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Estimation of Reference Melon Crop-Evapotranspiration using $Et_{o[Pan-Fao/Penman]}$ and Cropwat Models

Aiming at contributing to an adequate management of water resources, accurate estimation of reference evapotranspiration (ETo) using evaporation pan, FAO-Penman and CROPWAT model is very important for the computation of Egusi-melon crop evapotranspiration (ETc) at different stages of crop growth and development. The study was carried out at Research and Experimental Farm of Auchi Polytechnic, Auchi with area of 6.45 m^2. Measured daily evaporation depth and weather parameters for 52-day was used to compute reference evapotranspiration using evaporation pan, derived FAO-Penman and CROPWAT version 8.1 models. The maximum and minimum of EToPan, EToFAO-Penman are 4.1 mm; 5.7 mm and 3.5 mm; 4.2 mm. These values were applied to compute maximum and minimum crop-evapotranspiration (ETc) at initial crop developmental stage as 3.4 mm; 0.68 mm respectively. The maximum and minimum intermediate and maturity values for EToPan, EToFAO-Penman and ETc; 4.0 mm;0.7 mm, 3.9 mm; 0.5 mm ,3.4 mm; 0.68 mm and 0.7 mm; 3.0mm; 0.6 mm; 4.1 mm, 0.46 mm;3.25 mm respectively. The melon crop and evaporation pan coefficient for the three different stages are 0.15; 0.85; 0.60 and the pan coefficient ranged from 0.71 to 1.00 and total rainfall and irrigation depths were computed to 226.9 mm and 46.7mm.

Keywords: *Reference evapotranspiration, Crop evapotranspiration, CROPWAT, Rainfall, Irrigation, FAO-Penman, Crop coefficient*

1. Introduction

Egusi melon (Citrullus lunatus Thunb.) is a member of the family Cucurbitaceae (Badifu and Ogunsa, 1991). It originated from Africa, later introduced to Europe and Asia during the last 2000 years (Ogbonna and Obi, 2010) 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 (Allen, 1998). 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) (Allen *et al.*, 1998).

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 (Ogbonna, 2000). 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. (2007), 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.

2. 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%.

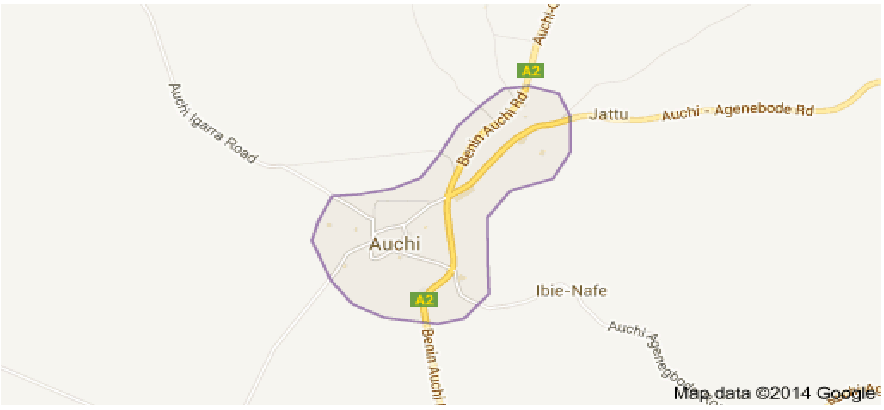

Figure 1. Source: Google, 2014

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 5cmx5.3cm. 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.

Figura 2. Plate 1. Growing melon plant with installed evaporameter .

Irrigation management was based on the estimate of the maximum crop evapotranspiration (ETcm) according to the method proposed by FAO 56 (ALLEN et al., 2006), 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.

Figura 3. Plate 2. Weeding of melon plant during flowering

Figura 4. Plate 3. Melon crop during maturity

The rainfall depth was computed using the relationship in equation [1]:

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

Soil moisture content was measured using the PR2 capacitance moisture meter as described in Calibration of Soil Moisture Measurement Using PR2 Moisture Meter and Gravimetric Approach for Effective Monitoring and Evaluation (Olotu et al., 2014). Table 2 shows average soil moisture measured during the period of experimentation. 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

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

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

Where: U_2 = daily mean wind speed measured at 2m height in km per day
RH = daily mean relative humidity (%);
F = upwind distance fetch of low growing vegetation in meters.

Equation (4) was applied for the ETc computations as follows:

$$ETc = ETo * Kc \quad (4)$$

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.

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

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \quad (5)$$

where: ET_o - Reference evapotranspiration [mm day^{-1}]; R_n - 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]; 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]; Δ - Slope of the vapour pressure curve [kPa °C^{-1}]; γ - Psychrometric constant [kPa °C

3. 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-5.7 mm [EToPan], 3.5 mm- 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 of4.0 mm-0.7 mm EToPan, 3.9 mm-0.5 mm EToFAO-Penman and 3.4 mm-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 -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. Meteorological and hydrological measurement on the melon field

S/N	T_{empMin} ºC	T_{emMax} ºC	Ave.T_{emp} ºC	Evp (mm)	RF (mm)	Irr (mm)	S.H	R.H	W. SP	Pan Coeff. E_{pan}	ET_o Pan mm/day	ET_o FAO mm/day	ET_c (mm/day)
1	28.2	44	36.2	5.4	-	3.32	7.11	64	77.5	0.75	4.1	3.5	0.62
2	26.2	38	31.5	6.0	-	3.32	6:58	68	69.5	0.76	4.6	3.7	0.69
3	25.1	38.2	31. 5	7.2	-	3.32	7.45	68.5	78.8	0.77	5.5	4.1	0.83
4	25.2	35.1	30.1	6.9	-	3.32	7.00	70	85.7	0.73	5.0	4.4	0.75
5	27.3	38.2	32.5	6.1	-	3.32	7.15	67.5	75.2	0.71	4.3	2.9	0.65
6	28.1	37.1	32.5	7.5	-	3.32	6:25	67.5	95.1	0.74	5.6	4.3	0.84
7	28.2	37.1	32.6	8.0	-	3.32	7:30	67.5	100.1	0.75	6.0	4.5	0.90
8	28.1	38.2	33.1	6.4	-	3.32	6:35	67	80.6	0.77	4.9	3.8	0.74
9	28.1	37.9	33.0	5.9	-	3.32	8.71	53.4	92.5	0.81	4.8	4.0	0.72
10	27.4	38.4	32.9	5.0	-	3.32	8.02	52.6	79.9	0.72	3.6	2.5	0.54
11	26.2	37.2	31.7	6.2	-	3.32	8.10	50.1	109.7	0.74	4.6	3.0	0.69
12	26.5	37.9	32.2	7.7	-	3.32	8.15	51.6	94.3	0.73	5.6	4.2	0.84
13	27.3	38.2	32.8	7.4	17.8		7.14	43.4	75.1	0.77	5.7	4.1	0.86
14	27.1	37.2	32.1	7.9	-	3.32	8.10	68	84.4	0.82	6.5	4.9	0.98
15	26.2	46.2	36.2	4.0	-	3.32	7:23	64	115.2	0.75	3.0	2.2	0.45
16	29.2	34.4	30.3	3.0	-	3.32	7:30	70	78.3	0.79	2.4	1.4	0.36
17	29.1	40.2	34.7	4.0	-	1.7	8:25	65.5	92.0	0.81	3.2	2.0	0.48

18	30.2	44.2	37.2	3.0	-	1.7	6:45	63	80.7	0.73	2.0	1.3	0.30
19	27.3	45.2	36.3	7.0	-	1.7	8:45	64	95.8	0.77	5.4	3.9	0.81
20	29.3	39.3	34.3	5.0	-	3.32	8:02	64	110.3	0.80	4.0	3.4	0.60
21	27.4	40.1	33.8	3.0	-	3.32	8:25	62.5	95.1	0.71	2.0	1.2	1.70
22	30.4	38.2	34.5	3.0	-	3.32	8:27	63.5	79.2	0.78	2.3	1.9	1.96
23	27.2	36.2	31.6	3.0	2.5		8:05	63.5	85.1	0.73	2.2	1.8	1.87
24	28.4	36.4	32.4	2.0	-	1.7	8:45	68	94.9	0.82	1.6	1.1	1.36
25	27.6	43.2	35.4	1.0	-	1.7	7:13	65	95.5	0.77	0.8	0.6	0.68
26	24.2	31.4	27.8	5.0	21.7	-	8:52	72.5	84.4	0.72	3.6	3.1	3.06
27	30.3	36.3	33.3	2.0	-	-	6:56	67	74.5	0.77	1.5	1.1	1.28
28	26.2	36.4	31.3	5.0	-	-	8:28	69	101.3	0.72	3.6	3.3	3.06
29	26.4	40.3	33.4	4.0	-	1.7	6:55	67	105.5	0.74	3.0	2.4	2.55
30	30.2	37.4	33.3	1.0	-	-	7:16	66.5	98.6	0.72	0.7	0.5	0.60
31	25.3	30.6	27.9	1.0	17.3	-	6:34	72.5	90.8	0.76	0.8	0.6	0.68
32	28.5	44.5	37.1	5.0	-	-	7:45	64	85.4	0.79	4.0	3.3	3.40
33	25.3	31.3	28.3	2.0	2.9	-	11:13	72	99.3	0.71	1.4	1.0	1.19
34	28.2	34.5	31.3	4.0	-	-	6:00	69	85.1	0.82	3.3	3.0	2.81
35	26.1	38.5	32.3	3.0	-	-	8:05	68	97.5	0.73	2.2	1.9	1.87
36	29.3	36.4	32.9	1.0	-	1.7	6:05	67.5	83.7	0.78	0.8	0.5	0.68
37	27.3	35.3	31.3	1.0	-	-	7:30	69	78.9	0.81	0.8	0.5	0.68
38	27.4	31.4	29.4	2.0	20.0	-	7:31	71	79.4	0.75	1.1	0.7	0.94
39	25.3	33.3	29.3	2.0	8.7	-	5:00	71	81.7	0.71	1.4	1.1	1.19
40	23.1	31.3	27.2	3.0	-	-	9;15	73	82.6	0.82	2.5	2.2	2.04
41	29.1	34.2	31.6	3.0	43.4	-	7:37	68.5	80.9	0.77	2.3	1.9	1.50
42	28.2	32.2	30.2	2.0	-	-	5:11	70	95.4	0.81	1.6	1.3	1.04
43	31.2	36.4	33.8	3.0	-	-	5:08	66.5	97.7	0.75	2.3	2.0	1.50
44	26.2	36.3	31.2	3.0	13.0	-	8:27	69	107.2	0.82	2.5	2.1	1.63
45	24.3	30.3	27.3	2.0	22.3	-	6:20	73	107	0.74	1.5	0.8	0.98
46	24.2	35.2	29.7	2.0	-	-	9:31	70.5	119	0.77	1.5	0.9	0.98
47	26.3	38.4	32.4	2.0	-	-	8:15	68	120	0.72	1.4	0.8	1.19
48	33.2	35.4	34.3	1.0	-	-	7:08	66	115	0.71	0.7	0.6	0.46
49	26.5	31.5	28.6	4.0	14.5	-	6:23	71.5	92.4	0.79	3.2	2.9	2.08
50	26.2	31.4	28.8	6.0	-	-	6:32	71.5	98.1	0.83	5.0	4.1	3.25
51	26.3	30.3	28.3	3.0	43.4	-	7:00	72	78.3	1.0	3.0	2.4	1.95
52	24.4	31.4	27.9	1.0	43.6	-	6:49	72.5	87.0	1.0	1.0	0.7	0.65

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

The reading of the soil moisture obtained with PR2 capacitance moisture meter on the Egusi-melon is are shown in the table 2. Profile Probes gave instantaneous readings of soil moisture using a hand-held meter and this aids quick decision to be taken on irrigation scheduling through the period of experimentation. The regression analysis of soil moisture shows that the field is heavy clay. The intercept a_0 = 1.8. This indicates that the soil is heavy clay.

Table 2. Soil moisture content

S/N	Depth (mm)	MC (m^3/m^3)	MC (%Vol)	MC (mV)	MC (V)	Rfractive index √
1	1000	0.037	3.60	347	0.347	1.907
2	600	0.031	3.10	333	0.333	1.845
3	400	0.051	5.10	382	0.382	2.062
4	300	0.097	9.80	491	0.491	2.545
5	200	0.182	18.30	649	0.649	3.245
6	100	0.252	25.20	752	0.752	3.701

Source: Field data

MC - Moisture content (volumetric, in percentage, V and in mV); √ - reactive index

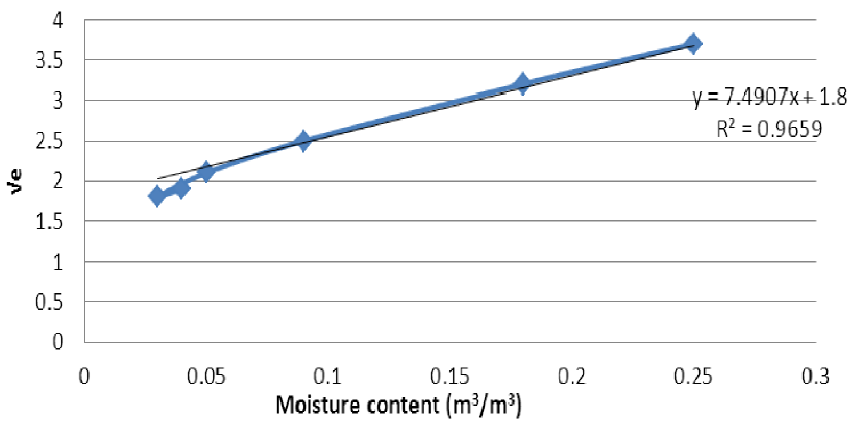

Figure 5. PR2 calibration

Average monthly weather-parameter in the year 2013 was used to run Crop-Wat 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 (i.e. the water transpired by vegetation and evaporated from the soil).

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**

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.

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**

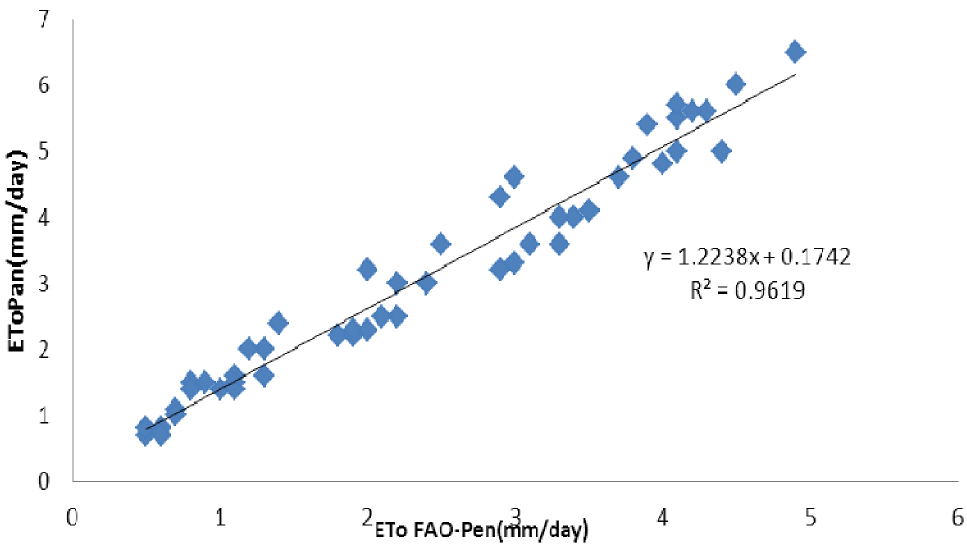

Figure 6. Calibration of Et_oPan evaporation Method-FAO Penman Montheith Model

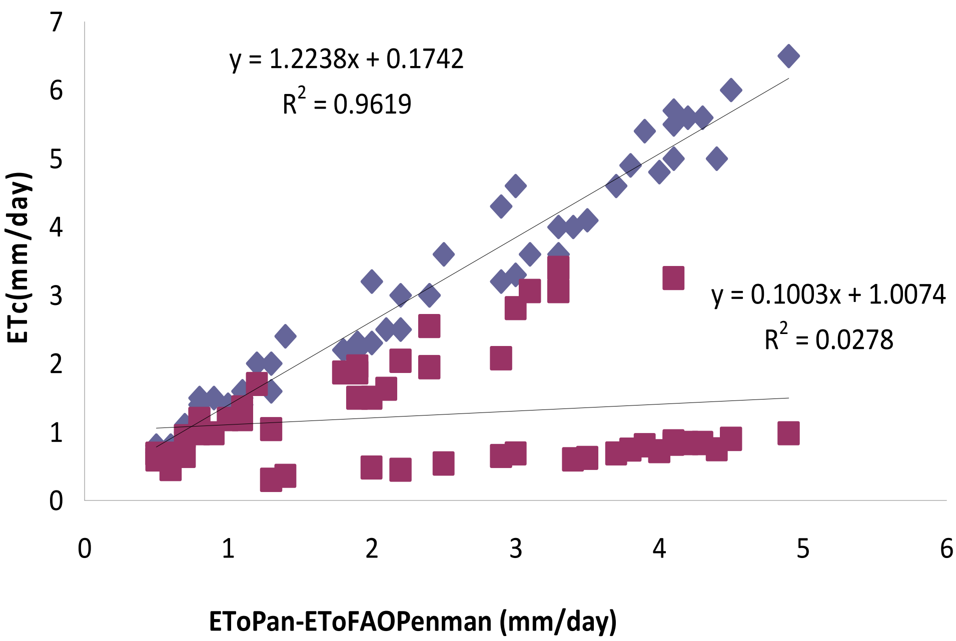

Figure 7. Regression of Crop Evapotranspiration(ETc) and EToPan-FAOPenman

Comparison of daily ET_o values estimated using pan evaporation method and FAO-56 Penman – Monteith method are shown in Fig.1 for a duration 52-day. The values generated with Pan Evaporation model are slightly higher than FAO-Penman model with coefficient of determination R^2=0.96. Fig 2 shows the regression model of ETc against EToPan and EToFAO-Penman with R^2 values of 0.962 and 0.0278 respectively.

4. 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 generate reference evapotranspiration values of FAO-Penman model. Crop-evapotranspiration (ETc) using the generated EToPan-EToFAO-Penman and the melon crop coefficient at different Egusi-melon growth and developmental stages. Evapotranspiration and crop coefficients of melon plants estimated using EToPan-EToFAO-Penman. EToFAO-Penman underestimates crop evapotranspiration 5%. Generally, the approaches for estimating reference evapotranspiration on melon field produced realistic and precise to generate melon crop evapotranspiration.

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