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Evapotranspiration, water use efficiency and yield of okra (*Abelmoschus esculentus)* under varied irrigation water volumes and different soil textural classes

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Abstract

The Screen house study was conducted at the Federal University of Agriculture, Abeokuta to evaluate the effects of irrigation volume and soil textural classes on evapotranspiration (ET), water use efficiency (WUE) and yield of okra. The treatments, replicated three times, were four irrigation volumes (25, 50, 75, 100% ET demand (ETdd)) and three soil textural classes (loamy sand (LS), sandy loam (SL) and sandy clay loam (SCL)). The ET was determined using the moisture depletion method while WUE was estimated as the ratio of the dry weight of total plant biomass to the cumulative amount of water supplied to the plants. It was observed that ET was consistently higher with an increase in irrigation volume, though, these increments ranged between 3.0 to 7.9% from the beginning to the end of the study. The ET under LS and SL were statistically similar but SCL gave significantly ($P<0.05$) lower ET than those of LS and SL. Application of water at 25% ETdd resulted in significantly higher WUE than other ETdds while SCL gave a significantly higher WUE than SL and 18.2% higher WUE than LS. Except for 100% ETdd that gave a significantly highest okra fruit yield, there were no significant differences among the other three ETdds. The SL produced okra fruit weight that was 12.8% and 19.3% higher than those produced by SCL and LS, respectively. Therefore, good soil and water management under okra cultivation could be achieved using SL soil with water application at 100% ET demand, especially where water scarcity is not an issue.

Keywords: Evapotranspiration, irrigation volume, moisture depletion, water use efficiency
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1.0 Introduction

Soil texture plays a major role in the availability of water to crop and also in the evaporation of water from the soil. According to Woodruff (1980), the supply of water to plants is usually greater in moderately fine texture compared with coarse texture soil. This suggests that the success or failure of irrigation water supply to crops is dependent on the texture of the soil. One of the major factors limiting optimum crop production in the tropics, under irrigated agriculture, is the lack of adequate information on how water volume to be applied could be appropriately related to the texture of the soil.

Also, the knowledge of the application of the adequate amount of water needed for plants is essential for the development of the most suitable irrigation schedule to get optimum crop yield. Underestimating irrigation amount may cause yield decrease (Ertek *et al*., 2002) while overestimating water supply may result in wastage and can initiate soil degradation process.

The use of crop evapotranspiration demand (ET demand) to estimate irrigation water supply is a new technique and offers means of guaranteeing the supply of an appropriate amount of water for crop growth. However, irrigation water scarcity in many parts of the world has motivated interest in improving whole-plant water use efficiency (WUE), by applying less water than full crop-water requirements which is termed deficit irrigation (Busari et al., 2019). Therefore, the solution to water scarcity and competition for water resources by other non-agricultural sectors lies mostly on improving the efficiency of water use under irrigation agriculture (Jury and Vaux, 2005).

Since okra is a moderately drought-tolerant crop, with types of soil determining, to a greater extent, the volume of water the crop will receive (*Masabni,* 2021), it is important to understand the ET demand at which okra performance will be optimum. This study was therefore, carried out to evaluate the effects of irrigation volume and soil textural class on evapotranspiration (ET), water use efficiency (WUE) and yield of okra.

2.0 Materials and Methods

2.1 Description of experimental site

The experiment was carried out in the Screen house of the Federal University of Agriculture, Abeokuta (FUNAAB), with latitude 7^0 15′ N and longitude 3^0 25′ E.

Experimental design

The experiment was a 4 x 3 factorial arranged in a completely randomized design (CRD). The factors were four levels of irrigation volume (determined based on crop daily ET demand) and three soil textural classes (loamy sand, sandy loam and sandy clay loam). The four ET demands used included 100%, 75%, 50% and 25%. Each of the treatments was replicated three times.

Determination of soil textural classes

Table 1: Soil textural classes determined at the onset of the study

Particle size distribution	Value (%)
Sand	80.5
Clay	12.5
Silt	7.0
Textural class	Loamy sand
Sand	70.0
Clay	10.0
Silt	20.0
Textural class	Sandy loam
Sand	65.0
Clay	20.2
Silt	14.8
Textural class	Sandy clay loam

Soil samples were collected within the campus of the Federal University of Agriculture, Abeokuta and tested to establish their textural classes before the commencement of the study. The samples were sieved using 2 mm mesh sieve size and the soil texture was determined using Bouyoucos hydrometer method. The three textural classes used are presented in Table 1. The soils were then filled into 7 L capacity buckets according to treatments.

Determination of crop ET demand

Two okra seeds were planted per pot which were thinned to one at 3 weeks after planting (WAP). Up to this time, the pots were watered uniformly. At 3 WAP all pots were watered until water started dripping down from the bottom of the pots. The pots were then left to freely drain for 24 hrs , after which they were weighed using an electronic balance of 0.1 g sensitivity. This weight served as a reference weight (Day 0). The potted plants were allowed to stand in the screen house without adding water and were weighed again after another 24 h (Day 1). The difference between Day 0 and day 1 weights stands for the ET demand (ETdd) of the crop. This was taken for each pot and pots were then allocated randomly according to treatments: the control, which was the 100% ETdd where plants that received 100% of the previous day's ET on daily basis; the 75%, 50% and 25% ETdd treatments received 75%, 50% and 25%, of their respective previous day's ET and were also irrigated daily. Irrigation was manually carried out. The ET for each treatment were then recorded throughout the study

2.2 Okra yield parameters

Harvesting of the matured okra fruits started at 5 WAP and this continued until the fruit production stopped. The fruits were counted while the weight of each fruit plucked was measured using an electronic balance. The dry matter yield was obtained as the oven-dried (at 65 ^oC for how long???) weight of the total biomass per pot.

Determination of water-use efficiency (WUE)

The WUE was calculated as the sum of the dry weight of total biomass in kg divided by the cumulative amount of water used in m^3 (Fasinmirin and Olufayo, 2009).

$$WUE = M_b/C_w \ (kg/m^3) \quad (1)$$

Where, WUE = water use efficiency

M_b = total biomass in kg

C_w = cumulative amount of water used in m^3

Statistical analysis

Data collected was subjected to Analysis of Variance (ANOVA) using General Statistics (GENSTAT Discovery Edition 4). Significant means were separated using least significant difference (LSD) at 5% level of probability.

3.0 Results and Discussion

3.1 Effect of irrigation volume on evapotranspiration of okra

Evapotranspiration (ET) was higher consistently with increase in irrigation volume, though, these increments in ET ranged between 3.0 to 7.9% from the beginning to the end of the sampling period, but during the 9^{th} to 18^{th} days after treatment application (DAT), only 100% ETdd had significantly the highest ET while other treatments similarly affected the ET statistically (Table 2). This is because the amount of water that was evaporated or transpired is a function of the quantity of water available in the soil at that particular time. Similar to this report, Guang *et al.* (2019) observed that ET was positively related to the amount of irrigation water used. Also, Irmak (2017) reported that under the condition of water-deficit irrigation (DI) (like 25%, 50% and 75% ETdd in this study) ET was lesser than in well-watered conditions (100% ETdd) because transpiration in crops under DI cannot be high like those of well-watered crops. The differences in ET among the treatments means were not significant ($P \le 0.05$) at the early stage (3-6 DAT) and during the latter part of the crop growth. This is a possibility that evaporation directly from the soil surface accounted majorly for the ET at these stages as okra leaves were too small at the early growth stages and were withered towards the later growth stage and therefore could not provide enough soil coverage. Relatedly, Irmak (2017) stated that during the early crop growth stage, most ET takes place as evaporation from the soil surface.

Table 2: Effect of irrigation volume on evapotranspiration of okra

Irrigation Volume	Days after treatment application										
(%ETdd)	3	6	9	12	15	18	21	24	27	30	33
25	12.20	12.02	11.52	11.28	11.0	10.89	11.31	11.01	10.56	10.98	11.28
50	12.44	12.05	11.93	11.63	11.22	11.00	11.29	11.02	10.55	10.87	11.52
75	12.48	12.11	11.97	11.74	11.27	11.10	11.41	11.20	10.74	11.02	11.66
100	12.73	12.47	12.44	12.25	11.86	11.59	11.66	11.41	10.95	11.34	11.90
LSD ($P \leq 0.05$)	ns	ns	0.46	0.45	0.42	039	ns	ns	ns	ns	0.41

ETdd – Evapotranspiration demand; ns - not significant

Effect of soil textural class on evapotranspiration of okra

There were no significant differences in the ET under loamy sand (LS) and sandy loam (SL) but sandy clay loam (SCL) gave ET that were significantly lower than those of LS and SL throughout the measurement period (Table 3). This suggests that sandy clay loam, due to its finer and closely packed particles, was able to hold water more tightly against ease of evapotranspiration. Holding of water for a longer period by clay loam soil than in sandy soil (Lichner *et al.,* 2020) has also been linked with slower evaporative loss in the former than in the latter.

Table 3: Effect of soil textural classes on evapotranspiration of okra

Soil textural Classes	**Days after treatment application**										
	3	6	9	12	15	18	21	24	27	30	33
Loamy sand	13.2	12.9	12.7	12.5	12.2	12.0	12.3	12.1	11.6	12.0	12.6
Sandy loam	13.4	13.1	12.8	12.6	12.2	12.1	12.4	12.2	11.7	12.1	12.7
Sandy clay loam	10.8	10.6	10.4	10.1	9.63	9.39	9.51	9.22	8.78	9.14	9.51
LSD (P<0.05)	0.33	0.36	0.4	0.39	0.37	0.34	0.35	0.32	0.31	0.33	0.35

Effect of irrigation volumes on yield parameters and water use efficiency of okra

Irrigation water volume at 100% ETdd significantly resulted in the highest number of okra fruits than other treatments (Table 4). With the exception of 100% ETdd that significantly gave the highest okra fruit yield (weight) than other ETdd, there were no significant differences among the other three ETdd but 25% ETdd applications gave the fruit weight that was about 16% and 7% higher than those of 50% and 75% ETdd, respectively. As evidence in our study that irrigation water application at full ET demand on a daily basis could give more economic yield than DI, Owusu-Sekyere and Annan (2010) observed that the use of DI during vegetative growth led to a reduction in crop yield. However, the highest WUE significantly(P<0.05) given by treatments that received water at 25% ETdd compared with other treatments (Table 4) implies that farmers can save as high as 75% of water without much economic yield loss. This water-saving benefit of DI is what has motivated farmers' interest in improving plant water use efficiency (WUE), by applying less water than full crop-water requirements, most especially in water scarcity areas of the world (Busari et al., 2019).

Table 4: Effect of irrigation volume on yield parameters and water use efficiency of okra

Irrigation volume (%ETdd)	**Number of fruits**	**Fruit weight (g plant^{-1})**	**DMY (g plant^{-1})**	**WUE (kg m^{-3})**
25	5.0	34.7	6.49	6.12
50	4.0	29.9	5.91	2.54
75	4.0	32.3	6.01	1.83
100	6.0	45.7	8.95	1.98
LSD (P<0.05)	1.12	10.45	ns	1.37

ETdd – Evapotranspiration demand; DMY - Dry matter yield; WUE - Water use efficiency; ns - not significant

Effect of soil textural classes on okra yield parameters and water use efficiency

Sandy loam soil produced okra fruit weight that was 12.8% and 19.3% higher than those produced by SCL and LS, respectively while SCL significantly gave higher WUE than SL but only 18.2% higher WUE than LS (Table 5). Judy et al. (2015) reported that, in many cases, soil textural classes do have significant effects on crop yield and water use efficiency. Sandy loam soil can hold water moderately higher than loamy sand and lower than sandy clay loam due to their particles and pore arrangements. Thus, the ability to make more water available to the crop could have possibly influenced SL to give a higher okra yield than LS and the yield in SCL might have been lower than that of SL apparently because the water held was too much than okra consumptive use. This is also evident as WUE observed under SCL was higher than other textural classes.

Table 5: Effect of soil textural class on yield parameters and water use efficiency of okra

Soil textural class	**Number of fruits**	**Fruit weight (g plant^{-1})**	**DMY (g plant^{-1})**	**WUE (kg m^{-3})**
Loamy sand	5	32.2	8.96	3.20
Sandy loam	5	39.9	6.51	2.24
Sandy clay loam	5	34.8	5.06	3.91
LSD (P<0.05)	ns	ns	2.37	1.18

DMY - Dry matter yield; WUE - Water use efficiency; ns - not significant

4.0 Conclusions

From this study, it could be concluded that direct evaporation from the soil surface is responsible for a major component of the ET at early and later stages of okra growth. Irrigation water application at full ET demand daily could give more economic yield, however, in the regions where water scarcity is an issue, the significantly highest WUE given by treatments that received water at 25% ETdd compared with other treatments suggested that farmers can save as high as 75% of water without much economic yield loss in okra. Also, in an area with limited water supply, planting okra on a fine-textured soil like sandy clay loam which holds water more tightly against evaporative loss and increases WUE is recommended against the use of coarse-textured soil.

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