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Original Research Article

Modelling Irrigation Water Requirements at Physiological Growth Stages of Okra Life Cycle Using CROPWAT Model for Derived Savannah and Humid Forest Zones of Nigeria

OrevaOghene Aliku, Suarau Odutola Oshunsanya

Department of Agronomy, Faculty of Agriculture and Forestry, University of Ibadan, Ibadan, Nigeria

Abstract

Accurate quantification of irrigation water requirement at different physiological growth stages of okra (*Abelmoschus esculentus* L.) life cycle is important to prevent over or under irrigation. Field experiments were therefore initiated to model okra irrigation water requirements at the four physiological growth stages of okra life cycle using CROPWAT model. Derived savannah 1 (DS1), derived savannah 2 (DS2) and humid forest (HF) occupying 493.36 ha, 69.83 ha and 305.25 ha respectively were used. Some selected soil physical properties coupled with weather parameters were used to develop irrigation water requirements for okra crop. In DS1, the estimated crop co-efficient (K_c) values were 0.30, 0.52, 0.84 and 0.70 for the germination, crop growth, flowering and fruiting stages, respectively. Corresponding K_c values in DS2 were 0.30, 0.54, 0.90 and 0.84 and in the HF were 0.30, 0.56, 0.87 and 0.86 respectively. Daily crop evapo-transpiration values ranged from 1.16 to 3.36, 1.17 to 3.64, and 1.2 to 3.38 mm day^{-1} for DS1, DS2 and HF respectively with significant ($p = 0.05$) peak at the flowering stage for the three locations. Sustainable okra cultivation would require maximum daily irrigation water at flowering stage (reproductive phase) to meet the crop physiological needs and evapo-transpiration demand of the atmosphere.

Keywords: crop co-efficient; crop evapo-transpiration; irrigation schedule; okra.

INTRODUCTION

Over the past decade, many countries around the world have witnessed a growing scarcity of water and competition for water among different users (domestic, municipal, industrial, and environmental purposes), with increase in population resulting in higher demand for food. The need for increase in food production to match the population growth is becoming a major concern to all governments of the world. All-season crop production programmes are only possible in the presence of sustained availability of adequate moisture. Irrigation practice, therefore, becomes a most reasonable option as it is able to assist agriculture in areas with either low amount of rainfall or erratic rainfall distribution pattern. Hence, this ever increasing need has resulted in the transformation from arid land farming to irrigated agriculture relying, to a great extent, on the ground water as the main source of irrigation water. The groundwater is a non-renewable resource in the fragile arid ecosystems of the world, and its exploitation calls for an environmentally compatible and ecologically sustainable water resource management (Saif-ud-din et al., 2004; FAO-Aquastat, 2009).

The groundwater exploitation, if not managed judiciously, will result in environmental degradation of the fragile arid ecosystem and increase in the frequency and intensity of extreme weather events, such as droughts and floods (El-Quasy, 2009), which may cause economic, social and environmental effects (Abu Zeid and Abdel Megeed, 2004; Ouda et al., 2011). Under such circumstances, adoption of optimum water management practices is very important for attaining national food and water security. In agricultural water management, significant improvements can be achieved through irrigation scheduling. Irrigation schedule deals with when and how much to irrigate a crop. Efficient use of water resources can be made possible through the assessment of crop water requirements and proper scheduling of irrigation. Temporal prediction of soil moisture and evapotranspiration plays a crucial role in irrigation water management (Abdelhadi et al., 2000; Ali et al., 2007) and drought monitoring (Narasimhan and Srinivasan, 2005). This can be achieved using information derived from detailed irrigation evaluation study. According to Ojanuga (1979), several irrigation projects that disregarded these studies have failed because they could not predict salinity and drainage problems, among others, that soon developed after the inception of the projects. The results of such study form the basis for the decision to either go ahead or not to invest. It has been demonstrated that optimal irrigation scheduling requires accurate estimation of daily evapo-transpiration (ET_c) (Kamel et al., 2012). Quantitative irrigation scheduling methods are based on three approaches, namely, crop monitoring, soil monitoring and water balance technique. However, most irrigation schedules and crop water requirement studies have been based on crop monitoring and water balance technique, which provides little information on the relevance of soil data to irrigation schedules. Methods based on estimated

Table 1. Summary of sites description

Parameter	Location		
	Derived savannah 1 (Ogun State)	Derived savannah 2 (Oyo State)	Humid forest (Edo State)
Area (ha)	493.36	69.83	305.25
Rainfall (mm/year)	1150	1200 – 1400	1200
Temperature range (°C)	20.0 – 34.7	22 – 33	15 – 34
Geology	Eocene sediment	Crystalline basement complex rocks	Alluvial kandiudult deposits of River Niger
Slope (%)	≤ 2	≤ 4.5	2 – 3%
Drainage	Well-drained	Fairly drained	poorly-drained
Agro-ecology	Derived savannah	Derived savannah	Humid forest
Type of vegetation	Secondary forest	Secondary forest	Secondary forest
Soil series (area coverage)	Owode series (49.336 ha), Igbessa series (24.663 ha), Agege series (39.4688 ha), Yanpere series (157.8752 ha), Iweke series (14.8008 ha), Alagba series (207.2112 ha)	Adio series (15.38 ha), Oyo series (9.44 ha), Temidere series (23.07 ha), Owutu (22.01 ha)	Ipaja (76.31 ha), Katcha (30.53 ha), Iweke (97.68 ha), Orlu (82.42 ha), Kulfo (18.32 ha)

ratio of irrigation water to cumulative pan evaporation (Aiyelaagbe and Ogbonnaya, 1996), open pan evaporation rate (Singh, 1987; Manjunath et al., 1994) and soil moisture depletion (Home et al., 2000) have been widely used for scheduling irrigation.

However, these methods are expensive and tedious, and are best done in research settings. Allen et al. (1998) reported that factors such as soil salinity, poor soil fertility, presence of hard or impenetrable soil profiles and soil water content may reduce evapo-transpiration (ET). According to Van Genuchten and Leij (1992), difficulty in assessing the water characteristics of soils and measuring soil moisture under cropped surfaces has led to the often use of models. According to Phene et al. (1990), models that employ the use of water balance techniques in combination with the analysis of historical climate and soil data have been recommended for irrigation scheduling. CROPWAT software has been widely used for predicting reference evapotranspiration, crop evapotranspiration, irrigation scheduling, deficit irrigation scheduling and cropping patterns in Greece, Taiwan, USA, Morocco, Turkey, Zimbabwe and Pakistan (George et al., 2000; Anadranistakis et al., 2000; Sheng-Feng et al., 2006; Kang et al., 2009; Nazeer, 2009; Mimi and Jamous, 2010; Stancalie et al., 2010; Mhashu, 2007).

Ogun, Oyo and Edo States are agriculturally based areas which involve the cultivation of a wide range of crops such as okra, maize, yam, cassava, potato etc. Like most Southern States in Nigeria, with near optimum rainfall, Ogun, Oyo and Edo States have both dry and wet seasons characterised with an occasionally erratic rainfall distribution pattern. In spite of all these, there is no known functional irrigation scheme for okra crops produced in these regions. Furthermore, studies on possible effects of variation in soil characteristics on crop water requirement for okra in these regions are also limited; while understanding of such effects is important to aid water resources management as Ojanuga (1979) attributed the agricultural failure in Nigeria to refusal to incorporate a detailed soil survey into the overall irrigation investigations. Hence, the objective of this study was to predict crop water requirements and irrigation schedules for various stages of okra life cycle for derived savannah and humid forest agro-ecological zones of Nigeria.

MATERIALS AND METHODS

Study area

The field studies were conducted in the three locations; derived savannah1 (Ogun state), derived savannah2 (Oyo state) and Humid forest (Edo State) and CROPWAT 8.0 model was used to model okra crop water requirement and irrigation water requirement. General description of the study areas are presented in Table 1.

CROPWAT model description

CROPWAT is a collection of modules that integrates several models necessary to predict crop water requirement (CWR), irrigation water management and irrigation scheduling (Smith 1991). It utilizes the FAO modified Penman–Monteith method to predict reference evapotranspiration (ET_o), crop evapotranspiration (ET_c) and irrigation water management (FAO, 1998; Smith, 1991). It is to be noted that ET_c represents the amount of water that crop losses due to evapotranspiration while CWR represent the amount of water to be supplied (Mhashu, 2007).

CROPWAT data input and application

Modelling of crop evapotranspiration and irrigation water requirements were carried out with inputs of climatic, crop and soil data. The model required the following data for estimating crop water requirements (CWR).

Climatic data

In calculating the reference evapotranspiration, the study utilised 10 years (2004 – 2014) of monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data obtained from the CLIMWAT 2.0 database as no such data were available in the study locations of the three agroecological zones (Anaç et al., 1999). Figure 1 shows the CLIMWAT 2.0 local station distribution in Nigeria. The ET_o was calculated from climatic data using the FAO Penman-Monteith method as described by Allen et al. (1998) in Equation (1):

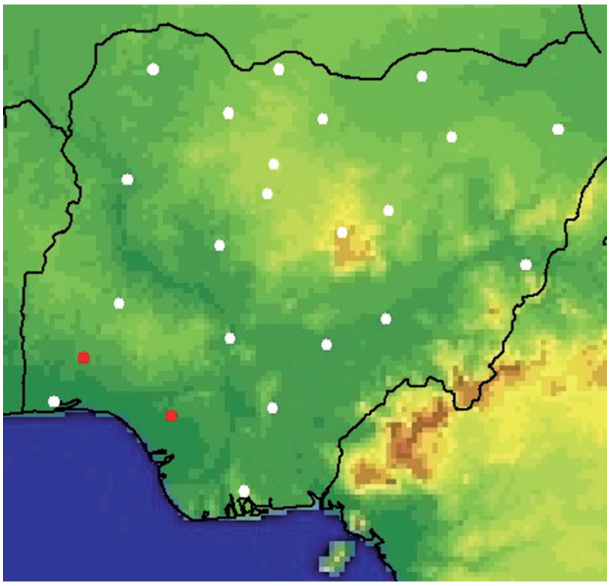

Fig. 1: Local Station Distribution in Nigeria
Note: ● : Satelite Stations Derived Savannah (Ogun and Oyo States) and Humid Forest (Edo State) respectively;
Source: CLIMWAT 2.0

$$ET_o = \frac{0.408\Delta (R_n - G) + \gamma [900/ (T + 273)]\, u_2 (e_s - e)}{\Delta + \gamma (1 + 0.34u_2)} \qquad (1)$$

Where: R_n = Net radiation at the crop surface (MJ/m²/day)
G = Soil heat flux density (MJ/m²/day)
T = Mean daily air temperature at 2m height (°C)
U_2 = Wind speed at 2m height (m/sec)
e_s = Saturation vapour pressure (KPa)
e_a = Actual vapour pressure (KPa)
Δ = Rate of change of saturation specific humidity with air temperature (KPa)
γ = Psychrometric constant ($\gamma \approx 66$ KPa)

Rainfall data

The annual rainfall range of the study locations are presented in Table 1, with average maximum monthly rainfall occurring in July, and the minimum occurring in December and January in all the locations. The average monthly rainfall data for a period of 10 years (2004 – 2014) were obtained from meteorological stations in each study location, respectively for the estimation of effective rainfall. Effective rainfall is the amount of rainfall that is actually added and stored in the soil during the growing period of a crop, and it is available to meet the crop's consumptive water requirements (Farmwest, 2013). Effective rainfall was calculated using the United States Department of Agriculture, Soil Conservation Service (USDA-SCS) method as described in FAO publication (Dastane, 1978). This is the default method for calculation of effective rainfall in the CROPWAT model (Marica, 2013). Hence, in assessing the CWR for okra over the cultivated area, the effective rainfall was calculated as described by Sheng-Feng et al. (2006):

$$P_{eff} = \frac{P_{tot} \times 125 - 0.2P_{tot}}{125} \qquad (2)$$

$$P_{eff} = (125 + 0.1 \times P_{tot}) \qquad (3)$$

Where, P_{eff} = effective rainfall (mm) and P_{tot} = total rainfall (mm). Equation (2) is valid for a rainfall of $P_{tot} \leq 250$ mm, while Eq. (3) is valid for rainfall of $P_{tot} \geq 250$ mm

Cropping pattern data

Information on okra, its cropping pattern (crop name, planting date and harvesting date) and crop coefficient data in the three regions, over the different development stages: initial, development, mid and late stages as required by the crop module (FAO, 1996) were obtained from a past survey and screen-house study on the crop water requirement of okra variety NH 47-4 (Aliku, 2013). The growing season was February – May, while the crop coefficient (K_c) values were 0.27, 0.62 and 0.58 at the initial stage, mid-season and the late season, respectively. The crop was assumed to be planted in all the locations at the same time and covered 100% of the projected area. Hence, this enables the CROPWAT model to predict ET_c, using Equation (4) as follows:

$$ET_c = ET_o \times K_c \qquad (4)$$

Where ET_c is the crop evapotranspiration, ET_o is the potential evapotranspiration and K_c is the crop coefficient. Crop coefficient, a property of plants used in predicting evapotranspiration (ET) was obtained using data from Aliku (2013) as described in Equation (5):

$$K_c = ET_c/ET_o \qquad (5)$$

Soil sampling

Soil identification and mapping was done in the three locations using the rigid grid method with the aid of a soil auger. A predetermined format of 50 m × 50 m sampling procedure was adopted. Traverses were cut at 50 m apart along a predetermined baseline and observation points were made at 50 m apart along the traverses. Auger holes were made at every observation point down to a depth of 1.2 m and soil was examined at each of 0 – 0.15 m, 0.15 – 0.30 m, 0.30 – 0.60 m, 0.60 – 0.90 m and 0.90 – 1.2 m depths. Profile pits (1.5 – 2.0 m deep) were dug at points typical of each mapping units. The profiles were described following FAO guidelines (FAO, 1977). Soil samples were collected from all the horizons of each profile using 5 cm diameter cores for laboratory analysis. Soil properties such as bulk density, infiltration rate, maximum rooting depth, available soil moisture, and initial soil moisture depletion (%TAM) relevant to CROPWAT 8.0 model for scheduling irrigation were determined. Infiltration rate was measured at a surface depth of 0 – 15 cm using the double ring infiltrometer as described by Smith and Mullins (1991).

Statistical analysis

All experimental data were statistically analysed using the analysis of variance (ANOVA) based on the randomised complete block design using GenStat statistical software (8th edition). Means were separated using least significant difference (LSD) at 5% level of significance.

RESULTS AND DISCUSSION

Soil properties

Soil properties from derived savannah 1 (DS1) in Ogun state, derived savannah 2 (DS2) in Oyo state and humid forest (HF) in Edo state are presented in Table 2. At DS1, the clay content ranged from 37 – 177 g/kg; silt, 7.0 – 27 g/kg and sand was from 806 – 956 g/kg indicating a coarse textured soil. Derived savannah 2 had clay content that ranged from 97 – 450 g/kg; silt from 17 – 107 g/kg; and sand from 483 – 866 g/kg, indicating a range of coarse texture to fairly fine texture soil. In the HF agro-ecological zone, the clay content ranged from 26 to 446 g/kg silt from 14 – 224 g/kg and sand from 430 – 960 g/kg revealing a coarse texture to a fine texture. On the average, DS2 and HF soil particles are finer than DS1, an indication of their ability to retain more water for crop use when irrigated than DS1 soils (Hillel, 2003). The soils in all the locations were deep, consistently more than 1.80 m. Mean equilibrium infiltration rate was highest in DS1 (7.4 – 27.0 cm/hr), followed by HF (4.5 – 19.6 cm/hr) and least by DS2 (1.2 – 23.08 cm/hr). Variation in equilibrium infiltration rates among the three locations could be attributed to differences in soil texture, which affects the surface entry, profile transmission characteristics and soil water storage capacity (Hillel, 2003). Drip irrigation could be suggested for these sites so as to avoid runoff situations in DS2 and loss of irrigation water via deep percolation in DS1 and HF. Oshunsanya et al. (2016) reported that drip irrigation could make large volume of water available to plants by gradually dispensing water such that runoff and deep percolation losses are avoided.

Table 2. Summary of land characteristics relevant to irrigation

Land characteristics	Locations		
	DS1	DS2	HF
Bulk density (g/cm^3)	1.13 – 1.64	0.80 – 1.80	1.09 – 1.97
Pore space (%)	38.1 – 57.4	32.1 – 69.8	25.7 – 58.9
Slope (%)	0.15 – 3.5	0.2 – 29.05	0.20 – 2.79
Depth of groundwater (cm)	>180	>180	>210
Effective depth (cm)	>180	>180	>180
*Infiltration rate (cm/hr^1)			
Mean equilibrium rate	SR – VR	VR – O	SR – NO
Soil Texture			
Surface	S – LS	LS – SCL	S – SC
Sub-surface	LS – SL	SCL – SC	LS – SCL

*According to Sys (1985): SR = Somewhat rapid; VR = Very rapid; NO = Nearly optimal; O = Optimal

S=Sandy; LS=Loamy sand; SL=Sandy loam; SCL= Sandy clay loam; SC=Sandy clay. Note: DS1 – Derived Savannah 1 (Ogun State), DS2 – Derived Savannah 2 (Oyo State), HF – Humid Forest (Edo State)

Effective rainfall

The results of the effective rainfall for the three agro-ecological zones for a decade of okra cultivation were presented in Figure 2. The weather data for different soil types from DS1, DS2 and HF gave the highest effective rainfall at the flowering stage of crop growth. This gave significant differences in effective rainfall at the germination, crop growth and fruiting stages of okra life cycle, respectively. Though, there was no significant difference at the flowering stage among the three locations, humid forest had significantly higher

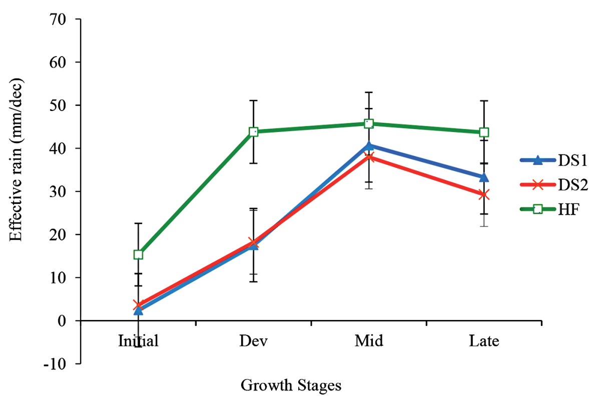

Fig. 2. Mean effective rain of the three agro-ecological zones

Note: DS1 = Derived Savannah 1 (Ogun State); DS2 = Derived Savannah 2 (Oyo State); HF = Humid Forest (Edo State)

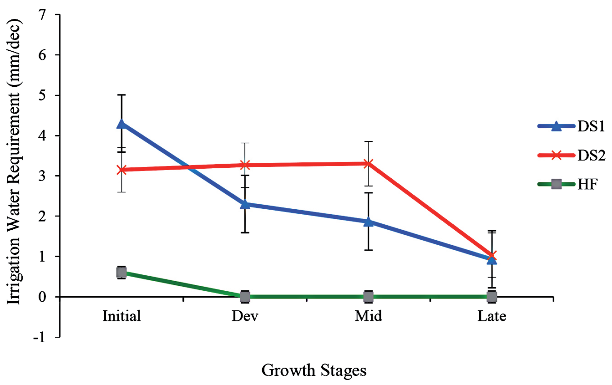

Fig. 3. Irrigation water requirement for different growth stages of okra under three agro-ecological zones

Note: DS1 = Drived Savannah 1 (Ogun State); DS2 = Drived Savannah 2 (Oyo State); HF = Humid FGorest (Edo State)

effective rainfall (p = 0.05) than derived savannah 1 and 2 at the germination, crop growth and fruiting stages. The highest effective rainfall was estimated at humid forest, with a mean of 45.73 mm/decade at the flowering stage of okra, where derived savannah 1 and 2 had mean values of 40.67 and 37.97 mm/decade, respectively. On the other hand, Figure 3 presents the estimation of okra irrigation water requirement for a decade. The irrigation water requirement for derived savannah 1 and 2 were estimated for germination stage (4.3 and 3.15 mm/decade, respectively), crop growth stage (2.30 and 3.27 mm/decade, respectively), flowering stage (1.87 and 3.30 mm/decade, respectively) and fruiting stage (0.93 and 1.03 mm/decade, respectively) for the next 10 years. This is due to the fact that the precipitation which is received during this growing period of okra is available to meet the consumptive water requirement of the crop (Dastane, 1978). The high effective rainfall which resulted to high soil moisture content could also have resulted from low initial soil moisture content. The high effective rainfall and soil moisture consequently resulted to low irrigation water requirement and as such little or no water should be programmed in the irrigation schedule for that period of crop growth. This situation is especially true for the humid forest, where okra cultivation will require little irrigation (0.6 mm/decade) especially at the germination stage where the effective rainfall is low.

Crop evapotranspiration/crop water requirement

The daily ET_c values for okra under the different agroecological zones are presented in Table 3. The values of ET_c and crop water requirements (CWR) are identical, whereby ET_c refers to the amount of water lost through evapotranspiration while CWR refers to the amount of water that is needed to compensate for that loss. In other words, ETc values are values for CWR. The study presents ET_c values for a decade with the lowest ET_c of 6.45 mm recorded in the derived savannah 1 at the germination stage, while the highest value was obtained as 37.57 mm during the flowering stage in derived savannah 2. Mean daily ET_c of okra was observed to increase from 1.16 to 3.36 mm/day and dropped to 2.99 mm/day at the end of the fruiting stage (Table 3). The corresponding values for derived savannah 2 were 1.17 to 3.64 mm/day for germination stage which later dropped to 3.28 mm/day at fruiting stage, while those of humid forest increased from 1.20 to 3.38 mm/day for germination stage and finally dropped to 3.04 mm/day at the fruiting stage. This trend agrees with the findings of Odofin et al. (2011) who reported that average weekly ET_c for *Amugbadu* okra variety rose from an initial value of 2.7 to 6.8 mm/day and dropped to 2.2 mm/day at the end of the late season, with corresponding values of 2.8, 6.6 and 2.0 mm/day for *Oniyaya*. The low ET at the initial stage could be due to the low canopy cover of the crop at that stage and this suggests higher soil evaporation rate than transpiration in the early growth stage. The soil evaporation would then gradually decrease while transpiration increases as the plant develops more overlapping leaves and increase its canopy cover. At the later stages of okra development when senescence and leaf aging begins, soil evaporation increases while transpiration reduces.

Daily soil moisture balance

The components of daily soil moisture balance which involved the use of daily stress coefficient (K_s) values based

Table 3. Estimated crop evapotranspiration for three agro-ecological zones

Locations	Initial	Dev	Mid	Late	Initial	Dev	Mid	Late
	ETc (mm day^{-1})				ETc (mm dec^{-1})			
DS1	1.16	2.06	3.36	2.99	6.45	19.73	34.70	21.53
DS2	1.17	2.18	3.64	3.28	6.50	20.90	37.57	23.53
HF	1.2	2.18	3.38	3.04	7.20	21.78	33.83	29.70
LSD	ns	ns	ns	ns	ns	ns	ns	ns

NOTE: DS1 – Derived Savannah 1 (Ogun State), DS2 – Derived Savannah 2 (Oyo State), HF – Humid Forest (Edo State), ns: not significant at p=0.05

on the depletion of available soil water content to estimate the actual crop evapo-transpiration (ET_a) are discussed as follows. There was no significant ($p = 0.05$) difference in the mean actual evapotranspiration (ET_a) which was calculated by multiplying the water stress coefficient (K_s) by the crop evapotranspiration (ET_c) for locations, respectively. However, Figure 4 presents the ET_a to be the highest at the flowering stage in the derived savannah 2 (3.59 mm/day), followed by humid forest (3.40 mm/day) and least by derived savannah 1 (3.36 mm/day). Figure 5 presents the result of soil available water and soil depleted moisture for derived savannah 1, derived savannah 2 and humid forest, respectively. Although, there was no significant ($p = 0.05$) difference in soil available moisture and soil depleted moisture among the locations, the mean highest percentage depletion during the period of growth was obtained at the germination stage of okra growth in derived savannah 2 (24.93%), followed by derived savannah 2 (21.71%) and least by humid forest (19.21%). The water stress coefficient (K_s) was equal to 1 throughout the growth period in all the three locations (Tables 4, 5 and 6). This may be due to the fact that the soil available water exceeded the depleted soil water in all locations after the cessation of rainfall. Snyder and Bali (2012) reported that until the soil water depletion exceeds the readily available water, no water stress is assumed and K_s is equal to 1. The Net irrigation application was found to be zero in all locations throughout the season (February to May). This implies that the locations require little or no supplementary irrigation during these months. Though similar in trend,

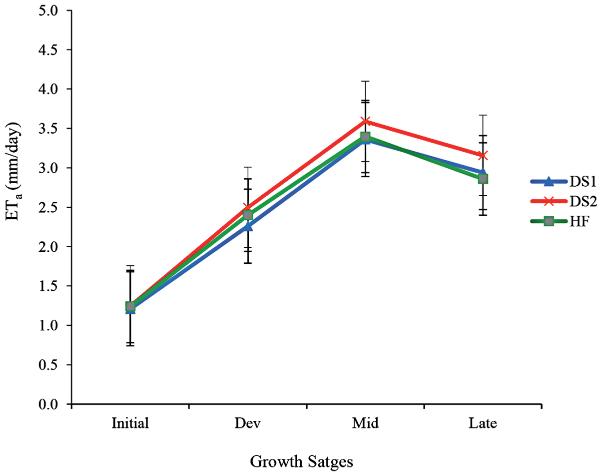

Fig. 4. Daily actual crop evapotranspiration of okra under three agro-ecological zones

Note: DS1 = Derived Savannah 1 (Ogun State); DS2 = Derived Savannah 2 (Oyo State); HF = Humid Forest (Edo State)

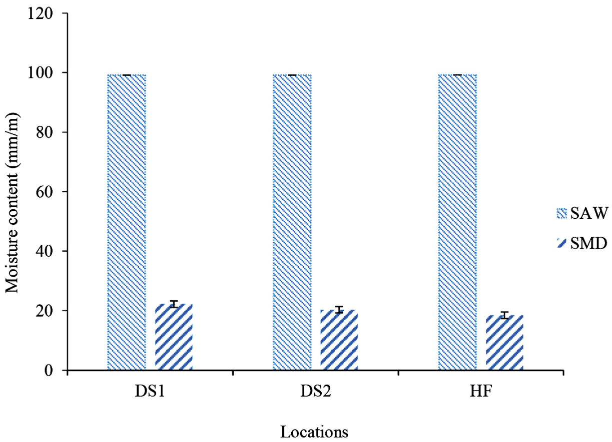

Fig. 5. Soil moisture content

Note: DS1 = Derived Savannah 1 (Ogun State); DS2 = Derived Savannah 2 (Oyo State); HF = Humid Forest (Edo State)

Table 4. Soil moisture balance and irrigation schedule for Derived Savannah 1 (Ogun State)

Weeks	Stage	Rain (mm)	Ks	ETa (mm/day)	Depletion (%)	Net Irri	Deficit	Loss	Gross Irri	Flow
						(mm/day)				
1	Init	0.29	1.00	1.19	19.43	0.00	12.36	0.00	0.00	0.00
2	Init	1.14	1.00	1.24	24.00	0.00	19.99	0.00	0.00	0.00
3	Dev	0.86	1.00	1.50	23.00	0.00	23.87	0.00	0.00	0.00
4	Dev	2.71	1.00	2.00	19.00	0.00	23.83	0.00	0.00	0.00
5	Dev	1.79	1.00	2.69	21.29	0.00	30.79	0.00	0.00	0.00
6	Dev	4.64	1.00	3.01	20.00	0.00	33.07	0.00	0.00	0.00
7	Mid	2.86	1.00	3.30	16.14	0.00	28.01	0.00	0.00	0.00
8	Mid	4.29	1.00	3.39	15.00	0.00	25.77	0.00	0.00	0.00
9	Mid	9.71	1.00	3.40	6.29	0.00	10.57	0.00	0.00	0.00
10	Mid	5.43	1.00	3.40	5.43	0.00	9.14	0.00	0.00	0.00
11	End	10.63	1.00	3.20	6.29	0.00	10.29	0.00	0.00	0.00
12	End	4.94	1.00	3.09	6.14	0.00	10.36	0.00	0.00	0.00
13	End	4.94	1.00	2.57	5.14	0.00	8.42	0.00	0.00	0.00

Note – Irri: Irrigation, Init: Initial growth stage, Dev: Development stage, Mid: mid-season stage, End: Late season growth stage

Table 5. Soil moisture balance and irrigation schedule for Derived Savannah2 (Oyo State)

Weeks	Stage	Rain (mm)	Ks	ETa (mm/day)	Depletion (%)	Net Irri (mm/day)	Deficit	Loss	Gross Irri	Flow
1	Init	0.47	1.00	1.19	23.86	0.00	17.56	0.00	0.00	0.00
2	Init	1.44	1.00	1.29	26.00	0.00	25.23	0.00	0.00	0.00
3	Dev	0.97	1.00	1.60	24.86	0.00	30.09	0.00	0.00	0.00
4	Dev	2.86	1.00	2.10	21.71	0.00	31.60	0.00	0.00	0.00
5	Dev	1.83	1.00	2.87	24.14	0.00	41.09	0.00	0.00	0.00
6	Dev	4.47	1.00	3.26	24.00	0.00	46.47	0.00	0.00	0.00
7	Mid	2.64	1.00	3.60	23.00	0.00	45.86	0.00	0.00	0.00
8	Mid	3.76	1.00	3.60	24.14	0.00	48.31	0.00	0.00	0.00
9	Mid	8.40	1.00	3.60	15.86	0.00	31.63	0.00	0.00	0.00
10	Mid	4.64	1.00	3.60	7.29	0.00	14.64	0.00	0.00	0.00
11	End	8.80	1.00	3.50	5.71	0.00	11.17	0.00	0.00	0.00
12	End	3.79	1.00	3.33	5.71	0.00	11.29	0.00	0.00	0.00
13	End	3.79	1.00	2.74	5.14	0.00	9.18	0.00	0.00	0.00

Note – Irri: Irrigation, Init: Initial growth stage, Dev: Development stage, Mid: mid-season stage, End: Late season growth stage

Table 6. Soil moisture balance and irrigation schedule for Humid Forest (Edo State)

Weeks	Stage	Rain (mm)	Ks	ETa (mm/day)	Depletion (%)	Net Irri (mm/day)	Deficit	Loss	Gross Irri	Flow
1	Init	2.57	1.00	1.20	7.43	0.00	4.87	0.00	0.00	0.00
2	Init	2.57	1.00	1.29	5.14	0.00	4.93	0.00	0.00	0.00
3	Dev	7.86	1.00	1.50	3.00	0.00	3.47	0.00	0.00	0.00
4	Dev	4.99	1.00	2.27	5.29	0.00	7.07	0.00	0.00	0.00
5	Dev	9.90	1.00	2.74	5.14	0.00	8.03	0.00	0.00	0.00
6	Dev	4.91	1.00	3.20	5.00	0.00	8.77	0.00	0.00	0.00
7	Mid	9.37	1.00	3.50	6.00	0.00	10.69	0.00	0.00	0.00
8	Mid	4.73	1.00	3.44	6.29	0.00	11.43	0.00	0.00	0.00
9	Mid	4.73	1.00	3.39	5.86	0.00	10.76	0.00	0.00	0.00
10	Mid	9.77	1.00	3.30	5.00	0.00	9.03	0.00	0.00	0.00
11	End	5.11	1.00	3.19	7.00	0.00	13.00	0.00	0.00	0.00
12	End	5.11	1.00	3.06	5.29	0.00	9.57	0.00	0.00	0.00
13	End	10.57	1.00	2.40	3.71	0.00	8.07	0.00	0.00	0.00

Note – Irri: Irrigation, Init: Initial growth stage, Dev: Development stage, Mid: mid-season stage, End: Late season growth stage

these results are contrary to the findings of Hashim et al. (2012) who reported higher values than the values obtained from this study. The irrigation schedules resulting from the contributions of various moisture balance components for derived savannah 1, derived savannah 2 and humid forest respectively are presented in Tables 4, 5 and 6.

Crop coefficient

The crop coefficient curve of okra across the germination, growth, flowering, and fruiting stages is presented in Figure 6. There was no significant ($p = 0.05$) difference among K_c values obtained from all locations across okra growth stages. The crop coefficient (K_c) values increased from the germination to the flowering stage for all locations, with the peak crop coefficient of

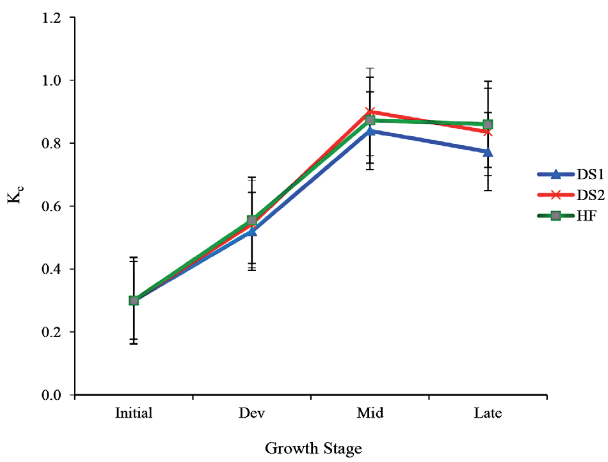

Fig. 6. Estimated crop coefficient values for of okra under three agro-ecological zones of Nigeria

Note: DS1 = Derived Savannah 1 (Ogun State); DS2 = Derived Savannah 2 (Oyo State); HF = Humid Forest (Edo State)

0.90 in the flowering stage of okra growth in derived savannah 2. During the fruiting period, the K_c for derived savannah 1, derived savannah 2 and humid forest dropped from their peak values of 0.84, 0.90 and 0.87 respectively at the flowering stage to 0.77, 0.84 and 0.86 respectively. Similar observations were made by Snyder and Bali (2012) where K_c was reported to have dropped from peak during the irrigation schedule of Alfalfa in California. The values estimated at the germination stage is in line with the values of the initial growth period observed by Hunsaker et al. (2002) who stated that the basal K_c is in the range of 0.20 and 0.40.

CONCLUSION

Daily crop evapo-transpiration and crop coefficient values for okra were significantly different among derived savannah 1, derived savannah 2 and humid forest agro-ecological zones of Nigeria. This indicates that the amount of water needed by okra to offset evapo-transpirational demand of the atmosphere varied across the three agro-ecological zones due partly to differences in climatic factors. Variation in available soil moisture and moisture depletion also occurred due to differences in soil properties in the three agro-ecological zones. It must be noted that crop coefficient increased as daily crop evapo-transpiration and actual crop evapo-transpiration increased in all locations. In addition, water requirement of okra was found to depend on age of the plant with maximum demand at reproductive (flowering) stage. Therefore, effective modelling of irrigation water for okra will require data on soil properties, climatic factors and age of the crop for sustainable cultivation.

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Corresponding author:

OrevaOghene Aliku
Department of Agronomy
Faculty of Agriculture and Forestry
University of Ibadan, Ibadan, Nigeria
E-mail: orevaoghenealiku@gmail.com
Phone: +234 803 939 7324