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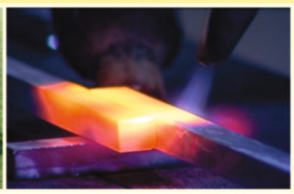


Journal of Engineering and Engineering Technology

Soil Charcterization and Maize(Zea mays L.) Evapotranspiration (etc) in Omu-aran Humid Geological Zone of Nigeria

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Keyword:
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Bulk Density;
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A B S T R A C T

Development of crop coefficient (Kc) can enhance crop water requirement estimates at specific crop growth stages. However, local Kc data are lacking for maize in Omu-aran. Therefore, this research was aimed at quantifying water use and specific Kc values at different growth stages for maize (Zea mays L.) inOmu-Aran,a sub-humid agro-geological zone of Nigeria. A 60cm diameter and 45cm high drainage lysimeter was designed, constructed from a 2.5 mm thick plastic drum, and installed. CROPWAT 8.0 model was later used to develop the Kc and ETc(crop evapotranspiration) using the local weather data of the study site. Soil physical and chemical properties, moisture content, bulk density, and porosity of the site were determined. Weather parameters such average monthly temperature, wind speed, rainfall and relative humidity etc. were collected from an automatic meteorological station located around the research site. Also, irrigation requirements and scheduling for the crop were determined from the model. The average ETc values were 14.6, 43.75, 60.38, and 38.67.0 mm during the initial, development, mid-season and late-season stages, respectively, and the total ETc was 561.8 mm, while the average Kc values for maize were 0.30, 0.73, 1.29 and 0.91 for the initial, development, mid-season, and late-season stages, respectively. The values obtained are suitable for a successful design and implementation of irrigation programme for maize in the study area and this will eventually mean higher productivity and economic development.

1. Introduction

The water is one of the most important elements in crop production. It is a major structural component held in cells which add bulk, affect form through turgor development and is responsible for many of the physical and structural characteristics of the plants (Fasinmirin *et al*., 2015). As such, agriculture has been seen as the major user of world is freshwater, accounting for about 70% of the world's freshwater consumption (Grafton, 2011), but climate change and recent rise in global warming have resulted in increased scarcity of the much needed water between the various sectors of the economy of the world. The result of this is that limit has been put on efforts to increase agricultural production to meet up with the rise in demand for food by the fast growing world's population; hence, the need for every sector to make judicious use of water and set strategies in place for managing the available water.

Fasinmirin et al. (2015)reported that effective management of water necessitates the estimation of the consumptive use of crop from the period of establishment to maturity. The ability to measure, estimate, and predict evapotranspiration and cropwater requirements enables one to better satisfy the water needs of crops, improve crop water-use efficiency and subsequently save water for other purposes (Fisher, 2012).Hence to properly plan irrigation works (i.e. scheduling),a detailed knowledge of crop water requirements, its magnitude, its temporal and spatial variability is essential for the assessment of water and storage requirements, the capacity of irrigation systems, optimal allocation of water to crops and for the decision making in agriculture (Oguntunde, 2004).

Hitherto, many researches have been conducted on water requirement of maizein Nigeria, but locally determined

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water use information on maize is scarce in Omu-Aran tropical climate of Nigeria. The objective of this research was to determine irrigation and crop water requirements of maize (*Zea mays L.*) using crop water model (CROPWAT 8.0).

2 Material and Methods

2.1 The study Area

The research was conducted at the Teaching and Research Farm of Landmark University Omu-Aran, Kwara State, Nigeria. Omu-Aran, which falls within the sub-humid agro-ecological zone of Southern Guinea Savannah, Nigeria is located on latitude 8° 8′00′′N and longitude 5°6′00′′ E, and on altitude 564 m above mean sea level. The region is dominated by a long wet seasoned tropical maritime climate forming a moderate weather with daily air temperature ranging from 16°C – 32°C(www. Omuaran.com, 2015). Omu-Aran is the closest area in Kwara State to the rainforest and the derived savanna in the North central (middle belt) of Nigeria and, hence forming the zone with highest rainfall in the State. The average rainfall depth is between 500 – 1500 mm and is scattered over 6 - 8 months of the year, depending on the variation of the hot and cold weather as the season changes (Opeke, 2006). The two distinct seasons of the year in the study area are the wet and dry seasons with March and November, respectively marking the takeover points. November marks the start of the hotter dry season which terminates in March, while the rainy season starts at April and ends in October. The region is endowed with soil rich in fertility, on which a lot of crops such as Maize, Sorghum, Millet, Legumes, Roots and Tubers, Rice, Locus beans etc and such cash crop as Cocoa, Kola-nut and Oil Palm can be grown (www. Omuaran.com, 2015)

The area has environmental characteristics such as length of growing period, which for instance is 151-180 days for the northern Guinea savanna, 181-210 days for the southern Guinea savanna and 211-270 days for the derived savanna/coastal savanna (Salako, 2007).

2.2 Soil Sampling and Analysis

A 25 x 25 m^2 land area was cleared at the location of the experiment and sixteen soil samples were randomly collected from the 0 – 15 cm layer (superficial layer) of the cleared land. The soil samples collected were transferred to the soil science laboratory of Landmark University for the analysis of particle size distribution, percent Nitrogen, exchangeable phosphorus, and extractable potassium, Magnessium, Calcium, organic matter and cation exchange capacity (CEC). The soil particle size distribution was determined using the Bouyoucos hydrometer method (Ryan *et al.*, 2001). Soil organic carbon on the plot was determined using method described by Eleanor *et al.* (2009). The exchangeable potassium (k^+) was extracted with HCl solution and their levels determined by flame photometry. The cation exchange capacity (CEC) at pH 7.0 with ammonium acetate was determined following the procedure described by Carter (1993), Agbede and Ojeniyi (2009).

Another samples of the soil were collected using soil corers of diameter 5 cm and height 4 cm to an approximate depth of 45cm at an interval of 15 cm i.e. 0-15, 15-30 and 30 – 45 cm for the determination of the followings: Soil moisture content, bulk density (BD), field capacity (FC), and permanent wilting point (PWP), Total porosity, micro and macro porosities. The soil extending beyond each end of the sampler was trimmed to ensure soil is contained in exactly the volume of the cylinder. Thus, soil sample volume was established to be the same as the volume of the sampler holder. The soil cores were wrapped in polyethylene, placed in wooden box and transferred to the laboratory for analysis. The soil samples were placed on flat container and then transferred into the oven at 105^0 C, and dried to constant weight. The weight of soil was recorded and bulk density was calculated using method described by Blake and Hartge (1986), and Horn and Fleige (2003). The particle density was assumed 2.65 g/cm^3 since quartz is the predominant mineral in the sample (Osunbitan*et al.*, 2005; Fasinmirin and Adesigbin, 2012).

$$\textbf{\textit{Bulk Density}}\ (\rho) = \frac{weight of ovendreid soil}{volume of the soil} \tag{1}$$

Total porosity (% pore space) was estimated using the same soil samples collected for soil bulk density. Total porosity of the soil was calculated from bulkdensity assuming a particle density of 2.65 mg/m3following the method described by Suzuki et al. (2004); Sultaniet al.(2007); Adesigbin and Fasinmirin (2011).

$$PT = \left[1 - \frac{DS}{DP}\right] \times 100\ \% \tag{2}$$

$$Mic = \frac{Ww - Wd}{Vc} \times 100\ \% \tag{3}$$

$$Mac = PT - Mic \tag{4}$$

where

PT is total porosity (%), Mac is macro porosity (%), Mic is micro porosity (%), Ds is Bulk density (g cm^{-3}), Dp is Particle density (g cm^{-3}), Ww isWeight of fresh sample (g), Wd is Weight of dried sample at 105° (g), vcis volume of the cylinder (cm^{-3}).

2.3 Climatic Data Analysis

2.3.1 Reference Evapotranspiration Estimation

The Landmark university weather station uses the Microclimatological data collection system of the standard Campbell Scientific, Inc. weather station which sample data every 6 s and record such at 15-min intervals. The station automatically collects data such as; solar radiation, windspeed, air temperature, dew point temperature, relative humidity, precipitation, and barometric pressure which were used to estimate the reference evapotranspiration, ET_0using FAO- Penman Monteith model given as:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (5)$$

where:

ETo= Reference evapotranspiration (mm day-1); Rn= net radiation of crop surface ($MJm^{-2}day^{-1}$);

G= soil heat flux density (MJ m^{-2} day^{-1})= 0 for daily calculations of ET as G is small;

T= mean daily airtemperature at 2 m height (℃); u2 =wind speed at 2 m height (ms^{-1});

es = saturation vaporpressure (kPa); ea = actual vapor pressure (kPa);

(es-ea) = saturation vapor pressure deficit(kPa);

Δ= gradient of the saturated vaporpressure–temperature curve (kPa℃-1), and the

γ= psychometric constant (kPa$℃^{-1}$). (Allen et. al., 1998, Fasinmirin et al., 2009)

The data generated by the weather station such as Precipitation, Air temperature, Relative humidity, Wind Speed and Solar radiation were used as input into the Crop Water Model (CROPWAT 8.0) to estimate the Reference evapotranspiration, crop evapotranspiration, net irrigation requirement, crop water requirement and irrigation schedule for maize.

2.3.2 Evapotranspiration and Crop Factor Estimation from CROWAT Model

CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications (Smith. 1997)

As a starting point, and only to be used when local data are not available, CROPWAT 8.0 includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained for over 5,000 stations worldwide from CLIMWAT, the associated climatic database. The development of irrigation schedules in CROPWAT 8.0 is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern defined by the user, which can include up to 20 crops (Smith, 1997).

3. Results and Discussion

3.1 Climatic Variables in the Study Area

The average monthly air and soil temperature variation for close to two years i.e. from June 2014 to April 2016 in the study area is as shown in Figures 1 (A-B). Soil temperature was observed to be higher than the ambient temperature throughout the 22 months with an average of 28.280c and 24.320C, respectively. This can be attributed to low or no vegetation cover especially during the dry seasons to shield the effect of direct solar radiation. February and March recorded the highest air temperatures of 26.420C and 26.670C, respectively in 2015 and 27.130C and 26.450C, respectively in 2016. Moreover, a trend was observed that the temperatures drops as the wet season approaches, attains lowest value at the wettest month of the year and thereafter increases gradually as the dry season approaches before attaining its highest value at the driest/hottest months (February, March). However, the temperature of the harmattan periods (December and January) is lower than that of other dry months. This is caused by the cool dry wind, which blows across this area from the Sahara desert during the period.

Figure 2 shows the relative humidity values of the study area for 22 months. The relative humidity in Omu-Aran evenly distributed. Though there exist periods with extremely high and low relative humidity which can be attributed to changing seasons.

Throughout this period, it was observed that relative humidity followed the temperature trend across the year whereby the wettest months (August and September) had the highest relative humidity of 93.44% and 91.65%, respectively in 2014 and 91.76% and 92.21%, respectively in 2015. As the rainfall declines towards the end of a year the relative humidity reduces. During the period locally known as the harmattan, the relative humidity remain low because the north-east dry wind blowing across the country from Sahara desert is dry.

The rainfall variation of the study area for the 1.8 years is as shown in Figure 3. A gradual increasing trend of the precipitation was observed from March to August and then starts to decline from the end of September, until it finally gets to zero in December. A sharp drop is noticed around end of July and early august which can be attributed to a phenomenon known as August break. After the break, the precipitation peaked at September and then decreases toward the end of the years due to the approaching dry season.

As represented in Figure 4, the highest average monthly wind speed of 350 km/day was recorded in March 2016. However, on the average, higher wind speeds were observed in the wetter months than the dry months. Usually the average wind speed drops to about 150 km/day in December and then increase non-uniformly from February to July. The average annual wind speed is 247.6 km/day in 2015. The wind speed variation in the study region can be attributed to the Tropical Maritime Airmass (MT) in the country that causes rainfall. The Tropical Maritime Air mass which blows across the country from February in the southern part takes longer time to fully cover the whole of the country, reaching the northern part of Nigeria in June (Adefolalu.1993). Its invasion is as a result of the northward retreat, of the tropical continental air mass (harmattan)

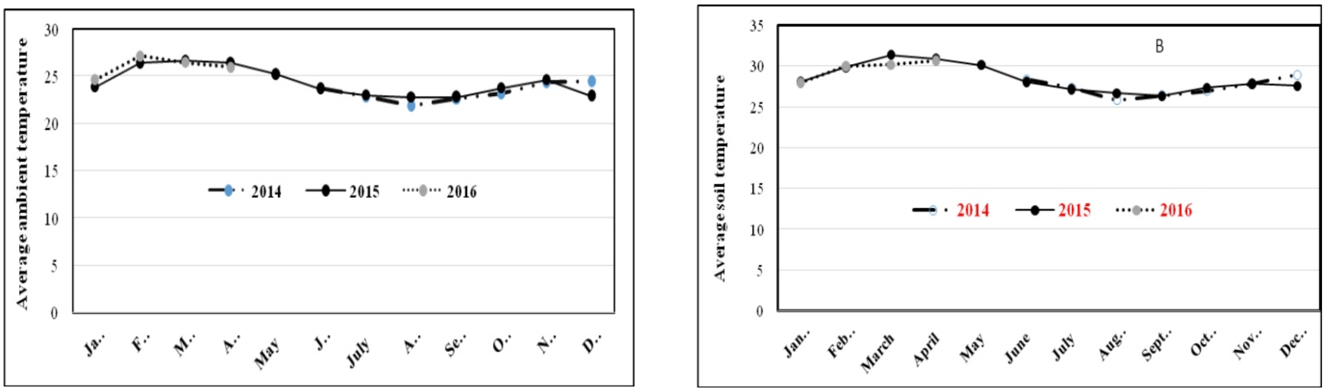


Fig. 1(A-B):Average monthly ambient and soil temperature of the study area for the past 22months.

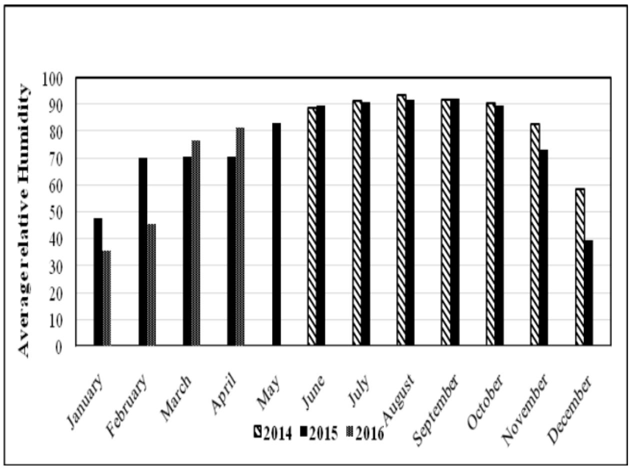


Fig. 2. Ambient Relative humidity of the site for a period of 12 months

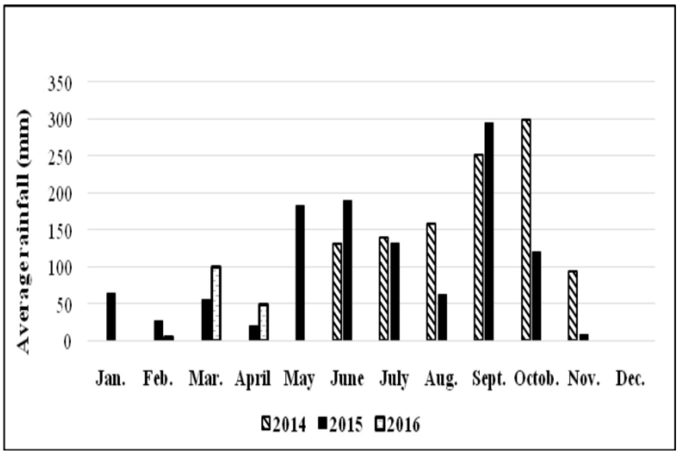


Fig. 3:Monthly rainfall of the research area for the past 1.8 years

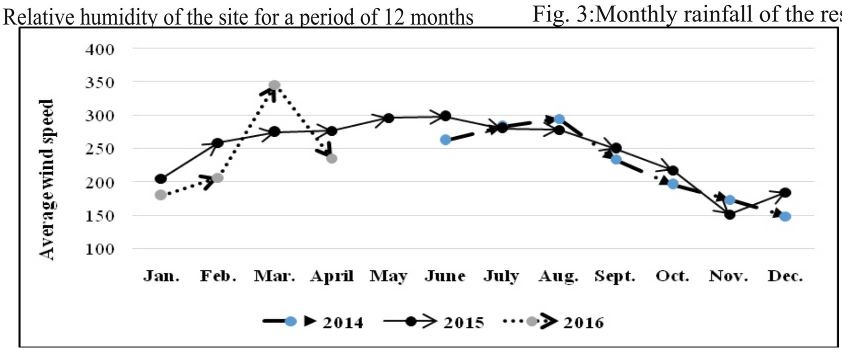


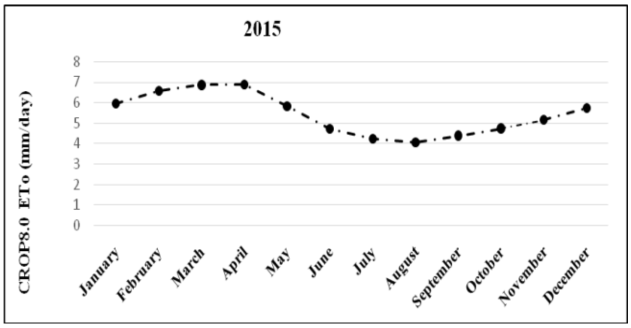
Fig. 4: Average monthly wind speed for 1.8years of the research site

3.2 Reference Evapotranspiration in the Study Area

Figure 5 (A-B) shows the monthly reference evapotranspiration of the research area. The highest values ET_o were observed at the dry season months (from November to March) while the wet months had the lowest ET values. This is directly proportional to the Net radiation (R_n). Analyses of the reference crop evapotranspiration (ET) values from the Penman – Monteith CROPWATT model used showed a similar trend. There was a rise in the ET_o value from October to December, then a drop towards the end of April and decrease from May to august before the commencement of another cycle from October.

3.3 Soil Physicochemical Properties of the Study Area

The textural classification (USDA) of the soil samples at different depths is presented in Table 1. The soil samples at different depths is identically loamy sand, while the chemical properties of the soil are shown in Tables 1 and 2.



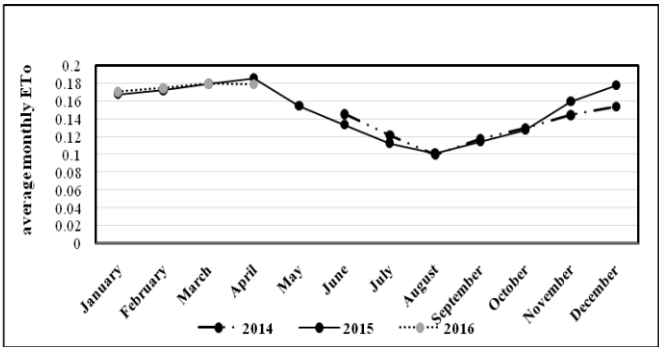


Fig 5: Average monthly (ETo) of the study area computed from (A) CROPWAT 8 and (B) data of the weather station

Table 1: Textural Classification of Landmark University Teaching and research farms soil

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	USDA Textural class
0-15	78.90	8.22	12.88	Loamy Sand
15-30	75.65	9.02	15.33	Loamy Sand

Table 2. Chemical properties of Landmark university teaching and research farm soil

Parameter	Depth (cm)	
	0-15	15-30
EC (dsm^{-1})	7.80	8.30
pH	5.80	5.70
N (%)	0.10	0.10
K (Mol Kg^{-1})	0.88	1.22
Ca (Mol Kg^{-1})	8.01	12.0
P (%)	8.67	12.0
Mg ($MolKg^{-1}$)	2.00	3.02

It was observed that the electrical conductivity (Ec), potassium (K), calcium (Ca), phosphorus (P), and Magnesium (Mg) level all increased with soil depth, while the nitrogen level remained constant. However, high values of the cations is an indication of high cation exchange capacity (CEC), which invariably means moderate soil fertility (Brady *et al.,* 2004). However, the pH (H_2O) of the soil within the experimental site ranged between 5.70 and 5.80 at the 15-30 cm and 0-15 cm depths, respectively. The pH values showed that the soil falls within the slightly acidic range, which is suitable for growing of arable crops such as maize, cowpea and vegetables (Foth and Ellis, 1997).

3.4 Moisture Content, Bulk density and volumetric moisture at Field capacity

Table 3 shows the results of soil moisture content, bulk density and soil moisture volume at depths 0 - 15 cm and 15 - 30 cm of the experimental site. Higher moisture was observed at the 0 - 15 cm depth compared to 15 – 30 cm depth as at the time of test. This could be attributed to the nature of the soil being loamy sand having the capacity to retain more moisture at field capacity (Rawls *et al*., 2003). However, this is largely due to onset of rainfall, which may not really infiltrate deep into soil as a result of long dry spell and moisture loss from the superficial layer of the soil. Moisture depletion from soil surface will be high even at early growth stages of crops due to evaporation as the water is located close to the soil surface. As the crops advance in growth (vegetative stage) and root begin to develop, there will be need for more water supply to meet of the root demand since infiltration will take gradual process due to the water retaining capacity of the soil. The bulk density results shows that soil compaction is higher at higher depths (15 – 30 cm), where compaction is mostly predominant leading to increased bulk density. This is in accordance to the observation that compacted soils have higher bulk densities (Adesigbin and Fasinmirin, 2011)

Table 3. Moisture content, Bulk density and soil moisture volume of the research site

Depth (cm)	Sample No	Bulk Density (g/cm3)	SMC (%)	Vol. SMC at FC cm^3/cm^3
0-15	1	0.742	27.11	0.193
	2	0.686	27.24	0.194
	mean	0.714	27.18	0.194
15-30	1	1.314	9.11	0.114
	2	1.209	9.01	0.114
	mean	1.261	9.06	0.114

SMC – Soil moisture content; FC – Field capacity

4.5 Total, Macro and Micro Porosity

The mean porosities of the soil were in the range 0.20 to .73 for depth 0-15 cm and 0.12 to .0.52 for depth 15-30 cm (Table 4). It was observed that the porosity of the soil inversely correlate with increasing depth from 0 – 30cm. Thus, having higher porosities at the topmost part of the soil is an indication it is a medium-textured soil and is considered a good topsoil for plant growth (Brady and Weil, 1996). Moreover, the mean topsoil porosity around 0.5 is not only in agreement with that fact, but indicates that the soil is well aerated. The structure (aggregation) is probably the cause of the high porosity found in the topsoil (Blake, 1986).

Table 4. Total, macro and micro porosity of the soil

Depth (cm)	Sample No	Total Porosity	Macro porosity	Micro porosity
0-15	1	0.72	0.52	0.20
	2	0.74	0.55	0.19
	mean	0.73	0.54	0.20
15-30	1	0.50	0.38	0.12
	2	0.54	0.44	0.11
	mean	0.52	0.41	0.12

3.5 Crop evapotranspiration (ETc) and ETo of maize (Zea mays) from CROPWAT 8.0 model

Figure 6 shows the decadal ETc of maize and the ETo of the area calculated using CROPWAT8.0 model as a function of days after planting. The graph indicates the ETc values during the initial, development, mid-season and late season stages of the crop. Consequently it is a representation of the water requirement based on crop growth stage throughout the course of its development. The highest water requirement was recorded at the mid-season growth stage followed by the development stage while the lowest was observed at the initial and the late season growth stage. This is because of the short length of the growth at the initial stage, also because of the ageing and less physiological activities of the leaves at the late season. Lower water volume is required at the late season stages because of leaf drying and defoliation (Kassam*et al.,* 1975). Recording of higher ETc values at mid-season than the beginning and end of the crop life cycle may have resulted from higher water requirement for catabolic and metabolic activities in plant owing to increased surface area of leaf and increased plant height (crop development) and daily changes in weather parameters such as radiation, humidity, wind speed, and temperature (Irmak, 2009). The total ETc of the crop considered in this study was within the range previously reported by Doorenbos and Kassam (1979). ETc exceeded ETo from 50 - 100 days after planting (mid-season stage) and this can be attributed to a high demand for water due to flowering, grain formation, and filling. The ETo line indicated in Figure 4.6 also shows that the ETo attained its maximum value during the initial crop growth stage. This can be attributed to low vegetative cover giving room for high evaporative demand from the atmosphere. Subsequently, there was a non-uniform decrease in ETo to the end of the late season stage due to variability of climatic variables during the growing season (Abebe*et al., 2013)*

Crop Coefficient (Kc) from the CROPWAT Model

The Kc curve presented in Figure.7 is a representation of the changes in the vegetation and ground cover during plant development and maturation that affect the ratio of ETc to ETo. The decadal Kc increased from the initial to the development stages while it reached its highest and relatively remained constant at the mid-season stage, and then decreased rapidly during the late season stage. It can be observed that there is a high variation in Kc values among stages. This is basically as a result of the changes in crop development. During the initial period, the leaf area was small, and ET was predominately in the form of soil evaporation. Consequently, the advancement of Kc values reflected the effects of crop growth, development and physiology on ETc (Allen *et al*., 1998). The increase in Kc values from the initial stage up to the mid-season stage of growth is attributable to the increases in leaf area and plant height which increased the rate of water extraction from the soil and in turn increased the ETc (Irmak, 2009). The maize Kc values obtained from the CROPWAT model are higher in the first three crop growth stages than the range recommended by FAO. However, at the late season stage of growth, the Kc value was within the range reported in FAO publications. The variation between the CROPWAT8.0 Kc values and those reported in FAO and other publications is because of the differences in the growing seasons, climate, crop variety, and soil type (Abebe*et al.*, 2013)

4.8 Irrigation Requirements and Scheduling

The irrigation requirement of the crop as a function of days after planting is as shown in Figure 8. The graph shows irrigation demand with respect to the amount of rainfall and the available soil moisture at a particular time during the development of the maize crop. As earlier discussed, though the water requirement the crop increases from initial to mid growth stage and then later decrease at the late season stage, irrigation demand is largely affected by the effective rainfall amount and the amount of moisture present in the soil. Hence, effective rainfall exceeded irrigation requirement throughout the growth vegetative growth stages notwithstanding the high water requirement at this stages. An exception is observed at the initial stage when the rainfall was low (Figure 8).

The graph showing the irrigation schedule for maize in the study area is presented in Figure 9. The result showed increase in moisture depletion rate with increase in days after planting at the different stages of growth of the crop. Obviously, it points out that during the initial stage, depletion increases gradually until no more moisture is retained in the soil which results to need to replenish the soil moisture by irrigation or rainfall as the case might be. Consequently, moisture retention level decreases rapidly and frequently from the development to mid-season stage, leading the frequent demand for irrigation. However, at the late season stage, soil moisture retention remains constantly high as the rate of depletion that would have resulted due to transpiration decreases. This can be attributed to the aging and less physiological activities of the leaves at this stage (Abebeet al., 2013)

Conclusion

The Etc of the crop increased gradually during the vegetative and flowering stages indicating that the crop water requirement is greatest during these crop growth stages. In addition, the crop water use (ETc and Kc) values obtained means that more water should be applied during the vegetative and flowering stages of Zea mays than at sprouting, development and aging stage. This results gives farmers who intend to embark on short duration rainfall and dry seasons growing of maize assurance for conserving water and yet obtaining optimum yield possible from the crop.The ETc values obtained from the CROPWAT 8.0 model for each growth stages of Zea mays were validated using the FAO standard and other data obtained from publications from similar geological zone. The CROPWAT model can therefore be said to be functional tool for determination of water requirement of crops. The research revealed evapotranspiration or crop water use of Maize in Omu-aran throughout is cropping season is 561.8 mm. The soil bulk density, and porosity of the site varied with depths. The bulk density increased, while the porosity reduced at depth 30 cm with lower moisture content. This means that there is an increase in soil compaction from the soil superficial layer up to the 30 cm depth, which consequently could result to low waterintake.

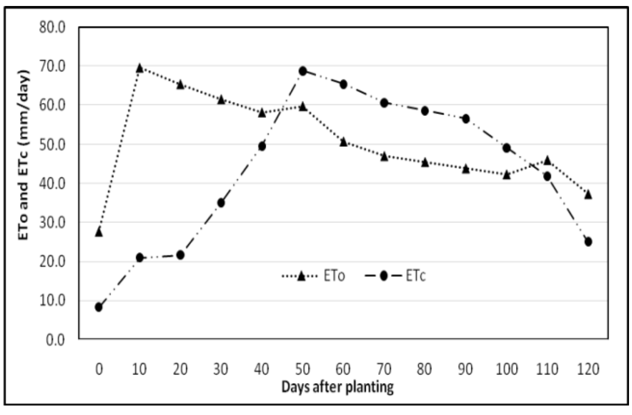


Figure 6. Decadal (ETc) and (ETo) as a function of days after planting for the crop from CROPWAT 8.0 model3.6

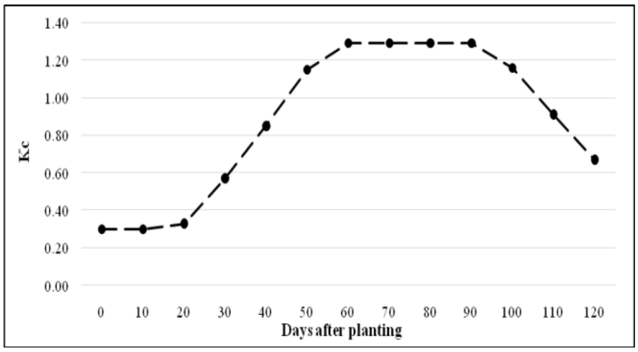


Figure 7 crop coefficient curve of maize from CROPWAT8.0 model

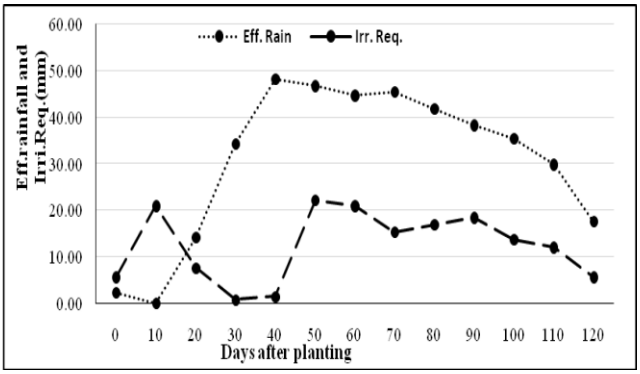


Figure 8.Irrigation requirement of maize crop for the study area using CROPWAT 8.0

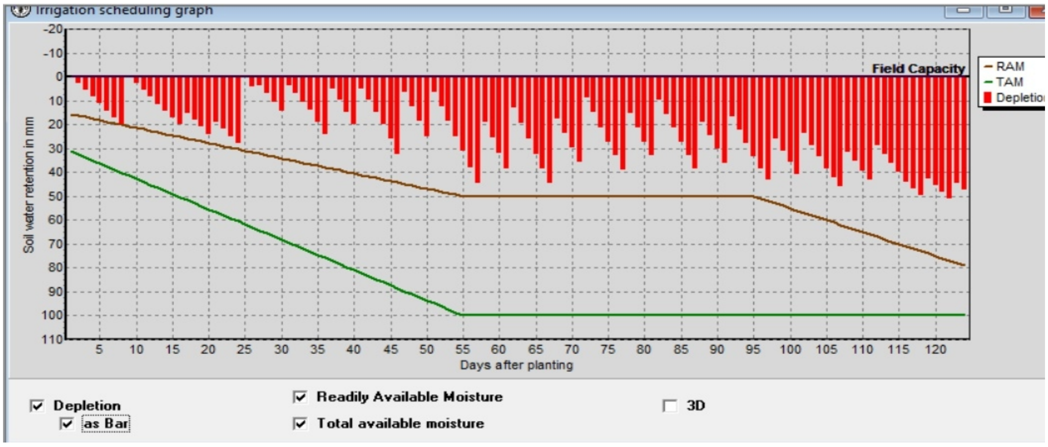


Figure 9 Irrigation scheduling graph for Maize using CROPWAT 8.0

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