Effects of varying water applications on growth, yield and water use efficiency of okra (*Abelmoschus esculentus*) under drip irrigation in Akure

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Abstract: The conservation of water is crucial to sustainable agricultural production during dry season when there is little or no rainfall to improve crop production. Thus, this study is aimed to evaluate the effects of different levels of water applications on the growth, yield and water use efficiency of okra under drip irrigation system during dry season. Sixteen drip irrigation plots (2×2 m^2) were established following a 4×4 completely randomized block design with four replicates to determine the water consumptive use of okra. The growth, yield and water use efficiency of okra under four different irrigation management i.e. irrigation water applied at 100 FIT (full irrigation treatment), 80 FIT, 60 FIT and 40 FIT were measured. Results showed that highest growth parameters were observed under 100 FIT and the least under 40 FIT. The differences in plant height, number of leaves and leaf area in all the treatments blocks were not significant ($p>0.05$) for all the stages of development of okra. The yield obtained at 100 FIT, 80 FIT, 60 FIT and 40 FIT are 3.60 t ha^{-1}, 3.54 t ha^{-1}, 3.56 t ha^{-1} and 2.05 t ha^{-1} respectively. Using error bar there is significant effect of the treatment on the yield with 100 FIT, 80 FIT and 60 FIT having highest yields compare to 40 FIT. The irrigation water use efficiency (IWUE) ranged from 0.024-0.041 t ha^{-1} mm^{-1} while the crop water use efficiency (CWUE) ranged from 0.0088-0.0139 t ha^{-1} mm^{-1}. Okra crop irrigated with drip irrigation at 60 FIT recorded the highest IWUE, CWUE and about 73% more yield than the 40 FIT, i.e. 0.041 t ha^{-1} mm^{-1}, 0.0139 t ha^{-1} mm^{-1} and 3.56 t ha^{-1} mm^{-1} respectively. It can be concluded that okra crop irrigated at 60 FIT should be adopted in order to save 40% water to irrigate additional land.

Keywords: okra yield, water use efficiency, irrigation

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1 Introduction

In recent times, water supply has become a major hindrance to crop production due to competing water demand from other sector of the economy such as rapid industrialization and high population growth (Konyeha and Alatise, 2013). Water is very essential in the growth and production of crop. It is essential to ensure the availability of vegetable crops all year round most especially during dry season when there is little or no rainfall for production. This entails adoption of irrigation water management strategy that can facilitate the achievement of the goal of producing more crops per drop of water, which is the use of drip

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irrigation system (Panigrahi and Sahu, 2013). Properly managed irrigation increases crop yields, increases product quality, reduces pest pressures, and precisely delivers and manages nutrients (Panigrahi and Sahu, 2013).

Okra (*Abelmoschus esculentus*) is one of the most well-known and utilized species of the family *Malvaceae* and originated from Africa (Abid et al., 2002). It is also a chief vegetable crop grown for its immature pods that can be consumed as a fried or boiled vegetable or may be added to salads, soups and stews (Kashif et al., 2008). Okra is a vegetable that has a lot of stored nutrient. Okra contains two kinds of fiber, the soluble and insoluble fibers. The soluble fiber helps in lowering cholesterol serum and the risk of having heart disease, while the insoluble fiber ensures that the intestinal track stays healthy. The pods of okra plants should be harvested when they are young; as long as they are about 10 cm long, they are ready for picking. Okra plays an important role in human nutrition by providing carbohydrates, protein, fat, minerals and vitamins that are generally deficient in basic foods. Despite the high economic value of the crop and the available potentials for its high production in Nigeria, okra is widely cultivated by farmers in the country under rain-fed condition. This is possible in the south-western Nigeria because of high rainfall for about two-third of the months of the year. Unlike tropical countries where a lot of researchers have studied the production of okra under different irrigation management (Abid et al., 2002; Panigrahi et al., 2011). The few researchers who worked on the production of okra in Nigeria are Ijoyah et al. (2010), Akanbi et al. (2010) and Iyagba et al. (2012). Akanbi et al. (2010) researched on the response of okra to organic and inorganic source of nitrogen fertilizers using pot and field experiment. Akanbi et al. (2010) concluded that, small quantity of fertilizer being added to okra increased its yield. Ijoyah et al. (2010) also evaluated the response of okra to different intra-row spacing and he concluded that 30 cm intra-row spacing gave the highest yield. According to the few research carried out in Nigeria, response of okra to irrigation management have not been taking into consideration which implies that water has been applied without proper consideration and this might have led to wastage of water most especially dry season.

It is important to determine both the seasonal and peak water requirements of crop to be irrigated when planning for irrigation system. Okra requires adequate water supply and relatively moist soil throughout the growing season in order to have high yield. The flowering and the fruiting stage of okra is considered to be the most sensitive stage in the entire growing season. Water shortage at this stage reduces the yield of okra. Therefore, to improve the yield of okra there is the need for controlled irrigation system. According to Al-Harbi et al. (2008), controlled irrigation is essential for high yields in okra cultivation, because the crop is sensitive to both over and under irrigation. Agricultural sector consumes about 83% of water, whereas about 50%-70% of water is wasted through conveyance, evaporation, field application and distribution losses in conventional irrigation method (Al-Harbi et al., 2008). These losses can be reduced by adopting drip irrigation with efficient water management practices (Dahiya et al., 2005). Therefore, the objective of this research is to evaluate the effect of water applications on the growth, yield and water use efficiency of okra under drip irrigation system in Akure South-Western city of Nigeria.

2 Materials and methods

2.1 Description of the study area

The experiment was conducted during dry season of January - April 2018 at Teaching and Research Farm of the Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure as shown in Figure 1. Akure is located within the humid region of Nigeria at Latitude 7016’N; Longitude 5013’E. Akure has a land area of about 2,303 km^2 and is situated within the Western upland area. The area has a general elevation of between 300 and 700 meters above the mean sea level and mean rainfall ranges between 1300 mm to 1500 mm. The climate is tropical and lies on 345 m above sea level. The average weather condition obtained from the metrological station at Nigerian Metrological Services

(NIMETS) for the growing season during the experiment is shown in Table 1.

Figure 1 shows the drip lines layout on the experimental field and the design layout is shown in Figure 2.

Table 1 Average weather data for crop growing season

Months	Relative humidty (%)	Min.temp (^oC)	Max.temp (^oC)	Solar radiation MJ m^{-2} day^{-1})	Wind speed(m s^{-1})	Rainfall (mm day^{-1})	ET (day^{-1})
Jan	60.48	18.07	30.32	19.25	2.08		5.4
Feb	77.88	21.72	31.33	17.09	2.28	6.00	4.1
Mar	83.12	22.58	30.61	18.17	2.51	4.00	4.1
April	86,68	22.77	29.62	18.77	2.51		4.0

Note: Nigerian Metrological Services (NIMETS), 2018

Figure 1 Experimental location of the study area

2.1.1 Soil physical and chemical properties of the experimental site

Three samples were taken for the soil analysis before and after the experiment. The average is presented in Table 2. The site has a mean soil texture of sandy clay loam in the top soil (0-10 cm) which forms mainly the agricultural layer required for the cultivation of shallow rooted crops. The soil is predominantly sandy and it allows downward movement of water, which requires constant irrigation.

Bulk density ofthe soil was determined by core method (ISO, 2017; ASTM, 2015) using 20 cm long by 4.4 cm diameter of cylindrical can.

The soil moisture content was determined once in 2 weeks at 20 and 40 cm depth using gravimetric method (Gardner et al., 2001). The soil chemical properties and particle size distribution were determined in the laboratory using standard procedures (Andrews and Carroll, 2001).

The mean bulk densities of soil at the experimental site at depths 0-20 cm and 20-40 cm are 1.32 and 1.44 g cm^{-3} respectively.

Table 2 Physical and chemical properties of the soil at depth 0-40 cm

Parameters	Before planting	After planting
pH	4.76	5.07
P (mg kg^{-1})	8.76	6.98
Na (cmol kg^{-1})	0.53	0.43
Ca (cmol kg^{-1})	3.10	2.90
Mg (cmol kg^{-1})	1.30	1.10
K (cmol kg^{-1})	0.60	0.24
CEC (cmol kg^{-1})	12.14	9.26
O.C. (%)	1.21	0.88
O.M. (%)	2.08	1.52

N (%)	0.12	0.08
Sand (%)	52.80	52.80
Clay (%)	31.20	33.20
Silt (%)	16.00	14.00

P=Phosphorus; Na=Sodium; Ca=Calcium; Mg=Magnesium; K=Potassium; N=Nitrogen C.E.C= Cation Exchange Capacity; O.C=Organic Carbon Content; O.M=Organic Matter Content

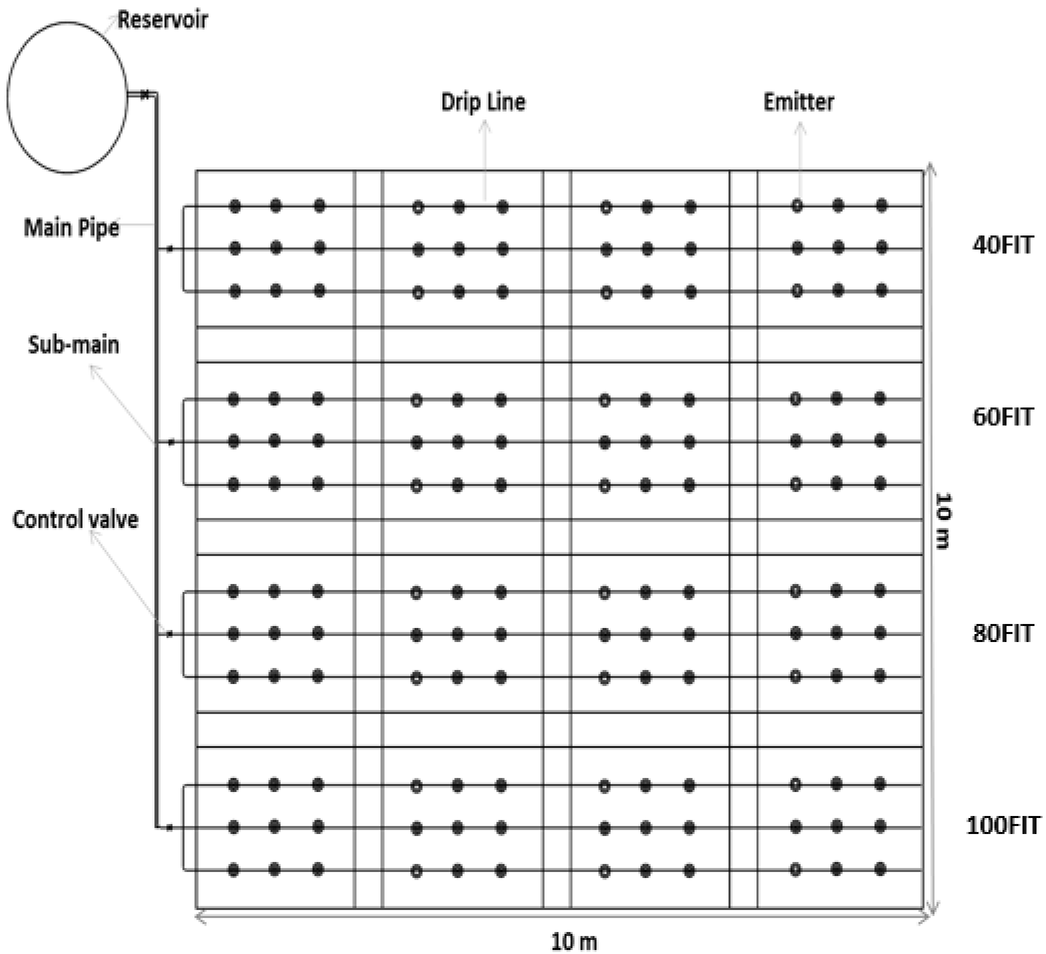


Figure 2 Layout of the experiment

2.2 Experimental setup and layout

An area of 10 m × 60 m was first slashed, ploughed and harrowed to ensure good soil tilth for crop growth and 10 m × 10 m of the prepared bed was divided into sixteen seed beds using drip irrigation system. A variety of okra (*Abelmoschus esculentus*) was planted at equal distance of 90 cm within rows and 50 cm between rows. Cultural practices such as thinning, weeding and controlled of pests and diseases were carried out appropriately. The sixteen plots consist of four treatments (2 m × 2 m) with four replicates in a complete randomized block design. The emitter is an on-line pressure compensating and anti-drain type with nominal discharge of 3.0 L h^{-1}, orifice area of 1.45 mm^2, emitter discharge coefficient of 1.911, emitter discharge exponent of 0.02 and manufacturing coefficient of variation of 4 according to manufacturer's manual. Each drip line of 25 mm diameter was installed at a spacing of 90 cm on the treatment blocks and making a total of three drip lines on each treatment blocks. Each of the treatments blocks was connected to a main pipe which supplies water from the reservoir with pressure head of 207 kPa to the field. The first treatment was 100% full irrigation treatment (FIT) while the second, third and fourth treatments were 80 FIT, 60 FIT and 40 FIT respectively.

Rainfalls were measured during the experiment with the aid of an automated rain gauge installed at the experimental site. The yield of the okra was weighed using weighing balance of good precision of 0.01g. Water consumptive use was determined using soil water balance method and water use efficiencies were also calculated using Equation 1;

$$ET = I + P \pm \Delta S - R - DP \quad (1)$$

Where;

ETc=evapotranspiration (mm)

P=precipitation i.e. rainfall (mm); I=water applied by irrigation (mm)

DP=deep percolation (mm); R=runoff (mm); ΔS = change in soil water storage (mm)

Runoff and deep percolation were assumed negligible because occasional rainfall was observed not adequate enough to cause runoff and deep percolation into soil and only crop water requirement at the required depth was applied through drip irrigation system.

2.3 Crop growth parameters measurement

Weekly measurements of agronomic parameters, which are the plant height, number of leaves and leaf area, were measured starting from the 2nd week of planting (14 days after planting, DAP) to maturity stage, that is, 7th week after planting (49 DAP) in order to monitor the growth response to varying water applications. The leaf area was also measured weekly. Three plants were selected to monitor all these growth parameters measurements. The greatest leaf width was measured with ruler and breadth of the leaf was multiplied by a correction factor of 0.62 (Musa et al., 2016) as given in Equation 2

$$Leaf\ area = 0.62 \times L \times W \quad (2)$$

Where L (cm) and W (cm) are the leaf length and leaf width respectively. LAI was determined as the ratio of total leaf area to land over an experimental plot. The leaf area index was calculated using Equation 3 (Musa et al., 2016)

$$LAI = \frac{0.62 \times \mathrm{L} \times \mathrm{W} \times \mathrm{NP} \times \mathrm{NL}}{\text{Land area covered}} \quad (3)$$

Where NP and NL are number of plants and leaves respectively.

2.4 Water use efficiency

Water use efficiency is defined as a ratio of biomass accumulation, which is usually expressed as carbon dioxide assimilation, total dry matter yield, or crop grain yield, to water consumed, expressed as transpiration, evapotranspiration, or total water input to the system (Eric, 2014). Water use efficiency can be divided into irrigation water use efficiency (IWUE) and crop water use efficiency (CWUE).

3 Results and discussion

3.1 Soil moisture content variation in each treatment blocks

It was observed that the soil moisture increased downward in the soil profile as shown in Figure 2-5.

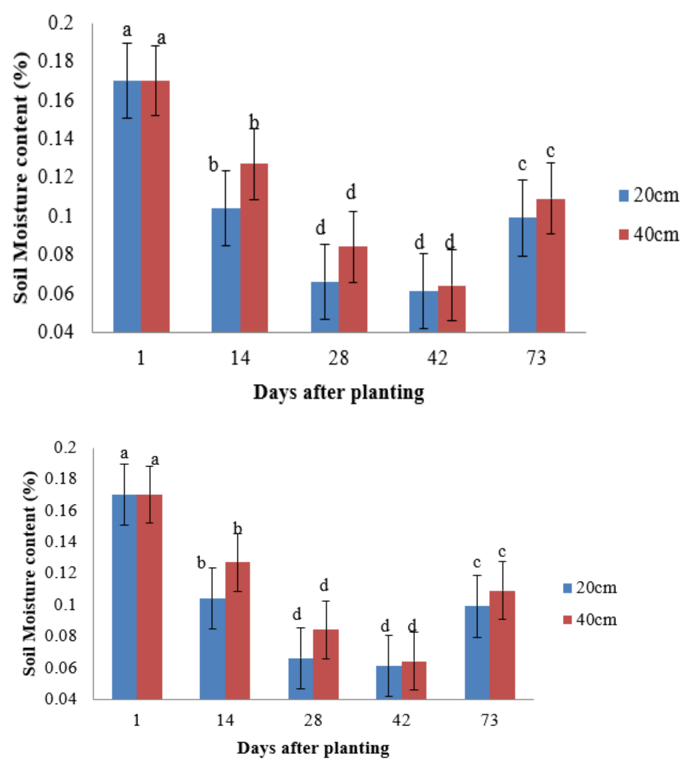
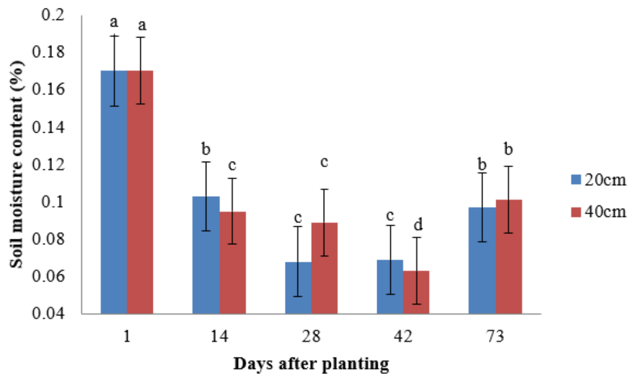


Figure 2 Variation of soil moisture content at different depth (average ± error bar) in 100 FIT treatment block under drip irrigation system. Different letters mean significant (p<0.05) differences.

Soil moisture content was high in the first day after planting for all the treatments compared to other days. The fluctuations must have been facilitated by the application of irrigation water, rainfall at different days after planting and evaporation at the soil surface (Konheya and Alatise, 2013). They show the relationship between the variation of soil moisture content stored under drip irrigation system in each treatment blocks at depth of 0-20 cm and 20-40 cm and their replicates.

The moisture content at field capacity was high because the soil was fully saturated before planting the okra. The reduction in the soil moisture content up to 40 days after planting was due to high demand of water by the crop during the flowering and fruiting stage when water is most required. At maturity and harvesting stage, small amount of water is required by the crop thereby increases the moisture content of the soil up to 70 days after planting.



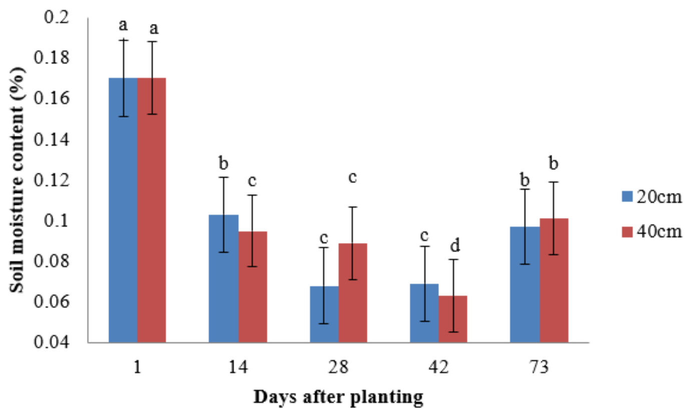


Figure 3 Variation of soil moisture content at different depth (average ± error bar) in 80 FIT treatment block under drip irrigation system. Different letters mean significant (p<0.05) differences.

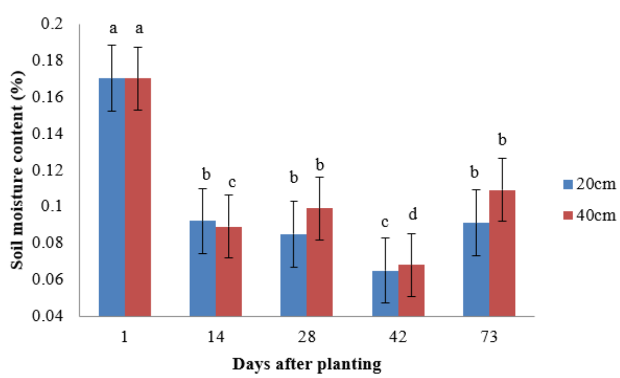


Figure 4 Variation of soil moisture content at different depth (average ± error bar) in 100 FIT treatment block under drip irrigation system. Different letters mean significant (p<0.05) differences.

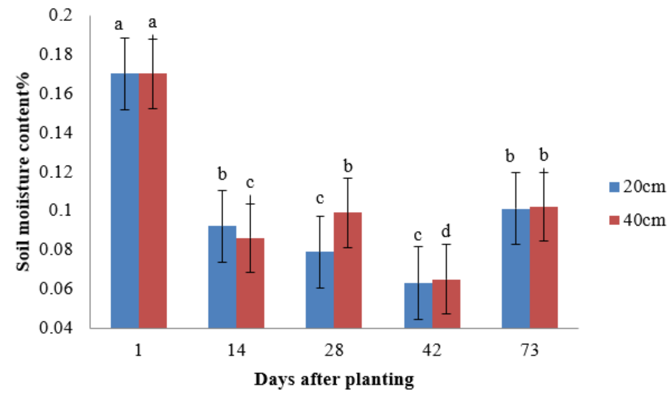


Figure 5 Variation of soil moisture content at different depth (average ± error bar) in 100 FIT treatment block under drip irrigation system. Different letters mean significant (p<0.05) differences.

3.2 Agronomic response of okra

The relationship between the growths parameters with respect to days after planting in all the treatment blocks are shown in Figure 6-10. It was observed that there was no rapid increase in the means of all the growth parameters during the emergence and the growing season of the okra crop until it got to the fruiting stage which was 35 days after planting. This rapid increase was observed until the crop reached the maturity at 60 days after planting when it no longer developed and the leave started dropping to add more crop cover to the soil. Analysis showed no significant difference in the means of all the growth parameters of okra in all the treatment blocks at $p>0.05$ level of significance as presented in Table 3.

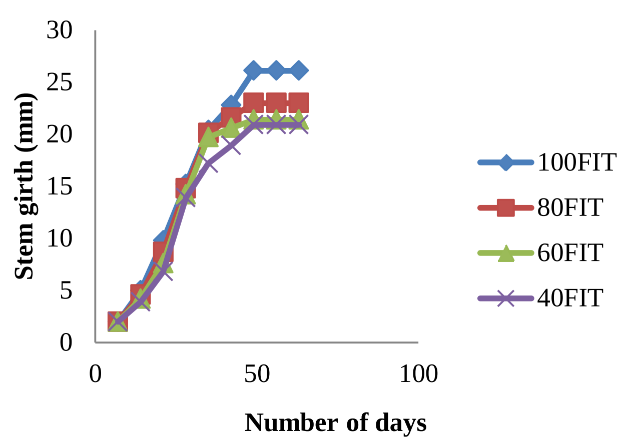


Figure 6 Mean stem girth with respect to days after planting in all treatment blocks

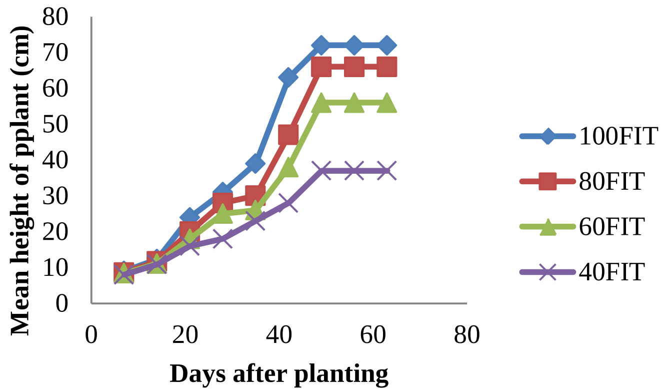


Figure 7 Mean height with respect to days after planting in all the treatment blocks

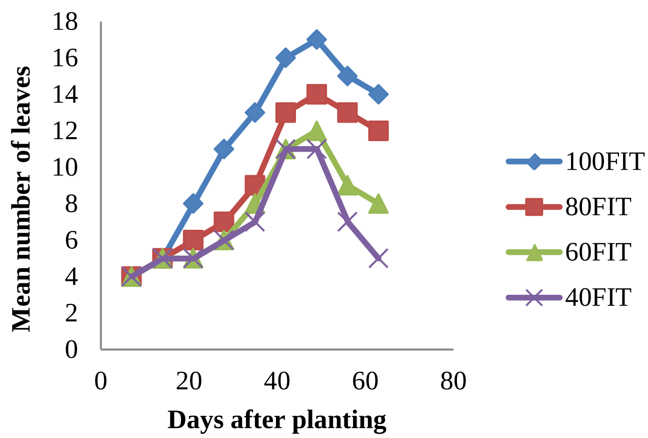


Figure 8 Mean number of leaves with respect to days after planting in all treatment blocks

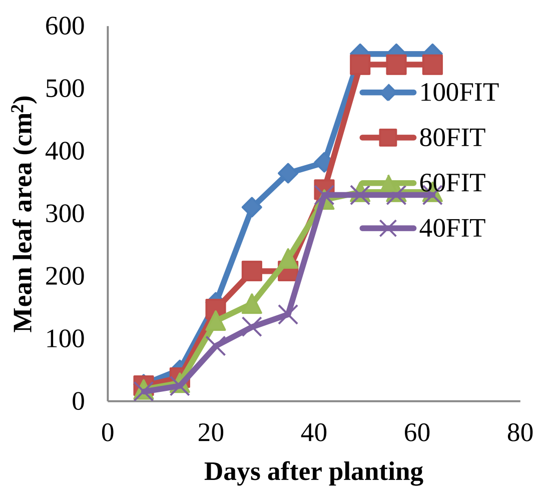


Figure 9 Mean leaf area with respect to days after planting in all treatment blocks

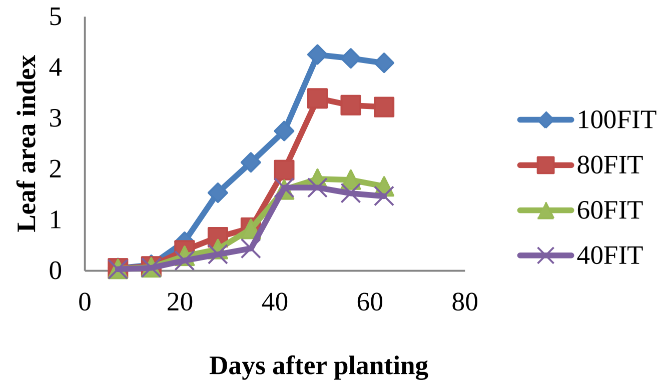


Figure 10 Mean leaf area index with respect to days after planting in all treatment blocks

Table 3 Analysis of Variance (ANOVA) on the effect of treatments on agronomic parameters

Source of Variation	SS	df	MS	F	P-value	F crit
Mean height	1943.04	3	647.68	1.47	0.24	2.90
Numbers of leaves	115.19	3	38.40	2.94	0.48	2.90
Stem girth	48.57	3	16.19	0.23	0.88	2.90
Leaf area	11.48	3	38.26	1.22	0.32	2.90
Leaf area index	10.73	3	3.58	2.20	0.11	2.90

3.3 Okra pod yield

The results of okra pod yield are given in Figure 11. The average value of okra pod yield obtained was the highest in the 100 FIT treatment and lowest in the 40 FIT treatment.

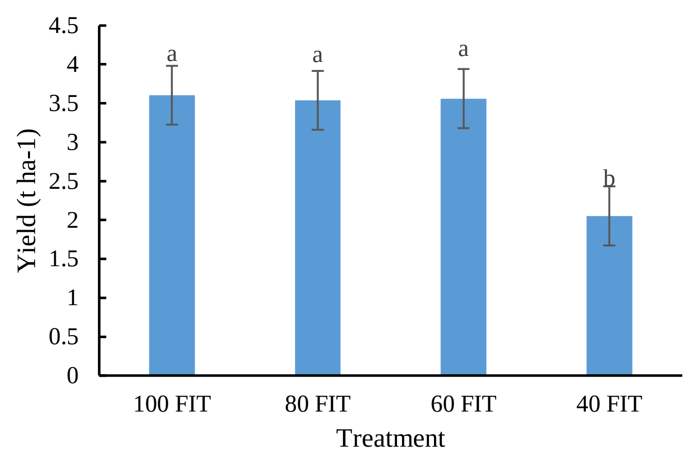


Figure 11 Average okra yield and error bars for all the treatments. Different letter means significant differences ($p<0.05$).

The higher yield can be obtained due to the efficient application of water and proper aeration in the root zone which helps for the favorable conditions for growth of the plant. Statistical treatment showed that there was no difference in the mean of the yield obtained in 100 FIT, 80

FIT and 60 FIT. This implies that 40% reduction in crop water requirement had no negative effect on the okra yield. The yield ranged from 2.05 t ha^{-1} to 3.60 t ha^{-1} which was within the range obtained from that of Babu et al. (2015). Poor yield obtained in 40 FIT was due to the insufficient water application to meet crop growth requirement.

3.4 Water use efficiecny

Both the IWUE and CWUE were calculated and recorded in Table 4 and 5.

Table 4 IWUE for all the treatment blocks and replications (R).

Treatments	IWUE (t ha^{-1} mm^{-1})				Average
	R1	R2	R3	R4	
100FIT	0.015	0.028	0.024	0.029	0.024
80FIT	0.017	0.031	0.029	0.040	0.029
60FIT	0.037	0.037	0.047	0.042	0.041
40FIT	0.031	0.035	0.031	0.039	0.034

Table 5 CWUE for all the treatment blocks and replications (R)

Treatments	CWUE (t ha^{-1} mm^{-1})				Average
	R1	R2	R3	R4	
100FIT	0.0072	0.0138	0.0115	0.0141	0.0116
80FIT	0.0069	0.0129	0.0118	0.0162	0.0120
60FIT	0.0127	0.0127	0.0159	0.0145	0.0139
40FIT	0.0081	0.0090	0.0080	0.0100	0.0088

Table 6 ANOVA for the effect of treatments on IWUE

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	60.91	1	60.91	92.58	9.86E-12	4.098172
Within Groups	25.00	38	0.66			
Total	85.91	39				

Table 7 ANOVA for the effect of treatments on CWUE

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	61.92	1	61.92	94.12	7.87E-12	4.10
Within Groups	25.00	38	0.66			
Total	86.92	39				

Results showed that treatment 60 FIT had significant effect on IWUE and CWUE with 0.041 t ha^{-1} mm^{-1} and 0.00139 t ha^{-1} mm^{-1}, respectively, compared to the other treatment and it was considered to be the best among all the other treatments. Table 6 shows ANOVA results on the effect of treatments on IWUE and it was observed that there was significant difference ($p<0.05$) in the IWUE, which might be due to the different irrigation water applied which in turn resulted to different yield being obtained. Table 7 shows ANOVA results on the effect of treatments on CWUE and it was observed that there was no significant difference ($p>0.05$) in the CWUE. Reduction in the IWUE and CWUE for 80 and 100 FIT showed that addition of water had no significant effect on the yield of okra rather, it only led to wastage of water since the crop water requirement was fully met at 60 FIT.

4 Conclusion

A field experiment was carried out to investigate the effects of varying water application on the growth, yield and water use efficiency of okra. The yield obtained from all the treatment blocks was significantly different ($p<0.05$) and this was as a result of different levels of water applications. The highest IWUE and CWUE were recorded under 60 FIT as 0.041 t ha^{-1} mm^{-1} and 0.0139 t ha^{-1} mm^{-1} respectively. The yield obtained under 60 FIT was 3.56 t ha^{-1} which had no significant difference to the yield obtained under 100 FIT. It is then concluded that okra crop irrigated under 60FIT should be adopted in the study area and this would save 40% of water to irrigate additional land.

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