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Crop Water Requirements during Growth Period of Maize (*Zea mays* L.) in a Moderate Permeability Soil on Coastal Plain Sands

Bassey E. Udom*, **Onyinyechi J. Kamalu**

Department of Crop and Soil Science, University of Port Harcourt, Port Harcourt, Nigeria

Abstract Water requirement in a cropped field can be measured directly with tensiometers or neutron probe method or it can be estimated from meteorological data by means of empirical formulae. A field experiment was carried out at the University of Port Harcourt to determine the pattern of water used by maize crop during the growth period, calculated by the Blaney-Criddle and Standard Class A Pan Evaporation data. Results showed that total crop water requirement during the growing season was 456.9 mm, with mean daily consumptive used rate of 4.22 mm and 3.91 mm using the Blaney-Criddle and Pan Evaporation data. Peak period of water used by the crop was found at tasseling (5.66 mm day^{-1}), and during yield formation period (6.31 mm day^{-1}), calculated with the Blaney-Criddle, 5.03 mm day^{-1} and 4.78 mm day^{-1} respectively with pan evaporation data. The functional model: $Y = 12.04 + 1.617x$, $R^2 = 0.604$ for leaf area index (LAI) and $Y = 22.01 + 0.914x$, $R^2 = 0.620$ for plant height can be used to predict water used by the plant. Sand content tended to increase the amount of water used by the plant while clay content showed non-significant negative effect on water used by the crop. Therefore, both the Blaney-Criddle and Pan Evaporation formulae can be used to estimate the amount of water used by the crop in the study area and similar areas in the humid tropics.

Keywords Water use, Growth period, Leaf area index, Sandy loam soil, Blaney-Criddle, Pan Evaporation

1. Introduction

Water as an environmental variable has received and will continue to receive major attention in the global need to increase food production. The pattern of crop-water requirement is of agronomic and economic importance, particularly where water is a scarce resource. In recent times, there is competition for water among the municipal, industrial and agricultural users (Hamdy *et al*., 2003). Therefore, estimating water use of crops accurately is important for crop planning, scheduling, management and productivity (Michael, 2009; Barhom, 2012). Crop water requirement is the measure of the amount of water required for evapotranspiration, when sufficient soil water is maintained by precipitation and/or irrigation so that it doesn't restrain plant development and yield (Djaman et *al*., 2017).

Consumptive water use pattern in a cropped field can be quantified by the use of a water balance, which is the computation of all water fluxes at the boundaries of the system under consideration (Varga *et al*., 2013, Gicheru *et al*., 2004). At the soil surface boundary, rainfall (P) and irrigation (I) are considered gains; evapotranspiration (ET), deep percolation (Ql), and the run-off (R) are losses (Reichardt *et al*., 2012). The water balance gives an important overview of the water regime and is an essential tool for effective crop management. Soil water balance is related to the moisture by precipitation and/or irrigation to that lost through evaporation, overland flow and deep drainage.

The amount of water required for maize (or any other crop) depends on the duration of growth and development stages of the crop, the evaporative demand of the environment, and expansion of canopy, crop species and planting density (Wright and Bell, 1992). On sandy soils with low water storage capacity in the same climate, more water would be needed to maintain adequate moisture in the root zone for crop uptake. Moisture stress during the period beginning approximately at tasseling and through cob setting/cob filling could have adverse effect on optimum yield of maize (Nageswara *et al*., 1989). If the root zone is lacking sufficient water, many cobs will be empty or will contain only a few grains. Therefore water use pattern during the growth stages of the crop would enable one to match the peak period of water needs of the plant.

* Corresponding author:
ebassidy@yahoo.com (Bassey E. Udom)
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Water use for a crop can be estimated if water supplied by rainfall and/or irrigation, the amount used by the crop in evapotranspiration, the change in soil moisture storage and the amount lost by deep percolation are known (Olasantan, 2008). The amount used by the crop in evapotranspiration can be measured with Tensiometers or by Neutron Probe method directly in the field or from meteorological data by means of empirical formulae (McVicar *et al*., 2005).

The daily soil water balance equation is written in the form of:

$$Mn = Rn - AEn - Ron - Dn \quad (1)$$

where Rn, AEn, Ron, Dn and Mn represent the amount of rainfall, actual evaporation, surface run-off, deep percolation, and change in soil moisture storage respectively (Allen *et al*., 1998). The equation can also be written as:

$$P + I - ET \ \pm R \ \pm Qt = \Delta S \quad (2)$$

where P, I, ET, R, Q_L, ΔS represent total precipitation, irrigation, evapotranspiration, run-off, underground flow and change in soil moisture storage respectively. Other methods of estimating or predicting crop-water requirement includes the use of Standard Pan Evaporimeter (Pruitt, 2008), which takes into account the wind velocity, temperature, radiation and humidity and calculated as:

$$ETcrop = Eo\ K \quad (3)$$

where ETcrop is the reference crop evapotranspiration, Eo is the standard pan evaporation, K is the Pan coefficient.

Maize or corn is a cereal crop that is grown widely throughout the world in a range of agro ecological environment (Michael, 2009). More maize is being produced annually across the world than any other grain (FAO, 2013). The crop exists and consists of different colours, textures and grain shapes and sizes. The white, yellow and red maize are the most commonly cultivated and used types. (Gilliam *et al*., 1993).

Literature revealed that there are many valuable theoretical attempts and complicated models to estimate water requirements of crops, notably maize, cotton, wheat, tea, rice, radish and cowpea using equations such as the Penman (1948), Pan Evaporator and Lysimeters (Dahmardeh *et al*., 2010; Akinifesi et al., 2006; Amede and Nigatu, 2001; Grant *et al*., 1989; Kowal and Kassam, 1973). These studies did not consider the pattern of water use periods with hydraulic properties of the soils. The availability of water (Hamdy *et al*., 2003), its movement and its retention are governed by the properties of the soil especially texture. Authors agreed that different crops have different water use requirements under the same weather conditions. (FAO, 2013; Evett, 2013). Effective management of water resources for crop production requires the need to understand the influence of soil and water on crop, especially maize due to its worldwide importance for food and industries.

Literature is scanty on documented evidence of water-use pattern during the growth stages of crops on soils with moderately rapid hydraulic conductivity (Lipiec and Hakansson, 2000; Gicheru et al., 2004). This information is important for planning the cropping periods of the crop, reducing crop failure and increasing productivity. In this study, we estimated the water use of maize crop at growth stages by the simplified empirical water balance model of Blaney and Criddle (1950). We also provided functional models relating water use of the crop during the growing season with leaf area (LA) and leaf area index (LAI). This will provided input data for better planning of the cropping cycles, to reduce the risk of crop failure and increase yield.

2. Materials and Methods

2.1. Study Area

This study was conducted at the Teaching and Research farm of the University of Port Harcourt, Nigeria (Latitude 04°15′N and Longitude 07°15′E). The area is characterized with more than 2400 mm annual rainfall, mean annual temperature of about 29°C, and 89-93% relative humidity. The soil is derived from the coastal plain sands and classified as *Arenic acrisol* (USDA, 2012). It is coarse textured, highly weathered soils occurring south of the south-eastern Nigeria and have low activity clays (Agboola, 2000). Saturated hydraulic conductivity is moderately rapid (21.0 cm hr^{-1}) and low water retention characteristics (Table 1). During the 2016 and 2017 growing seasons which the experiments were conducted, the mean monthly rainfall (P_{mean}), minimum temperature (T_{min}), maximum temperature (T_{max}) mean temperature (T_{mean}), and sunshine hours (Rs) were obtained at the Department of Geography and Environmental Management, University of Port Harcourt weather station on a daily basis and averaged on the growing seasons (May – August) (Table 2).

Table 1. Some physical properties of soil of the experimental site

Soil properties	Unit	Value
Sand	g kg^{-1}	684
Silt	g kg^{-1}	211
Clay	g kg^{-1}	105
Textural class	-	Sandy loam
Bulk density	g cm^{-3}	1.43
Total porosity	%	32.5
Water holding capacity	g g^{-1}	0.23
Saturated hydraulic conductivity	cm hr^{-1}	21.3
Permeability class	-	Moderately rapid

2.2. Cropping and Crop Data Collection

The experiment was arranged in randomized complete block design (RCBD) in four replications. The maize variety (FAZE 7) was planted in two seasons. In the first planting season, the crop was planted on May 3, 2016 and harvested in July 29, 2016. The second planting was on May 24, 2017 and harvested in August 19, 2017. The planting was done on a uniformly cropped area of 0.45 ha with plant population of about 23,000 plants ha^{-1}. Basal rate of poultry manure at 10 tons ha^{-1} was applied during the 2 cropping seasons to increase the soil fertility.

Maize plant height and leaf area were measured at the crop's growth stages (FAO, 1979) viz: 0 - establishment (at 10% of vegetative phase) (28 – 30 days after planting) (DAP), 1 - vegetative (at 80% of vegetative phase) (40 - 48 DAP), 2 - tasseling (65 - 72 DAP) and 3 - cob setting/cop filling (83 - 91 DAP) and grain yield at maturity. Leaf area (A) was determined by the method of Shih and Gastro (1990) as:

$$A = KLB \quad (4)$$

where A = leaf area (cm^2), L = leaf length (cm), B = breath at mid-point, and K = reduction factor determined for the crop under investigation.

Table 2. Mean seasonal (May – August) meteorological data during the 2016 – 2017 period

Growth stages	Month	P_{mean} (mm)	T_{min} (mm)	T_{max} (mm)	T_{mean} (mm)	Rs (hrs)	RH_{mean} (%)	Stnd. Pan (mm)
0-Establishment	May	227	25	31	28	7.41	90	4.24
1-Vegetative	June	315	25	29	27	7.23	89	5.41
2-Tasseling	July	440	23	29	26	6.11	89	4.42
3-Cobsetting/cob filling	August	504	24	28	26	5.43	91	4.43
4-Maturity	August	352	24	28	26	5.21	91	4.11
Mean		368	24	29	27	6.28	90	4.53

P_{mean}- mean rainfall, T_{min} – mean temperature, T_{max}- maximum temperature, T_{mean}- mean temperature, Rs- mean sunshine hours, RH_{mean}- mean relative humidity, Stnd. Pan- Standard pan evaporator

2.3. Maximum Evapotranspiration Estimation (ET_m)

The maximum evapotranspiration (ET_m) at the growth stages of the crop was computed for the growing period by the modified Blaney and Criddle (1950) and Allen *et al.* (1998) equations:

$$ETm = Kc\ Fc \quad (5)$$

where ET_m is the maximum crop evapotranspiration (mm), K_c is crop consumptive use coefficient and fc the consumptive use factor, computed from the meteorological data for the growing periods. Data collected on Class "A" Pan Evaporimeter during the period was also used in determining the reference crop evapotranspiration (ET_o) using the formulae of Penman (1948) as:

$$ETo = EoK \quad (6)$$

$$ETcrop = ETo.Kc \quad (7)$$

where ET_o is reference evapotranspiration (mm), E_o is Standard Pan Evaporation (mm), K and K_c are standard pan coefficient and crop coefficient respectively (dimensionless). In order to obtain the crop water requirement ET_{crop}), the reference crop evaporation (ET_o) was multiplied by the crop coefficient (K_c) (Allen *et al.*, 1998). The crop coefficient varied according to the growth stages.

The consumptive water use was calculated at the crop development stages during the growth period, corresponding to mean number of days after planting. Adjustment for growth periods was estimated by multiplying the consumptive use period by the number of days for the growth stage.

2.4. Soil Sampling and Laboratory Analysis

The disturbed bulk and core soil sample were collected at the 0-15 cm top soil for analysis of some hydrological and structural properties of the soil could affect water movement into and within the soil. The disturbed soil samples were sieved through 2 mm sieve and stored in plastic containers for laboratory analysis.

2.4.1. Determination of Particle Size-distribution, Bulk Density, and Total Porosity

Particle size distribution was determined by the method of Gee and Bauder (1986) after dispersion with sodium haxametaphosphate. The bulk density was determined with core sample (Grossman and Reinsch, 2002) and calculated as:

$$\text{Bulk density} = \frac{Md\ (g)}{Vb\ (cm3)} \quad (8)$$

Where, Md is mass of oven-dried soil and Vb is the volume of bulk soil.

Total porosity was calculated with core samples using the method of Flint and Flint (2002) as:

$$\%Total\ porosity\ = \frac{volume\ of\ water\ at\ saturation\ \ (cm3)}{volume\ of\ bulk\ soil\ (cm3)}\ x\ \frac{100}{1} \quad (9)$$

This method is suitable for sandy soils, because, at saturation (0 kpa) tension after 24 hours, all the pore spaces are filled up.

2.4.2. Saturated Hydraulic Conductivity and Water Holding Capacity

Saturated hydraulic conductivity (Ksat) was measured by the constant head soil core method (Reynolds *et al.*, 2002). Leachate volume was measured over time until flow was constant at which time the final flow rate was determined from the equation

$$Ksat = \frac{Q}{AT}\ x\ \frac{L}{\Delta H} \quad (10)$$

where Ksat is saturated hydraulic conductivity ($cm\ h^{-1}$), Q is volume of water (cm^3) that flows through a cross-sectional area A (cm^2), T is time (s), L is length of core (cm), and ΔH is hydraulic head difference (cm). Permeability class was according to Soil Survey Staff (1993). Water holding capacity was calculated as:

$$WHC\ (g\ g-1) = \frac{Mw-Md}{Md} \quad (11)$$

Where Mw is mass of wet soil at 0 kpa potential and Md is mass of oven-dried soil at 105°C.

2.5. Data Analysis

Data on crop water requirements at growth stages were analyzed using the analysis of variance (ANOVA) followed by multiple comparisons using the SAS software (SAS, 2001). Means were separated by the least significant difference using the Fisher's protected test (Gomez and Gomez, 1984) at 5% probability. Correlation analysis was used to determine the relationships between some growth parameters and water use pattern. Significant correlation coefficient was tested at 5% probability.

3. Results

3.1. Crop Water Requirements

Table 3. Computed water use for maize at growth stages with the Blaney-Criddle equation

Growth stages	Water use per growth stages (mm)	Water use (mm day^{-1})
0-Establishment (21 DAP)	48.6c	2.31c
1-Vegetative (44 DAP)	105.9b	4.41b
2-Tasseling (68 DAP)	141.4a	5.66a
3-Cob setting/cob filling (87 DAP)	126.6a	6.31a
4-Maturty (92 DAP)	34.4c	2.4c
Total	456.9	21.09
Mean	91.38	4.22

DAP- days after planting, Means followed by the same letter were not significantly different at $p < 0.05$

Table 4. Computed water use of maize at growth stages by Standard Pan Evaporation

Growth stages	Pan evaporation (mm day^{-1})	ET_o (mm day^{-1})	ET_{crop} (mm day^{-1})
0-Establishment (21 DAP)	4.24b	2.15c	2.51b
1-Vegetative (44 DAP)	5.41a	4.63a	4.98a
2-Tasseling (68 DAP)	4.42a	3.01b	5.03a
3-Cob setting/cob filling (87 DAP)	4.43a	3.78b	4.36a
4-Maturty (92 DAP)	4.11b	2.46c	2.64b
Total	22.61	12.25	19.52
Mean	4.52	2.45	3.91

DAP- days after planting, Means followed by the same letter were not significantly different at $p < 0.05$

The pattern of crop water requirement computed with the Bleney-Criddle formula and Pan evaporative data are shown in Tables 3 and 4. The crop seasonal water requirement was 456.9 mm computed with the Bleney-Criddle formula (Table 3). Mean daily water requirements during the growing season were 4.22 mm and 3.91 mm obtained with the Bleney-Criddle and Pan Evaporation formulae respectively. Seasonal and daily water use pattern varied significantly ($p < 0.05$) at growth stages of the maize crop, showing significant increase at periods of rapid growth and declined at maturity.

Peak water use period was found during the tasseling and cob setting/cob filling growth stages at 68 and 87 days after planting (DAP) respectively. At tasselling and cob setting/cob filling, daily water use were 5.66 and 6.31 mm respectively (Table 3), while reference crop evapotranspiration (ET_{crop}) obtained from Pan evaporation were 5.03 and 4.36 mm respectively during similar growth periods (Table 4). There was non-significant ($p > 0.05$) different in the amount of water used by the crop at establishment and maturity growth periods, indicating rapid decline between cob setting/cob filling and maturity (from 6.31 mm day^{-1} to 2.4 mm day^{-1}, and a sharp increase between establishment and maximum vegetative period (2.31 mm day^{-1} to 4.41 mm day^{-1}) at 44 DAP. More than 82% of the crop seasonal water requirement was used during vegetative, tasseling and yield formation growth stages that was 23%, 31% and 28% respectively.

3.2. Growth Parameters

Table 5. Plant height and leaf area index of maize plant at growth stages

Growth stages	Plant height (cm)	Leaf area index
0-Establishment (21 DAP)	57.3c	0.84c
1-Vegetative (44 DAP)	104.5b	3.12b
2-Tasseling (68 DAP)	153.3a	4.11a
3-Cob setting/cob filling (87 DAP)	161.1a	4.23a
4-Maturty (92 DAP)	162.7a	3.00b

DAP- days after planting, Means followed by the same letter were not significantly different at $p < 0.05$

Table 6. Functional model between water use and leaf area index, plant height, saturated hydraulic conductivity and particle size

Independent	Equation	R^2	R
Leaf area	Y = 12.04 + 1.617x	0.604*	0.777*
Plant height	Y = 22.01 + 0.914x	0.620*	0.788*
Ksat	Y = 0.823 + 1.072x	0.415ns	0.644ns
Sand	Y = 1.601 + 0.836x	0.521*	0.722*
Clay	Y = - 0.621 +0.511x	0.341	-0.584

*significant at $p < 0.05$, R^2 – coefficient of determination,
R – coefficient of correlation, Ksat – saturated hydraulic conductivity

Table 5 showed that there was non-significant ($p > 0.05$) in plant height of the maize at maximum vegetative (44 DAP), tasseling (68 DAP) and yield formation (87 DAP), growth periods. Maximum plant height of 161.1 cm with corresponding leaf area index (LAI) of 4.23 cm was attained at cob setting/ cob filling period. The lowest plant height \of 57.3 cm and LAI of 0.84 were obtained at the establishment growth period. There was a marginal decrease in LAI at maturity due to shrinking of the upper leaves and drying up of the lower leaves.

Functional relationships in Table 6 showed significant linear model between water use and plant height (Y = 22.01+0.914x, $R^2 = 0.620$, $p < 0.05$), and LAI (Y = 12.0 + 1.617x, $R^2 = 0.604$, $p < 0.05$). The model accounted for 62% and 60.4% of the data respectively, indicating that as plant height and LAI increases, amount of water needed and/or used by the crop increases. These models could be used to estimate the amount of water used by the maize crop. Relationships between water use and soil particle fractions showed significant positive linear model with sand fractions (Y = 1.601 + 0.836x, $R^2 = 0.521$, $p < 0.05$) and a non-significant relationship with clay fractions (Y = -0.621 + 0.511x, $R^2 = 0.341$, $p > -0.584$), indicating that clay fraction limits the amount of water used by the crop.

4. Discussions

The soil is sandy loam and moderate permeability and had influence in the amount of water used by the crop. The soil satisfied the use of modified Blaney-Criddle and water balance formulae in which water used by the crop is usually obtained from irrigation and/or rainfall minus deep percolation (Smith *et al*., 2002, Smith *et al*., 2005). The low amount of water used during establishment period (21 DAP), was most probably due to the number and size of leaves and the plant height which also affected the reference crop evapotranspiration. This is consistent with previous reports by Broner and Schneekloth (2003) and Bob (2015) who related the development stages of crop and associated canopy densities to the crop water requirement and irrigation scheduling.

On the other hand, the sharp increase in the amount of water used by the maize during tasseling (68 DAP) and yield formation period (87 DAP), and rapid decline at maturity was not surprising. This is because; crop water requirements tend to increase at periods of maximum vegetative growth and yield formation, which is consistent with previous reports by Allen *et al*. (1998) and Barhom (2012) that the critical water used period of crops were during flowering and periods following yield formation. However, the amount of water used during the growing season was lower than the upper limit obtained for the drier northern Nigeria, due to the more humid nature of the southern Nigeria, and differences in planting and harvesting dates (Agboola, 2000). Similarly, the influence of climate and planting dates further confirmed the low values of crop water use calculated with the Standard Pan Evaporimeter.

Low leaf area index (LAI) found at maturity compared with value obtained during yield formation period could be linked to shrinkage and low turgidity of the leaves due to low water content commonly found in older leaves. The significant positive model relating LAI and plant height can be used to predict the amount of water required by maize or similar plants. Modeling crop water requirements with the LAI and plant height provided simple linear relationships for irrigation scheduling (Djaman *et al*., 2018). The non-significant linear relationships between clay content and water use and significant positive relationship with the sand content further confirmed the high energy of soil water in clay soils (Udom and Kamalu, 2016).

5. Conclusions

It is concluded through this study that: The seasonal water use of maize crop depends on planting and harvesting dates. The average amount of water used by the maize during the growing seasons (early May – August) was 456.9 mm. Mean daily water use rate was 4.22 mm day^{-1} and 3.91 mm day^{-1} with the Blaney-Criddle and Pan Evaporation data respectively. Peak period of water use was during tasseling and yield formation stage. Pan Evaporation data was influenced by the month and season of the year, as maximum evapotranspiration was low during the wet season. Linear model predicting seasonal and daily water use pattern was 78% for LAI and 79% for plant height. Sand content showed a positive relationship with water used by the crop, while clay content has a non-significant negative influence on the water use pattern of the crop. The Blaney-Criddle and Pan Evaporation formulae can be used to calculate the seasonal and daily water pattern of maize crop in moderate permeability sandy loam soils.

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