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Determination of Crop Growth Specific Coefficients and Water Requirement of Okra (*Abelmoschus esculentus*) under Greenhouse Conditions in Ibadan, Nigeria

OYEDOKUN, JO; *OMOBOWALE, MO; RAPHAEL, OD

Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria
[2]Landmark University, Omu-Aran, Nigeria

**Corresponding Author Email: mo.omobowale@ui.edu.ng*
Co-Authors Email: joanoyedokun@gmail.com; rafdaolu2@gmail.com

ABSTRACT: This study was conducted to determine crop growth specific coefficients for Daily Consumptive Use (CU) and growth stage-specific crop coefficients (K_c) and water requirement of Okra (*Abelmoschus esculentus*) under greenhouse conditions using soil samples from Ibadan, Nigeria, using standard techniques. The Kc values determined over the growing season of Okra were 0.9, 0.85, and 0.7 respectively representing Kc initial, Kc mid-season, and Kc late season, respectively. The observed Kc was validated using relevant statistical methods. The consumptive use (CU) of Okra (*Abelmoschus esculentus*) was 380.35 mm, while the reference evapotranspiration increased from July to September from 6.32 to 6.72mm/day. The crop factor per month was highest in July, 1.78 and decreased to 1.17 in August, and was the lowest in September, 0.83. It is inferred that the application of growth stage-specific Kc will assist in irrigation management and would serve as a useful guide for precise water applications in greenhouses around the humid tropics.

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Okra (*Abelmoschus esculentus*) is widely recognized as a highly popular and frequently consumed vegetable (Kumar *et al*., 2010). Belonging to the family Malvaceae, it is commercially cultivated and commonly referred to as lady's fingers. Okra cultivation typically requires well-drained, fertile soil and a warm climate to thrive. The process involves planting the seeds directly in the ground, as they are sensitive to transplanting. Once established, okra plants require regular watering and occasional fertilization to promote healthy growth (Davis, 2022). With its origins traced back to Ethiopia, today, it is cultivated in various climates, including tropical, subtropical, and warm temperate regions across the globe (Priya, 2014). Beyond being a flavorful addition to meals, okra holds remarkable nutritional value, fulfilling the demand for vegetables, and possesses significant medicinal properties with extensive pharmacological applications. In agriculture, understanding the concept of crop water requirement is fundamental. It represents the amount of water necessary to compensate for evapotranspiration losses from cultivated fields (Wanniarachchi and Sarukkalige, 2022). Though crop evapotranspiration and crop water requirement values are identical, the former signifies water lost through evapotranspiration, while the latter pertains to the required water supply (Allen *et al*., 1998). Properly managing irrigation is crucial in optimizing water resources for agricultural purposes. The irrigation water requirement encompasses not only the difference between crop water requirement and effective precipitation but also accounts for additional water needed for salt leaching

**Corresponding Author Email: mo.omobowale@ui.edu.ng* and compensating for uneven water distribution (Jha *et al.*, 2022).

Water's significance in crop production cannot be overstated; it plays a pivotal role in ensuring food security (Shree, 2023). However, water scarcity poses a significant challenge to agricultural production, and mismanagement of the limited available water further exacerbates the problem (Akinbile and Sangodoyin, 2011). To effectively address this issue, precise water application, especially during droughts, is crucial for water conservation. Emphasizing the importance of proper irrigation, it has been observed that irrigated agriculture contributes substantially to stabilizing agricultural output in numerous countries worldwide. Drip irrigation systems have played a key role in increasing crop yield and enhancing quality by delivering the required amount of water efficiently (Ewemoje *et al.*, 2006). Omobowale (2020) defined Controlled Environment Agriculture as the alteration of the environmental conditions to achieve a desired conducive environment for crop and animal production. He stated further that cultivation of crops in greenhouses can be independent of the macro-environmental conditions which in turn enhances multiple harvest as compared to the seasonal open field agriculture. Various forms of Controlled Environment Agriculture include hydroponics, aeroponics, aquaculture and aquaponics. Mijinyawa and Osiade (2011) reported that in a greenhouse, all plant growth factors can be controlled and maintained at optimum level all year round, thereby making it possible to cultivate crops throughout the year. To achieve optimal irrigation design, planning, and scheduling, a comprehensive understanding of crop water usage and crop coefficients of the intended crops is essential (Jewpanya *et al.*, 2022). By recognizing the crop water requirements and the intricate relationship between water supply and agricultural output, farmers can make informed decisions and implement sustainable practices to support both their crops' health and overall food production. Given the growing interest and investment in greenhouse agriculture in Nigeria, this study was carried out to determine crop growth specific coefficients (K_c) and water requirement of Okra under greenhouse condition using soil samples from Ibadan, Nigeria.

MATERIALS AND METHODS

Soil sample Collection: A representative soil sample was collected from the study site and immediately taken to the laboratory for analysis. These samples have all the characteristics of the soil on the farm. The soil samples were taken to the Soil Science Laboratory of the University of Ibadan and the analyses were carried out: pH (H_2O), organic carbon, total nitrogen, available phosphorus, calcium, magnesium, potassium sodium, manganese, iron, zinc, sand, silt and clay. The soil samples were measured in weight.

The weight of the soil was recorded, and bulk density was calculated using the method described by Fasinmirin and Adesigbin (2012) which is expressed as:

$$\text{Bulk Density } (\rho b) = \frac{Ws}{Vs} \qquad (1)$$

Where W_s = Weight of oven-dried soil; V_s = Unit volume of the soil

Total porosity (% pore space) was estimated using the same soil samples collected for soil bulk density. The total porosity of the soil was calculated from bulk density assuming a particle density of 2.65 mg/m^3 following the method described by (Adesigbin and Fasinmirin, 2011).

$$TP\ (\%) = \left[\frac{D_s}{D_p}\right] * 100 \qquad (2)$$

Where: TP= total porosity (%), Dp = Particle density (g cm^{-3}) Ds = Bulk density (g cm^{-3}),

Reference Evapotranspiration Estimation: Climate data were collected from the Weather Station at the Agricultural and Environmental Engineering Department, University of Ibadan. The station collects data such as; dew point temperature, relative humidity, precipitation, reference evaporation, solar radiation, wind speed, air temperature, and barometric pressure. These parameters were used to estimate the reference evapotranspiration. ET_o using FAO- Penman Monteith:

$$\text{ETo} = \frac{0.408\Delta(\text{Rn}-\text{G})+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34u2)} \qquad (3)$$

Where: ET_o= Reference evapotranspiration (mm day^{-1}); R_n = net radiation at the crop surface (MJ m^{-2}day^{-1}); G= soil heat flux density (MJ m^{-2} day^{-1}) = 0 for daily calculations of ET as G is small on daily basis; T= mean daily air temperature at 2 m height (℃); $\underline{U_2}$ =wind speed at 2 m height (ms^{-1}); e_s = saturation vapor pressure (kPa);
e_a = actual vapor pressure (kPa); (e_s-e_a) = saturation vapor pressure deficit (kPa); Δ= gradient of the saturated vapor pressure-temperature curve (kPa℃$^{-1}$), and the γ= psychometric constant (kPa℃$^{-1}$). (Singh *et al.,* 2016)

Construction of weighing lysimeter: The lysimeter used for the experiment was made from a locally sourced cylindrical plastic drum with a diameter of 600mm and a circular cross-sectional area of 0.28m^2. The lysimeter tank has a depth of 450mm with a wall thickness of 3 mm. The lysimeter depth is appropriate as it permits normal root development for the studied plant okra *(Abelmuschus esculentus)*, without hindrance. The plastic material with which the lysimeter was made helped to minimize heat transfer by conduction down the lysimeter walls.

The lysimeter depth is appropriate as it permits normal root development. The soil was obtained from a nearby virgin land that was previously cultivated. The soil was cautiously collected and loaded into the lysimeter to minimize disturbance. The drain system allows for any excess water accumulated in the inner tank to be eliminated if the need arises. There is also a rectangular plank base frame to guide the automobile tube on the interior as it is being loaded and to serve as a point of attachment for the graduated glass tube (burette). The frame was made from the pipe to avoid the formation of shade over the plant in the soil tank.

Estimation of consumptive use of okra (Abelmuschus esculentus): In order to estimate the consumptive use of okra, daily evapotranspiration values for the Okra (*Abelmuschus esculentus)* in the lysimeters during the months of July through September were recorded and analyzed. The evapotranspiration rate was measured by three weighing lysimeters. The difference in weight from one time period to the next gave an estimate of the amount of water that evaporated and transpired. The changes in water content from one day to the next were determined by calculating the difference in lysimeter weights between 7:00 am and 8:00 am on consecutive days. The time period was chosen before the evapotranspiration for the next day began. The expression used for the computation of daily crop water use is given as in (Igbadun 2012):

$$\mathrm{CUi} = \mathrm{Ii} - \mathrm{Rfi} - \mathrm{Di} - [(\mathrm{Wi} + 1 - \mathrm{Wi}) * \mathrm{cf}] \qquad (4)$$

Where, I_i = Irrigation water (mm) of day i applied, Rf_i = Runoff (mm) of day i, D_i = Drainage (mm) of day i, W_i = Weight of the lysimeter soil on day i, W_i+1= Weight of the lysimeter soil the next day at an interval of 24 h,
CU_i = Crop water use of day i, C_f = A factor converting weight to equivalent depth of water.

Any of these with minor effects are neglected and assumed zero. The differences in the weight of the lysimeter tank shown by the alteration in water level in the burette thus obtained on a daily basis were translated to the depth of water in mm/day using a factor of 6.04 as reported in (Igbadun 2014). This factor was based on the surface area of the lysimeter tank and the density of water.

Development of crop coefficient (Kc) curve: To estimate the reference evapotranspiration (ET_c), the data generated by the weather station were used as input into the crop water model (CROPWAT 8.0). The ratio of the daily crop evapotranspiration (ET_c) and reference evapotranspiration (ET_o) was used to calculate the crop coefficient for the different growth stages. ET_o The daily crop coefficient Kc values were then plotted against the day after planting, (Raphael *et al*., 2018). The four growth stages based on the description of the signs of the growing stages were noted and recorded. The indicators of stages were: (i)initial stage: planting up to 10% of ground cover; (ii) development stage: from the end of the initial stage up to effective full cover or to 80% of ground cover; (iii) Mid stage: from 80% of ground cover (effective full cover) to maturity, indicated by yellowing of leaves, leaf droppings, and browning of fruits (iv). Late/end: Maturity to harvest. For the final phase, the Kc obtained on the day of harvest was considered. Time for other phenological changes in plants was also noted.

RESULTS AND DISCUSSION

Physicochemical properties of the soil in the study area: The data of the physical and chemical composition of the soil (Table 1) revealed that the soil of the plot was Loamy sand, containing 794.0g/kg, 144.0g/kg, and 62.0g/kg of sand, silt, and clay respectively. The nutrient content was found to be low but was later improved by adding organic manure to raise its level.

Table 1: Mean of Soil Physical and Chemical Properties of the study site

Parameters	Mean
pH (H_2O)	6.80
Organic Carbon g/kg	24.49
Total Nitrogen g/kg	2.25
Available Phosphorus mg/kg	14.40
Exch Acidity (cmol/kg)	0.55
Ca (cmol/kg)	1.57
Mg (cmol/kg)	0.99
K (cmol/kg)	0.17
Na (cmol/kg)	0.14
Mn (mg/kg)	22.65
Fe (mg/kg)	9.82
Cm (mg/kg)	0.82
Zn (mg/kg)	3.02
Sand (g/kg)	794.0
Silt (g/kg)	144.0
Clay (g/kg)	62.0
Bulk density (g/cm^3)	1.67
Sat Hydraulic Conductivity %Vol	36.8

Calibration of hydraulic lysimeter: The observed pattern is that increase in cumulative weight causes an increase in the level of water in the burette but results in a reduction in the value of readings on the burette. Burettes are usually graduated from zero ml at the top and the 50ml at the bottom, hence the negative slope value in the regression equation. Figure 1 illustrates the simple regression between the Cumulative Loads in the Lysimeter, the impact of the weight observed in the fluctuation of water in the graduated glass tube (Burette) experiment, and the calculation of the regression parameters. A high linearity of data was verified, indicating a close relationship in the loading and unloading processes that occurred between the observed and measured values estimated in the lysimeters, which gave the lysimeters the ability to adequately detect weight differences with high sensitivity in determining the water balance components in the soil-plant-atmosphere system.

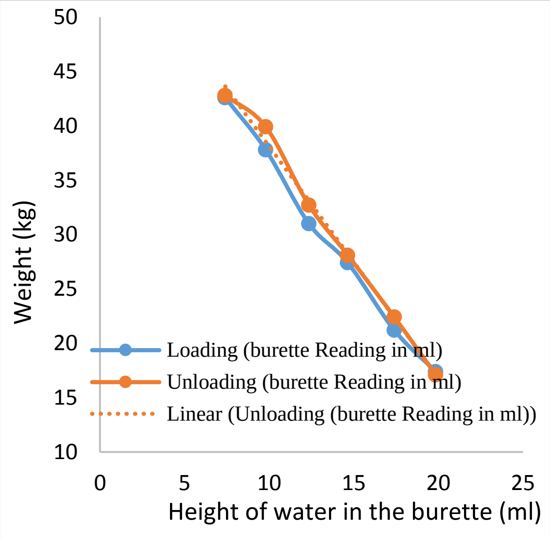

Fig 1: Lysimeter Calibration Curve

Measured crop coefficient Kc of maize and okra: It is difficult to estimate ET_c values for okra in any region. Panigrahi and Sahu, (2013) also noted that the estimated Kc value from measured ET_c values for okra under partial irrigation, and under full irrigation is very limited worldwide. Hence from this study, the Kc value obtained for the initial, mid, and final stages of the growth of *Abelmoschus esculentus* was read from the quadratic crop coefficient curve with polynomial regression equation and the R-squared value as in (Raphael *et al.*, 2018) and presented as Figure 2 and found to be 0.78, 1.09 and 0.88 respectively. The lengths of the growth stages were determined based on the crop phenological phase and the Kc curve.

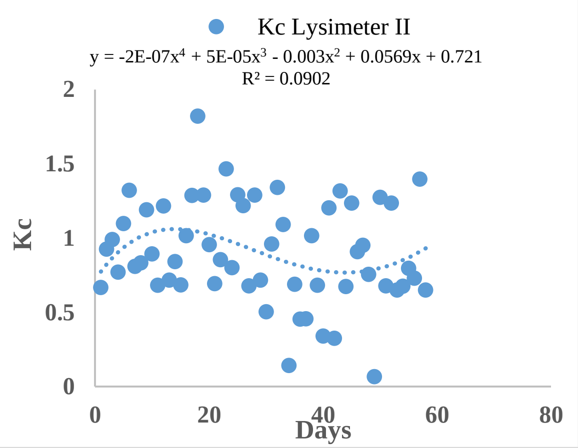

Fig 2: Days vs Kc II (Polynomial Order 4)

Consumptive Use of Okra: The climatic data collected from the Campbell weather station were substituted in the FAO Penman-Monteith equation to calculate the daily ET_o for the study period of July to September 2021 for both inside the greenhouse and outside and the results are shown in Table 2. The daily measured Consumptive use values for *Abelmoschus esculentus* in the lysimeters for the growing season (July to September) were recorded and the analyzed results is shown in Table 2.

Table 2: Table of value of ET_c for the growing season of *A. esculentus* in the study site

Month	July	August	September
ETo (mm/day)	6.32	6.76	6.72
Growth Stage	Initial	Mid	End
Kc for growth stage	0.9	0.85	0.7
ETcrop (mm/day)	6.32	6.76	6.81
ETcrop (mm/month)	82.19	209.66	88.5

From Table 2, the total crop water needed for the whole growing season of Okra is 380.35 mm while the reference evapotranspiration increased from July to September from 6.32mm/day to 6.72mm/day. In the greenhouse, the ET value is usually lower due to the reduced evaporative demand and decrease in solar radiation inside the greenhouse and the windspeed is nearly zero. However, there is only a slight difference in the crop evapotranspiration values measured by the lysimeter and the reference evapotranspiration. The crop factor per month was highest in July, 0.9, decreased to 0.85 in August, and was the lowest in September, 0.7. This is to respond to the increase in ETo to keep the ETc high and vice versa. Likewise, the daily crop water needs increased from 6.32mm/day in July to reach its peak at 6.81mm/day in September. The monthly crop water need for okra increased from 82.19mm/month in July to attain its peak of 209.66mm/month in August before declining to 88.5mm/month in September.

Conclusion: Findings from this study reveal that the water consumption of okra, measured as evapotranspiration rates, notably increases with higher levels of solar radiation, air temperature, and vapor pressure deficit. One key observation is the increased water usage during the mid-stage, also known as the flowering stage. During this phase, okra plants are actively growing, producing flowers, and preparing for fruit production, leading to heightened water demand. In contrast, the initial stage, where the focus is on root establishment and initial leaf development, experiences lower water consumption due to the plant's smaller size and emphasis on the establishment. In the final stage, when okra is in the fruiting and harvesting phase, water remains essential, although the demand is not as high as in the mid-stage. However, it is worth noting that there is only a minor difference between crop evapotranspiration values measured using the lysimeter and reference evapotranspiration.

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