academicJournals

Vol. 6(2), pp. 24-28, February, 2015
DOI 10.5897/JSSEM2014.0460
Articles Number:666634B50919
ISSN 1996-0816

http://www.academicjournals.org/JSSEM

Journal of Soil Science and Environmental Management

Full Length Research Paper

Estimation of water requirements of early and late season maize in Umudike southeastern Nigeria, using Penman's equation

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Received 20 October, 2014; Accepted 18 February, 2015

The estimation of water requirements of early and late season maize was carried out based on 10 years meteorological data at Umudike, typical of the humid tropical zone using the Penman's equation. The results obtained showed that the seasonal crop evapotranspiration (ETo) value for early season maize (April - July) was 450.66 mm while that of late season (June - September) was 369.72 mm. The irrigation water requirement was zero for early and late season maize. Supplementary irrigation is not necessary for both early and late season maize in Umudike area.

Key words: Estimation, water requirements, maize, southeastern Nigeria, Penman's equation.

INTRODUCTION

Maize originates in the Andean region of Central America. It is one of the most important cereals both for human and animal consumption and is grown for grain and forage. Present world production is about 130 million ha (FAOSTAT, 2000). It tolerates hot and dry atmospheric conditions so long as sufficient water is available to the plant and temperatures are below 45°C.

Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate. Maize flourishes on well-drained soils and water-logging should be avoided particularly during the flowering and yield formation periods.

Maize is the most important cereal crop in sub-Saharan Africa (SSA) and an important staple food for more than 1.2 billion people in SSA and Latin America. All parts of the crop can be used for food and non-food products. In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial products. Maize accounts for 30 to 50% of low-income household expenditures in Eastern and Southern Africa. A heavy reliance on maize in the diet, however, can lead to malnutrition and vitamin deficiency diseases such as night blindness and kwashiorkor (IITA, 2014).

Climate is an important environmental factor that influences what crop can be grown in any particular location (Agugo, 2001). Of all the climatic variables, availability of moisture throughout the growth cycle of a

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crop is an index of crop suitability to a particular agroecology. Most maize production in Africa is rain fed. Irregular rainfall can trigger famines during occasional droughts.

This is because water is a raw material of photosynthesis (Lawlor, 1995) and therefore forms the basis for crop growth and yield. However, both excess and inadequate moisture supply to crops is detrimental to optimal yield and crop quality (Agugo et al., 2009).

Crop water use, also known as evapotranspiration (ET), is the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system, which represents transpiration and is no longer available as stored water in the soil. Consequently, the term "ET" is used interchangeably with crop water use. All these terms refer to the same process, ET, in which the plant extracts water from the soil for tissue building and cooling purposes, as well as soil evaporation (Al-Kaisi and Broner, 2012).

Various equations of reference potential evapotranspiration have been used to estimate reference potential evapotranspiration. They include: Penman's 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 the maize crop in Umudike area of Southeastern Nigeria, using the Penman's equation.

MATERIALS AND METHODS

This study was carried out at Michael Okpara University of Agriculture, Umudike. Umudike is located in the humid forest zone of Nigeria and lies within latitude 050 29^{1}N and longitude 07° 33^{1}E with an altitude of 122 m above sea level. Annual rainfall in Umudike ranges from 1900 to 2200 mm, bimodally distributed with peaks in July and September. The soil is sandy clay loam (coarse-textured) and classified as an Ultisol (Njoku et al., 2001). The soil is largely dominated by the kaolinitic, low base status Ultisols classified as Typic Paleudult according to USDA system of classification (USDA, 2003).

This study was based on 10 years (1997-2006) meteorological data collected from the meteorological station of the National Root Crops Research Institute, Umudike. The meteorological data are presented on Table 1. These data were used for the computation of the reference or potential crop evapotranspiration (ETo).

Crop water requirements

The crop water requirements was estimated with a ten-year meteorological data (1997-2006) collected at Umudike (05° 29N; 07° 33^{1}E), typical of the study area. The water requirements of maize were determined for 2 seasons (early and late). A total growth duration of 125 days for each cropping period was disaggregated into 20, 35, 40 and 30 days representing respectively the initial, crop development, mid-season and harvest stages (Figure 1). The estimation of crop evapotranspiration involved 3 stages given below.

Calculation of reference evapotranspiration

Reference crop evapotranspiration (ETo) is defined as the rate of evaporation of an extended surface of 8 to 15 cm tall green grass cover actively growing, completely shading the ground and not short of water (Iren and Osodeke, 2006). It represents the climatic evaporation demand and predicts the effect of climate on crop.
Thus, reference crop evapotranspiration was calculated based on Penman's equation given as:

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

Where: ea-ed = vapour pressure deficit, that is, the difference between saturation vapour pressure (ea) at T mean in mbar and actual vapour pressure (ed) in mbar where ed = ea.RH/100 f(U) = wind function of f (U) = 0.27 (1+ U/100) with U in Km/day measured at 2 m height, Rn = total net radiation in mm/day or Rn = 0.75Rs - Rnl where Rs is incoming shortwave radiation in mm/day either measured or obtained from Rs = (0.25 + 0.50 n/N) Ra. Ra is extra-terrestrial radiation in mm/day; n is the mean actual sunshine duration in hour/day and N is maximum possible sunshine duration in hour/day. Rnl is net long wave 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, and c = adjustment factor for ratio U day/U night, for RH max and for Rs

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). Crop coefficients of 0.4, 0.78, 1.13 and 0.58 were used for the initial, crop development, mid season and late season (harvest) stages respectively.

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

$$Kc/month = \frac{Kc\ growth\ stage}{30} \times N$$

N = number of days growth stage lasted

Maximum evapotranspiration (ETm)

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

Table 1. Mean of 10 years climatic data of Umudike (from 1997 to 2006).

Months	Rainfall (mm)	Rain days	Max RH (%)	Min RH (%)	Mean RH (%)	Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)	Sunshine duration h/day	Wind speed (Km/h)	U day (m/s)	U Night (m/s)	U day/U night (m/s)	ETo (mm/day)	ETo (mm/month)
Jan.	16.65	2	58.38	40.29	49.34	32.60	21.70	27.20	4.82	9.50	3.00	2.00	1.50	3.71	115.01
Feb.	47.41	2	69.86	45.86	57.86	34.30	22.90	28.60	5.19	10.20	3.00	2.00	1.50	3.76	105.28
Mar.	86.86	6	76.86	56.00	66.43	33.90	23.60	28.75	4.29	10.20	3.00	2.00	1.50	4.03	124.93
April	172.37	11	80.14	64.71	72.43	32.90	23.90	28.40	5.23	8.80	3.00	2.00	1.50	4.04	121.20
May	261.05	15	81.71	70.14	75.93	31.90	23.30	27.60	5.63	8.80	3.00	2.00	1.50	4.00	124.00
June	314.02	18	85.00	74.71	79.86	30.60	22.90	26.75	4.53	8.80	3.00	2.00	1.50	3.48	104.40
July	304.30	21	86.57	67.57	77.07	29.60	22.80	26.20	3.18	9.50	3.00	2.00	1.50	3.26	101.06
Aug.	264.99	19	74.71	68.14	71.43	29.20	22.70	25.95	2.37	8.80	3.00	2.00	1.50	2.26	70.06
Sept.	324.07	21	85.29	76.71	81.00	29.70	22.60	26.15	2.70	8.80	3.00	2.00	1.50	3.14	94.20
Oct.	262.77	18	83.14	73.00	78.07	30.70	22.70	27.70	3.75	8.80	3.00	2.00	1.50	3.44	106.64
Nov.	56.25	4	80.57	55.43	68.00	32.00	23.00	27.50	5.08	8.80	3.00	2.00	1.50	3.72	111.60
Dec.	4.21	1	73.00	50.57	61.79	32.00	21.50	26.75	5.57	9.50	3.00	2.00	1.50	3.63	112.53
Total	2114.95	138	934.99	743.01	839.21	379.40	273.60	326.50	49.64	110.50	36.00	24.00	18.0	42.77	1290.91
Mean	176.25	12	77.92	61.92	69.94	31.62	22.80	27.21	4.14	9.20	3.00	2.00	1.50	3.54	107.58

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

ER = 0.8R - 25, if R> 75 mm/month
Or
ER = 0.6R - 10, if R< 75 mm/month

Where, R = monthly rainfall (mm), and IR (irrigation water requirement) was calculated as the difference between ET crop and effective rainfall (ER).

RESULTS AND DISCUSSION

Table 1 presents the meteorological data of Umudike (1997 - 2006). From the table, the rainfall amount was highest in the month of September (324.07 mm), spread over 21 days, mean relative humidity was highest in the same month (76.71), mean temperature was also lowest (26.15). The reference crop evapotranspiration (ETo) varied from 70.06 to 124.93 mm/month with a mean of 109.21 mm/month. The ETo values were higher in the drier months of January, February, March and April but lower in the wetter months of July, August. This was similar to the results of earlier reporters such as Iren and Osodeke (2006), Chukwu and Igboekwe (2001). It is expected that the more the rainfall, the higher the relative humidity of the air and the atmospheric temperature is supposed to be lower (Singh and Dhillon, 2004).

Crop coefficient and maximum evapotranspiration for early and late season maize

The calculated monthly crop coefficient (kc/month) values for the early season and late season maize from the initial stage, vegetative stage, reproductive and to the maturity stages are presented in Table 2. This result is similar to that of 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. The highest kc values were observed in the months of May and June (0.91 and 1.51) for early season and July, August (0.91 and 1.51) for the late season maize. These months coincided with the reproductive and maturity stages of growth in maize which are reportedly the most active growth stages FAO (1986).

If maize is sown in Umudike in April (early maize), 125 days growth duration period allowed

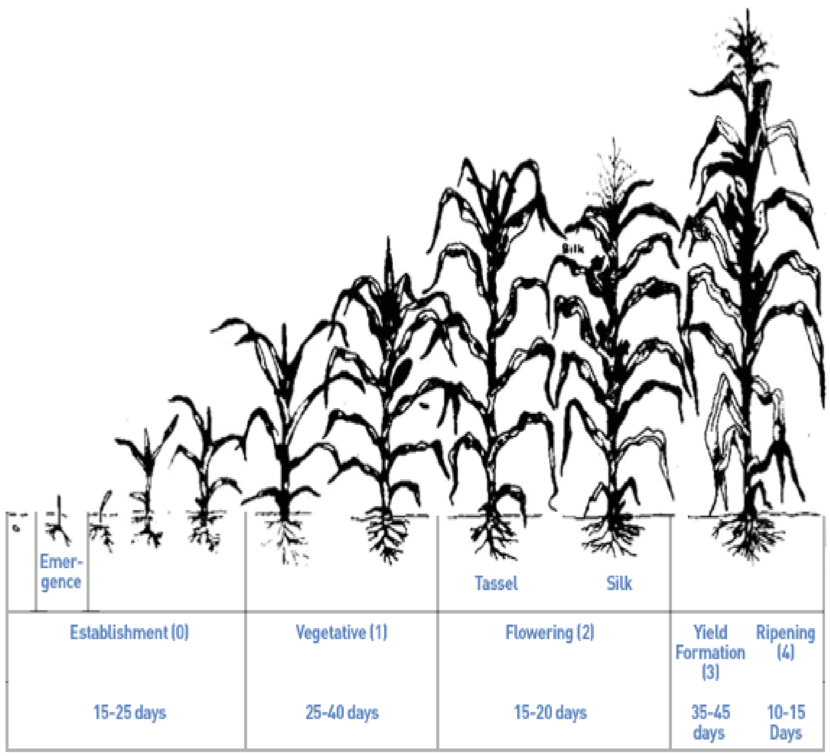

Figure 1. Growth stages of the maize crop.

Table 2. Calculated monthly crop coefficient and maximum evapotranspiration for early and late season maize.

Months	ETo/month (mm)	Kc/month	ETm/month (mm)
Early season maize			
April	121.20	0.27	32.724
May	124.00	0.91	112.84
June	104.40	1.51	157.64
July	101.06	0.58	58.61
Late season maize			
June	104.40	0.27	28.19
July	101.06	0.91	91.96
August	70.06	1.51	105.79
September	94.20	0.58	54.64

effective rainfall of 714.40 mm is obtained.

Crop evapotranspiration (ET crop), effective rainfall (ER) and irrigation water requirements (IR) of early and late season maize production in Umudike

Table 3 shows the crop evapotranspiration (ET crop), effective rainfall (ER) and irrigation water requirements (IR) of early and late season maize production in Umudike. Crop evapotranspiration for the early season was 361.81 mm, while that of the late season was 280.58 mm. The effective rainfall was 714.40 and 865.91 mm respectively for early and late seasons. From the table, throughout the growing period of maize (early and late seasons), the effective rainfall exceeded the maximum evapotranspiration values of maize (ET crop), therefore no irrigation was required throughout the growth period of maize in Umudike. Gaiser et al. (2013) reported that extending irrigation produced little effect on maize yield at

Table 3. Crop evapotranspiration (ET crop), effective rainfall (ER) and Irrigation water requirements (IR) of early and late season maize production in Umudike.

Month	ETm/month (ET crop) (mm)	ER (mm)	ER - ET crop	Total rainfall	Irrigation water requirement (IR)
Early season maize					
April	32.724	112.90	80.18	172.37	0
May	112.84	183.84	71	261.05	0
June	157.64	226.22	68.58	314.02	0
July	58.61	218.44	159.83	304.30	0
Seasonal values	361.81	714.40	379.59	1051.74	0
Late season maize					
June	28.19	226.22	198.03	314.02	0
July	91.96	218.44	126.48	304.30	0
August	105.79	186.99	81.20	264.99	0
September	54.64	234.26	179.62	324.07	0
Seasonal values	280.58	865.91	585.33	1207.38	0

the current level of nitrogen (N) and phosphorus (P) application rates.

Conclusion

Crop water requirements of maize can be met by effective precipitation both in the early and late season growing of maize in Umudike area without any need for irrigation. In view of excess moisture availability beyond the optimal crop requirements, special farming techniques may be necessary to ameliorate the impact of excess moisture on growth and yield of maize in this area.

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