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Estimation Models for Computing Egusi-Melon Crop Water Requirements

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ABSTRACT

Precise estimation of crop water requirements (CWR) is essential to design robust irrigation scheduling for effective water management. Hence, the study was aimed at computing CWR for Egusi-melon using the in-built mechanism of CROPWAT software and evaporation pan at various developmental stages. The research study covers an area of 6.45 m^2. The results showed that computed reference evapotranspiration (ETo) from the selected models was used as inputs in combination with a crop coefficient (Kc) to estimate Egusi-melon CWR. Hence, the maximum and minimum daily computed CWR values for the intermediate to maturity for evaporation pan (Pan-CWR) and CROPWAT software (CRP-CWR) were 3.5 mm, 0.7 mm; 3.4 mm, 0.4 mm; 3.0 mm, 0.52 mm; 2.8 mm, 0.4 mm, 3.0 mm, 0.4 mm and 3.8 mm to 0.6 mm. Melon crop coefficients of 0.14, 0.73, and 0.6 were applied to estimate CWR at initial, developmental, and maturity stages. In conclusion, the two selected models performed very well in estimating CWR. Therefore, the CROPWAT model is preferable to other approaches due to its use of large meteorological and crop datasets.

Key words: Crop water requirements, Egusi-melon, CROPWAT model, Evaporation pan

INTRODUCTION

Egusi melon (Citrullus lunatus Thunb.) is a member of the family Cucurbitaceae [1]. It originated from Africa, later introduced to Europe and Asia during the last 2000 years [2] and now widely distributed throughout the tropics. A significant change in climate on a global scale will impact agriculture and consequently affect the world's melon supply [3]. More erratic rainfall patterns and unpredictable high temperature spells will consequently reduce crop productivity. However, climate change mainly affects melon plant through the crop evapotranspiration. Crop water requirements correspond to the quantity of water to be consumed by a crop during its growth season. It corresponds to the crop evapotranspiration (ETc). It is commonly estimated through the use of crop coefficients defined for each crop development stage initial, development, mid-season and late season – and the reference evapotranspiration (ETo) [4].

The semiarid region of Nigeria has a recognized potential of being a major producer of tropical fruits. However, droughts have inhibited the expression of this potential, which makes irrigation a necessary activity for agricultural purposes. The estimate of reference crop Evapotranspiration is an important factor in irrigation and agriculture water research, management and development [5]. The general knowledge of the spatial distribution of reference Evapotranspiration, (ETo) is still sketchy despite its importance for global ecosystem research. One reason is that ETo is difficult to observe directly as it depends on several meteorological parameters which are observed only at major stations. The successful use of water for irrigation depends, among other requirements, of the precise knowledge of the crop water demand. Thus, it becomes necessary to use suitable coefficients, specifically crop coefficients (Kc), determined based on the crop evapotranspiration (ETc) and reference evapotranspiration (ETo), whose estimates allow the assessment of the amounts of water to be applied to crops.

A large number of empirical methods have been developed to estimate Evapotranspiration from different climate variables. Currently, studies have been conducted to determine ETc using direct methods, especially the use of weighing lysimeters. This allows accounting the values of water balance accurately, enabling a reliable estimate of the real need of the crops being justified and used in the calibration of estimation methods. According to LOOS et al. [6], if well managed, lysimeters are the most accurate tools to reproduce the real field conditions. Therefore, this research is designed to measure Crop evapotranspiration of melon plant at different stages using CropWat model.

MATERIALS AND METHODS

The experiment was conducted at the Experimental and Research Farm of Auchi Polytechnic, Auchi, located at Etsako-West, its geographical coordinates are 7° 4' 0" North, 6° 16' 0" East and its original name (with diacritics) is Auchi, 20km away from Aviele. The climatic classification of Auchi is divided to dry climate, very hot and with the rainy season, with an average temperature of 30.4° C, very irregular annual rainfall, with an average of 1256.2 mm and relative humidity of 65.9%.

The Egusi melon crop plantation was held on 14th March, 2014 and germinated 5 days after planting covering a total of 0.015 hectare. The spacing used was of 5 cm x 5.3 cm. The plant density per hectare is 38,000 plant populations. The melon used in the study was Egusi (Citrullus lunatus Thunb.) from the family of Cucurbitaceae.

Irrigation management was based on the estimate of the maximum crop evapotranspiration (ETcm) according to the method proposed by FAO 56 [7], and daily soil moisture and weather-hydrological parameters around the experimental field were carried out to determine the depth of water application and daily crop evapotranspiration of the melon plant. The rainfall depth was computed using the relationship in equation [1]:

$$Rd(mm) = \frac{RV(mm^3)}{A(mm^2)} \quad (1)$$

Where Rd (mm) is rainfall depth, RV is rain volume of a catchment (mm^3) and A is the catchment area (mm^2).

Evaluation of crop-evapotranspiration (ETc) using FAO 56 (ETcFAO), crop coefficients (Kc) recommended in Bulletin 56 for the melon crop, of 0.15, 0.85 and 0.60 were used for the phases I, II and III and the end of the cycle which correspond to initial, intermediate and final phases, respectively. Since the evaporation rate from the open class A pan (E_{pan}) and ET rate from the vegetated surface differ (Snyder, 1992), the rates are related by a co-efficient, K_{pan}, as follows:

$$ET_o = E_{pan} * K_{pan} \quad (2)$$

$$K_{pan} = 0.482 + [0.24\ln(F)] - (0.000376U_2) + (0.0045RH) \quad (3)$$

Where; U_2 is = daily mean wind speed measured at 2m height in km per day; RH is daily mean relative humidity (%);

F= upwind distance fetch of low growing vegetation in meters.

The data collected were used to estimate the reference evapotranspiration using the FAO-Penman Monteith model as defined by Allen *et al.* (1998) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (4)$$

where;

ETo is Reference evapotranspiration [mm day-1]; Rn is Net radiation [MJ m-2 day-1]; G - Soil heat flux density [MJ m-2 day-1] = 0 (In general G is negligible in the daily calculation of reference ET because G is small on daily basis (Allen *et al*., 1998)); T - Mean daily air temperature at 2 m height [°C]; u2 - Wind speed at 2 m height [m s-1]; es - Saturation vapour pressure [kPa]; ea - Actual vapour pressure [kPa]; es-ea - Saturation vapour pressure deficit [kPa]; Δ - Slope of the vapour pressure curve [kPa °C-1]; γ - Psychrometric constant [kPa °C

Egusi-melon water requirement (ETc/CWR) was computed as follows:

$$ET_c = ET_o * K_c \quad (5)$$

ET_c is determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ET_o and the crop characteristics into the K_c coefficient.

RESULTS AND DISCUSSION

Daily maximum temperature, minimum temperature, average relative humidity, sunshine hours, average wind speed, evaporation depth, altitude and longitude of the study area were used to compute reference evapotranspiration using FAO-56 Penman Monteith and evaporation models respectively. Using crop coefficient of 0.15, 0.83 and 0.56 for the initial-intermediate-maturity, crop-evapotranspiration was computed for these three stages of melon growth and development as shown in Table 1. The computed daily evaporation depth increased from 5.4 mm of the first day of planting to the maximum value of 7.9 mm at the 14 DAP (Day after planting) and this corresponds to 17.8 mm rainfall depth, 25.3 mm water application, minimum and maximum values of 4.1 mm to 5.7 mm [EToPan], 3.5 mm to 4.2 mm [ETo FAO-Panman] and 0.62 mm-0.68 mm [ETc] for the initial stage respectively. During the intermediate stage, maximum and minimum evaporation values 5.0 mm and 1.1 mm were computed for maximum and minimum values of 4.0 mm to 0.7 mm EToPan, 3.9 mm to 0.5 mm EToFAO-Penman and 3.4 mm to 0.68 mm ETc respectively. Total rainfall and irrigation depths of 73.1 mm and 21.4 mm were measured. At maturity stage, total rainfall and irrigation of 136 mm and 0.0 mm were computed. The minimum and maximum values of EToPan, EToFAO-Penman and ETc were computed as 0.7 mm-3.0mm; 0.6 mm-4.1 mm and 0.46 mm to 3.25 mm respectively. Measured weather data such as sunshine, relative humidity and average wind speed were used to derive and compute pan coefficient which ranged from 0.71-1.00.

Table 1: Computed Meteorological and hydrological measurement on the melon field

S/N	Ave.Temp °C	Evp (mm)	RF(mm) (mm)	Irr (mm)	S.H (hr)	R.H	W. SP	Pan Coeff Epan	ETo(Pan Evaporation Method) in Mm/day	ETo (FAO Method) in mm/day	ETc(mm/day)
1	36.2	5.4	0.0	3.3	7.1	64.0	77.5	0.8	4.1	3.5	0.6
2	31.5	6.0	0.0	3.3	0.3	68.0	69.5	0.8	4.6	3.7	0.7
3	31.0	7.2	0.0	3.3	7.5	68.5	78.8	0.8	5.5	4.1	0.8
4	30.1	6.9	0.0	3.3	7.0	70.0	85.7	0.7	5.0	4.4	0.8
5	32.5	6.1	0.0	3.3	7.2	67.5	75.2	0.7	4.3	2.9	0.7
6	32.5	7.5	0.0	3.3	0.3	67.5	95.1	0.7	5.6	4.3	0.8
7	32.6	8.0	0.0	3.3	0.3	67.5	100.1	0.8	6.0	4.5	0.9
8	33.1	6.4	0.0	3.3	0.3	67.0	80.6	0.8	4.9	3.8	0.7
9	33.0	5.9	0.0	3.3	8.7	53.4	92.5	0.8	4.8	4.0	0.7
10	32.9	5.0	0.0	3.3	8.0	52.6	79.9	0.7	3.6	2.5	0.5
11	31.7	6.2	0.0	3.3	8.1	50.1	109.7	0.7	4.6	3.0	0.7
12	32.2	7.7	0.0	3.3	8.2	51.6	94.3	0.7	5.6	4.2	0.8
13	32.8	7.4	17.8		7.1	43.4	75.1	0.8	5.7	4.1	0.9
14	32.1	7.9	0.0	3.3	8.1	68.0	84.4	0.8	6.5	4.9	1.0
15	36.2	4.0	0.0	3.3	0.3	64.0	115.2	0.8	3.0	2.2	0.5
16	30.3	3.0	0.0	3.3	0.3	70.0	78.3	0.8	2.4	1.4	0.4
17	34.7	4.0	0.0	1.7	0.4	65.5	92.0	0.8	3.2	2.0	0.5
18	37.2	3.0	0.0	1.7	0.3	63.0	80.7	0.7	2.0	1.3	0.3
19	36.3	7.0	0.0	1.7	0.4	64.0	95.8	0.8	5.4	3.9	0.8
20	34.3	5.0	0.0	3.3	0.3	64.0	110.3	0.8	4.0	3.4	0.6
21	33.8	3.0	0.0	3.3	0.4	62.5	95.1	0.7	2.0	1.2	1.7
22	34.5	3.0	0.0	3.3	0.4	63.5	79.2	0.8	2.3	1.9	2.0
23	31.6	3.0	2.5	0.0	0.3	63.5	85.1	0.7	2.2	1.8	1.9
24	32.4	2.0	0.0	1.7	0.4	68.0	94.9	0.8	1.6	1.1	1.4
25	35.4	1.0	0.0	1.7	0.3	65.0	95.5	0.8	0.8	0.6	0.7
26	27.8	5.0	21.7	0.0	0.4	72.5	84.4	0.7	3.6	3.1	3.1
27	33.3	2.0	0.0	0.0	0.3	67.0	74.5	0.8	1.5	1.1	1.3
28	31.3	5.0	0.0	0.0	0.4	69.0	101.3	0.7	3.6	3.3	3.1
29	33.4	4.0	0.0	1.7	0.3	67.0	105.5	0.7	3.0	2.4	2.6
30	33.3	1.0	0.0	0.0	0.3	66.5	98.6	0.7	0.7	0.5	0.6
31	27.9	1.0	17.3	0.0	0.3	72.5	90.8	0.8	0.8	0.6	0.7
32	37.1	5.0	0.0	0.0	0.3	64.0	85.4	0.8	4.0	3.3	3.4
33	28.3	2.0	2.9	0.0	0.5	72.0	99.3	0.7	1.4	1.0	1.2
34	31.3	4.0	0.0	0.0	0.3	69.0	85.1	0.8	3.3	3.0	2.8
35	32.3	3.0	0.0	0.0	0.3	68.0	97.5	0.7	2.2	1.9	1.9
36	32.9	1.0	0.0	1.7	0.3	67.5	83.7	0.8	0.8	0.5	0.7
37	31.3	1.0	0.0	0.0	0.3	69.0	78.9	0.8	0.8	0.5	0.7
38	29.4	2.0	20.0	0.0	0.3	71.0	79.4	0.8	1.1	0.7	0.9
39	29.3	2.0	8.7	0.0	0.2	71.0	81.7	0.7	1.4	1.1	1.2
40	27.2	3.0	0.0	0.0	0.2	73.0	82.6	0.8	2.5	2.2	2.0
41	31.6	3.0	43.4	0.0	0.3	68.5	80.9	0.8	2.3	1.9	1.5
42	30.2	2.0	0.0	0.0	0.2	70.0	95.4	0.8	1.6	1.3	1.0
43	33.8	3.0	0.0	0.0	0.2	66.5	97.7	0.8	2.3	2.0	1.5
44	31.2	3.0	13.0	0.0	0.4	69.0	107.2	0.8	2.5	2.1	1.6
45	27.3	2.0	22.3	0.0	0.3	73.0	107.0	0.7	1.5	0.8	1.0
46	29.7	2.0	0.0	0.0	0.4	70.5	119.0	0.8	1.5	0.9	1.0
47	32.4	2.0	0.0	0.0	0.3	68.0	120.0	0.7	1.4	0.8	1.2
48	34.3	1.0	0.0	0.0	0.3	66.0	115.0	0.7	0.7	0.6	0.5
49	28.6	4.0	14.5	0.0	0.3	71.5	92.4	0.8	3.2	2.9	2.1
50	28.8	6.0	0.0	0.0	0.3	71.5	98.1	0.8	5.0	4.1	3.3
51	28.3	3.0	43.4	0.0	0.3	72.0	78.3	1.0	3.0	2.4	2.0
52	27.9	1.0	43.6	0.0	0.3	72.5	87.0	1.0	1.0	0.7	0.7

Source: Field measurement and computations:
Evap (mm) = Daily evaporation; RF(mm) = Rainfall depth
Irr (mm) = Irrigation depth; SH = Sunshine hour; R (%)= Relative humidity
W.Sp (km/day)= Wind speed; EToPan (mm/day) =Evapotranspiration using evaporation pan
EToFAO-Penmeman = Evapotranspiration using FAO-Penman model
ETc = Crop evapotranspiration

Average monthly weather-parameter in the year 2013 was used to run CropWat simulation model to generate solar radiation, reference evapotranspiration and effective rainfall as shown below. There is strong relationship between the solar radiation and reference evapotranspiration. April has the highest solar radiation (Rad) and reference evapotranspiration (ETo) of 21 MJ/m^2/day and 5.21 mm, while minimum value of 17.9 MJ/m^2/day and 3.73 mm were generated in November, 2013.

Effective rainfall corresponds to the water infiltrated through the soil layer and is the actual input signal of the hydro system. Effective rainfall computations with Soil-water balance depend mainly on vegetative cover interception, surface runoff, available soil water storage capacity (AWS) and evapotranspiration. Evapotranspiration is the water transpired by vegetation and evaporated from the soil. For studies which only took into account the effective rainfall signal, interception was disregarded. Indeed, evapotranspiration is the major factor influencing the effective rainfall signal. Runoff also plays an important role in effective rainfall estimation, especially in mountainous places or heavy rainfall location. Effective rainfall computed using rainfall depth of year 2013 above. Total rainfall and effective rainfall of 1303.1 mm and 914.1 were generated. The graphical interface for CROPWAT simulation for estimating solar radiation (Rs), reference evapotranspiration (ETo) and effective rainfall l (Eff Rain) is depicted in Fig. 3 and 4.

Plate 1: Growing melon plant with installed evaporameter

Plate 2: Weeding of melon plant during flowering

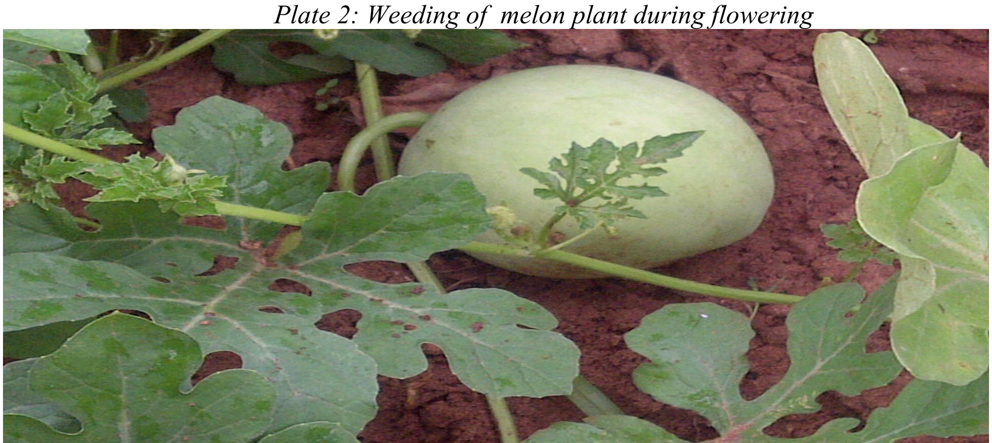

Plate 3: Melon crop during maturity

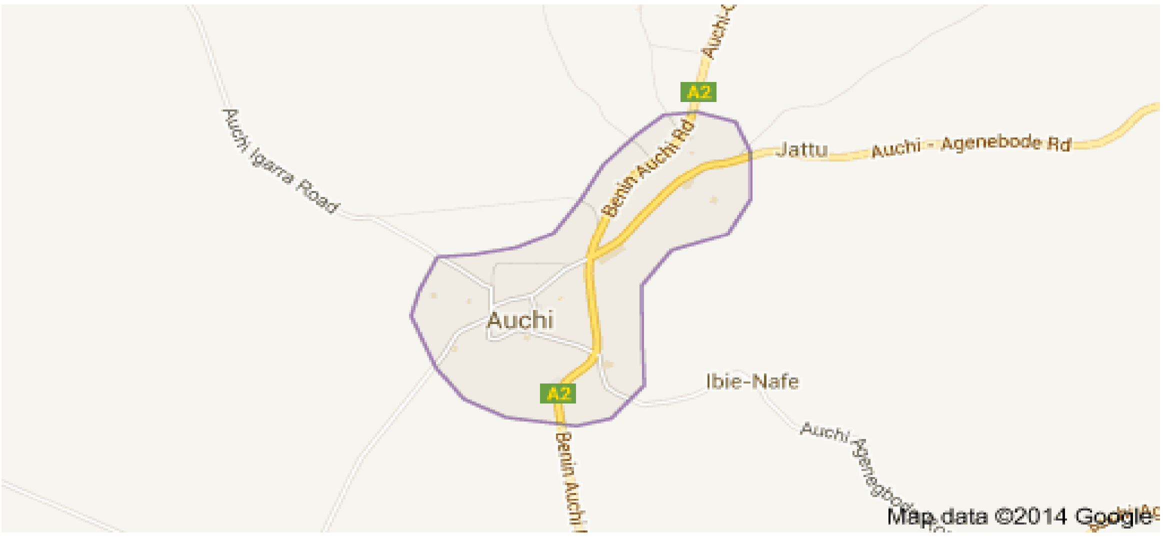

Plate 4: Location of study area: Google, 2014 [8]

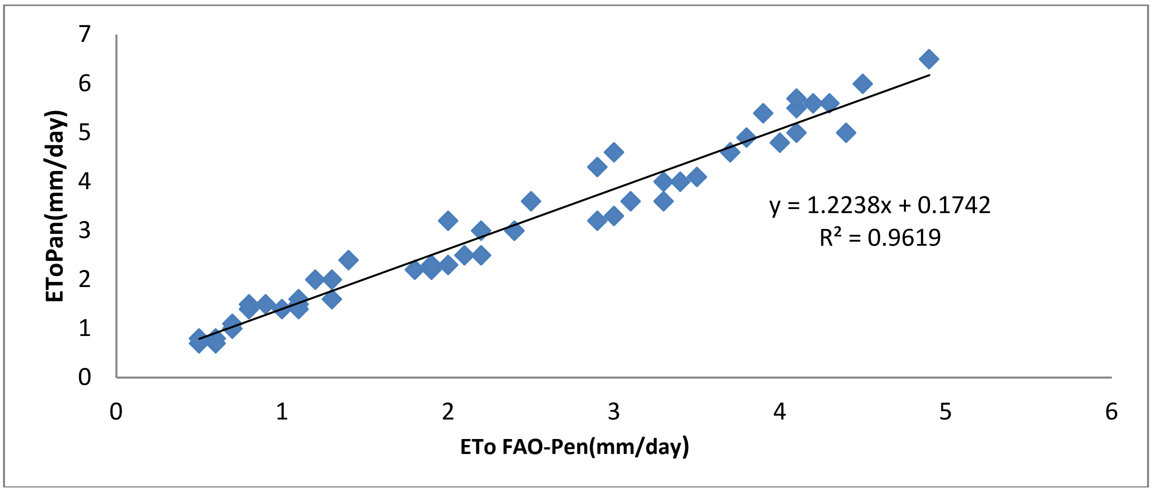

Fig. 1 Calibration of EToPan Evaporation Method-FAO Penman Montheith Model

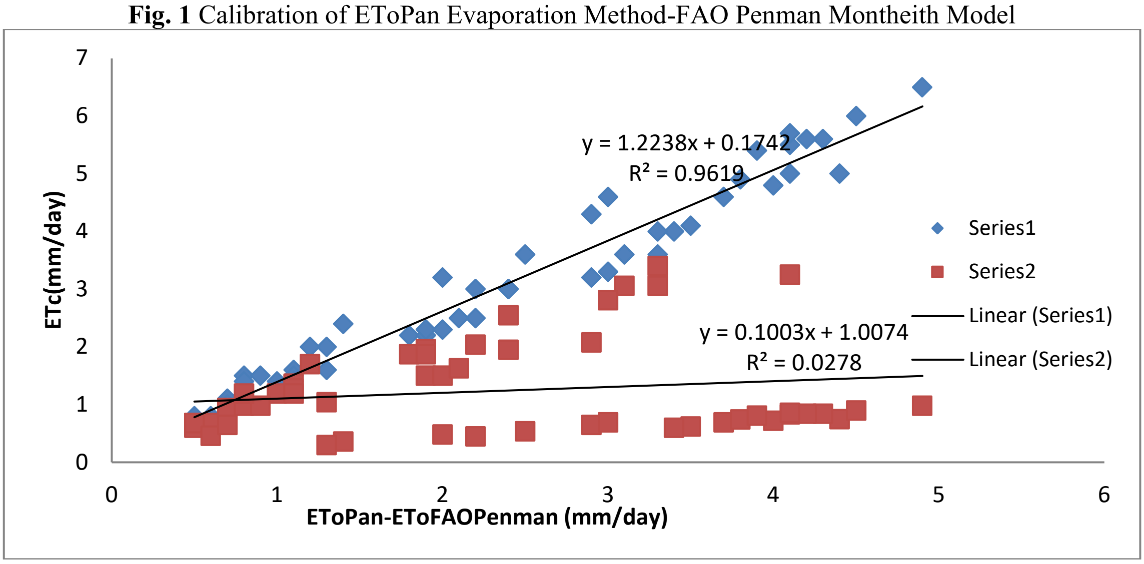

Fig. 2 Regression of Crop Evapotranspiration (ETc) and EToPan-FAOPenman

Monthly rain - untitled

Station: Auchi Polytechnic — Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	1.2	1.2
February	10.2	10.0
March	34.6	32.7
April	79.7	69.5
May	99.8	83.9
June	165.2	121.5
July	230.3	145.4
August	210.4	139.6
September	241.3	148.1
October	205.8	138.0
November	16.8	16.3
December	7.8	7.7
Total	**1303.1**	**914.1**

Fig. 3 CROPWAT interface for effective rainfall

Monthly ETo Penman-Monteith - untitled

Country: Nigeria — Station: Auchi Polytechic

Altitude: 351 m. — Latitude: 7.40 °N — Longitude: 6.16 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	28.2	38.7	64	64	7.1	18.4	4.43
February	29.5	39.2	68	68	6.6	18.7	4.78
March	28.1	38.2	69	69	7.5	21.0	5.21
April	26.2	36.3	70	70	7.0	20.3	4.95
May	24.3	30.3	67	68	7.2	20.0	4.41
June	23.1	28.9	64	68	6.3	18.2	3.94
July	22.1	28.4	64	70	7.3	19.8	4.09
August	23.3	29.2	68	66	8.3	21.9	4.48
September	22.0	28.0	65	63	6.5	19.3	4.00
October	22.1	28.2	66	67	6.5	18.7	3.81
November	24.3	30.2	70	68	6.6	17.9	3.73
December	24.7	33.4	69	69	8.2	19.5	4.11
Average	**24.8**	**32.4**	**67**	**68**	**7.1**	**19.5**	**4.33**

Fig. 4 CROPWAT interface for solar radiation and reference evapotranspiration

CONCLUSION

Reference evapotranspiration (ETo) was computed using the pan coefficient derived from weather-parameter and daily evaporation values derived. CropWat version 8.1 and derived equation was applied to evaluate Egusi-melon water requirement at different crop stage and development using melon crop coefficients. Generally, CROPWAT model produced better estimation of Egusi-Melon water requirement than the experimental method using the product of evaporation depth, pan and crop coefficients.

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