replicates was implemented in the experimental area.

- Treatments

For sugar beet crop four levels of soil moisture depletion (SMD) were investigated, SMD 0.10, SMD 0.30, SMD 0.40 and SMD 0.50 treatments i.e. Irrigation when soil moisture content was depleted to 10%, 30%, 40% and 50% of available water (AW), respectively. As for maize season three levels of soil moisture depletion water depletion (SMD) were investigated, SMD0.10, SMD0.25 and SMD 0.50 treatments i.e. Irrigation when soil moisture content was depleted to 10%, 25% and 50% of available water (AW), respectively.

- Irrigation water application

Water was added to each block using gated pipe.
The quantities of water added were estimated using a measuring meter. Soil moisture content was monitored daily using gravimetric method in soil depths (0-20, 20-40, 40-60 cm).

- **Actual crop evapotranspiration (ETa)**

  The values of actual evapotranspiration was calculated according to Israelsen and Hansen (1962) using the following equation:

  \[
  \text{ETa} = \frac{(FC - \theta_v) \times d}{100}
  \]

  Where,
  - \text{ETa} : actual evapotranspiration mm / interval.
  - FC : volumetric soil moisture content (%) at field capacity.
  - \theta_v : volumetric soil moisture content (%) at irrigation time, which depending on the irrigation treatments.
  - d : depth of soil layer (0.2m in initial stages, 0.6m fixed to end stages for the two crops).

- **Irrigation water requirements**

  The depth of irrigation water requirements (I) was calculated according to Ayers and Wastcot (1985)

  \[
  I = \frac{ET_a}{E_i} (1 - LR)
  \]

  where,
  - I = total depth of irrigation water requirements [mm]
  - ETa = actual evapotranspiration (consumptive use) [mm]
  - LR = leaching Requirements [R= 4%, 18% for sugar beet and maize calculated according to Ayers and Wastcot (1985), as EC water = 1.29 ds m$^{-1}$ (table 3)].
  - Ei = irrigation system efficiency [65%].

- **Reference evapotranspiration (ET_o)**

  I. **The combination methods**

  Values of ET_o were calculated according to Penman-Monteith equation (Allen et al., 1998).

  \[
  ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)}
  \]

  Where,
  - ET_o reference evapotranspiration [mm day$^{-1}$]
  - R_n net radiation at 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$^{-1}$]
  - e_s saturation vapour pressure (KPa)
  - e_a actual vapour pressure [KPa]
  - e-e_s saturation vapour pressure deficit [KPa]
  - \gamma slope vapour pressure curve (KPa °C$^{-1}$]
  - Y psychrometric constant [KPa °C$^{-1}$]

  II. **Temperature methods**

  Values of ET_o were calculated according to Blaney and Criddle equation (Doorenbos and Pruitt, 1984).

  \[
  ETo = a + b f
  \]

  where,
  - ETo = reference evapotranspiration in mm for the period considered.
  - T = mean daily temperature in °C over the period considered.
  - a, b = adjustment factors which depends on minimum relative humidity, sunshine hours and daytime wind estimates.
  - RH_min = is the relative humidity in percent.
  - n/N = is the ratio of actual to maximum possible sunshine hours.
  - Ud = is the daytime wind speed in m/sec at 2-m height.

  III Evaporation method

  Values of ET_o were calculated according to Pan Evaporation equation (Doorenbos and Pruitt, 1984)

  \[
  ETo = Kp.E_{pan}
  \]

  Where,
  - ETo = reference evapotranspiration (mm/day).
  - Epan = pan evaporation in mm/day and represents the mean daily value of the period considered.
  - Kp = pan coefficient (which depending on pan location and climatic condition (mean relative humidity and wind speed).

  IV. **Radiation method**

  According to Jensen et al. (1990), the Truc formula for estimating ET_o was used as follows
For RH > 50%
  - ETo = 0.013 (T / (T+15))(R_s +50)

For RH < 50%
  - \( E_{To} = \frac{0.013 \{ T/(T+15)(R_s+50)(1+((50-RH)/70) \}} {1}

Where,
- \( E_{To} \) = reference evapotranspiration (mm day\(^{-1}\))
- RH = relative humidity [%]
- T = the average temperature in [°C]
- \( R_s \) = solar radiation in [cal cm\(^{-2}\) d\(^{-1}\)].

Values of ETo were calculated according to Hargreaves equation (Allen et al., 1998).
  - \( E_{To} = 0.0023Ra(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} \)

Where,
- \( E_{To} \) = reference evapotranspiration (mm day\(^{-1}\))
- \( Ra \) = extraterrestrial radiation in the equivalent evaporation units, calculated or taken from table presented by Allen et al. (1998), [mm d\(^{-1}\)]
- 1 mm day\(^{-1}\) = 2.45 MJ m\(^{-2}\) day\(^{-1}\)
- \( T_{max} - T_{min} \) = the difference between maximum and minimum temperatures, [°C]
- \( T_{mean} \) = mean air temperature, [°C]

- **Crop coefficient (Kc):**
  Crop coefficient was calculated for each treatment according to Allen et al. (1998).
  - \( Kc = \frac{ETc}{ETo} \)

Where,
- \( ETc \) = Crop evapotranspiration under standard condition mm/day.
- \( E_{To} \) = Reference evapotranspiration mm/day.

- **Soil sampling and methods of analysis**
  Before planting undisturbed and disturbed soil samples were collected from three successive soil depths (0-20, 20-40 and 40-60 cm) to determine some physical and chemical characteristics of the investigated soil site, according to the methods described by Page et al. (1982) for chemical soil properties and Klute (1986) for physical soil properties.

- **Chemical analysis of irrigation water**
  Electric conductivity (EC), pH and soluble cations and anions were determined according to Page et al. (1982).

- **Water use efficiency (WUE)**
  Water use efficiency of crop was calculated according to Giriappa (1983).

\[
\text{CWUE} = \frac{\text{Yield (kg/fed)} / \text{Eta (m}^3\text{/fed)}}
\]

\[
\text{IWUE} = \frac{\text{Yield (kg/fed)} / \text{IWRa (m}^3\text{/fed)}}
\]

Where,
- \( \text{ETa} \) = actual evapotranspiration
- \( \text{IWRa} \) = actual irrigation water requirement
- \( \text{CWUE} \) = crop water use efficiency
- \( \text{IWUE} \) = irrigation water use efficiency

- **Crops measurements**
  - For sugar beet crop
    - Root yield (kg/fed).
    - Recoverable sugar yield (kg/fed).
    - Sugar yield = Root yield (kg/fed) * Sugar recovery%
    - (Sugar recovery % = \{pol% - 0.029-(0.343(Na+K)-0.094(amino-N))\})
    - Where pol% = sucrose% according to Renfield et al. (1974).
  - For maize crop
    - Grain yield (kg/fed).

**Statistical analysis**

The results obtained from field were statistically analyzed using F-value test and the mean were compared by L.S.D at the level of probability of 5%. WASP - WEB AGRI STAT PACKAGE 2.0 was used to carry out statistical analysis. WASP is the first Web Based Agricultural Statistics Software Package offered by ICAR Research Complex. The performance of all equations were compared to the filed data which were estimated on each growth stages for both crop using the standard error (SE).

**Results and Discussion**

**The response of sugar beet and maize crops to different irrigation regimes**

**Sugar beet crop**

Data offered in table reveal that the SMD 10% gave low root yield, In spite of high quantities of irrigation water compared with the SMD 30% AND SMD 40% this may be due to Irrigation by definition creates a more humid environment. Inevitably this favours the survival and spread of some disease and pest organisms while discouraging others (Camprag, 1976; Christmann, 1976). Besides aggravating certain disease and pest problems, very wet soils have other reverse effects on sugar beet associated with anaerobic conditions in the root environment (Dunham, 1993). Also perhaps the
convergence of irrigation periods too much does not make the roots deep in the soil significantly and this makes them do not take the appropriate size, subsequently decrease the productivity of yield. However, the effect of increasing irrigation in SMD 10% that was less than the effect of water stress in SMD 50% treatment, which have the lowest root yield. Increasing water stress from 30% to 50% decreased root yield.

The reduction in root yield with increased water stress from 30% to 50% may be owing to the depressive effect of drought stress on beet growth, in terms of, fresh and dry weight of root as a result of the reduction in Leaf area index and leaf chlorophyll content, which was reflected in lower relative growth rate (RGR) and net assimilation rate (NAR). These results was in agreement with Abd El-Wahab and Nameat Alla (2002).

As for sugar yield. Data presented in Table (4) revealed that sugar yield/fed-1 is significantly affected by water stress levels. Increasing water stress level from 30 to 40% decreased sugar yield by 14.18%, from 40 to 50% decreased sugar yield by 42.64%. Identical results were reported by Besheit et al. (1996) and Ucan and Gencoglan (2004) whom they reported that the decrease in sugar yield under the high level of water depletion may be credited to the reduction in root yield and/or translocated metabolic products from leaves to root. Topak et al. (2016) found that 75% deficit irrigation decreased sugar yield by 26.97% compared with full irrigation.

Obtained results exposed that sucrose percentage was significantly affected by water stress levels. Increasing water stress level from 30 to 50% gradually decreased sucrose, where the maximum value 21.04% resulted from 30% water stress. These results were confirmed by those of Hoffmann (2014), Davidoff & Hanks (1989) and Quebrajo et al. (2018). That may be due to seems to result from the plants inability to create new sink capacities under drought stress, as also Paul and Foyer (2001) suggested. When sucrose cannot be stored anymore in the storage root, it accumulates in the leaves Mäck and Hoffmann (2006) that directly affects enzymes of sucrose and starch metabolism causing a feedback reaction, which results in an inhibition of photosynthesis and in adaptive changes in assimilate partitioning (Paul and Foyer, 2001).

On the other hand, Ucan and Gencoglan (2004) reported that sucrose concentration increased with reduced water availability. Masri et al. (2015) reported that sugar content increased in response to deficit irrigation treatment.

**Maize crop**

Data of grain yield (Kg/fed-1) of maize crop as affected by irrigation regimes are existing in table 5. The

---

**Table 1 : Some Soil physical properties of the experimental soil site.**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Particle size distribution (%)</th>
<th>Tex. class</th>
<th>Soil bulk density (g/cm³)</th>
<th>Moisture content θv %</th>
<th>Available water (AW)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>12.7 20.4 34.6 32.3</td>
<td>C.L</td>
<td>1.13</td>
<td>40.8</td>
<td>20.2</td>
</tr>
<tr>
<td>20-40</td>
<td>13.1 17.2 35.7 34.0</td>
<td>C.L</td>
<td>1.22</td>
<td>43.00</td>
<td>22.1</td>
</tr>
<tr>
<td>40-60</td>
<td>16.5 21.5 31.7 30.3</td>
<td>C.L</td>
<td>1.16</td>
<td>40.2</td>
<td>18.9</td>
</tr>
</tbody>
</table>

F.C: Field capacity; W.P: wilting point.

**Table 2 : Some soil chemical properties of the experimental soil site.**

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>PH(1:25)</th>
<th>EC ds/m</th>
<th>Soluble cations (meq/L)</th>
<th>Soluble anions (meq/L)</th>
<th>CaCO₃%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Na⁺  K⁺  Ca²⁺ Mg⁺ HCO₃⁻</td>
<td>SO₄²⁻ Cl⁻</td>
<td></td>
</tr>
<tr>
<td>0-20</td>
<td>8.00</td>
<td>1.93</td>
<td>10.1 0.7 4.9 3.3 0.72</td>
<td>2.08 16.2 1.6</td>
<td></td>
</tr>
<tr>
<td>20-40</td>
<td>7.97</td>
<td>2.54</td>
<td>13.6 0.9 7.0 3.5 0.94</td>
<td>3.46 20.6 0.8</td>
<td></td>
</tr>
<tr>
<td>40-60</td>
<td>7.95</td>
<td>1.74</td>
<td>9.0 0.7 4.7 2.6 0.52</td>
<td>2.28 14.2 0.4</td>
<td></td>
</tr>
</tbody>
</table>

EC: electrical conductivity.

**Table 3 : Irrigation water quality.**

<table>
<thead>
<tr>
<th>PH</th>
<th>E.C (ds m⁻³)</th>
<th>Soluble cations (meq/L)</th>
<th>Soluble anions (meq/L)</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Na⁺  K⁺  Ca²⁺ Mg⁺</td>
<td>CO₃²⁻+HCO₃⁻</td>
<td>SO₄²⁻ Cl⁻</td>
</tr>
<tr>
<td>7.19</td>
<td>1.29</td>
<td>4.87 0.11 4.79</td>
<td>3.52</td>
<td>3.96 6.97 2.54</td>
</tr>
</tbody>
</table>

SAR: sodium absorption ratio; EC: electrical conductivity.
obtained results show that the yield of maize crop decreases with increasing the soil moisture depletion (SMD). This decrease may be rendered to water stress which hinder the carbohydrate accumulation, and consequently, visible reduction in plant growth and grain yield (Azab, 1998).

Actual Evapotranspiration (ETa)

Data presented in tables 4 and 5 shows the actual evapotranspiration (ETa) values under different treatments for sugar beet and maize. Data indicate that the maximum ETa value was obtained under SMD 10% at both crops and the ETa values were decreased with the increase in water stress, so the minimum ETa value was obtained under SMD 50% that may be due to that the seasonal actual evapotranspiration ETa are mostly influenced by moisture regime. The increase in consumptive use under the lowest treatment of available soil moisture depletion (10% SMD) possibly assign to the increase in direct evaporation resulting from the frequent wetting of the surface soil layer and the existence of relatively high quantities of available water whereas, the plants tend to consume more water under low tensions than under high moisture tensions. Also the irrigation water requirements (IWR) took the same trend.

Reference evaporapotranspiration (ETo)

Data illustrated in table 7 and figs. 1 and 2 shows the ETo values calculated at each growing stage and at the end of the seasons, according to Penman-Monteith, Pan-evaporation, Blaney-Criddle, Turg, Hargreaves equations for sugar beet and maize using climatological data for the experimental site (table 6). The obtained results indicate that gross ETo values calculated using Pan-evaporation and Blaney-Criddle equations are higher in all cases than the values of ETo calculated using Turg and Hargreaves equations in the two growing seasons.

In winter season (sugar beet crop) the ETo values have the order Pan-evaporation > Blaney-Criddle > Penman-Monteith > Turg >Hargreaves. As for summer season (maize crop) it follows the order Blaney-Criddle > Pan-evaporation > Penman-Monteith > Hargreaves > Turg.

The observed variances between the gross ETo values calculated using different empirical equations may be attributed to the variations of the climatic elements needed for calculation of each equation and differences in climatic elements between seasons.

Data offered in table 7 shows that the variations of the daily ETo values between equations were high according to equations differences and different growth stages of crops. High values of the daily ETo were obtained at the end stage for sugar beet crop, while it reached maximum at initial stage for maize. This are mainly related to climate conditions in table 6. Such as

---

**Table 4**: The response of sugar beet crop to different irrigation regimes.

<table>
<thead>
<tr>
<th>Irr. Regimes</th>
<th>Eta (mm)</th>
<th>IWRa (mm)</th>
<th>Sucrose (%)</th>
<th>Root yield (kg/fed.)</th>
<th>Sugar yield (kg/fed.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMD 0.10</td>
<td>861.12</td>
<td>1380.00</td>
<td>17.57   c</td>
<td>28826.67 c</td>
<td>4502.32</td>
</tr>
<tr>
<td>SMD 0.30</td>
<td>833.82</td>
<td>1336.25</td>
<td>21.04 a</td>
<td>33850.00 a</td>
<td>6600.46</td>
</tr>
<tr>
<td>SMD 0.40</td>
<td>798.72</td>
<td>1280.00</td>
<td>19.34 b</td>
<td>32600.00 b</td>
<td>5664.66</td>
</tr>
<tr>
<td>SMD 0.50</td>
<td>666.12</td>
<td>1067.50</td>
<td>16.51 c</td>
<td>22833.33 c</td>
<td>3249.43</td>
</tr>
</tbody>
</table>

L.S.D at 5%.

**Table 5**: The response of maize crops to different irrigation regimes.

<table>
<thead>
<tr>
<th>Irr. regimes</th>
<th>Eta (mm)</th>
<th>IWR (mm)</th>
<th>Yield (kg/fed.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMD 0.10</td>
<td>425.47</td>
<td>802.77</td>
<td>3403.40 a</td>
</tr>
<tr>
<td>SMD 0.25</td>
<td>340.08</td>
<td>641.66</td>
<td>2909 67 b</td>
</tr>
<tr>
<td>SMD 0.50</td>
<td>275.31</td>
<td>519.45</td>
<td>2238.13 c</td>
</tr>
</tbody>
</table>

L.S.D at 5%.

**Table 6**: Monthly meterological data during (2018-2019).

<table>
<thead>
<tr>
<th>EP</th>
<th>Wind (m/s²)</th>
<th>RH (%)</th>
<th>T min. (°C)</th>
<th>T max. (°C)</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beet crop (2018)</td>
<td>9.06</td>
<td>2.21</td>
<td>46.65</td>
<td>18.90</td>
<td>30.55</td>
</tr>
<tr>
<td>7.00</td>
<td>1.85</td>
<td>57.67</td>
<td>15.47</td>
<td>26.90</td>
<td>Nov.</td>
</tr>
<tr>
<td>5.37</td>
<td>1.92</td>
<td>60.67</td>
<td>11.60</td>
<td>21.33</td>
<td>Des.</td>
</tr>
</tbody>
</table>

| 5.27 | 2.12 | 53.00 | 8.07 | 21.80 | Feb. |
| 6.54 | 2.71 | 48.50 | 11.65 | 24.23 | Mar. |
| 9.10 | 2.83 | 32.50 | 18.05 | 34.35 | May.** |

| Maize crop (2019) | 12.10 | 2.81 | 42.67 | 24.27 | 38.17 | Jul. |
| 12.27 | 2.93 | 46.00 | 24.53 | 37.67 | Aug. |
| 10.50 | 2.89 | 53.33 | 22.47 | 34.83 | Sep. |
| 8.05 | 2.36 | 51.50 | 21.40 | 34.40 | Oct.** |

* Calculated from data 11-31 Oct., ** Calculated from data 1-20 May., *** Calculated from data 1-20 Oct.
(Source: meteorology station of giza –Egypt in Agriculture Research Center).
high temperature and low relative humidity in May, the end of the season of sugar beet crop and in July which represents the beginning of the growing season of maize crop and these parameters increase the evaporating power of the atmosphere.

**Calculated crop evapotranspiration (ETc)**

There is no hesitation that the value of crop evapotranspiration (ETc) is mainly depend on the physiological growth stage, crop characteristics, sowing date, rate of crop development, length of growing season and the climatic conditions. Data of the calculated crop evapotranspiration for sugar beet and maize are reported in tables 8 and 9. The data reveal that: The Total values of the ETc calculated using the different investigated equations and using Kc values proposed by Allen et al (1998) follow the order: Pan evaporation > Blaney-Criddle > Penman-Monteith > Turc > Hargreaves for sugar beet but, following Pan evaporation > Blaney-Criddle > Penman-Monteith > Hargreaves > Turc for maize.

On the meantime the highest value of ETc was recorded for mid-stage this is mainly owing to the maximum vegetation growth for sugar beet, the flowering and grain filling stages for maize, in addition to the climatic conditions in this stage, whilst, the lowest values of ETc were occurred in initial stages as plants in initial stage are still small and not cover most of soil surface and most of irrigation water goes back to the atmosphere through evaporation from soil surface only.

When comparing the total actual evapotranspiration (Eta) value of the sugar beet crop with the total evapotranspiration values (ETc) calculated using the experimental equations by the standard error (SE). The data indicate that the closest equation to the seasonal Eta at the field is the equation Pan evaporation calculated for ten days. Where there is non-significant difference between total Eta and total ETc calculated using this equation. The Same thing when comparing the seasonal Eta value of the maize crop with the total ETc values calculated using the empirical equations (table 9), we find that the closest equations to the actual evapotranspiration of the field experiment is Turc and Hargreaves equations calculated for ten days.
The differences of ETc values, which calculated using different experimental equations during each growth stage of crop, may lead to make the validity of the equations during each growth phase different. The closest equations for the growth stages of sugar beet and maize crop are Blaney-Criddle, Pan evaporation for initial and development stages, respectively. While, Penman-Monteith and Blaney-Criddle for end stage for sugar beet. Where there is non-significant difference between (Eta) actual evapotranspiration and (ETc) calculated using this equations at this stages. For maize there is non-significant difference between (Eta) actual evapotranspiration and (ETc) calculated using Blaney-Criddle for initial stage, Turc and Hargreaves equations for development stage, however, there is significant difference between (Eta) actual evapotranspiration and Blaney-Criddle for end stage.

### Table 7: Calculated reference evapotranspiration (ETo) using different equations for different growth stages periods for crops.

<table>
<thead>
<tr>
<th>Growth stages</th>
<th>Methods of calculation ETo</th>
<th>Initial stage</th>
<th>Develop. Stage</th>
<th>Mid. Stage</th>
<th>End Stage</th>
<th>Gross</th>
<th>season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm d⁻¹</td>
<td>mm</td>
<td>mm d⁻¹</td>
<td>mm</td>
<td>mm d⁻¹</td>
<td>mm</td>
<td>Mm</td>
</tr>
<tr>
<td>Panman-monteith</td>
<td>3.92</td>
<td>137.28</td>
<td>2.37</td>
<td>142.06</td>
<td>3.46</td>
<td>242.10</td>
<td>6.09</td>
</tr>
<tr>
<td>Class A pan</td>
<td>6.17</td>
<td>216.08</td>
<td>4.12</td>
<td>247.07</td>
<td>4.18</td>
<td>292.82</td>
<td>5.71</td>
</tr>
<tr>
<td>Blaney-criddle</td>
<td>4.73</td>
<td>165.58</td>
<td>2.80</td>
<td>167.78</td>
<td>3.56</td>
<td>249.26</td>
<td>6.32</td>
</tr>
<tr>
<td>Turc</td>
<td>3.58</td>
<td>125.36</td>
<td>2.34</td>
<td>140.58</td>
<td>2.98</td>
<td>208.92</td>
<td>5.23</td>
</tr>
<tr>
<td>Hargreaves</td>
<td>3.30</td>
<td>115.38</td>
<td>2.14</td>
<td>128.47</td>
<td>3.13</td>
<td>219.13</td>
<td>5.29</td>
</tr>
</tbody>
</table>

### Table 8: Crop evapotranspiration (ETc) mm of sugar beet calculated using different equations and actual evapotranspiration for treatment that have higher crop yield.

<table>
<thead>
<tr>
<th>Growth stages</th>
<th>KC FAO*</th>
<th>Panman-monteith</th>
<th>Pan-evaporation</th>
<th>Blaney-criddle</th>
<th>Turc</th>
<th>Hargreaves</th>
<th>Eta</th>
<th>SE**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0.49</td>
<td>67.27</td>
<td>105.88</td>
<td>81.13</td>
<td>61.43</td>
<td>56.54</td>
<td>81.12</td>
<td>7.33</td>
</tr>
<tr>
<td>Develop.</td>
<td>0.86</td>
<td>122.17</td>
<td>212.48</td>
<td>144.29</td>
<td>120.9</td>
<td>110.48</td>
<td>198.90</td>
<td>17.79</td>
</tr>
<tr>
<td>Mid.</td>
<td>1.23</td>
<td>297.78</td>
<td>360.17</td>
<td>306.59</td>
<td>256.97</td>
<td>269.53</td>
<td>343.20</td>
<td>16.45</td>
</tr>
<tr>
<td>End</td>
<td>0.76</td>
<td>208.16</td>
<td>195.11</td>
<td>216.17</td>
<td>178.91</td>
<td>180.88</td>
<td>210.60</td>
<td>6.47</td>
</tr>
<tr>
<td>Total</td>
<td>0.83</td>
<td>695.38</td>
<td>873.64</td>
<td>748.18</td>
<td>618.21</td>
<td>617.43</td>
<td>833.82</td>
<td>44.01</td>
</tr>
</tbody>
</table>

Kc FAO*: kc calculated from standard kc values for represent different weather according to Allen et al. (1998), SE**: standard error.

### Table 9: Crop evapotranspiration (ETc) mm of maize calculated using different equations and actual evapotranspiration for treatment that have higher crop yield.

<table>
<thead>
<tr>
<th>Growth stages</th>
<th>KC FAO*</th>
<th>Panman-monteith</th>
<th>Pan-evaporation</th>
<th>Blaney-criddle</th>
<th>Turc</th>
<th>Hargreaves</th>
<th>Eta</th>
<th>SE**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0.22</td>
<td>36.88</td>
<td>37.17</td>
<td>40.42</td>
<td>30.34</td>
<td>31.15</td>
<td>39.75</td>
<td>1.74</td>
</tr>
<tr>
<td>Develop.</td>
<td>0.74</td>
<td>177.27</td>
<td>187.92</td>
<td>194.09</td>
<td>142.19</td>
<td>144.83</td>
<td>141.33</td>
<td>10.01</td>
</tr>
<tr>
<td>Mid.</td>
<td>1.26</td>
<td>259.99</td>
<td>309.39</td>
<td>284.61</td>
<td>194.13</td>
<td>201.57</td>
<td>150.17</td>
<td>24.89</td>
</tr>
<tr>
<td>End</td>
<td>0.40</td>
<td>67.74</td>
<td>76.90</td>
<td>77.70</td>
<td>55.06</td>
<td>55.98</td>
<td>94.22</td>
<td>6.08</td>
</tr>
<tr>
<td>Total</td>
<td>0.66</td>
<td>541.88</td>
<td>611.38</td>
<td>596.82</td>
<td>421.72</td>
<td>433.53</td>
<td>425.47</td>
<td>36.27</td>
</tr>
</tbody>
</table>

Kc FAO*: kc calculated from standard kc values for represent different weather according to Allen et al. (1998), SE**: standard error.
(ETc) calculated using all the experimental equations in Mid stage for both crop and in end stage for maize that may come back to the significant variation in the values of crop coefficient that estimated in the field and the crop coefficient used from FAO, which is related to the variety of plant types and hybrid used. In addition to the effect of the date of agriculture (lug late) for maize crop.

As the climate change condition, it is recommended to conduct local calibrations for this equations, to ensure the correctness of results for each region.

**Crop coefficient (Kc)**

The Kc coefficient combines crop characteristics and averaged effects of evaporation from the soil. Therefore, it differs in accordance with the type of crop.
and soil.

The values of crop coefficient at different stages of plant growth usually estimated under optimum soil moisture conditions, in especial field tests using lysimeters, on experimental scale the values were obtained when the plants don’t suffer from any moisture stress or over-irrigation conditions. Under the experimental conditions the treatments are SMD 30% treatment of sugar beet crop and SMD 10% treatment of maize crop gives the highest yields. The kc values can be estimated using these treatments to give reliable values for the Kc.

Data presented in figs. 3 and 4 shows the behavior of Kc during the growing season for sugar beet and maize crops. The figs show that Seasonal crop coefficients (Kc) for sugar beet and maize calculated by Hargreaves and Turc equations are the highest that mainly related to the low values of reference evapotranspiration (ETo) calculated using Hargreaves and Turc equations. On the other hand, the lowest value of KC calculated was obtained using Pan evaporation and Blaney-Criddle method which have highest value of ETo for sugar beet and maize, respectively.

Data presented in figs. 3 and 4 shows the behavior of sugar beet crop and maize crop during the growing season. The results show that Seasonal crop coefficients (Kc) for sugar beet and maize calculated by Hargreaves and Turc equations are the highest that mainly related to the low values of reference evapotranspiration (ETo) calculated using Hargreaves and Turc equations. On the other hand, the lowest value of Kc calculated was obtained using Pan evaporation and Blaney-Criddle method which have highest value of ETo for sugar beet and maize, respectively.

The estimated values of Kc increase gradually from the initial stage to development stage and reach to the maximum value in mid stage then they decrease in end stage of growth. The peaks of Kc values are observed in mid stage for sugar beet and maize where the plants are in maximum leaf area index and maximum vegetation growth for sugar beet, the flowering and grain filling stages for maize.

Irrigation water requirements (IWR)

Data presented in figs. 5 and 6 shows that: The gross irrigation water requirements (IWR) values calculated using Pan-evaporation, Penman-Monteith and Blaney-Criddle equations are higher than the values of IWR calculated using Hargreaves equations and Turc. The same trend was obtained for both crops.

The total actual irrigation water requirements (IWRa) value of the sugar beet crop is closest to irrigation water requirements calculated using Pan-evaporation equation calculated for ten days. As for the total IWRa value of the maize crop is closest to IWR calculated using Turc and Hargreaves equations.

Water use efficiency (WUE)

Webber et al. (2006) mention that raise water use efficiency (WUE), which was characterized as the measure of plant material created per unit of water transpired, is a path for arid and semi-arid areas to increase their agricultural production through the suggestion of the best treatment for saving water with significant yield.

Data presented in table 10 shows that CWUE and IWUE values were significantly influenced by irrigation treatments for root and sugar yield. The maximum CWUE and IWUE were obtained from SMD 40% and SMD 30% for the root yield compared to the SMD 50% and SMD 10% treatments. While, the maximum CWUE and IWUE for the sugar yield were from SMD 30% followed by SMD 40% compared to the SMD 50% and SMD 10% treatment.

Also, data offered in table 10 shows that CWUE values were significantly influenced by irrigation treatments. While the highest CWUE and IWUE value for the grain yield was from SMD 25% treatment.

Acknowledgement

I feel indebted to Prof. Dr. Hamdi Nasr, professor of Soil Sciences, Department of Soil, Faculty of Agriculture, Cairo University, Giza, Egypt for his co-operation, help and review to take out this work.

References


Table 10: Water use efficiency.

<table>
<thead>
<tr>
<th>Sugar beet crop</th>
<th>CWU<em>R.</em></th>
<th>CWUES.*</th>
<th>IWUE*R.</th>
<th>IWUES.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irr. Regimes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMD 0.10</td>
<td>7.97b</td>
<td>1.24c</td>
<td>4.97b</td>
<td>0.78c</td>
</tr>
<tr>
<td>SMD 0.30</td>
<td>9.67b</td>
<td>1.88c</td>
<td>6.03b</td>
<td>1.18c</td>
</tr>
<tr>
<td>SMD 0.40</td>
<td>9.72b</td>
<td>1.69c</td>
<td>6.06b</td>
<td>1.05c</td>
</tr>
<tr>
<td>SMD 0.50</td>
<td>8.16b</td>
<td>1.16c</td>
<td>5.09b</td>
<td>0.72c</td>
</tr>
</tbody>
</table>

Maize crop

<table>
<thead>
<tr>
<th>Irr. Regimes</th>
<th>CWU</th>
<th>IWUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMD 0.10</td>
<td>1.90c</td>
<td>1.01bc</td>
</tr>
<tr>
<td>SMD 0.25</td>
<td>2.04c</td>
<td>1.08</td>
</tr>
<tr>
<td>SMD 0.50</td>
<td>1.93b</td>
<td>1.03</td>
</tr>
</tbody>
</table>

CWUE*; crop Water use efficiency, IWUE*; irrigation water use efficiency, R*.; root yield, S.* sugar yield.


