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ESTIMATION OF WATER REQUIREMENTS OF EARLY AND LATE SEASONS MAIZE (Zea Mays) PRODUCTION IN OWERRI SOUTHEASTERN NIGERIA, USING PENMAN'S EQUATION

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ABSTRACT

Despite the agronomic, economic and nutritional values of maize (Zea mays), there is still dearth of information on the water requirement of this crop in Imo State, South-eastern Nigeria. This study was therefore carried out in Owerri, typical of the tropical rainforest zone of South-eastern Nigeria to estimate the water requirement of early and late season maize planting based on ten (10) years meteorological data (2004-2014) from Nigeria Meteorological Institute, Owerri Directorate Office using the Penman's approach. Result shows that the seasonal crop evapotranspiration was 309.30mm for early (March – July) and 383.12mm for late (August – December) season planting. Generally, the total seasonal water supply from precipitation exceeded the crop water need by 227% and 141% for late and early season cropping respectively. However, moisture deficit of 67.91mm was observed during the maturity stage in late season cropping, suggesting the need for supplementary irrigation at this growth stage to meet the water requirement of the crop. This study has revealed that maize can be cultivated entirely rain-fed in Owerri without moisture stress if planted early season (March – June), but if it is late season cropping, supplementary irrigation of about 67.91mm must be provided in December for optimum performance. In view of the excess moisture availability beyond optimal crop requirement, it was further recommended that a complimentary crop should be intercropped with watermelon in the farming system as a soil management practice to capture the excess available moisture supplied through precipitation.

Keywords: Estimation, Maize, Water use, Penman's Equation

1. INTRODUCTION

The success or failure of any agricultural production depends upon the chain of five factors: seed or variety, soil, weather, technology and farmer. The strength of the link in this chain finally determines the crop output (Prasada, 2008). Any agricultural system is a man-made ecosystem that depends on climate to function just like the natural ecosystem (Ayoade, 2005). It has been variously demonstrated by many researchers that agriculture being an outdoor activity is very sensitive to weather and climatic conditions (Ojo, 2001). While climate influences the distribution of crops over different regions of the world, weather influences crop production and productivity (Prasada, 2008). Of the various weather elements affecting crop, temperature and rainfall are perhaps the most important.

According to Ayoade, (2005), the growing season is determined in the temperate region by temperature conditions unlike in the tropics where rainfall conditions determine the growing season and productivity of crops. This is due to the latitudinal position of tropical regions in relation to the position of the sun, hence, temperature is relatively high throughout the year, but with a marked seasonality of rainfall. Therefore in addition to soil, plant and management factors, the most important climatic variable that determines crop performances and yield in the tropics is moisture. Understanding moisture availability and the moisture requirement of tropical crops is paramount to formulating policies on water management strategies and in predicting the yield of tropical crops.

Maize which originated in the Andean region of Central America is one of the most important cereals used as staple food for human consumption. It is the major staple food for more than 1.2 billion people in Sub-Saharan Africa and Latin America and the present world production is about 130 million/ ha (FASTAT, 2000). Almost all parts of the crop can be used for food and non-food products. The grain and forage are also important feed materials for livestock ((Akinmutimi, 2015).

Climate is an important environmental factor that influences what crop can be grown in any particular location (Agugo, 2001). Of all the climate variables, availability of moisture throughout the growth cycle of a crop is an index of crop suitability to a particular agroecology. Maize is an efficient user of water in terms of total dry matter production and among cereals; it is the most potentially high yielding grain crop. For maximum production, a minimum maturity grain crop requires between 500 and 800mm 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. Most maize production in Africa is rain fed. The crop can tolerates hot and dry atmospheric conditions so long as sufficient water is available to the plant and temperatures are below $45^{O}C$. However, irregular rainfall can trigger famines during occasional droughts (0keke, 1991).

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). In order to ensure that plants are provided with the right amount of water at each growth stage to avoid both excess and inadequate moisture supply, the concept of crop water use/requirement was established.

Crop water requirements are normally expressed by the rate of evapotranspiration (ET) which relates to the evaporative demand of the air. The term “ET” is used interchangeably with crop water use and it represents the process by which the plant extracts water from the soil for tissue building and cooling purposes, as well as soil evaporation (Al-Kaisi and Broner, 2012).Similarly, the evaporative demand can be expressed as the reference evapotranspiration (ETo) which represents the rate of evapotranspiration of an extended surface of an 8 to 15cm tall green grass cover, actively growing, completely shading the ground and not short of water (FAO, 1986). Different approaches have been used by researchers to estimate the ETo and hence water requirement of tropical crops, they include; Penman's equation, FAO Blaney Cridde, lysimeter, FAO Radiation method etc (Valipour, 2012). Also, there are available data on water requirement of some tropical crops in Southeastern Nigeria (Akinmutimi, 2015; Iren and Osodeke, 2006; Eteng and Nwagbara, 2014), but information on the water requirement of maize in Owerri, Southeastern Nigeria is still dearth. Due to the critical role of maize in human nutrition and the need to ensure its sustainable production in Southeastern Nigeria, it is important to have holistic understanding of its climatic requirement especially, water need at each phonological stage. Hence, this study was carried out.

2.MATERIALS AND METHODS

This study was carried out at Nigeria Meteorological Agency (NIMET), Imo State Meteorological Inspectorate Office, Imo Airport Owerri. Owerri is located within the humid rainforest agro ecological zone of Nigeria and lies at Latitude $5^{O}25^{N}$ and longitude $7^{O}13E$. Annual rainfall in Owerri ranges from 1900 to 3200mm, bimodally distributed with peaks in July and September. The soil is sandy clay loam and classified as ultisol (Njoku *et al.*, 2001). The soil is largely dominated by Kaolinite, low base status ultiols classified as typic paleudult according to USDA system of classification (USDA, 2003).

This study was based on ten years (2004 - 2014) meteorological data obtained from Imo State Airport Meteorological Station (Table 1). In the absence of mean day wind speed (U day) and mean night wind speed (U night) record, the ratio 3:1.5 was adapted for the calculation of U day/U night. These data were used for the computation of the reference or potential crop evapotranspiration (ETo).

Crop Water Requirements

The crop water requirement was estimated with a 10 years meteorological data (2004-2014) which was collected at study area. The water requirement of maize was determined for 2 seasons (early and late). 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, midseason and harvest stages. It is assumed that for early season maize planting, planting was done on 25th March and harvested 30th July. For late season cropping, planting is assumed to have been on 25th August and harvest 30th December. The estimation of crop evapotranspirations involved three stages given below.

Calculation of Reference Evapotranspiration (ETo)

The ETo was calculated based on Penman's equation (Penman, 1948) expressed mathematically as:

$$ETo = c[W – Rn + (1 – W). f(U). (ea – ed)]$$

Where: ea – ed = vapour 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 x RH/100.

f(U) = wind function = $0.27(1 + {}^{U}/_{100})$ with U in km/day measured at 2m height.

Rn = total net radiation mm/day

W = temperature and altitude dependent factor (T in °C; altitude in m)

C = adjustment factor for ratio $\frac{\text{U day}}{\text{U night}}$, for RH max and for Rs.

Crop Coefficient (Kc)

Maize variety with total growth duration of 125 days was selected for this estimation for both early and late season cropping. The growth period was disaggregated into the following phenological stages: Establishment (20 days), vegetative (35 days), reproductive (40 days) and maturity (30 days). The crop was assumed to have been sown within the recommended period for the early and late season cultivation. It is assumed that for early season maize planting, planting was done on 25th March and harvested 30th July. For late season cropping, planting is assumed to have been on 25th August and harvest 30th December.

Crop coefficient (Kc) for various crops are presented in the work of Doorenbos and Pruitt (1977), crop coefficients of 0.4, 0.80, 1.15 and 0.70 was used for the initial, crop development, midseason and late season (harvest stages respectively. The Kc value of each of the growth stages was converted to monthly Kc as;

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

N = number of days growth stage lasted.

Maximum Evapotranspiration (ETm)

The maximum evapotranspiration (ETm) also known as crop water requirement values were obtained as a product of ETo and Kc/month.

$$\text{ETm} = \text{ETo x Kc/month}$$

Seasonal ET crop values were calculated by summing the monthly values for each season

Effective rainfall (ER) and Irrigation Water Requirement (IR)

The effective rainfall (ER) was calculated using the formulae:

$$ER = 0.8R - 25, \text{ if } R > 75\text{mm/month}$$

Or

$$ER = 0.6R - 10, \text{ if } R < 75 \text{ mm/month}$$

Where R = monthly rainfall in mm. Months with moisture deficit were determined when actual evapotranspiration ETa was less than maximum evapotranspiration (ETm).

The irrigation water requirement (IR) was calculated as the difference between ETm and effective rainfall (ER).

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3. RESULTS AND DISCUSSION

Metrological Characteristics of the Study Area

The meteorological data of the study area (Owerri) is presented in Table 1 above. From the table total annual rainfall of 2568.3mm with a mean of 214.03mm was observed. The rainfall pattern shows that August had the highest amount of rainfall (438.03mm), while January has the least amount of rainfall (17.23mm). Akinmutimi, (2015), Iren and Osodeke, (2006), Chukwu and Igboekwe, (2001), have reported that September had the highest rainfall for South-eastern Nigeria. The monthly temperatures were relatively high with a mean of 31.98^{o}C for maximum temperature and 23.54^{o}C for minimum temperature. This is in accordance with the tropical climate (Ayoade, 2008). The mean relative humidity was generally high above 70%. The mean wind speed ranged from 9.50km/hr in December to 7.40km/hr. The mean total sunshine duration ranged from 6.07hr/day in December to 1.13 in July.

Table 1.Mean of 10 years (2004-2014) Meteorological Data of Owerri, Southeastern Nigeria

Month	RF	Air Temperature (O^{C})			Relative Humidity (%)			MWS (u)	TSH (n)	MDWS (u day)	MNWS (u night)	u/u_2
	Mm	max	min	mean	max	min	mean	km/h	hr/day	m/s	m/s	m/s
Jan	17.23	33.67	29.78	31.73	1.83	44.60	48.22	8.00	5.73	3.00	1.50	2.00
Feb	54.98	34.29	23.38	28.84	0.22	63.13	66.68	9.00	4.15	3.00	1.50	2.00
Mar	90.62	34.11	23.86	28.99	0.48	61.92	66.20	8.50	4.32	3.00	1.50	2.00
Apr	186.20	33.13	23.57	28.35	83.00	63.16	73.08	8.00	4.98	3.00	1.50	2.00
May	311.74	32.09	23.32	27.71	87.15	70.00	78.58	8.20	3.73	3.00	1.50	2.00
Jun	327.39	30.70	23.04	26.87	88.52	70.23	79.38	7.60	1.41	3.00	1.50	2.00
Jul	404.95	29.41	22.79	26.10	85.93	68.00	76.97	9.80	1.13	3.00	1.50	2.00
Aug	438.03	29.11	22.66	25.89	85.08	64.10	74.69	7.40	2.23	3.00	1.50	2.00
Sep	405.58	30.01	22.60	25.63	87.00	70.33	78.67	8.70	2.56	3.00	1.50	2.00
Oct	249.88	31.09	22.70	26.89	82.06	70.18	76.12	8.30	3.80	3.00	1.50	2.00
Nov	59.24	32.47	23.00	27.74	77.50	60.27	68.89	9.00	5.54	3.00	1.50	2.00
Dec	22.46	33.71	21.66	27.69	69.81	54.46	62.14	9.50	6.07	3.00	1.50	2.00

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Total	**2568.3**	**383.79**	**282.42**	**313.04**	**938.58**	**760.37**	**849.52**	**101.0**	**45.65**	**36.00**	**18.00**	**24.0**
Mean	**214.03**	**31.98**	**23.54**	**26.09**	**78.22**	**63.37**	**70.79**	**8.42**	**3.81**	**3.00**	**1.50**	**2.00**

RF = Rainfall, MWS = Mean wind speed, TSH = Total sunshine hour, MDWS = Mean Day wind speed, MNWS = Mean Night wind speed, u/u_2 =u Day/ u Night.

The Reference Crop Evapotranspiration (Eto) and Monthly Crop Coefficient (Kc/Month).

The mean daily and monthly reference evapotranspiration (ETo) and the calculated monthly crop coefficient (Kc/month) for early and late season maize production is presented in Table 2. . Result indicated that the monthly reference evaportransportation (ETo) varied from 72.90mm/month in June to 120.90mm/month in April for early season planting and 91.80mm/month in August to 133.50mm/month in December for late season planting. Generally, there were sharp decreases in the amount of reference evapotranspiration from January to June. The values of ETo were higher in the drier months of January, February, March, April and December but lower in the wetter month of July, August and September. The rainfall patterns or regimes in South-eastern Nigeria is in such a way that the months of May, June, July and August usually have the highest amount of precipitation and thus, the least amount of evapotranspiration (ETo). Other researchers had made similar observations in the distribution of evapotranspiration in South-eastern Nigeria (Akpan and Osodeke, 2014; Iren and Osedeke 2006).

Table 2.Reference Evaportranspiration (ETo) and Monthly Crop Coefficient (Kc/Month) for Early and Late Season Maize Production in Owerri

Month	Eto(mm/day)	Eto(mm/month)	Kc/month
Early Season			
March	3.99	119.70	0.27
April	4.03	120.90	0.27
May	3.40	102.00	0.93
June	2.43	72.90	1.53
July	2.48	74.40	0.70
Late Season			
August	3.06	91.80	0.27
September	3.12	93.60	0.27
October	3.45	103.50	0.93
November	3.86	115.80	1.53
December	4.45	133.50	0.70

Similarly the calculated monthly crop coefficient (Kc/month) for early and late season maize production in Owerri were 0.27, 0.93, 1.53 and 0.70 for the growth phases of maize including establishment, vegetative, reproductive and maturity stages respectively Table 2. This result shows that Kc values increased from a low value at the time of crop establishment to a maximum value during the period of full development and then declines as the crop matures which is in accord with the report of other researchers (Iren and Osodeke; 2006; FAO 1986; Azu and Osisi; 2015). The highest crop coefficient (Kc) values were obtained in May, (1.53Kc/month) and October (1.53Kc/month) for early and late season maize cultivation respectively in Owerri. These months coincided with the flowering and yield formation stages, which are the most water sensitive growth stages of maize (FAO, 2015).

Crop evapotranspiration (ETm), effective rainfall (ER) and irrigation water requirement at various stages of early and late season maize production in Owerri.

The crop evapotranspiration, moisture surplus, moisture deficit and irrigation water requirement of maize at each phenological stage for both early and late season planting in Owerri, southeastern Nigeria is presented in Table 3. The crop evapotranspiration (ETm) for the establishment, vegetation, reproductive and maturity stages respectively were 32.20mm, 102.42mm, 122.60mm, and 52.08mm for early season planting and 24.87mm, 92.30mm, 172.50mm and 93.45mm for late season cropping. The vegetative stage in which flower development occurs had the highest moisture requirement of 122.60mm and 171.50mm for early and late season cropping respectively.

Table 3. Maximum Evapotranspiration (ETm), Effective Rainfall (ER) and Irrigation Water Requirement at Various Stages of Early and Late Season Maize Production in Owerri.

Growing season		Establishment stage(mm)	Vegetative stage(mm)	Reproductive stage(mm)	Maturity stage(mm)	ER-ETm (mm)	IR (mm)	Total (mm)
Early Season								
March-April	ETm	32.2	-	-	-	-		
	ER	47.50	-	-	-	15.30	-	-
April-May	ETm	-	102.42	-	-			
	ER	-	123.96	-	-	21.54	-	-
May-June	ETm	-	-	122.60	-			
	ER	-	-	224.39	-	101.79	-	-

July	ETm	-	-	-	52.08			
	ER	-	-	-	236.91	184.83	-	-
Seasonal	ETm							**309.30**
Values	ER							**632.76**

Late Season

August-Sept	ETm	24.87	-	-	-			
	ER	325.42	-	-	-	300.55	-	-
Sept-Oct	ETm	-	92.30	-	-			
	ER	-	299.46	-	-	207.16	-	-
Oct-Nov	ETm	-	-	172.50	-			
	ER	-	-	174.90	-	2.400	-	-
December	ETm	-	-	-	93.45			
	ER	-	-	-	25.54	-67.91	67.91	-
Seasonal	ETm							**383.12**
Values	ER							**825.32**

The total seasonal and maximum water requirements were 309.30mm and 383.12mm for early and late season maize cropping respectively, while the total seasonal effective rainfall were 632.76 for early and 825.32mm for late season periods of maize cultivation in Owerri.

It was also observed that although there was water deficit during the maturity stage, the total seasonal water supply exceeded the crop water need by about 141% just as in the case with the early season cultivation which had total effective rainfall exceeding the crop moisture need by 227%, requirement indicating that maize cultivation on Owerri can be successfully grown under rainfed in Imo State. The excess water observed in this study for both early and late season cultivation, suggests that practices that reduce excess water in the soil such as intercropping with suitable crop and proper drainage would be a better farming system options for maize cultivation in this agro ecological zone of Nigeria in order to utilize the excess moisture.

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4. CONCLUSION

Weather tuned agriculture has become necessary due to the recent change in the climate. One of the major weather elements that affect agricultural production especially in the tropics is rainfall. This is because while temperature in the tropics is fairly constant and optimal, there is marked seasonality of rainfall. Studies have shown direct relationship between water availability and crop yield. This study has revealed that maize cultivation in Owerri, South-eastern Nigeria can be done using rain fed agriculture for both early and late season planting. A moisture deficit was observed during the maturity stage for late season maize production in Owerri. Therefore, for late season maize production in Owerri, irrigation water requirement of about 67.91mm is necessary for optimum yield. In view of the excess moisture availability beyond optimal crop requirement, it is recommended that complementary crop should be intercropped with maize to capture excess available moisture supplied by rainfall.

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