

## Evaluation of Crop Water Requirements of Maize in Nigeria Using FAO Penman-Monteith Model

Aremu, A. S.<sup>1</sup>, Salami, A. W.<sup>1</sup>, Ayanshola, O. A.<sup>1</sup> and Dauda, K. A.<sup>2</sup>

<sup>1</sup>Water Resources and Environmental Engineering, Faculty of Engineering and Technology, University of Ilorin, Nigeria.

<sup>2</sup>Agricultural and Bio-Environmental Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin, Kwara State, Nigeria  
[daudaabdulkadir@yahoo.com](mailto:daudaabdulkadir@yahoo.com)

### Abstract

Irrigation practices are best done by estimating the crop water requirement in order to avoid over or under irrigation which may negatively affect crop yields. In this study, weather data spanned (1995-2015) were collected and analysed for eighteen weather stations in Nigeria. The data obtained include minimum and maximum temperature ( $^{\circ}\text{C}$ ), relative humidity (%), wind speed (km/day), sunshine (hr /day) and radiation ( $\text{MJ}/\text{m}^2/\text{day}$ ). The FAO Penman-Monteith model was used to compute the mean monthly reference evapotranspiration ( $\text{ET}_0$ ). The mean monthly  $\text{ET}_0$  estimated for each weather station by FAO Penman-Monteith model were multiplied by the average crop coefficient ( $K_c$ ) of Maize (0.60) to determine the crop water requirements. The results of the analyses showed that the mean monthly average crop water requirements ( $\text{ET}_c$ ), estimated for the six zones are 5.67, 6.95, 4.48, 3.30, 0.94, and 1.99 mm/day. The graphical relationship of mean monthly crop evapotranspiration ( $\text{ET}_c$ ) values across the period of record shows that  $\text{ET}_c$  estimates at North-East ranked 2<sup>nd</sup> with the highest values from 1996 to 2000 and North-West also have the highest values of  $\text{ET}_c$  in 1996, 2003, 2006, 2009, 2011, 2012, 2013 and 2015. The  $\text{ET}_c$  estimates at North-Central ranked 3<sup>rd</sup> with highest value in 2014 and  $\text{ET}_c$  estimates at South East and South West are in closest agreement followed by South-South  $\text{ET}_c$  estimates which has the lowest  $\text{ET}_c$  value except in 2002 that South-West has the lowest  $\text{ET}_c$  value. Therefore, this study will be useful to the agricultural water management and regional water resources planning.

**Keywords:** Irrigation, Evapotranspiration, Crop water requirement, Maize, Crop coefficient

### 1. 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. 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 (LFNL, 2003). For maximum production a medium maturity grain crop requires between 500 – 800 mm of water depending on climate (Akinmutimi, 2015).

The water need of a crop (Crop evapotranspiration) consists of transpiration and evaporation. Estimating crop water requirement by computing crop evapotranspiration is a widely used method (Ray and Dadhwal, 2000). Crop evapotranspiration ( $\text{ET}_c$ ) is 'the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12m, a fixed surface of 70 sec/m and an albedo of 0.23, closely resembling the evapotranspiration (ET) from an extensive surface of green grass of uniform height, actively growing, well-watered, and

completely shading the ground' (Suat and Dorota, 2014).

Water used by crops is predominantly lost by transpiration (T) but there are also evaporative (E) losses from the soil and from plant surfaces. The amount of water used by plants together with water losses through evaporation is called evapotranspiration (ET). Other potential areas of water loss during irrigation include lateral run off, deep drainage and leaks in the delivery system. ET is caused by an energy gradient between water in plants and soil and water in the atmosphere. This can be influenced by meteorological factors, such as wind speed, radiation and by the supply of water in the soil and on plant surfaces (Bithell and Smith, 2011).

The estimation of  $ET_c$  using ET models requires first estimating reference evapotranspiration ( $ET_o$ ) and then multiply with the proper crop coefficient ( $K_c$ ) to estimate actual crop evapotranspiration ( $ET_c$ ) (Suat and Dorota, 2014).  $ET_o$  is one of the key processes of hydrologic cycle from the soil and plant surface and transpiration from plants. The  $K_c$  is defined as the ratio of  $ET_c$  to  $ET_o$  and is used to scale the ET model to a specific crop. This coefficient depends on several factors including crop type, stage of crop growth, canopy height and density. Consequently, different crops will have different  $K_c$  coefficients (Allen *et al.*, 1998).

The number of meteorological stations where reliable data for the estimation of  $ET_o$  exist is very limited. This is especially true in developing countries where reliable collection of climatic data is limited (Droogers and Allen, 2002). However, for many locations, as is the case for Nigeria,

such meteorological variables are often incomplete or not available. The accessibility of required information is poor under Nigeria conditions because at most meteorological stations, the necessary information is not accessible, if accessible then they have missing records, this may be because of defective maintenance of the meteorological stations, low upkeep of climatic data records or lack of database management system.

Agro-meteorology plays a key role in the looming global water crisis (Smith, 2000). Appropriate strategies and policies need to be defined, including strengthening of national use of climatic data for planning and managing of sustainable agriculture and for drought mitigation.

The objectives of this study is to evaluate the crop water requirements for Maize by multiplying the crop coefficient with reference evapotranspiration, using the available twenty years weather data (1995-2015) and compare the  $ET_c$  values for the six geopolitical zones of Nigeria.

## 2. Materials and Methods

### 2.1 Study Area

Nigeria is located in the tropical zone of West Africa within Africa continent of the world, between latitudes 4°N and 14°N and longitudes 2°2'E and 14°30'E, and has a total area of 923,768 km<sup>2</sup>. Approximately 13,000 km<sup>2</sup> of the land is covered by water (1.4%) and the remaining 98.6% of the land cover ranges from thick mangrove forests and dense rain forests in the south to a near - desert condition in the north-eastern corner of the country (Kehinde, 2005). Figure 1 is a map of Nigeria showing weather stations used in the six geopolitical zones.

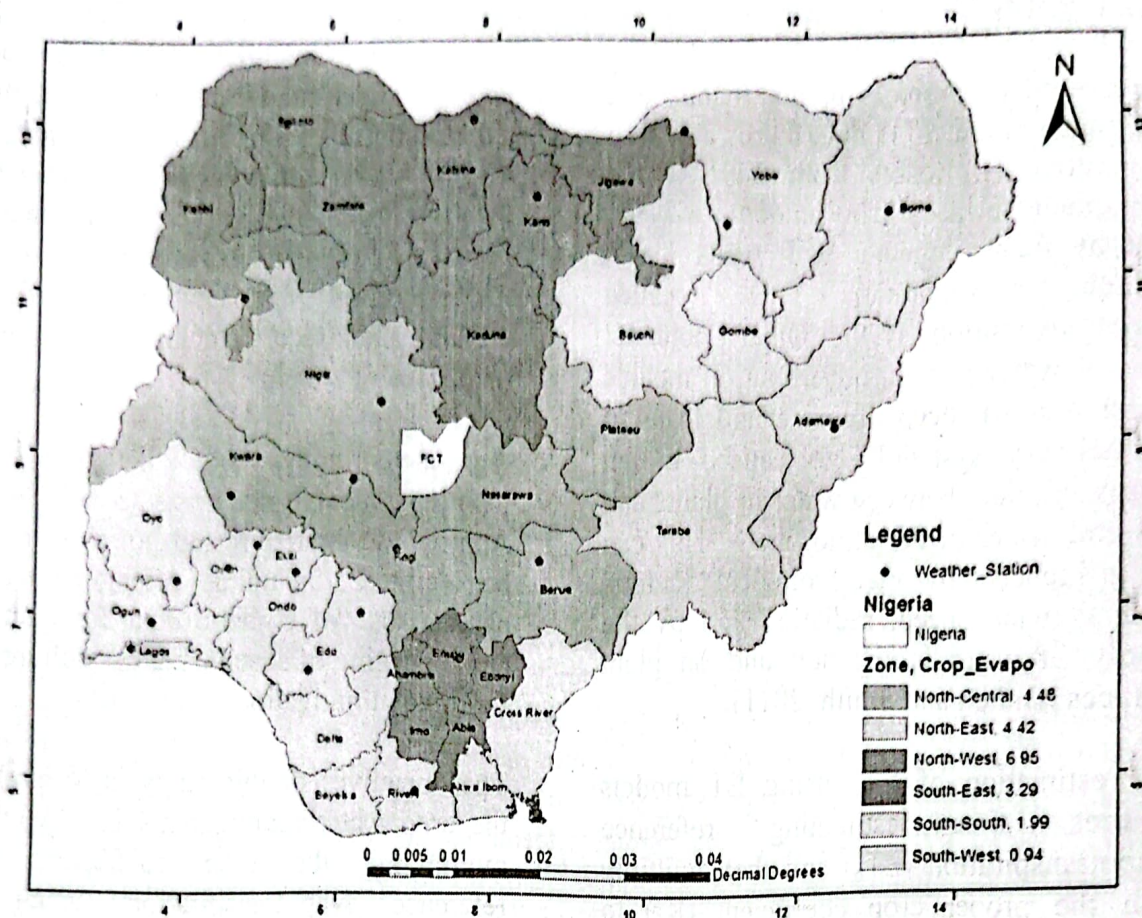


Figure 1: Map of Nigeria showing weather stations used in the six geopolitical zones

## 2.2 Data Availability

Twenty years of weather data were collected (1995-2015) from the Nigerian Meteorological Agency (NIMET), Abuja, Nigeria for the selected weather stations across the six geo-political zones making a total of twenty three stations for the study. The data involved in this study are minimum and maximum temperature ( $^{\circ}\text{C}$ ), relative humidity (%), wind speed (km/day), sunshine (hr./day) and radiation ( $\text{MJ}/\text{m}^2/\text{day}$ ).

## 2.3 Methodology

The daily weather data collected were summed and averaged to obtain the mean

daily values. Similarly, the mean daily values across the period of record for each station were averaged to obtain the mean monthly values.

The FAO Penman-Monteith model with grass reference crop (as suggested by the Food and Agriculture Organisation of the United Nations (FAO, 1990) was used for computing  $\text{ET}_0$  for each of the weather station representing the six geopolitical zones in the study area. An Excel computer program was developed to calculate  $\text{ET}_0$  for FAO Penman-Monteith model on monthly basis, using the mean monthly weather data for the eighteen weather stations. The mean

monthly  $ET_o$  estimated for each weather station were multiplied by the average crop coefficient ( $K_c$ ) of Maize (0.60) to determine the crop water requirements.

The crop water requirement per month for each representative weather station in the study area has been calculated with the following equation as recommended by Allen *et al.* (1998).

$$ET_c = ET_o \times K_c \quad (1)$$

where,

$ET_c$  = Crop evapotranspiration (mm/day),

$ET_o$  = Reference evapotranspiration (mm/day), and

$K_c$  = Crop coefficient.

Similarly, the mean monthly  $ET_c$  computed by FAO Penman-Monteith model for the six zones were graphically compared to identify the differences in evapotranspiration losses across the study area.

### 3. Results and Discussion

The average crop evapotranspiration ( $ET_c$ ) values obtained are presented in Table 1. The average  $ET_c$  estimates across the six weather stations in the study area ranged from the lowest value of 5.8 mm/day for South-South in the year 2014 to highest value of 27.8 mm/day for North-East in the year 1997. The lowest  $ET_c$  estimates experienced at North-East, North-West, North-Central, South-East, South-West and South-South are 11.4 mm/day in 2015, 12.3 mm/day in 2010, 9.8 mm/day in 1997, 7.3 mm/day in 1996, 7.1 mm/day in 2013 and 5.8 mm/day in 2014, respectively. The highest  $ET_c$  estimates recorded at North-East, North-West, North-Central, South-East, South-West and South-South are 27.8 mm/day in 1997, 16.8 mm/day in 2013, 15.8

mm/day in 2014, 13.4 mm/day in 2009, 11.3 mm/day in 2012 and 9.3 mm/day in 2002, respectively. The mean monthly average  $ET_c$  estimates by the FAO Penman-Monteith model for the North-East, North-West, North-Central, South-East, South-West and South-South are found to be; 15.8, 14.1, 12.3, 10.3, 9.1, and 7.4 mm/day, respectively.

Irrigation planning requires determination of crop water requirements and a dependable source of water supply. The results in Table 1 have provided valuable data and information to the water management agencies, irrigators, farmers, extension personnel, and researchers in terms of which crop water requirements to select and use for more accurate estimation of irrigation water requirement in all the six geopolitical zones of Nigeria to prevent wastage of water resources due to over irrigation or under irrigation that can affect crop yields, and for water analyses that can aid in more efficient and sustainable use of water resources.

This study serves to illustrate how the weather data can be integrated with ET model (FAO Penman-Monteith) to address the relationships between crop water requirements and availability of water resources for irrigation practices in order to provide more realistic information in support of irrigation planning and management in Nigeria. The estimated crop water requirements are useful to the precise agricultural water management, zonal water resources planning and other hydrological related studies that can aid in more proficient and viable water resources management.

The crop evapotranspiration ( $ET_c$ ) values obtained are plotted against the year of

Table 1: Average crop evapotranspiration ( $ET_c$ ) (mm/day) for three weather stations in each zone across the six geopolitical of Nigeria

| Year | North-East | North-West | North-Central | South-East | South-West | South-South |
|------|------------|------------|---------------|------------|------------|-------------|
| 1995 | 16.9       | 15.5       | 13.3          | 9.7        | 7.9        | 9.0         |
| 1996 | 12.6       | 13.7       | 10.6          | 7.3        | 8.4        | 6.9         |
| 1997 | 27.8       | 12.8       | 9.8           | 10.2       | 9.2        | 8.2         |
| 1998 | 24.7       | 14.5       | 11.2          | 8.9        | 7.5        | 7.6         |
| 1999 | 20.5       | 13.7       | 10.6          | 7.9        | 10.4       | 6.2         |
| 2000 | 19.6       | 17.2       | 14.5          | 11.5       | 11.2       | 6.9         |
| 2001 | 16.8       | 12.4       | 10.1          | 12.3       | 8.6        | 7.3         |
| 2002 | 16.0       | 12.6       | 11.7          | 10.1       | 6.8        | 9.3         |
| 2003 | 14.7       | 16.4       | 12.9          | 9.8        | 9.4        | 9.0         |
| 2004 | 17.3       | 16.3       | 13.1          | 7.8        | 8.6        | 7.3         |
| 2005 | 13.6       | 13.1       | 12.6          | 11.4       | 10.4       | 7.3         |
| 2006 | 12.6       | 14.6       | 11.9          | 9.5        | 9.3        | 6.0         |
| 2007 | 13.6       | 12.5       | 10.8          | 10.2       | 9.7        | 6.8         |
| 2008 | 14.9       | 12.7       | 10.6          | 11.1       | 9.2        | 5.9         |
| 2009 | 12.5       | 13.6       | 12.5          | 13.4       | 7.8        | 6.4         |
| 2010 | 13.6       | 12.3       | 13.5          | 10.6       | 9.7        | 7.8         |
| 2011 | 12.3       | 13.6       | 12.7          | 11.5       | 10.5       | 9.2         |
| 2012 | 13.6       | 14.7       | 13.6          | 12.0       | 11.3       | 7.6         |
| 2013 | 14.2       | 16.8       | 12.5          | 10.4       | 7.1        | 6.4         |
| 2014 | 12.8       | 13.3       | 15.8          | 11.2       | 8.8        | 5.8         |
| 2015 | 11.4       | 13.8       | 13.0          | 10.2       | 9.6        | 8.1         |
| Mean | 15.8       | 14.1       | 12.3          | 10.3       | 9.1        | 7.4         |

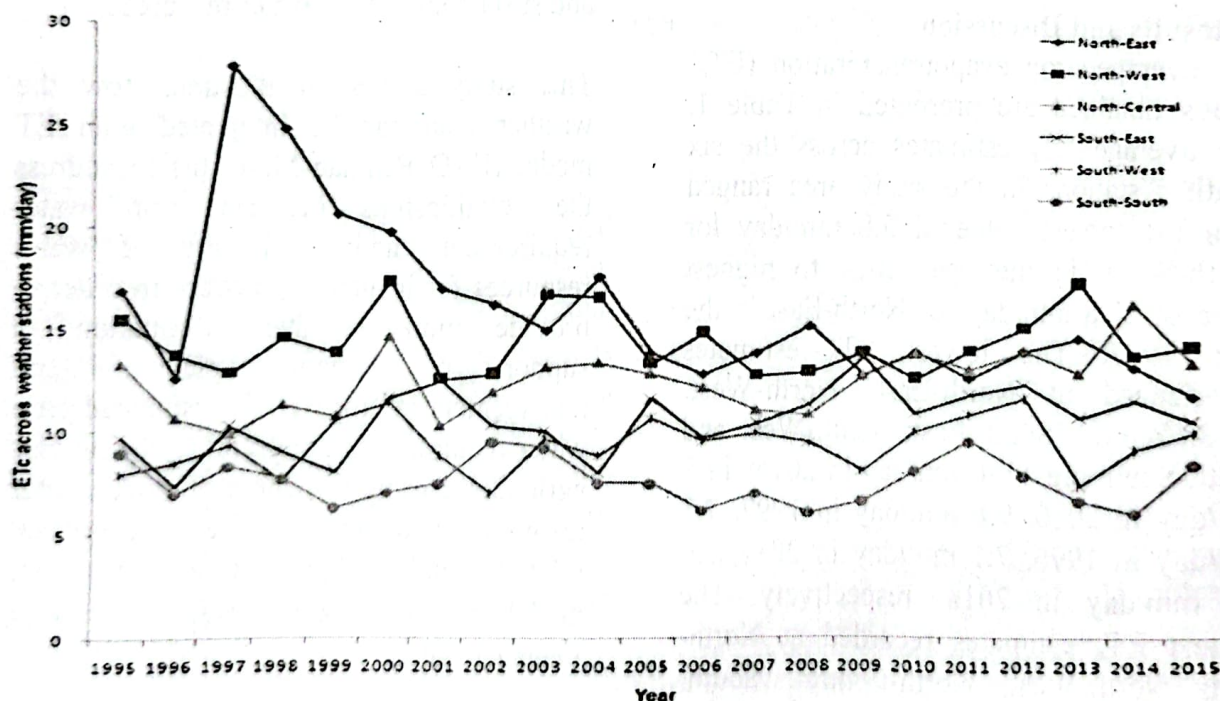


Figure 2: Mean monthly  $ET_c$  by FAO Penman-Monteith model for six weather stations

record across the six weather stations as shown in Figure 2. It is observed that  $ET_c$  estimates at North-East ranked 2<sup>nd</sup> with the highest values from 1996 to 2000 and North-West also have the highest values of  $ET_c$  in 1996, 2003, 2006, 2009, 2011, 2012, 2013 and 2015. The  $ET_c$  estimates at North-Central ranked 3<sup>rd</sup> with highest value in 2014 and  $ET_c$  estimates at South East and South West are in closest agreement followed by South-South  $ET_c$  estimates which has the lowest  $ET_c$  value except in 2002 that South-West has the lowest  $ET_c$  value.

#### 4. Conclusion

The FAO Penman-Monteith model was used to compute the mean monthly reference evapotranspiration ( $ET_0$ ) and multiplied by crop coefficient ( $K_c$ ) of Maize to obtain the mean monthly crop water requirement ( $ET_c$ ) for the six geopolitical zones of Nigeria. The mean monthly average  $ET_c$  estimated for the six weather stations ranged from 7.4 mm/day for South-South to 15.8 mm/day for North-East.

The mean monthly average  $ET_c$  estimated by the FAO Penman-Monteith model for the North-East, North-West, North-Central, South-East, South-West and South-South are found to be; 15.8, 14.1, 12.3, 10.3, 9.1, and 7.4 mm/day, respectively. Graphical relationship of mean monthly crop evapotranspiration ( $ET_c$ ) values show that  $ET_c$  estimated at North-East ranked 2<sup>nd</sup> with the highest values from 1996 to 2000 and North-West also have the highest values of  $ET_c$  in 1996, 2003, 2006, 2009, 2011, 2012, 2013 and 2015. The  $ET_c$  estimates at North-Central ranked 3<sup>rd</sup> with highest value in 2014 and  $ET_c$  estimates at South East and South West are in closest agreement followed by South-South  $ET_c$  estimates

which has the lowest  $ET_c$  value except in 2002 that South-West has the lowest  $ET_c$  value. This study therefore gave values of  $ET_c$  estimations in the six geopolitical zones of Nigeria and useful to the irrigation water management and regional water resources planning.

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