Plant Archives Vol. 20 Supplement 1, 2020 pp. 1961-1972 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

DETERMINATION OF EVAPOTRANSPIRATION OF SOME CROPS USING SOME EMPIRICAL EQUATIONS

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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

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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-Criddle, 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 m^2 (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 m^2 (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 :

- Eta ={(FC – θv)/100} × d

Where,

- ETa : actual evapotranspiration mm / interval.
- FC : volumetric soil moisture content (%) at field capacity.
- θ_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 =Eta/ E_i (1-LR) mm

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).

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

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_s-e_a saturation vapour pressure deficit [KPa]
- ▲ 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
  - f = p (0.46 T + 8)
  - a = 0.0043 RH_{min} -n/N -1.41
  - b = 0.82 + (- 0.0041* RH_{min}) + 1.07*n/N + 0.066*Ud + (-0.006* RH_{min} *n/N) + (-0.0006* RH_{min} *Ud)

Where,

- ET_o = 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%

- $ET_O=0.013 \{T/(T+15)(R_S+50)(1+((50-RH)/70)\}$

Where,

- ET_o = 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).
- $ET_o = 0.0023\ Ra\ (T_{mean} + 17.8)\ (T_{max} - T_{min})^{0.5}$

where,

- ETo = 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 = ETc /ETo

Where,

- ETc = Crop evapotranspiration under standard condition mm/day.
- ET_o = 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)

- CWUE = Yield (kg/fed)/Eta (m^3/fed)
- IWUE = Yield (kg/fed)/IWRa (m^3/fed)

Where,

- ETa = actual evapotranspiration
- IWRa = actual irrigation water requirement
- CWUE = crop water use efficiency
- 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 compered 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 e*t 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.

Soil depth (cm)	Particle size distribution (%)				Tex. class	Soil bulk density (g/cm^{-3})	Moisture content θv %		Available water (AW)%
	C. sand	F. sand	Silt	clay			F.C	W.P	
0-20	12.7	20.4	34.6	32.3	C.L	1.13	40.8	20.2	20.6
20-40	13.1	17.2	35.7	34.0	C.L	1.22	43.00	22.1	20.9
40-60	16.5	21.5	31.7	30.3	C.L	1.16	40.2	18.9	21.3

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

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

Soil depth (cm)	PH(1:25)	EC_e ds/m	Soluble cations (meq/L)				Soluble anions (meq/L)			$CaCo_3$%
			Na^+	K^+	Ca^{++}	Mg^+	HCO_3^-	$SO_4^=$	Cl^-	
0-20	8.00	1.93	10.1	0.7	4.9	3.3	0.72	2.08	16.2	1.6
20-40	7.97	2.54	13.6	0.9	7.0	3.5	0.94	3.46	20.6	0.8
40-60	7.95	1.74	9.0	0.7	4.7	2.6	0.52	2.28	14.2	0.4

EC: electrical conductivity.

Table 3 : Irrigation water quality.

PH	E C (ds m^{-1})	Soluble cations (meq/L)				Soluble anions (meq/L)			SAR
		Na^+	K^+	Ca^{++}	Mg^+	$CO_3^=+HCO_3^-$	$SO_4^=$	Cl^-	
7.19	1.29	4.87	0.11	4.79	3.52	3.96	6.97	2.54	0.11

SAR: sodium absorption ratio; EC: electrical conductivity.

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

Irr. Regimes	Eta (mm)	IWRa (mm)	Sucrose (%)	Root yield(kg/fed^{-1})	Sugar yield(kg/fed^{-1})
SMD 0.10	861.12	1380.00	17.57 ^{c}	28826.67 ^{c}	4502.32^{c}
SMD 0.30	833.82	1336.25	21.04^{a}	33850.00^{a}	6600.46^{a}
SMD 0.40	798.72	1280.00	19.34^{b}	32600.00^{b}	5664.66^{b}
SMD 0.50	666.12	1067.50	16.51^{c}	22833.33^{d}	3249.43^{d}

L.S.D at 5%.

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

Irr. regimes	Eta(mm)	IWR (mm)	Yield(kg/fed^{-1})
SMD 0.10	425.47	802.77	3403.40 ^{a}
SMD 0.25	340.08	641.66	2909.67^{b}
SMD 0.50	275.31	519.45	2238.13 ^{c}

L.S.D at 5%.

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 evapotranspiration (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, Turc, 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 Turc

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

EP	Wind (m/s^{2})	RH. (%)	T min. (^{0}C)	T max. (^{0}C)	Month
Sugar beet crop (2018)					
9.06	2.21	46.65	18.90	30.55	Oct.*
7.00	1.85	57.67	15.47	26.90	Nov.
5.37	1.92	60.67	11.60	21.33	Des.
Sugar beet crop (2019)					
5.13	2.06	51.67	6.97	19.63	Jan.
5.27	2.12	53.00	8.07	21.80	Feb.
6.54	2.71	48.50	11.65	24.23	Mar.
8.20	2.66	46.33	14.47	28.53	Apr.
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: meterology station of giza –Egyt in Agriculture Research Center).

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 > Turc >Hargreaves. As for summer season (maize crop) it follows the order Blaney-Criddle > Pan-evaporation > Penman-Monteith > Hargreaves > Turc.

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

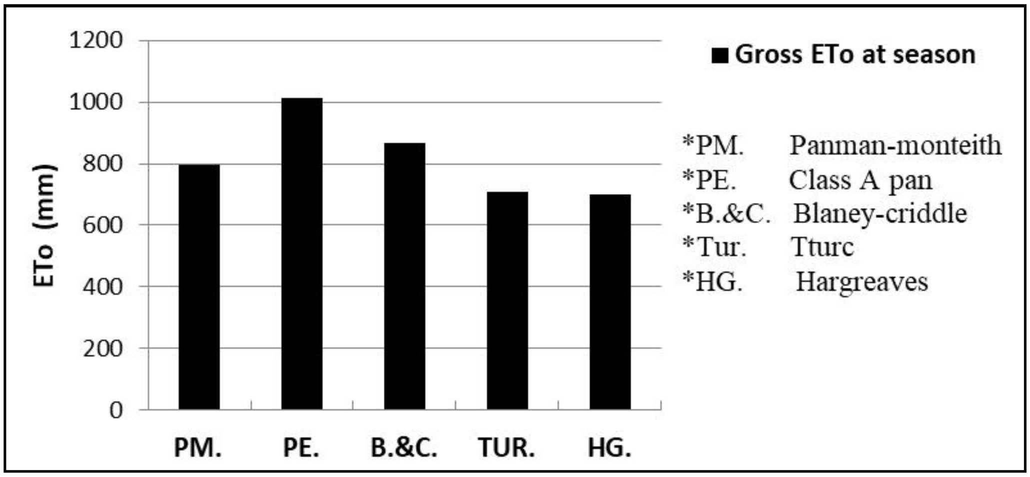

Fig. 1 : Reference evapotranspiration (ETo) using different equations for gross season for sugar beet.

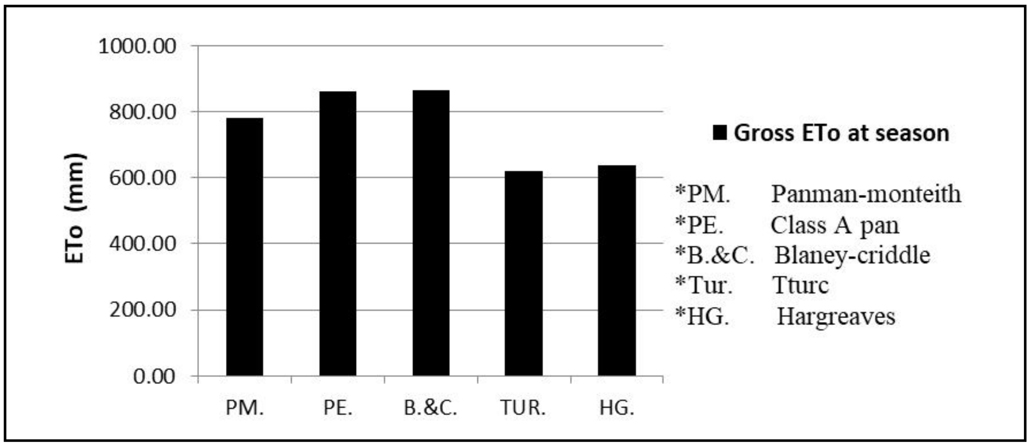

Fig. 2 : Reference evapotranspiration (ETo) using different equations for gross season for maize.

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.

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

Methods of calculation ETo	Growth stages								Gross season
	Initial stage		Develop. Stage		Mid. Stage		End Stage		
	mm d^{-1}	mm	mm d^{-1}	mm	mm d^{-1}	mm	mm d^{-1}	mm	Mm
Calculated reference evapotranspiration (ETo) using different equations for different growth stages periods for sugar beet.									
Panman-monteith	3.92	137.28	2.37	142.06	3.46	242.10	6.09	273.90	795.34
Class A pan	6.17	216.08	4.12	247.07	4.18	292.82	5.71	256.73	1012.70
Blaney-criddle	4.73	165.58	2.80	167.78	3.56	249.26	6.32	284.44	867.06
Turc	3.58	125.36	2.34	140.58	2.98	208.92	5.23	235.41	710.27
Hargreaves	3.30	115.38	2.14	128.47	3.13	219.13	5.29	238.00	700.98
Calculated reference evapotranspiration (ETo) using different equations for different growth stages periods for maize.									
Panman-monteith	8.38	167.62	7.99	239.56	6.88	206.34	5.46	169.36	782.88
Class A pan	8.45	168.96	8.46	253.94	8.19	245.55	6.20	192.25	860.70
Blaney-criddle	9.19	183.71	8.74	262.28	7.53	225.88	6.27	194.24	866.11
Turc	6.90	137.90	6.40	192.15	5.14	154.07	4.44	137.66	621.78
Hargreaves	7.08	141.60	6.52	195.72	5.33	159.98	4.51	139.94	637.24

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

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

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.

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

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

The differences of ETc values, which calculated using different experimental equations during each growth stage of crop. It 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

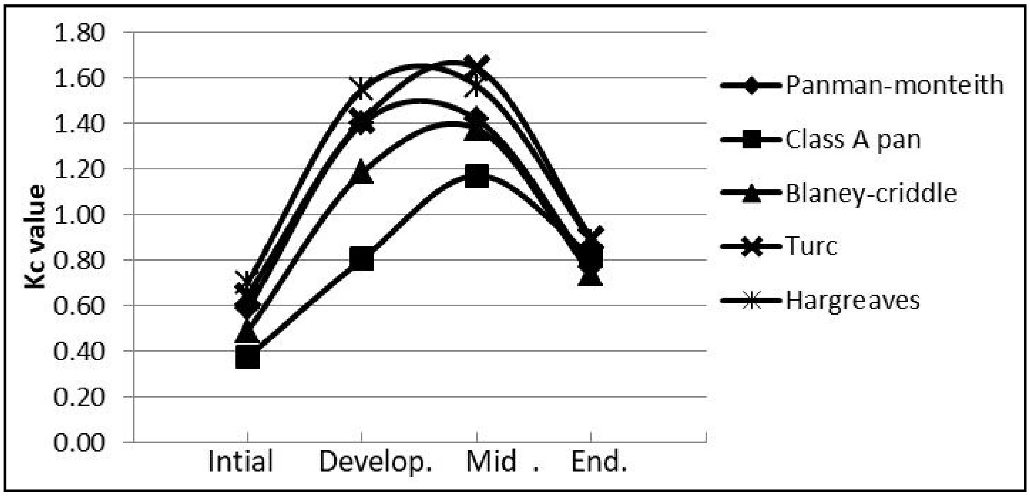

Fig. 3 : Kc values of sugar beet at different crop stages using different equations for calculating ETo.

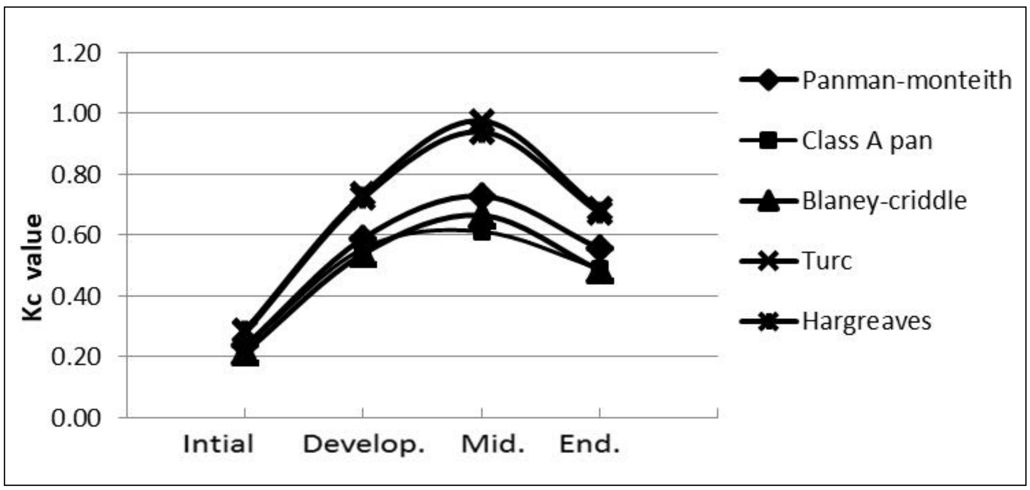

Fig. 4 : Kc values of maize at different crop stages using different equations for calculating ETo.

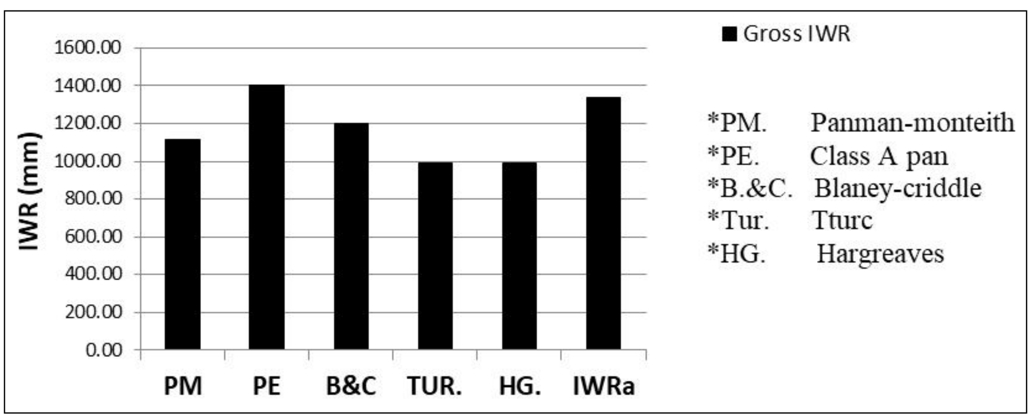

Fig. 5 : Relationship between calculated and actual irrigation water requirements for sugar beet.

(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

Table 10 : Water use efficiency.

Sugar beet crop				
Irr. Regimes	**CWU*R.***	**CWUE S.***	**IWUE*R.**	**IWUE S.**
SMD 0.10	7.97[b]	1.24[c]	4.97[b]	0.78[c]
SMD 0.30	9.67[a]	1.88[a]	6.03[a]	1.18[a]
SMD 0.40	9.72[a]	1.69[b]	6.06[a]	1.05[b]
SMD 0.50	8.16[b]	1.16[c]	5.09[b]	0.72[c]

Maize crop		
Irr. regimes	**CWUE**	**IWUE**
SMD 0.10	1.9 0[b]	1.01[n.s]
SMD 0.25	2.04[a]	1.08
SMD 0.50	1.93[b]	1.03

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

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.

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 leave 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

Abd El-Wahab, S. A. and E. A. E. Nemeat Alla (2002). Sugar beet response to zinc-application under different water regimes in Northen Delta soils. *J. Agric. Sci. Mansoura Univ.*, **27** : 1943–1953.

Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, Italy.

Amer, M. H., I. M. El-Naggar and H. H. Abdel-Maksoud (1990). Evaluation study for some empirical formulae applied for crop water requirements estimation. *Egypt. J. Appl. Sci.*, **5(2)** : 202214.

Asker, F. A., M. A. Barakat and M. M. Attia (1992). Suitability of different empirical methods for calculating crop water requirements in North Nile Delta region. *J. Agric. Sci. Mansoura Univ*., **17(5)**: 1160-1166.

Ayers, R. S. and D. W. Westcot (1985). *Water quality for agriculture* (Vol. **29**). Rome: Food and Agriculture Organization of the United Nations.

Azab M.A. (1998). Effect of water depletion and nitrogen rate on water consumption use and yield of wheat in sandy soil. *Al-Azhar J. Agric. Res*., **27** : 1-12.

Besheit, S. Y., B. B. Mekki and M. G. Beshay (1996). Effect of different levels of water supply on sugar beet yield and quality in calcareous soils. *J. Agric. Sci. Mansoura Univ.*, **21** : 3429-3436.

Borham, T. I., M. E. Shawky, R. E. Sabrah and F. A. Gomaa (2005). *Water Use Efficiency For Some Crops Under Intercropping Systems*. 3rd Conference on Recent Technologies in Agriculture, 2005 .

Camprag, D. (1976). The effect of irrigation on the occurrence of some important sugar beet pests in Yugoslavia and other countries of southeastern Europe.Proceedings of the 39th Winter Congress of the International Institute for Sugar Beet Research, pp. 449-57.

Christmann, J. (1976). Relations entre l'irrigation, les maladies et les ravageurs de la betterave a sucre. Proceedings of the 39th Winter Congress of the International Institute for Sugar Beet Research, pp. 149-57.

Davidoff, B. and R. J. Hanks (1989). Sugar beet production as influenced by limited irrigation. *Irrigation Science*, **10(1)** : 1-17.

Quebrajo, L., M. Perez-Ruiz, L. Pérez-Urrestarazu, J. Doorenbos and W. O. Pruitt (1984). Guidelines for predicting crop water requirements. F.A.O. Irrigation and Drainage paper No. 24. Rome.

Dunham, R. J. (1993). Water use and irrigation. In : *The sugar beet crop* (pp. 279-309). Springer, Dordrecht.

El-Gindy, A. M., M. A. Massoud and M. A. Hussein (1991). Calculation of evapotranspiration and crop coefficient for some irrigated Egyptian crops. *Egypt. J. Soil Sci*., **31(3)**: 403-419.

FAO (2002). *Deficit Irrigation Practices*. Water Reports No. 22. Rome.

Giriappa, S. (1983). *Water use efficiency in agriculture*. Oxford & IBH publishing C.O. New Delhi.

Hoffmann, C. M. (2014). Adaptive responses of *Beta vulgaris* L. and *Cichorium intybus* L. root and leaf forms to drought stress. *Journal of agronomy and crop science*, **200(2)** : 108-118.

Israelsen, O. W. and V. E. Hansen (1962). *Irrigation principles and practices*. 3rd Edit. John Willey and Sonsins, New York.

Jensen, M. E., R. D. Burman and R. G. Allen (1990). Evapotranspiration and irrigation water requirements. ASCE.

Kashyap, P. S. and R. K. Panda (2001). Evaluation of evapotranspiration estimation methods and development of crop-coefficients for potato crop in a sub-humid region. *Agricultural Water Management*, **50(1)** : 9-25.

Klute, A. (ed.) (1986). *Methods of Soil Analysis*. Part -1 "Physical and mineralogical Methods" 2nded . Amer. Soc. of Agron. Madison, Wisconsin, U.S.A.

Li, S., S. Kang, L. Zhang, J. Zhang, T. Du, L. Tong and R. Ding (2016). Evaluation of six potential evapotranspiration models for estimating crop potential and actual evapotranspiration in arid regions. *Journal of Hydrology*, **543** : 450-461.

Liu, X. Y., Y. Z. Li and Q. S. Wang (2006). Evaluation on several temperature-based methods for estimating reference crop evapotranspiration. *Transactions of the CSAE*, **22(6)** : 12-18.

Liu, X., C. Xu, X. Zhong, Y. Li, X. Yuan and J. Cao (2017). Comparison of 16 models for reference crop evapotranspiration against weighing lysimeter measurement. *Agricultural Water Management*, **184** : 145-155.

Lu, J., G. Sun, S. G. McNulty and D. M. Amatya (2005). A Comparison of Six Potential Evapotranspiration Methods for Regional Use in the Southeastern United States 1. *JAWRA Journal of the American Water Resources Association*, **41(3)** : 621-633.

Mäck, G. and C. M. Hoffmann (2006). Organ-specific adaptation to low precipitation in solute concentration of sugar beet (*Beta vulgaris* L.). *European journal of Agronomy*, **25(3)** : 270-279.

Masri, M. I., B. S. B. Ramadan, A. M. A. El-Shafai and M. S. El-Kady (2015). Effect of water stress and fertilization on yield and quality of sugar beet under drip and sprinkler irrigation systems in sandy soil. *International Journal of Agriculture Sciences,* ISSN, 2167-0447.

Moosavi, S. G. R., S. H. R. Ramazani, S. S. Hemayati and H. Gholizade (2017). Effect of drought stress on root yield and some morpho-physiological traits in different genotypes of sugar beet (*Beta vulgaris* L.). *Journal of Crop Science and Biotechnology*, **20(3)** : 167-174.

Page,A. L., R. H. Miller and D. R. Keeney (1982). Methods of Soil Analysis. Part-2 "*Chemical and Microbiological Properties*",**2**nd ed. Amer. Soc. of Agron. Madison, Wisconsin, U.S.A.

Paul, M. J. and C. H. Foyer (2001). Sink regulation of photosynthesis. *Journal of experimental Botany*, **52(360)** : 1383-1400.

Perera, K. C., A. W. Western, B. Nawarathna and B. George (2015). Comparison of hourly and daily reference crop evapotranspiration equations across seasons and climate zones in Australia. *Agricultural Water Management*, **148** : 84-96.

Quebrajo, L., M. Perez-Ruiz, L. Pérez-Urrestarazu, G. Martínez and G. Egea (2018). Linking thermal imaging and soil remote sensing to enhance irrigation management of sugar beet. *Biosystems Engineering*, **165** : 77-87.

Renfield, E., A. Emmerich, G. Baumarten, C. Winner and U. Beiss (1993). Zur voraussage des melosse suckers aus rubenanalyses. Zuker. In: 1st ed. In: Cock, D. A. and R. K. Scott (Eds.), *The Sugar Beet Crop 27*. Chapman & Hall (World Crop Series), London, UK, pp. 2–15 (1974).

Satti, S. R., J. M. Jacobs and S. Irmak (2004). Agricultural water management in a humid region: sensitivity to climate, soil and crop parameters. *Agricultural water Management*, **70(1)** : 51-65.

Sugar Crops Council (2017). *Annual report for sugar crops*. Arabic Ed.

Topak, R., B. Acar, R. Uyanöz and E. Ceyhan (2016). Performance of partial root-zone drip irrigation for sugar beet production in a semi-arid area. *Agricultural Water Management*, **176** : 180-190.

Tsonev, S., E. Todorovska, V. Avramova, S. Kolev, N. Abu-Mhadi and N. K. Christov (2009). Genomics assisted improvement of drought tolerance in maize: QTL approaches. *Biotechnol Biotechnol EQ* **23**:1410–1413

Uçan, K. and C. GENÇOĐLAN (2004). The effect of water deficit on yield and yield components of sugar beet. *Turkish Journal of Agriculture and Forestry*, **28(3)** : 163-172.

Vamerali, T., M. Guarise, A. Ganis and G. Mosca (2009). Effects of water and nitrogen management on fibrous root distribution and turnover in sugar beet. *European journal of Agronomy*, **31(2)** : 69-76.

Webber, H. A., C. A. Madramootoo, M. Bourgault, M. G. Horst, G. Stulina and D. L. Smith (2006). Water use efficiency of common bean and green gram grown using alternate furrow and deficit irrigation. *Agricultural Water Management*, **86(3)** : 259-268.

Zheng, H., G. Yu, Q. Wang, X. Zhu, J. Yan, H. Wang and J. Zhang (2017). Assessing the ability of potential evapotranspiration models in capturing dynamics of evaporative demand across various biomes and climatic regimes with China FLUX measurements. *Journal of Hydrology*, **551** : 70-80.