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Keywords: Calcareous mudstone; Soil properties; Taxonomic Classification; Nutrients

Introduction

Calcareous mudstone is a sedimentary rock and consolidated product of calcareous sands, limy mud and crushed shells (Anatala, 1996). It is composed of carbonates in the form of aragonite, calcite and dolomite. The mudstone formations have been referred to as River Shale group or the oldest marine carbonate sequence which are mostly impervious shale with

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Determination of Crop Coefficient of Okra Plant in Forest-Savannah Agro-ecology of Nigeria

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Abstract

Effective irrigation planning and management requires basic information on water requirement and coefficient of the crop. This study was designed to investigate crop coefficient (K_c) of okra grown in mini-drainage lysimeter during 2019 and 2020 late seasons. Five irrigation treatment blocks were adopted for five mini lysimeters used for the experiment. The treatments are, twice daily water application (T_1), Daily water application (T_2), every other day (T_3), two days interval (T_4) and control (T_5). Climatic variables were obtained for the determination of reference evapotranspiration (E_{To}) using the FAO-Penman Monteith model. The values for the crop evapotranspiration (E_{Tc}) was determined from the lysimeter using the soil water balance method on daily basis and the crop factor (K_c) was estimated from the ratio of E_{Tc} / E_{To} . The result indicated that both growth attributes of okra were significantly influenced by varying water application in all treatments. Okra planted with treatment T_1 (twice daily irrigation) produced the highest vegetative growth, while that subjected to no irrigation (T_5) has the least of vegetative growth irrespective of the year of planting. Consequently, yield parameters of okra subjected to treatment T_2 (daily irrigation) gave statistically superior yield characteristics to all other treatments and the least with T_5 (zero irrigation). The okra Crop Evapotranspiration (E_{Tc}) values ranged from 46.8 to 189.6 mm. Higher E_{Tc} values were recorded during flowering stages as compared to the values obtained in other parts of the crop life cycle or growth stages. The okra crop coefficient (K_c) at emergence, establishment, flowering and maturity stages are 0.53, 0.94, 1.86 and 0.77 respectively. Crop coefficient (K_c) values obtained indicated that *okra plant* requires more water application during the flowering stages than at emergence and maturity stages. It is therefore recommended that K_c developed from this study be used for irrigation scheduling and developing water budgeting procedures for irrigation for optimum okra production during the growing season of forest-savannah agro-ecology of Nigeria in the face of current climate change and variability.

Key words: Crop evapotranspiration, reference evaporation, crop coefficient, irrigation scheduling, growth and yield, climate change.

Introduction

Okra (*Abelmoschus esculentus* (L.) belongs to Mallow family. Okra is an herbaceous annual crop with thick branched and semi-woody stem that can reach up to 4 meters. It has large lobe, rough, bristly leaves and shiny yellow

flowers with a purple centre. It is a tropical to subtropical crop and is sensitive to frost; low temperature, water logging and drought conditions, (Fasinmirin and Olufayo, 2009) and the cultivation from different countries have certain adapted distinguishing characteristics specific to the country to which they belong. Okra is

usually consumed for its green tender fruits as a vegetable in a variety of ways. These fruits are rich in Vitamins, calcium, potassium and other mineral matters (Scchippers, 2000). The mature okra seed is a good source of oil and protein has been known to have superior nutritional quality. Okra seed oil is rich in unsaturated fatty acids such as linoleic acid (Scchippers, 2000), which is essential for human nutrition. Its mature fruit and stems contain crude fibre, which is used in the paper industry. It is a fat-free and a low calorie food that is ideal for weight loss diets. Its seeds are high in protein. Aside from food and industrial uses, okra can also be utilized for cattle feeds. Likewise, it has also a number of medical applications. Okra can be grown from low to mid elevation areas throughout the year (Zwart and Bastiaassen, 2007).

Water is the most precious resource in all its forms (i.e. rainwater, aquifers, streams, lakes, rivers and water vapour). It plays a vital role in both environment and human life which provides a number of uses i.e. domestic uses, irrigation water for agriculture, hydroelectric power generation, transportation, tourism and recreation (Ateawung, 2010; Urama and Ozor, 2010). The shortage of water is one of the main problems resulting from combined effects of climate change and increase in water demands for agricultural food production, urbanization and industries (IPCC, 1998). Water use has been growing twice more than the rate of population growth with 70% for irrigation agriculture, 22% for industry and 8% for domestic use (Blumenfeld et al., 2009). According to the UN Comprehensive Assessment of Fresh

Water Resources of the World, about 31 countries are facing water stress and scarcity and over one billion people lack adequate access to clean drinking water (Barlow, 2001). The problem is more serious in Africa where the greater part of the population directly depends on agriculture as a source of livelihood and managing water resources has become more essential in the continent (Ateawung, 2010).

Crop growth, development and yield depends more on water. The negative effect of climate change and variability on crop yield is severe especially during the dry season. In order to improve and sustain crop yield, it is necessary to practice conservation and effective use of water for good cropping. Improved crop production during the period of dry spell is possible through irrigation. While irrigation is an effective way of continuous cropping, it is important to have adequate knowledge about the amount and frequency of irrigation to be applied in order to achieve sustainable cropping system.

Crop Water Requirement (CWR) is the total amount of water needed to compensate all the water losses through evapotranspiration. Therefore, knowledge about evapotranspiration is a pre requisite for estimating crop water requirements. CWR varies with varying growth stage and hence different amount of water evapotranspiration as characterized by different crop coefficients (Konyeha and Alatise, 2013). To minimize the impact of rainfall instabilities, there is a need to adopt irrigation as an alternative source of water for crop production. Despite the economic and nutritional importance of okra, its crop

water requirements study is very scanty. Therefore, this study on the determination of crop coefficient for okra production will help in computing the crop water requirements for the crop in the forest-savannah agroecology of Nigeria.

Evapotranspiration can be measured using experimental weighing lysimeters directly on the field. Lysimeters are devices or tanks filled with soil and buried in the ground to measure the direct loss of water from the soil and crop surfaces as evapotranspiration. This method involves growing of crops in the lysimeter installed in crop fields and measuring the water balance components (input and output of water i.e. precipitation, soil moisture storage and deep percolation) of the lysimeter (Weligepolage, 2005).

There are two main types of lysimeters, the drainage and the weighing types. In the first case, potential evapotranspiration is obtained as the difference between applied and drained water quantity. In the second case, changes in the total weight of the soil sample are measured and the actual evapotranspiration is determined by the changes in weight as water evaporates (Burnett, 2007). Lysimeters are the most accurate and direct measurement methods of estimating evapotranspiration. Therefore, they can be used as a standard measurement method for evaluating the performance of other physically based evapotranspiration models. Therefore, the study was designed to develop crop coefficients (K_c) specific to multiple phenological stages for okra grown in the forest-savannah agroecology of Nigeria for accurate irrigation scheduling in the region.

Materials and Methods

Study area

The experiments were conducted during the 2019 and 2020 late seasons at the research farm section of Federal University of Technology Akure, Ondo State (Long; 05.30, Lat; 07.20) is within the forest-savannah agro-ecology of Nigeria. The site has an altitude of 78 m above mean sea level. The area is within the tropical rainforest of Southwestern Nigeria. The climate of Akure can be described as humid to sub-humid tropics with distinct dry and wet seasons. The dry season runs end of November to mid-March, while the wet season is from mid-March to November. There are two rainfall peaks in June and September with dry spell in August (August break) which produces the bimodal rainfall pattern. Based on the rainfall pattern, there are two growing seasons: early (March to August) late (mid-August to November). The mean annual rainfall recorded for a period of 10 years at Akure was 1441 mm. The temperature of the area is generally high, ranging from 22.6 to 35°C. It is characterized by minimal fluctuations, usually less than 5°C throughout the year. It is referred to as iso-hyperthermic temperature regime. The mean monthly temperature ranges between 28°C and 35°C for the period of 10 years, while the mean monthly minimum temperature ranged between 22.6°C and 26.7°C. February and March have the highest evaporation rate, and it is as high as 6.9 mm. The least evaporation rate (1.6 mm) is recorded in June/July. This pattern is directly related to the pattern of rainfall/cloud cover and atmospheric temperature. The relative

humidity is relatively high throughout the year. It ranges from 64.5% in February to 91% in June. The soil is deep, well drained with red (2.5YR 4/8) to brownish-red (5YR 5/4) in colour. It has a sandy loam texture at the surface (0 – 15 cm depth) and belongs to Ultisol, classified as Rhodic Kanhaplustult (Okusami *et al.*, 1997; Soil Survey Staff, 2006). The soil was locally classified as Alagba series (Moss, 1957).

White velvet variety of okra was used as test crop. Recommended planting space of 50x60 cm was employed in this study.

Lysimeters Design and Experimental Setup

Five mini-drainage lysimeters were constructed and used for this study (Figure 1). Each set of mini lysimeters consisted of cylindrical drum, slightly tapered at the bottom to allow good drainage of water. A drum of 50 cm diameter and 110 cm deep served as the lysimeter tank where the crop (okra) was grown. The lysimeters were filled with repacked soil based on the weight of soil obtained from the surface area of the lysimeters and bulk density. The soil depth in the lysimeter was 100 cm, additional 10 cm layer for gravel and a sheet of mosquitoes net underneath which collects excess water from the upper soil and discharge it to the drainage collector. The gravel and sheet of mosquitoes net were placed at the bottom of each lysimeter to facilitate water drain and prevent entrance of soil from blocking the perforated drainage pipe. The pipe was connected to water collecting container (20 litres bucket) placed underneath the lysimeter. The heights of the lysimeter rims are maintained

near the ground level to minimize boundary layer effect in and around the lysimeter. The rims of lysimeter were protruded 20 cm above the soil surface so that no surface runoff water enters into the lysimeter. Another vessel (20 litres) was used in collecting the runoff water. The runoff collector was connected with a pipe extended with rubber hose to an outlet fitting made on the top edge of the lysimeter tank. This runoff collector was placed at a lower elevation so that the runoff water from the lysimeter can flow by gravity into the collector. Both the runoff and drainage collectors were covered with lid to prevent additional water from rain and also evaporation from taking place in the collectors. Drainage was collected daily from the container that collected water underneath the lysimeter using graduated bucket likewise was the runoff water. Water application was 2 litres per plant per irrigation. Plants in lysimeters were watered in the same way as those plants in the surrounding areas to maintain a favourable moisture regime in the root zone. The crop was irrigated in accordance to the design of the treatments (Table 1).

Rainfall and other climatic parameters were measured using rain gauge from nearby meteorological station of the department of Meteorology and Climate Science (MCS), Federal University of Technology Akure, Nigeria. The change in storage is accounted for by the change in soil water storage (SWS) in the entire lysimeter for a given period of time. SWS were computed for every 20cm increments and difference in two consecutive days to determine the change in soil water storage. Daily volumes of water inputs and outputs

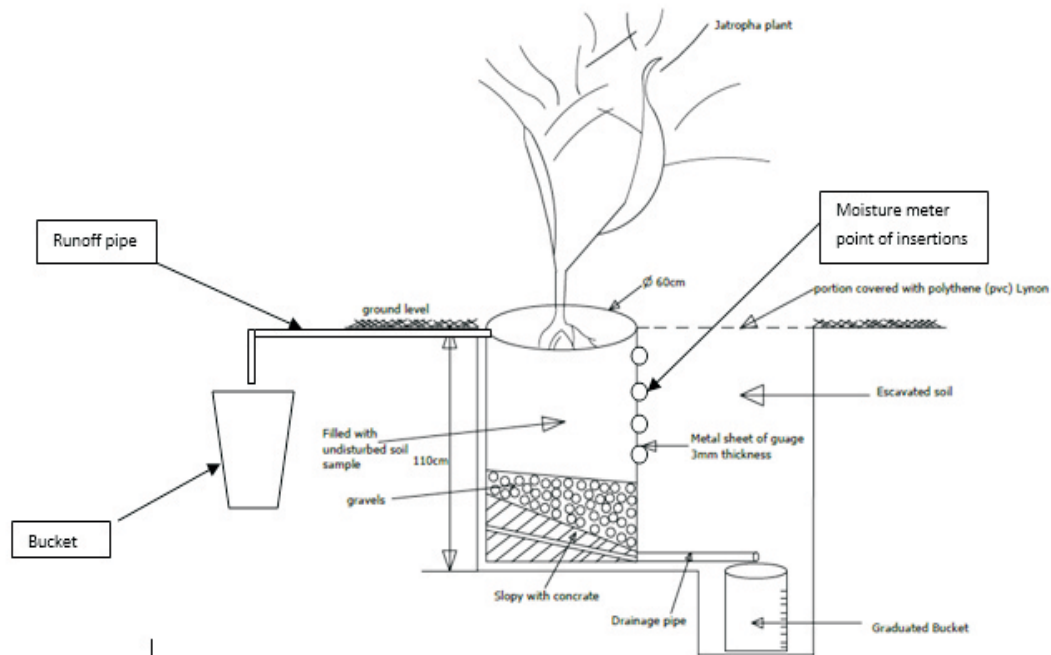


Figure 1: Diagram of the lysimeter layout design

Table 1: Experimental treatment descriptions

Treatments	Treatment code	Description
1	T ₁	Twice daily water application
2	T ₂	Daily water application
3	T ₃	Every other day
4	T ₄	Two days interval
5	T _c	Control (rain-fed)

to give the weekly.

$$ET_c = I + P - D - R_o \pm \frac{S}{1}$$

where, S is the change in soil moisture storage between soil moisture measurements (mm),
 I is irrigation (mm)
 P is rainfall (mm)
 D is drainage (mm)
 R_o is runoff (mm).

to the lysimeters were totalled and average values obtained to compute the daily input and output volumes (expressed in mm). The soil water storage (SWS) were computed using daily soil moisture reading (è) obtained using the digital moisture meter PMS -714. The readings obtained from the PMS – 714 meter were converted to volumetric soil water content which was determined by The runoff collected was emptied manually after measurements were taken. The runoff volume was measured using a calibrated container. Daily evapotranspiration was computed and averaged for the weeks during the experimental seasons multiplying soil water content from each layer with their respective bulk density. The volumetric soil water was then converted into mm of water so as to account for each incremental soil depth (Mehmet *et al.*, 2005; Foroud *et al.*, 1993; Stone *et al.*, 1987).

Reference crop evapotranspiration (ET_o)

The reference evapotranspiration (ET_o, mm week⁻¹) was computed following the FAO Penman Monteith method given as FAO 56 (Allen *et al.*, 1998).

Determination of the Crop Coefficient (K_c)

The crop coefficient (K_c) was determined by dividing the estimated crop evapotranspiration (ET_c) by a weather-based reference evapotranspiration (ET_o), using equation as stated in Fasinmirin *et al.* (2009) and Allen *et al.* (1998) thus:

$$ET_c = K_c \times ET_o$$

ET_c = Crop evapotranspiration in mm/day
K_c = crop coefficient, (dimensionless)

ET_o = Reference crop evapotranspiration in mm/day

The K_c values were computed on daily basis and later expressed as average of the four growth stages of the okra. The stages are: emergence, establishment, flowering and maturity.

Data on plant height, number of leaves, number of branches, number of flowers per plant, number of pods per plant and yield per hectare were recorded from each lysimeter and the entire field.

Analysis of variance (ANOVA) was computed to evaluate treatments effects on the growth and yield parameters. Turkey tests were used to compare and rank the treatment means and differences were declared significant at $P < 0.05$.

RESULTS AND DISCUSSION

The result of analysis of variance of growth parameters of okra are presented in Table 2. The result indicated that both growth attributes of okra were significantly influenced by varying water application in all treatments. For the growth parameters of okra planted during 2019 late season, treatment T₁ (twice daily irrigation) produced the highest plant height (29.42 cm) and number of leaves (7.64) while treatment T_c (zero irrigation) had the minimum plant height (16.48 cm) and number of leaves (4.82). The reaction of the number of branches/plant of okra to irrigation treatments shows the same trends as plant height and number of leaves. Okra subjected to twice daily irrigation treatment performed best with average of 9.08 branches, while those subjected to no irrigation has the least of 4.09 branches. Although, in case of plant height from the

Table 2, there were no significance difference in treatments T₁₁ and T₂₁, while there were significance difference with other treatments T₃₁, T₄₁, T_{c1} at 0.05 probability. In the case of growth parameters of okra planted during the dry season of 2020, the responses of okra planted to irrigation treatment were not different from that planted in 2019. Okra subjected to T₁₁ (twice daily irrigation) produced the highest in all the growth parameters; plant height (11.50 cm), number of leaves (7.84) and number of branches per plant (9.14), while okra planted with no irrigation had the least growth parameters in the responses to irrigation treatment; plant height (9.46 cm), number of leaves (5.04) and number of branches per plant (5.00). The study results were in agreement with the findings of these

researchers: Anil *et al.*, (2017); Azza *et al.*, (2010) and Sarhan *et al.*, (2010).

Table 3 shows the result of yield parameters of okra to irrigation intervals during the 2019 and 2020 late seasons. In 2019, yield parameters of okra subjected to treatment T₁₁ (twice daily irrigation) gave statistically superior number of flowers/plant, number of fruits/plant, fruit length and yield (t/ha) while treatment. T_c (zero irrigation) gave the least values number. Treatment T₁₁ (twice daily irrigation) produced the highest number of flowers/plant, number of fruits/plant of 9.4 and 92 respectively, while fruit length and fruit yield are 19.04 and 6.6 t/ha respectively. Treatment T_{c1} (zero irrigation) had the minimum number of flowers (5.0}, number of fruits (28), length (16.47) and fruit yield (2.2 t/ha). Similar trends were

Table 2: Effects of Irrigation scheduling on Growth Parameters of Okra

Treatment	Plant height (cm)			No. of leaves/plant			No. of branches/plant		
	10	20	30	10	20	30	10	20	30
2019 season									
T ₁₁	11.37 ^a	15.26 ^a	24.92 ^a	4.47 ^a	5.42 ^a	7.64 ^a	3.2 ^a	6.86 ^a	9.08 ^a
T ₂₁	11.35 ^a	15.25 ^a	24.90 ^a	4.48 ^a	5.40 ^a	7.62 ^a	3.2 ^a	6.84 ^a	9.02 ^a
T ₃₁	11.37 ^a	14.80 ^{ab}	22.56 ^{ab}	4.07 ^b	4.97 ^b	6.85 ^{ab}	2.8 ^{ab}	5.86 ^{ab}	8.08 ^b
T ₄₁	9.82 ^b	12.64 ^b	20.81 ^b	4.04 ^b	4.82 ^{bc}	5.62 ^b	2.5 ^b	4.96 ^b	7.30 ^{bc}
T _{c1}	8.46 ^c	10.64 ^c	16.48 ^c	4.00 ^b	4.24 ^c	4.82 ^{bc}	2.0 ^c	3.86 ^c	4.09 ^c
SEM	0.94	1.34	1.86	0.32	1.03	1.25	0.26	1.58	0.98
2020 season									
T ₁₂	11.50 ^a	16.19 ^a	25.48 ^a	4.58 ^a	5.43 ^a	7.84 ^a	3.3 ^a	6.72 ^a	9.14 ^a
T ₂₂	11.48 ^a	16.10 ^a	25.06 ^a	5.00 ^a	5.44 ^a	7.86 ^a	3.3 ^a	6.88 ^a	9.14 ^a
T ₃₂	10.32 ^b	14.55 ^{ab}	24.24 ^{ab}	4.27 ^{ab}	4.86 ^{ab}	6.92 ^{ab}	2.4 ^b	5.04 ^{ab}	8.42 ^{ab}
T ₄₂	9.46 ^c	12.48 ^b	20.12 ^b	3.96 ^b	4.40 ^b	6.04 ^b	1.8 ^c	4.08 ^b	7.24 ^b
T _{c2}	6.48 ^c	9.98 ^c	16.55 ^c	3.04 ^c	4.00 ^{bc}	5.04 ^c	2.0 ^c	3.12 ^c	5.00 ^c
SEM	1.05	1.56	2.09	1.46	1.26	1.36	0.53	1.62	1.08

T₁ - Twice daily Irrigation; T₂ Daily Irrigation; T₃ Every other; T₄ - Two days interval; T_c - Control

Table 3: Effects of Irrigation scheduling on Yield Parameters of Okra

Treatment	No. of flowers/plant	No. of fruits/plant	Average length of fruits (cm)	Yield (t ha ⁻¹)
2019 season				
T ₁₁	9.4 ^a	42 ^a	19.04 ^a	6.60 ^a
T ₂₁	9.4 ^a	42 ^a	19.02 ^a	6.65 ^a
T ₃₁	8.0 ^b	36 ^b	18.79 ^a	5.70 ^{ab}
T ₄₁	6.0 ^{bc}	31 ^c	18.23 ^{ab}	4.34 ^b
T _{c1}	5.0 ^{bc}	28 ^d	16.47 ^b	2.24 ^c
SEM	1.1	2.5	0.56	0.74
2020 season				
T ₁₂	9.0 ^a	40 ^a	19.00 ^a	6.58 ^a
T ₂₂	9.2 ^a	40 ^a	18.92 ^a	6.57 ^a
T ₃₂	8.6 ^{ab}	36 ^b	18.24 ^{ab}	5.84 ^b
T ₄₂	6.2 ^b	28 ^{bc}	16.46 ^b	4.89 ^{bc}
T _{c2}	5.2 ^{bc}	24 ^c	12.32 ^c	2.48 ^c
SEM	1.20	3.4	1.32	0.98

discovered on okra planted during the planting season of 2020 as number of flowers/plant, number of fruits/plant, fruit length and yield has 9.0, 40, 19.0 and 6.38 t/ha respectively. This is in agreement with Lhomme *et al.*, (2015) and Lopresti *et al.*, (2015) findings that plants responded very well to irrigation in terms of yield. Similar trends were discovered on okra planted during the planting season of 2020. The reason behind the response of the treatments in relation to vary water application may be due to the fact that T₁₁ got the most favourable soil moisture conditions to produce healthy plants as seen from the data of growth and yield parameters.

The okra Crop Evapotranspiration (ET_c) values ranged from 46.8 to 189.6 mm (Table 4). Higher ET_c values were recorded during flowering stages as compared to the values obtained in other stages of the crop life cycle. Changes occurred in the ET_c throughout the season and this may be due to change in the crop development. Reference Evapotranspiration (ET_o) values

ranged from 88.1mm during the emergence stage to 135mm during the establishment stage of okra growth and development stages. Table 4 also shows that water requirement of okra plant varied throughout the crop development and it is a function of the crop growth stages. The okra crop coefficient (K_c) ranged from 0.53 to 1.86. The values for emergence, establishment flowering and maturity stages are 0.53, 0.77, 1.86, and 0.94 respectively.

Conclusion

The study estimates crop evapotranspiration (ET_c), reference evapotranspiration (ET_o) and crop coefficients (K_c) of okra plant grown inside a mini-lysimeter in an open field. Results obtained showed that the ET_c highest during the flowering stage and followed by establishment stage, indicating that crop water requirement was highest during this crop growth stages. Crop coefficient (K_c) values obtained indicated that *okra plant* requires more water application during the flowering and

Table 4: Estimation of Crop Coefficient of Okra plant

Growth Stages	Crop ET _c (mm)	Reference ET _o (mm)	Average Crop Coefficient
Emergence	46.8	88.1	0.53
Establishment	124.5	132.6	0.94
Flowering	189.6	101.8	1.86
Maturity	104.5	135.6	0.77

flowering stages than at emergence and maturity stages. Results from the finding is useful in providing precise assessment of crop water requirement of the okra crops, determine the irrigation water requirement devoted for improving irrigation water allocation for the crop and adjusting the selected K_c coefficients for frequency of wetting or climatic conditions during the stages of growth

It is therefore recommended that K_c developed from this study should be used for irrigation scheduling and developing water budgeting procedures for irrigation for optimum okra production during the growing season of forest-savannah agroecology of Nigeria in the face of current climate change and variability.

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