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Evaluation of direct and indirect methods used to determine crop coefficient and crop evapotranspiration of sugar beet plants grown under fayoum conditions.

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Abstract

With increasing water scarcity, the determination of reference evapotranspiration ETo and crop coefficient (Kc) is a critical factor in determining the crop water demand ETc. Therefore, the current investigation aimed to evaluate and compare the estimated sugar beet crop evapotranspiration (ETc) values computed by different empirical methods (e.g. Hargreaves, Penmen-Monteith and Class-A pan) with the measured actual sugar beet evapotranspiration (ETa). To determine the ETa for sugar beet crop field experiment was conducted during two growing seasons (2019/2020 and 2020/2021) in Demo farm, Faculty of Agriculture, Fayoum University, Egypt. Sugar beet seeds (*Beta vulgaris L.*, Baraca) was planted in 1st October and harvested in April during two successive winter seasons. Irrigation water was applied when the soil moisture content was depleted by 30% of available water. All the obtained results were statistically analyzed to evaluate the best method for estimating the reference evapotranspiration and suitable for optimizing the irrigation management practices for sugar beet plants grown under arid and semi-arid conditions. The obtained results concluded that among the used methods (Hargreaves, Penmen-Monteith and Class A pan) for estimating sugar beet crop evapotranspiration (ETc) in comparison with ETa measured values, the Penmen-Monteith performed well in describing the ETc and Kc for sugar beet plants grown in Fayoum Governorate, Egypt.

Key words:

Sugar beet, crop evapotranspiration, reference evapotranspiration, crop coefficient

Introduction

The agriculture sector is the largest consumer of the available water in Egypt, by about 85% of the total water supply. In addition, due to the expected increase in water demand by municipal and industrial sectors, that negatively affects the sustainability of the agricultural system Allam, and Allam, 2007. Therefore, optimizing and increasing the efficiency of irrigation system is becoming an essential target.

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Reference evapotranspiration (ET_o) is a key component in hydrological studies. ET_0 is used for agricultural and urban planning, irrigation scheduling, regional water balance studies, and agroclimatological zoning. Various equations are available for estimating the reference ET_0. These equations range from the most complex energy balance equations requiring detailed climatological data Allen et al., 1998 to simpler equations requiring limited data, i.e. Blaney and Criddle equation, Hargreaves and Samani equation, Jensen and Haise equation, Turc… etc. The Penman-Monteith equation is widely recommended because of its detailed theoretical base and its accommodation of little time periods. However, the detailed climatological data required by the Penman-Monteith are not often available, especially in developing countries.

Crop reference evapotranspiration is an important factor in managing irrigation system whether under irrigated and non-irrigated (rain-fed) conditions. The direct and indirect methods for reference evapotranspiration determination have been widely proposed by several researchers. The direct methods are generated from ETo of perennial grass, while the indirect ways for ETo estimation are mainly independent on the meteorological data using some temperature, radiation and combination models Djaman et al., 2018. Determination of evapotranspiration of grown crops is essential component in planning and calculating the amount of irrigation water applied as well as the designing of irrigation systems (Aydin, 2019). Thus, ETo parameter should be precisely computed since it plays an essential role in the accurate evaluation of water losses by evaporation from soil and transpiration from plants (Trajkovic, 2008; Çobaner et al., 2016).

Knowledge of consumptive use of water, or evapotranspiration (ETc) is necessary in irrigation development, planting and operating projects and one of the most basic components of the hydrological cycles, in additions, it has been particularly important in arid and semi-arid irrigated areas of the world Jensen et al., 1990. Evapotranspiration (ETc) is generally expressed in two steps by computing the water consumption of the grass that completely covering the soil surface and multiplying it by specific coefficient of grown crop. It is known that there are several equations for the calculation of potential evapotranspiration such as (temperature, radiation, Class A Pan, mass transfer…etc.), ecological conditions (arid or humid) and assumptions Lu et al., 2005. Researchers have been focused on the evaluation and compliance of these models under different ecological conditions to assess the validity and performance of these methods under certain climate conditions Castaneda and Rao, 2005; Tabari et al., 2013. Allen et al. 1998 developed the FAO-56 Penman-Monteith method (PMF-56) which it widely used as the standard method worldwide under different agricultural and climate conditions (Fisher and Pringle, 2013; Çobaner et al., 2016).

Crop coefficient (Kc) is the ratio of evapotranspiration under maximum production conditions (ETc) to evapotranspiration of a reference crop (ETo). Calculating Kc at different growth stages of grown crop allows the accurate evaluation of crop water demand, accordingly allows precise water management for optimum application of irrigation water, optimum crop productivity.

The purpose of the present investigation was 1) to compute and evaluate the estimated ETo, Kc and ETc of sugar beet crop computed by different empirical methods (Hargreaves, Penmen-Monteith and Class-A pan). 2) To determine the actual values of ETa sugar beet. 3) Compare the estimated sugar beet evapotranspiration with the actually measured ETa in field and select the most suitable ETc calculation method under Fayoum conditions.

3. Materials and Methods

3.1. The field environmental conditions

3.1.1Climate: The current investigation was implemented at the experimental Demo farm of Faculty of Agriculture, Fayoum University, Egypt, (29◦29_N latitude, 30◦91_E longitude). From Table (1) the climate in experimental site is arid, hot in summer months with high temperatures and little or absent rainfall. The highest values of maximum temperature 32.30 °C, minimum temperature 18.62°C were observed in Oct.2019. The pan evaporation rates were in line with the changes in temperature, accordingly the maximum values of Pan evaporation (4.8 and 5.2 mm day^{-1}) occurred in the of Oct. and Apr. months respectively, while the lowest 1.45 and 1.55 (mm day^{-1}) were observed in Dec. and Jan. months respectively. Relative humidity during the cultivation period was ranged between were 43 and 34% (as average). The meteorological data including daily air temperature, relative humidity, wind speed, sunny hours, precipitation and Pan evaporation were recorded by the Fayoum meteorological station.

Table (1). The meteorological data of experimental site.

Month	Year	Temperature C°			Relative humidity (%)	Wind speed (m sec^{-1})	Pan evaporation (mm day^{-1})
		Max.	Min.	Mean			
October	2019	32.3	18.6	25.4	38	2.0	4.5
	2020	33.0	21.6	27.3	39	1.9	4.8
November	2019	26.2	13.4	19.8	41	1.9	2.3
	2020	28.1	15.6	21.9	42	1.7	2.1
December	2019	23.6	12.7	18.2	43	1.8	1.4
	2020	21.1	9.5	15.3	42	1.9	1.5
January	2020	21.3	9.4	15.4	43	2.2	1.5
	2021	20.4	8.5	14.5	42	1.8	1.6
February	2020	23.4	9.7	16.6	41	1.9	1.5
	2021	22.0	8.3	15.1	42	2.0	2.3
March	2020	29.4	12.7	21.1	37	2.2	4.0
	2021	26.7	12.7	19.7	37	2.1	3.5
April	2020	21.1	9.2	15.2	36	2.2	4.4
	2021	31.2	15.6	23.4	34	2.2	5.2

3.1.2. Soil: The field work was conducted in newly reclaimed soils with sandy loam in texture. Soil salinity was 10.98 dS m^{-1}. As shown in Table (2) soil physical properties were measured as described by Klute and Dirksen 1986. Soil bulk density and hydraulic conductivity were 1.53 (Mg m^{-3}) and 1.96 (cm h^{-1}), respectively, as averages in soil depth (0-60 cm). Soil moisture constants % (at 0.33 bar and at 15 bar) averaged 23.43 and 13.45 % respectively at the same soil depth. Soil chemical analysis were measured as described by Page et al. 1982 (e.g., soil pH (1: 2.5 soil-water extracts), organic matter content, cation exchangeable capacity (CEC) and $CaCO_3$) amounted 7.52, 0.68%, 9.29 cmole kg^{-1} and 7.2% respectively, as averages in soil depth (0-60 cm).

Table (2). Some initial physico- chemical characteristics of the studied soils.

Depth (cm)	Particle size distribution, %			Texture class	ρ_b g.cm^{-3}	K_{sat} cm h^{-1}	F.C %	W.P %	A.W %	EC (dS/m)	pH	O.M %	CEC cmole kg^{-1}	$CaCO_3$
	Sand	Silt	Clay											
0-20	79.90	9.60	10.50	S.L.	1.49	2.10	24.04	14.18	9.86	11.21	7.49	0.75	9.31	7.54
20-40	76.60	12.50	10.90	S.L.	1.53	2.01	23.62	13.42	10.20	10.54	7.51	0.65	8.57	6.21
40-60	75.80	11.50	12.70	S.L.	1.58	1.77	22.63	12.76	9.87	11.19	7.56	0.64	9.99	7.89

Where: EC means the electrical conductivity, O.M = organic matter content%, SL=sandy loamy, ρ_b = bulk density, K_{sat} = hydraulic conductivity, F.C = field capacity, W.P = wilting point and A.W= available water.

3.2. Irrigation water applied

Irrigation water applied was controlled according to the daily estimations of soil moisture content in the subsequent soil depths (0-20, 20-40 and 40-60 cm). Irrigation water was applied when soil moisture content in the subsequent soil depths was depleted by 30% of available water. The amounts of irrigation water application (IWA) that compensate the losses of water and equal the amount of actual crop evapotranspiration was expressed by the following equation:

$$\mathbf{ETa} = \frac{\mathbf{Fc} - \boldsymbol{\theta}\mathbf{v}}{\mathbf{100}} \mathbf{x\ d}$$

Where ETa: actual crop evapotranspiration mm, FC: field capacity%, θv; pre-irrigation volumetric soil moisture content%, d: soil depth (20 cm in the initial growth stage, and from the start of dev. stage to the late stage of sugar beet crop the soil depth was fixed to 60 cm).

The amount of IWA was controlled through plastic pipe (spiles) of 5 cm diameter and 80 cm in length. One spile per plot was used to deliver irrigation water to each plot area. The amount of water delivered through a plastic pipe (spiles) was calculated according to Israelsen and Hansen equation (1962).

$$\mathbf{Q} = \mathbf{CA}\sqrt{\mathbf{2\,g\,h}} \times \mathbf{10^{-3}}$$

Where: Q is the discharge of irrigation water (l sec.$^{-1}$), C is the coefficient of discharge, A is cross-section area of irrigation pipe (cm^2), g is gravity acceleration (cm sec^{-2}) and h is the average of effective head of water (cm) above pipe.

Sugar beet seeds (*Beta vulgaris L.*, Baraca) planted in 1st October and harvested in April along two successive winter seasons.

3.3. ETo estimation methods

1) **FAO-56 Penman Monteith method (P-M).** The FAO-56 Penman Monteith method used for determining reference crop water consumption depending on the daily weather data (Allen et al., 1998) as the flowing equation.

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

Where: ETo: reference evapotranspiration (mm day^{-1}); Rn: net radiation (MJ m^{-2}), G: soil heat flux (MJ.m^{-2}); T mean: average air temperature (°C); U_2: wind speed at 2 m height (m.sn^{-1}), es: saturation vapor pressure (kPa), Δ: slope of vapor pressure curve (kPa.°C^{-1}), γ: psycrometric constant (kPa.°C^{-1}). The components FAO-56 Penman were processed by CROPWAT software package to calculate ETo from collected meteorological data.

2) Hargreaves-Samani method (H-S). Determining of ETo requires only the maximum and minimum values of air temperature (Tmax-Tmin) and extraterrestrial radiation (Ra) (Hargreaves and Samani, 1985).

$$ET_{0-HS} = 0.0023\frac{R_a}{\lambda}\sqrt{(T_{max} - T_{min})}(T + 17.8)$$

Where: ETo: Reference evapotranspiration (mm day^{-1}), 0.0023: an empirical coefficient, Ra: extraterrestrial radiation (mm day^{-1}), λ: the latent heat of vaporization (MJ kg^{-1}) for the mean air temperature (T mean in °C) given as:

$$\lambda = 2.501 - 0.002361 * T_{mean}$$

λ: is generally assumed 2.45 $MJ.kg^{-1}$.

3) Pan evaporation method (Pan) as described by Allen et al. (1998) Class-A Pan was used for estimating (ETo) as the following.

$$ET_o = K_p * E_{pan}$$

Where: ETo: Reference evapotranspiration, mm day^{-1}; Kp: pan coefficient (equal=0.80). Epan: pan evaporation, mm day^{-1}.

3.4. Statistical analysis The ETo values calculated daily according to the P-M method were compared statistically with the daily ETo values. Paired comparisons were made for determining the value of R^2 which were then subject to linear regression analysis and the R^2 equation was determined for the obtained curve.

4. Results and Discussion

4.1. Reference evapotranspiration (ETo)

From Table (3) and Fig (1-a) values of ETo which estimated by (Class A pan, P-M and H-S) equations. For growth stages, the values of ETo was varied, where the maximum values of ETo recorded at the late growth stage, and the lowest values observed at mid. stage. The changes in estimated ETo between growth periods were similar under all the used calculation methods. The fluctuation in ETo values induced by growth periods it could by contributed to the changes in climatic conditions during the whole growth period of sugar beet. However it worth to indicate that the computed ETo by H-S method totaled 440.91mm, which higher by 17.73 and 19.99% than those expressed by P-M and Pan respectively. These results were agreement with those found by Abdou 2004 who concluded that the ET_0 values, estimated using the Class A Pan method were overestimated grain sorghum evapotranspiration values at Fayoum. Evaporation pan method and Turc methods gave low ET_0 values lower than Jensen and Haise, modified Penman and FAO- Penman-Monteith methods. The highest ET_0 values were detected by using Jensen and Haise method. Modified Penman method gave ET_0 values nearly closed to the values of FAO-Penman-Monteith values. It was added that the FAO-Penman-Monteith method is the most ideal for ET_0 estimation if the involved climatological data are required and the evaporation pan method can be also used, and all factors affecting its records are considered Islam et al., 2021.

Table (3). Calculated ETo during sugar beet growth stages by different empirical equations.

Empirical equations methods	Measuring unit	Growth stages				
		Init. (30 day)	Dev. (55 day)	Mid. (60 day)	Lat. (35 day)	Total (180 day)
Pan	mm day^{-1}	3.64	1.59	1.17	2.88	-
	mm stage^{-1}	109.12	87.28	70.08	100.95	**367.43**
P-M	mm day^{-1}	2.92	1.6	1.59	2.96	-
	mm stage^{-1}	87.6	87.76	95.51	103.61	**374.48**
H-S	mm day^{-1}	3.15	1.99	1.97	3.39	-
	mm stage^{-1}	94.5	109.29	118.45	118.67	**440.91**

ETo, reference evapotranspiration; Pan, class A pan; P-M, penman-Monteith; H-S, Hargreaveas-Samani.

4.2. Crop evapotranspiration ETc

From Table (4) and Fig. (1-c) the values of computed ETc by different equations were differed between the sugar beet growth stages. The changes in ETo as mentioned above directly led to remarkable variations in estimated ETc. Sugar beet plants at the late stages exhibited higher ETc demand compared with the other stages. Although the late growth (35 days) is shorter than dev. stage (55 days) and/or mid. stage (60 days) but the crop water demand was higher. The increases in air temperature during the late season (March month) accelerate the evapotranspiration rate of sugar beet plants. In addition due to the decrease in ground cover by plant at initial growth stage leading to little water consumption by the root system. Conversely, the greatest values of ETc at mid. growth stage, indicates higher water losses by the maximum vegetation growth for sugar beet. To evaluate the used ETc calculation methods, ETa was measured in field and all the obtained data were statistically analyzed. The values of RMSE (0.10), MAE (0.09) and R^2 (0.97) indicated that the ETc values estimated by P-M method were in close relation with the observed ETa values. However it could be concluded that the most suitable equation that describe ETc of sugar beet crop under the experimental conditions could be ordered in the following ascending P-M > H-S > Pan.

Table (4). Calculated ETa and ETc during sugar beet growth stages using different empirical equations

Calculation methods		Growth stages				RMSE	MAE	R^2
		Init. (30 day)	Dev. (55 day)	Mid. (60 day)	Lat. (35 day)			
Pan	mm day^{-1}	1.27	1.22	1.40	2.02	0.22	0.18	0.76
	mm stage^{-1}	38.19	67.21	84.1	70.67	-	-	-
P-M	mm day^{-1}	1.02	1.23	1.91	2.07	0.10	0.09	0.97
	mm stage^{-1}	30.66	67.58	114.61	72.53	-	-	-
H-S	mm day^{-1}	1.10	1.53	2.37	2.37	0.33	0.27	0.91
	mm stage^{-1}	33.08	84.15	142.14	83.07	-	-	-
ETa	mm day^{-1}	1.16	1.32	1.81	2.11	-	-	-
	mm stage^{-1}	34.8	72.6	108.6	73.85	-	-	-

ETc, crop evapotranspiration; ETa, actual crop evapotranspiration; Pan, class A pan; P-M, Penman-Monteith; H-S, Hargreaveas-Samani; RMSE, root mean square error; MAE, mean absolute error; R^2, determination coefficient.

4.3. Crop coefficient Kc

Data in Tab. (5) and Fig. (1-b) represent seasonal Kc values of sugar beet crop during growth periods. The mean value of Kc expressed by Calss-A pan was the highest as compared with those derived by other methods. The calculated values of Kc increased gradually from the initial stage to dev. stage and reached their maximum values in mid. season to decrease in the late stage. Also as mentioned above P-M calculation method gave the highest R^2 value (0.999) with the proposed Kc by FAO for sugar beet. However, the variations between Kc values are non-significant or relatively similar between the different calculation methods Mahmoud et al., 2020.

Table (5). Kc of sugar beet crop during different growth stages using different empirical equations.

Calculation methods	Growth stages							
	Init. (30 day)	Dev. (55 day)	Mid. (60 day)	Lat. (35 day)	average	RMSE	MAE	R^2
FAO	0.35	0.77	1.20	0.7	0.76	-	-	-
Pan	0.33	0.96	1.56	0.87	0.93	0.21	0.16	0.988
P-M	0.40	0.85	1.17	0.73	0.79	0.05	0.05	0.999
H-S	0.37	0.68	0.94	0.64	0.65	0.14	0.11	0.993

Kc, crop coefficient; Pan, class A pan; P-M, Penman-Monteith; H-S, Hargreaveas-Samani; RMSE, root mean square error; MAE, mean absolute error; R^2, determination coefficient.

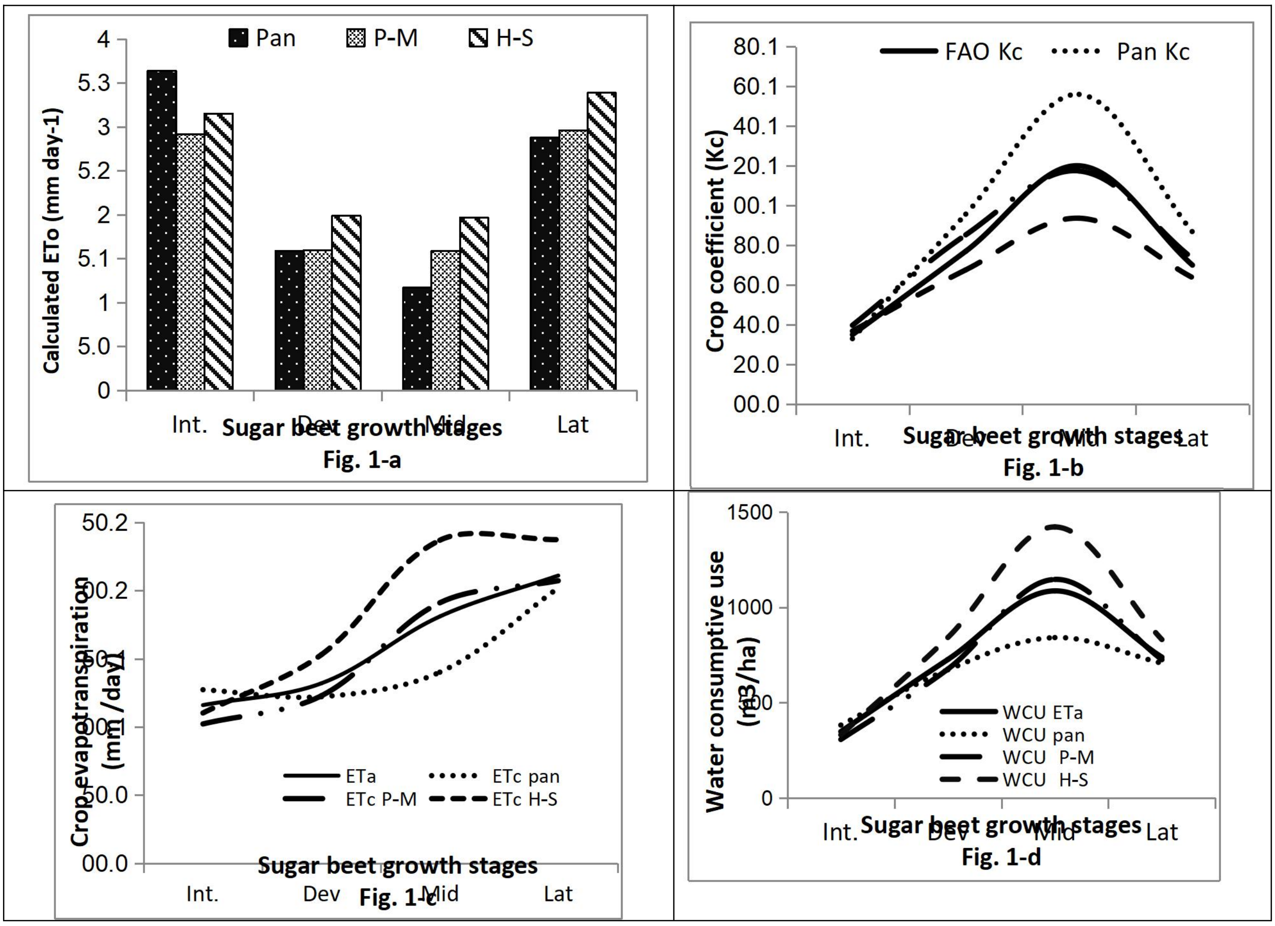

Fig. (1). Some crop water relations of the sugar beet crop under different growth stages, (1-a) ETo, (1-b) Kc, (1-c) ETc and (1-d) WCU.

4.4. Water consumptive use and irrigation water applied.

From Table (6) and Fig. (1-d) the lowest values of both water consumptive use (WCU) and irrigation water applied (IWA) were recorded when Class-A pan equation was used, meanwhile the highest values 3424 and 5268 m^3 ha^{-1} were observed with H-S equation. Among the growth stages of sugar beet crop, which could be referred to the maximum vegetation growth at Mid. stage, the maximum irrigation water was applied. P-M equation gave the highly correlation ship (R^2 =0.99) with the actually applied irrigation water.

Table (6). Water consumptive use and irrigation water applied for sugar beet crop during different growth stages using different empirical equations.

Calculation methods	Growth stages				WCU	IWA	RMSE	MAE	R^2
	Init. (30 day)	Dev. (55 day)	Mid. (60 day)	Lat. (35 day)	(m^3 ha^{-1})	(m^3 ha^{-1})			
Pan	382	672	841	707	2602	4002	127.59	91.19	0.94
P-M	307	676	1146	725	2854	4390	44.8	41.25	0.99
H-S	331	842	1421	831	3424	5268	183.64	140.9	0.95
ETa	348	726	1086	739	2899	4459	-	-	-

WCU, water consumptive use; IWA, irrigation water applied; ETa, actual crop evapotranspiration; Pan, class A pan; P-M, penman-Monteith; H-S, Hargreaveas-Samani; RMSE, root mean square error; MAE, mean absolute error; R^2, determination coefficient.

Conclusion

The experimental field measurements and estimated crop evapotranspiration of sugar beet indicated that, the Penman-Monteith equation could be recommended as a helpful tool for determination of ETo. In addition the close link between measured and calculated data by F-M equation could enhance water use efficiency, minimizing water losses and increasing the productivity of sugar beet crop grown in arid and semi-arid conditions under Fayoum conditions.

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تقييم الطرق المباشرة والغير مباشرة المستخدمة في تقدير البخر نتح ومعامل المحصول لنباتات بنجر السكر النامية تحت ظروف محافظة الفيوم

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قسم الأراضي والمياه – كلية الزراعة – جامعة الفيوم – الفيوم 63514 – مصر

مع تزايد ندرة المياه، فإن تقدير البخرنتح المرجعيETo)) ومعامل المحصول (Kc) يعتبر هو العامل الاساسي في تحديد الطلب على المياه للمحصول وتقدير البخر نتح المحصولي، ولذلك فإن الدراسة الحالية تهدف إلى تقييم ومقارنة قيم البخر نتح لمحصول بنجر السكر (ETc) المحسوبة ببعض الطرق المختلفة من المعادلات التجريبية والمعتمدة على بيانات المناخ مثل طريقة Hargreaves و Penmen-Monteith و Class-A Pan) بالإضافة الى تقدير قيم البخر نتح الفعلي (الاستهلاك المائي) بالطريقة العملية المباشرة لمحصول بنجر السكر (ETa).
ولتقدير قيم البخر نتح الفعليETa لمحصول بنجر السكر أجريت تجربة حقلية خلال موسمي زراعة (2020/2019 و 2021/2020) في مزرعة دمو، كلية الزراعة - جامعة الفيوم، مصر. تمت زراعة بذور بنجر السكر (Beta vulgaris .L) صنف Baraca في موسمين شتويين متتاليين على مدار عامي (2020/2019 و 2021/2020) تربة متأثرة بالاملاح (ECe = 10 ds/m.) وقد تمت زراعة البذور في 1 أكتوبر والحصاد في 10 أبريل. وكان موسم النمو 190 يوما". حيث كانت تتم عملية الري لنباتات بنجر السكر عند استنفاد 30٪ من الماء الميسر الموجود التربة. تم تحليل جميع النتائج التي تم الحصول عليها إحصائياً لتقييم أفضل طريقة لتقدير البخرنتح المرجعي والتي تتلاءم مع الإدارة المثلى لري محصول بنجر السكر المنزرع تحت ظروف المناطق الجافة وشبه الجافة. أشارت النتائج إلى أنه تم حساب القيم المتوسطة لمقدار البخر نتح لمحصول بنجر السكر الناتج عن الطرق التجريبية بمعادلات كل منHargreaves و Penmen-Monteith و Class-A Pan بالإضافة الى تقدير البخرنتح الفعلي لنباتات بنجر السكر. وتشير النتائج الى أن طريقة Penmen-Monteith وطريقة Hargreaves كانت أفضل الطرق لتقدير البخرنتح المرجعي لمحصول بنجر السكر تحت ظروف لمحافظة الفيوم، مصر بسبب انخفاض الخطأ والانحراف المعياري بين الطرق المحسوبة ETo والطريقة العملية في التقدير للبخر نتح الفعلي ETa.

الكلمات الدالة: بنجر السكر ، البخرنتح المرجعي ، البخرنتح الغعلي ، معامل المحصول.