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ESTIMATION OF WATER REQUIREMENTS OF EARLY AND LATE SEASON TOMATO (*Solanum lycopersicum*) IN UMUDIKE SOUTHEASTERN NIGERIA, USING PENMAN'S EQUATION

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ABSTRACT

The estimation of water requirements of tomato was carried out based on 10 years meteorological data in Umudike Southeastern Nigeria, typical of the humid tropical zone. The climatic data used to calculate the crop evapotranspiration (ETo) for estimation of water requirement of tomatoes were obtained from National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction (NOAA/NCEP) under the National Weather Service, United States of America using Penman's equation. Results obtained showed that the crop evapotranspiration (ETo) value for early tomato (April - July) was 429.6mm while late season was 375.4mm. Irrigation water requirement was zero for tomato which shows that there was no water deficit. Therefore, no Supplementary irrigation is necessary for tomato in Umudike but there may be need for irrigation to guide against water stress of tomatoes to supplement rain water in late season in the study area.

KEYWORDS: Estimation, Water Requirements, Tomato, Southeastern Nigeria, Penman's Equation.

INTRODUCTION

Crop water need/requirement is the quantity of water needed for evapotranspiration, when enough soil water is maintained by precipitation and/or irrigation so that it does not restrain plant growth, development and yield (Djaman *et al*., 2017). Water is highly important for crop production and remains a critical input limiting global food production (D'Odorico *et al.*, 2018) and one of the most important inputs essential for the production of crops. It profoundly influences photosynthesis, respiration, absorption, translocation and utilization of mineral nutrients, and cell division besides some other processes. It also affects evapotranspiration which is a joint process of evaporation of water from the earth surface and plant surfaces and transpiration of water through the plant stems and tissues. Water affects the performance of crops not only directly but also indirectly by influencing the availability of other nutrients, the timing of cultural operations, etc.

Among all sectors of the economy, agriculture is the largest consumer of water withdrawals (UN-Water 2021). It has been noted that agricultural developments require a consistent and sustainable provision of large quantities of good quality water for food security and so, major water investments in agriculture are necessary toward meeting food production needs (Elhassadi, 2008). The water use in agriculture comes mainly from rain, surface and underground water sources. Rainfed agriculture, i.e. non-irrigated, is entirely dependent on rainwater stored in the soil. This type of farming is only possible in regions where the distribution of rains allows the soil to keep enough moisture during critical periods of crop growth. According to FAO (2013), rainfed agriculture accounts for around 60% of total production in Africa. Major water-related climate changes include changes in volume, intensity and variability of precipitation.

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Changes in the timing and distribution of rainfall are associated with more frequent and severe flood and drought problems in cases of deficient supply and so the need for water supply through irrigation (Bates *et al*, 2008).

Tomato (*Solanum lycopersicum*) grown worldwide for its edible fruits, is an annual warm-season crop that contains vitamin C, beta carotene and antioxidants. These components of tomatoes destroy free radicals in the body which in turn prevents cancer. Also, it has very high lycopene content which helps the body in the prevention of prostate cancer and improves the health of the heart and also has a high level of potassium and contain fibres which are good for the digestive health. Nigeria is currently the second largest producer of fresh tomatoes in Africa (Taofiq, 2017) producing 10.8% of fresh tomatoes in the region with it being farm predominantly in the Northern part of the country. Globally, the country is the 14th largest tomato producer with 2.3 million tonnes (Sahel Research, 2017). Various equations of reference evapotranspiration (ET_O) have been used to estimate reference potential evapotranspiration. They include: Penmans equation (Eteng and Nwagbara, 2014; Iren and Osodeke, 2006) FAO Penman Monteith, FAO Blaney Criddle, Turc, FAO Radiation Macking, Priestley Taylor, Hargreaves Samani, Thornthwaite, and Corrected Jensen Haise (Valipour, 2012). Objective of this study therefore is to establish the crop water requirements of tomato crop in Umudike area of Southeastern Nigeria, using the Penmans equation.

MATERIALS AND METHODS

This study was carried out at Michael Okpara University of Agriculture, Umudike. Umudike is located within the rainforest ecological zone of Nigeria. The area has acidic soil and a characteristic bimodal rainfall regime with peaks in July and September, and an average rainfall of 1916 mm per annum. It lies at Latitude $05^0 29^I$ North and Longitude $07^0 33^I$ East with an elevation at 122 meters (400 ft.) above sea level. Mean annual maximum temperatures range from 30^0C to 33^0C and mean annual minimum temperatures range from 21^0C to 29^0C while the soil temperature ranges from 23.0 ^{0}C to 24.6 ^{0}C. Relative humidity varies from 51% to 87% (NRCRI, 2013).

This study was based on 10 years (2012-2022) meteorological data. An hourly meteorological data used for this study were obtained from the National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction (NOAA/NCEP) under the National Weather Service, United States of America (NOAA/NCEP, 2021). The meteorological data are presented in Table 1 and were used for computation of reference or potential crop evapotranspiration (ETo).

Crop Water Requirements

The water requirements of tomatoes were determined for two seasons (early and late). The growth period of tomato varies from 90 to 150 days (Phene, 1989). The growth stages are grouped into initial, crop development, mid-season and late season stages of 30, 40, 40 and 25 days respectively (Adelana and Simons, 1980; Phene, 1989 and Quinn, 2000). The crop was sown within the recommended periods for early and late season cultivation of tomato according to Thompson (1996). The early season tomato was planted on 1st April while late season tomato was planted on the 20th of August. The estimation of tomato water requirement was done in three (3) stages presented thus:

(1) Reference Evapotranspiration (ETo)

Reference crop evapotranspiration (ETo) is known as the rate of evaporation of an extended surface of 15-18cm tall green cover, actively growing, completely shading the ground and not short of water (FAO 1986; Irene and Osodeke, 2006; Akinmutimi, 2015; Eteng and Nwagbara 2014). It therefore represents the climatic evaporation demand and tends to predict the effect of climate on crop. The reference crop evapotranspiration (ETo) was therefore calculated based on Penman's equation. The Penman's equation is mathematically expressed as:

$$ET_O = c\,[W.\,Rn + (1-W).\,f(U).\,(ea-ed)] \quad \text{.........(1)}$$

***Where*:**

ea – ed = vapour pressure deficit (mbar). Where ea-ed = RH/100

F (u) = wind function (km/day) = 0.27(1 +U/100) with U in km/day measured at 2m height.

Rn = total net radiation in mm/day or Rn = 0.75RS as incoming shortwave radiation in mm/day either measured or obtained from RS = (0.25 =0.50n/N)Ra

Ra = extra-terrestrial radiation in mm/day.

n = mean actual sunshine duration in hour/day

N = maximum possible sunshine duration in hour/day

Rnl = net longwave radiation in mm/day and is a function of temperature, f(T), of actual vapour pressure, f(ed) and sunshine duration, f(n/N), or Rnl = f(T).f(n/N).f(ed)

W = temperature and altitude dependent weighting factor (T in ^{0}C, altitude in M)

C = adjustment factor for the ratio Uday/Unight, for RHmax and for Rs.

(2). Crop Coefficient (*Kc*)

Empirically determined crop coefficient relates reference evapotranspiration rate (ETo) to the maximum evapotranspiration rate (ETm) when water supply fully meets the water requirements of the crop. This was obtained based on the length of the total growing season disaggregated into:

(1). Duration of the early growth or initial stage (germination to 10% ground cover);

(2). Duration of the crop development stage (from 10 to 80% ground cover);

(3). Duration of the mid-season stage (from 80% ground cover to start ripening); and

(4). From start of ripening to harvest.

Crop coefficient (*Kc*) for various crops are presented in Doorenbos and Pruitt 1977; FAO 1986. Crop coefficient of 0.45, 0.75, 1.15 and 0.8 were used in this study for the initial, crop development, mid-season and late season (harvest) growth stages of tomato respectively.

The *Kc* value at each of the growth stages was converted to monthly *Kc* as:

$$Kc/\text{month} = \frac{Kc \text{ growth stage} \times N}{30} \quad \text{……... (2)}$$

Where N = number of days growth stage lasted in a month and each month was assured to have about 30 days

(3). Maximum Evapotranspiration (ETm)

Maximum evapotranspiration rate of the crop when soil water is not limited, also called the water requirements in mm/dd or mm/period was obtained as a product of ETo and Kc/month. Seasonal ETcrop values were calculated by summing the monthly values. Irrigation water requirement (IR) was calculated as the difference between ETcrop and effective rainfall (ER) using the formulae:

The Kc value at each of the growth stages was converted to monthly *Kc* as:

$$ETm = Kc \times ETo \quad \text{........................ (3)}$$

Effective Rainfall (ER):

ER = 0.8R – 25, if R is >75mm/month

Or

ER = 0.6R – 10, if R is <75mm/month

Given that the monthly rainfall during the growing season of tomato was >75mm/month in the study area, thus effective rainfall is;

$$ER = 0.8R - 25 \quad \text{…..................... (4)}$$

Where,

R = Monthly rainfall (mm), and

ER= Effective rainfall

Table 1. Mean of 10 years climatic data of Umudike (from 2012 to 2022).

Months	Rainfall (mm)	Max RH (%)	Min RH (%)	Max Temp (°C)	Min Temp (°C)	Sunlight duration (h/day)	Wind speed (km/h)	Uday (m/s)	Unight (m/s)
Jan	36.63	70.21	64.97	28.30	24.81	4.14	9.29	3.73	3.15
Feb	80.45	73.70	68.30	28.40	24.90	3.82	9.23	4.46	2.92
March	136.50	82.57	77.67	28.19	24.44	3.30	10.22	3.54	3.32
April	187.81	84.01	79.24	28.30	24.66	3.38	10.01	4.50	3.01
May	327.49	87.09	83.32	27.15	23.80	3.04	9.20	4.32	3.47
June	364.62	89.40	86.74	25.87	22.66	2.36	8.93	4.16	2.69
July	430.05	90.31	87.07	25.25	22.01	1.98	9.24	3.90	2.77
August	288.35	88.32	84.88	25.34	22.10	2.27	9.59	3.61	3.35
September	339.48	89.44	85.96	25.69	22.46	2.21	8.64	4.29	3.27
October	350.07	89.67	86.61	25.54	22.44	2.22	7.60	3.53	2.77
Noveember	193.78	87.80	84.60	26.91	23.56	2.95	7.94	3.84	2.83
December	6.39	72.75	67.12	27.32	24.03	4.52	8.47	3.64	2.80
Total	**2741.62**	**1005.27**	**956.48**	**322.26**	**218.87**	**36.19**	**108.36**	**47.52**	**36.35**
Mean	**228.46**	**79.70**	**83.77**	**23.48**	**26.85**	**3.01**	**9.03**	**3.96**	**3.02**

ETo= Reference crop evapotranspiration; Max=maximum; Min=minimum; Uday=day wind speed; Unight= night wind speed; RH= Relative humidity; Temp= temperature.

RESULTS AND DISCUSSION

Table.1 presents the meteorological data of Umudike (2012 – 2022). From the table, the rainfall amount was highest in the month of July (430.05 mm) and the lowest in December with the value (6.39mm), mean relative humidity was highest in the same month with the value (90.31%) but lowest in Jan (70.21), mean maximum temperatures range from (28.40°C - 25.25°C) and mean minimum temperatures range from (24.90°C–22.01°C). From the table, it was observed that as rainfall increases from the month of establishment of crop (tomato) in the field in April (187.81mm), sunshine was decreasing from 3.38-2.95 h/day (April-Nov).

The reference crop evapotranspiration (ETo) varied from 86.1 to 126.6mm/month in the early season and from 86.8 -99.9 in the late season (Table 2). The ETo values were higher in the months of April, May, and June but lower in the month of July to November. This was similar to the results of Iren and Osodeke (2006), Chukwu and Igboekwe (2001), Akinmutimi (2015). It is expected that the more the rainfall, the higher the relative humidity of the air and the atmospheric temperature lower (Singh and Dhillon, 2004; Akinmutimi 2015).

Crop evapotranspiration, Crop coefficient and maximum evapotranspiration for early and late season tomato

Table 2 shows the crop reference evapotranspiration (ETo), maximum evapotranspiration (ETm) and crop coefficient (*Kc*/month) for early and late season tomato in Umudike. From initial stage, vegetative stage, reproductive and to the maturity stage and are presented below. Reference evapotranspiration for the early season of tomato increased from 112.2mm/month to 126.6mm/month while the late season tomato was 86.8 - 99.9mm/month. The highest *Kc* values were observed in the months of May and June (1.00 and 1.53) for early season and September and October (1.00 and 1.53) for the late season tomato. This result is similar to Agugo *et al*. (2009), Iren and Osodeke (2006), FAO (1986) which revealed that *Kc* values increases from a low value at the time of crop emergence to a maximum value during the period when the crop reaches full development, and declines as the crop matures.

Table 2: Calculated monthly crop coefficient and maximum evapotranspiration for early and late season tomato

Months	ETo (mm/day)	ETo (mm/month)	Kc/month	ETm (mm/day)	ETm (mm/month)
Early season					
April	3.75	112.2	0.45	1.68	50.40
May	3.38	104.7	1.00	3.38	104.78
June	4.22	126.6	1.53	6.45	193.5
July	2.78	86.1	0.73	2.02	62.62
Late season					
August	2.80	86.8	0.45	1.26	39.06
September	3.15	94.5	1.00	3.15	94.50
October	3.04	94.2	1.53	4.65	144.15
November	3.33	99.9	0.73	2.43	72.90

Crop evapotranspiration (ETcrop), effective rainfall (ER) and irrigation water requirements (IR) of early and late season tomato production in Umudike.

Table 3 shows the crop maximum evapotranspiration (ETm), effective rainfall (ER) and irrigation water requirements (IR) of early and late season tomatoes production in Umudike. Crop maximum evapotranspiration for early season values was 411.3mm, while the late season was 350.61mm. The effective rainfall was 947.96 and 837.33 mm respectively for early and late seasons. From the table, throughout the growing period of tomatoes (early and late seasons), the effective rainfall exceeded the maximum evapotranspiration values of tomatoes (ETm) and reference evapotranspiration (ET_O) therefore, no irrigation was required throughout the growth period of tomatoes in Umudike but there may be need for irrigation to guide against water stress to supplement rainfall in the late season. Gaiser *et al*. (2013) reported that extending irrigation produced little effect on yield.

Table 3. Crop evapotranspiration (ETcrop), effective rainfall (ER) and irrigation water requirements of early and late season tomatoes production in Umudike

Month	ETm/month (ETcrop)(mm)	ER (mm)	ER - ETcrop	Total rainfall	Irrigation water requirements(IR)
Early season					
	50.40			187.81	
April		125.24	74.84		0
May	104.78	236.99	132.21	327.49	
June	193.5	266.69	73.19	364.62	
July	62.62	319.04	256.42	430.05	
Season values	**411.3**	**947.96**	**536.66**	**1309.97**	
				288.35	
Late season	39.06				
August		205.68	166.62		
September	94.50	246.58	152.08	339.48	
October	144.15	255.05	110.90	350.07	
November	72.90	130.02	57.12	193.78	
	350.61				
Season values		**837.33**	**486.72**	**1171.68**	

If tomatoes is sown in Umudike in April (early tomatoes) and 135days growth duration period is allowed, effective rainfall of 947.96mm is obtained

CONCLUSION

The present study revealed that water is not a limiting factor for cultivation, growth and yield of tomato at Umudike area of Nigeria. This is as both daily and monthly effective rainfall (ER) obtained exceeded ETm throughout the growing period of tomato which begins in April and ends in November. This observation implies that there is no irrigation requirement for tomato cultivation in the study area. However, with current fluctuation in climate in tropical regions of the world, it is recommended that water requirement of tomato should be checked regularly in this location in order to maintain optimal yield.

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