Evapotranspiration and Leaf Area Index (LAI) of Irrigated Okra (*Abelmoschus esculentus* L. Moench*)* in Akure, South-Western City of Nigeria

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Abstract
In view of the increasing competitive demands for water, there is the need to ensure optimum use of the available water for irrigation purposes. However, determination of crop water use in irrigation systems can be achieved through the measurements of certain growth parameters as evapotranspiration and leaf area index. Thus, the present study was aimed at determining the Evapotranspiration and Leaf Area Index (LAI) of Okra (*Abelmolescus esculentus*) grown under micro-sprinkler irrigation system during off-seasons. Nine micro-Irrigation plots (2×2 m^2) were established following a 3×3 completely randomized block design to determine the consumptive use of water in okra field. Evapotranspiration and Leaf Area Index (LAI) of okra under three different irrigation water management i.e. irrigation water application at 20% (Treatment 1, Low irrigation), 50% (Treatment 2, medium irrigation) and 75% (Treatment 3, high irrigation) were measured. Results showed a high positive correlation range (0.7591-0.8727) between actual evapotranspiration and days after plating (DAP) reaching its peak between 30 and 40 DAP (peak of vegetative growth) in most treatments. Leaf Area Index (LAI) of Okra increased from 0.2088 at the 3 weeks after planting (WAP) to 1.4994 at 5 WAP under high irrigation water treatment and increased thereafter to 4.3974 at crop maturity. LAI was least in plots irrigated at low irrigation and increased from 0.1332 to 2.2592 in Treatment 1 during the 2008/2009 experiment. The difference in LAI between plots irrigated in the treatments were not significant (P = 0.05) both at flowering and maturity stages. The mean of LAI of Okra was least 0.166 at 3 WAP and highest 3.282 at 7 WAP and standard deviation ranged between 0.04 and 1.07 for the same period. It was concluded that the period of flowering and fruiting was most critical in term of water requirement in okra and as such, adequate irrigation water application should be ensured during the period.

KEYWORDS: Irrigation, Water use, Okra, Evapotranspiration, Leaf Area Index

1.0 Introduction

In recent time water supply has become a major hindrance to crop production due to competing water demands from other sectors of the economy such as rapid industrialization and high population growth. The new paradigm shift in water resources management which seeks to allocate water to all sectors equitably (WWF, 2008) also calls for optimum use of water. For these reasons, availability of water for irrigation purpose might become minimal in the nearest future (Panigrahi, and Sahu, 2013). Therefore, minimizing scarcity of irrigation water for crop production will require efficient water conservation and management practices even in high rainfall areas for sustaining food supply (Panda et al., 2004). In addition, as much as water is essential for crop growth, it is required at different proportion at various stages of growth. This is why application of irrigation water should take cognizance of optimum utilization of per drop of irrigation water while considering the best water use efficiency associated with any crop (Panigrahi and Sahu, 2013).

Okra (*Abelmoschus esculentus* L. Moench) or Lady's finger belongs to the family Malvacea, originated in Africa (Abid et al., 2002) and is one of the important vegetables grown throughout the tropics and subtropics. The crop is highly nutritive (Abid et al., 2002) as a 100 g of edible portion of okra contains 1.9 g protein, 0.2 g fat, 6.4 g carbohydrate, 0.7 g minerals and 1.2 g fiber (Gopalan et al., 1989). The green pods are rich sources of vitamins, calcium, potassium and other minerals (Lee et al., 2000) while the dried form is used as soup thickner (Owonubi and Yayock, 1981) and can also serve as a means of preservation. The stem of the plant is a good source of fiber which can be used in the paper industry (Balooch, 1994). Okra is either consumed in form of fresh tender pod when cooked and when ripe, the black or white-eyed seeds are sometimes roasted and used as substitute for coffee (Abid et al., 2002). In Nigeria, although the crop is widely cultivated as a sole crop or mixed with other vegetables, there are no data to show its annual output, perhaps because its production is for domestic consumption. Yet it is an economic crop since its marketing serves as a means of income to many women and farmers who specialize in its cultivation (Ijoyah et al., 2010). As obtained in other regions of the world, majority of the fresh pods are used as boiled vegetable in the country.

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 a rain-fed condition. This is especially so in the south-western Nigeria where there is rainfall for about two-third of the months of the year. Unlike in other tropical countries where many studies have been conducted on the production of okra under different irrigation systems (see Abid, et al., 2002; Jayapirathata et al., 2010; Panigrahi et al., 2011), few researches done in Nigeria have focused on the influence of some cultural practices (e.g. Akanbi et al. 2010; Ijoyah et al., 2010; Iyagba et al. 2012) on the production of the crop. All these, therefore, have limited production to the raining season and as well hindered the attainment of optimum productivity of the crop in the country. This is because, irrigation has the capacity to ensure all-year-round cultivation of the crop in Nigeria.

However, when planning for irrigation, one must determine both the seasonal and peak water requirements for the crop to be irrigated. In okra, an adequate water supply and relatively moist soils are required during the total growing period to ensure high yields (Abd El-kader, et al., 2010). Reduction in water supply during the growing period in general has an adverse effect on yield and the greatest reduction in yield occurs when there is a continuous water shortage until the time of first picking. Nevertheless, the beginning of the flowering period is said to be most sensitive to water shortage and soil water depletion in the root zone during this period should not exceed 25% (Abd El-kader, et al., 2010). Water shortage just prior and during early flowering reduces the number of fruits. Thus, to prevent poor yield, there is the need for controlled irrigation. According to Al-Harbi et al., (2008), controlled irrigation is essential for high yields in okra field, because the crop is sensitive to both over and under irrigation.

Nonetheless, controlled irrigation is anchored on efficient irrigation scheduling, but Panigrahi, and Sahu (2013) stated that quantification of crop-evapotranspiration (ETc) in different growth stages of a crop is a pre-requisite for efficient irrigation scheduling and ETc of a crop grown in any region depends upon the management practices including irrigation. Oguntunde (2004) also opined that a detailed knowledge of irrigation water requirements, its magnitude, temporal and spatial variability is essential for the assessment of water resources, and soil storage requirements, the capacity of irrigation systems, optimal allocation of water to crops and for decision making in operation of irrigation systems and water resources. Despite the wide acceptability of furrow irrigation as probably the best method of water application to okra (Panigrahi, and Sahu, 2013), the use of micro-sprinkler system has the advantage of saving water and reduce salinity of soils (Pitts and Clark, 1991). Alao et al., (2012) also stated that sprinkler irrigation systems apply water directly to the surface of the crop as well as the soil around the roots of the crop with high efficiency, thereby reducing water loss, ponding and flooding. The objectives of this research, therefore, are to determine the Evapotranspiration (ET) and Leaf Area Index (LAI) of okra under micro-sprinkler irrigation in Akure, South-Western City of Nigeria.

2. Material and Methods

The study was carried out at the Teaching and Research Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure during the dry season of 2008/2009 and 2009/2010. Akure is on latitude $7^0 16^1$N, Longitude $5^0 13^1$E with relatively dry season from November to March and a raining season from April to October. Average annual rainfall ranges between 1405 mm and 2400 mm of which raining season accounts for 90% and the month of April marks the commencement of rainfall. An area of 10 m x 60 m portion of the farm site was ploughed and harrowed for effective seed bed formation and 10 m x 10 m part of the prepared land was divided into nine seed beds (micro-sprinkler plots), 2.0 m long, 2.0 m wide and 0.15 m deep while allowing 0.5 m spacing between beds. A variety of Okra, LD88 (*Abelmoscus esculentum* L. Moench) was planted at equal distance (30 cm) within row, while maintaining spacing of 60 cm between rows. Such cultural practices as thinning, weeding and insects pests and diseases control were carried out as appropriate, but there was no fertilizer application in view of the perceived high fertility of the experimental plot. The micro sprinklers were installed at the centers of the nine 2.0 m x 2.0 m plots with three treatments replicated three times in a randomized complete block design. Each treatment plot was connected to separate supplies (0.1 m^3 capacity reservoirs) placed at higher elevation of the field, supplying water to the emitters under uniform pressure head of 1.5 m. The three treatments replicated were namely High, Medium and Low irrigation which were applied at 75%, 50% and 40%, of the total water requirement of okra, respectively.

Soil particle size distribution, organic matter and bulk density were determined using standard procedures as described by Vogelmann et al. (2010). Soil moisture content was also determined in each of the plot once a week at 10, 20, 30, 40, 50 and 60 cm soil depth using gravimetric method. Soil bulk density (g/cm^3) was determined by the core method using a 6.2 cm long by 6.2 cm diameter cylindrical can. Rainfalls were measured during the experiment with the aid of automated rain gauge and the consumptive use of okra was estimated at the phenological stages of the crop using the water balance approach (Rushton et al., 2006; De Silva and Rushton, 2007). The method which involves the measurement of the changes in the incoming and outgoing water into the crop root zone over sometime (Hillel, 1998) was used to determine the water use of okra.

$$ET = P \pm I \pm D \pm R \pm \Delta S$$

Where

ET = Consumptive use (mm)
P = Precipitation i.e. rainfall (mm)

I = Water applied by irrigation (mm)
D = Drainage (mm)
R = Runoff (mm)
ΔS = Change in soil water storage (mm).

Precipitation (P) measurements during the period of experiment were estimated from average of water volume in farm site. The runoff (Ro) and the drainage (D) were not determined because occasional rainfall events were observed not adequate enough to cause runoff and deep water percolation into soil.

Leaf Area Index (LAI)

Leaf Area Index (LAI) was determined weekly beginning from the 3 WAP to crop maturity 7 WAP. Four representative stands were selected per treatment plots for the measurement of plant leaf area and averages estimated. Leaf area was measured graphically using an approximate method and Leaf Area Index was estimated as stated below:

$$Leaf\ Area\ Index\ (LAI) = \frac{Area\ of\ leaf\ per\ plant}{Area\ of\ soil\ covered\ per\ plant}$$

Statistical analysis was carried out to determine the mean, standard deviation, and coefficient of variation of the climatic, soil and crop data collected, using SPSS and excel software packages.

Soil Properties at the Experimental Site

Presented in Table 1 and 2 are the soil properties at the experimental site. The soil texture at the topsoil which is the agricultural layer required for the cultivation of most vegetables, is consisted mainly of sandy-loam. Minimum and maximum organic carbon content of 0.88% and 1.58% respectively were observed within the top 30 cm depth of the soil during the experiment. The top soil average carbon content falls within the recommended range (0.6-1.2%) desirable for tropical crop production. The high organic carbon content may be due to the fact that the site was cleared from fallow vegetation and primary carbon production is high. This is in agreement with the report of Nelson et al. (1994).

The soil pH varies from acidic to neutral on the surface soil (5.7-7.1); the values fall within slightly acidic range (6.4) and are close to the average value of 6.5 which was considered ideal for good availability of plant nutrients in mineral soils (Forth and Ellis, 1997). The bulk density of the experimental site ranges from 1.20 – 1.50g/cm^3 within the first 0.3 m depth of soil. This is below the critical value of 2.1g/cm^3, beyond which plant growth is severely limited (Agyare, 2004).

Table 1: Description of soil properties at the sprinkler irrigation plots during 2008/2009

Sample	pH in water 1:2	Organic carbon %	Organic matter %	N %	P Mg/kg	K^+ Cmol/kg	Na^+ Cmol/kg	Ca^{2+} Cmol/kg	Mg^{2+} Cmol/kg	Sand %	Clay %	Silt %
1	5.73	1.32	2.27	0.70	24.67	0.20	0.11	1.90	1.20	62	20	18
2	5.94	1.02	1.75	0.51	19.50	0.17	0.10	1.40	0.80	64	18	18
3	5.71	0.36	0.62	0.11	6.30	0.09	0.05	0.90	0.50	68	20	12
4	6.27	1.14	1.96	0.57	23.15	0.21	0.11	1.50	1.40	56	20	24
5	5.61	1.58	2.72	0.79	28.90	0.23	0.13	1.70	1.00	66	20	14
6	5.96	0.52	0.89	0.26	9.80	0.09	0.06	0.80	0.60	68	20	12
7	6.26	1.06	1.82	0.53	21.42	0.18	0.10	1.10	0.80	72	20	08
8	5.65	0.08	0.14	0.10	5.99	0.07	0.04	1.00	0.90	68	20	12
9	6.18	0.96	1.65	0.48	11.41	0.15	0.07	1.40	0.80	64	20	16
Min	5.61	0.08	0.14	0.10	5.99	0.07	0.10	0.80	0.50	56	18	12
Max	6.27	1.58	2.72	0.79	28.90	0.23	0.13	1.90	1.40	72	20	24
Mean	5.92	0.89	1.54	0.45	16.79	0.15	0.09	1.30	0.89	65.33	19.80	14.9

Table 2: Description of soil properties at the sprinkler irrigation plots during 2009/2010

Sample	PH in water 1:2	Organic carbon %	Organic matter %	N %	P Mg/kg	K^+ Cmol/kg	Na^+ Cmol/kg	Ca^{2+} Cmol/kg	Mg^{2+} Cmol/kg	Sand %	Clay %	Silt %
1	5.72	1.31	2.26	0.69	24.66	0.19	0.09	1.70	1.10	61	19	17
2	5.94	1.02	1.75	0.51	19.50	0.17	0.10	1.40	0.80	64	18	18
3	5.70	0.35	0.61	0.12	6.29	0.08	0.04	0.89	0.49	69	19	13
4	6.27	1.14	1.96	0.57	23.15	0.21	0.11	1.50	1.40	56	20	24
5	5.61	1.58	2.72	0.79	28.90	0.23	0.13	1.70	1.00	66	20	14
6	5.96	0.52	0.89	0.26	9.80	0.09	0.06	0.80	0.60	68	20	12
7	6.26	1.06	1.82	0.53	21.42	0.18	0.10	1.10	0.80	72	20	08
8	5.65	0.08	0.14	0.10	5.99	0.07	0.04	1.00	0.90	68	20	12
9	6.18	0.96	1.65	0.48	11.41	0.15	0.07	1.40	0.80	64	20	16
Min	5.61	0.08	0.14	0.10	5.99	0.07	0.10	0.80	0.50	56	18	12
Max	6.27	1.58	2.72	0.79	28.90	0.23	0.13	1.90	1.40	72	20	24
Mean	5.92	0.89	1.54	0.45	16.79	0.15	0.09	1.30	0.89	65.33	19.80	14.9

Water Application to the Treatment Plots during Experiments

Table 3 shows the total water applied to okra under various treatments during the experiment. The total amount of water applied at treatments T1, T2 and T3 are 94.08 mm, 188.44 mm and 282.73 mm respectively.

Table 3: The total amount of water applied to okra at various treatments

Treatment	Irrigation Interval (days)	Irrigation Water Applied (mm/week)	Total Irrigation Water Applied to Maturity (mm)
T1	3	13.44	94.08
T2	3	26.92	188.44
T3	3	40.39	282.73

3.0 Results and Discussion

3.1 Moisture storage in the Soil Profile

Figures 1 and 2 show the variations in the soil moisture stored in the okra field measured at a depth of 60 cm. The stored moisture in the soil profile was observed to increase down the soil profile. The fluctuations must have been facilitated by the application of irrigation water, rainfall at different days after planting and evaporation at the soil surface. The moisture regime in T3 was highest among all plots in the sprinkler irrigation plots perhaps as a result of high rooting volume (Ahmet and Ali, 2009). As the crop reaches maturity defoliation of leaves around this time resulted into soil exposure to direct solar radiation and hence increased evaporation from bare soil surface. However, moisture stored in T2 was highest (8.24cm) at the 71 DAP even during the fruiting stage of okra. This might have been so because of the water accumulation around the root zone of the crop thus permitting moisture build-up at the topsoil. A general rise in stored soil moisture was observed in treatment T3 because of their location down the slope of the site which resulted in accumulation of water at the topsoil, the increase in moisture stored in T3 was also due to high irrigation.

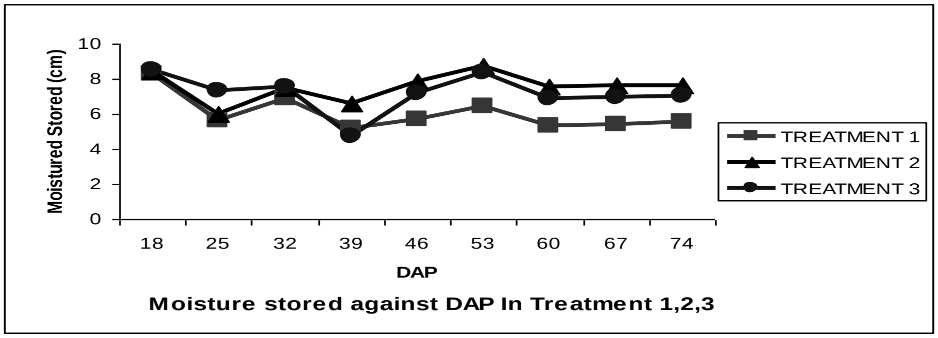

Figure 1: Moisture stored in soil DAP at various treatments in 2008/2009

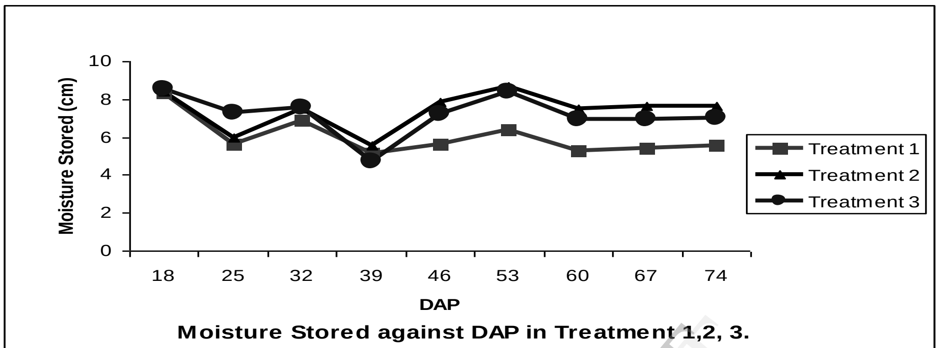

Figure 2: Moisture stored in soil DAP at various treatments in 2009/2010

3.2 Evapotranspiration

The results of evapotranspiration measured at different plots are shown in Figures 3-8. Evapotranspiration values were high at the 42 DAP during the vegetative stage of the crop which might not be unconnected to increased leaf number and leaf area of okra. The general increase in evapotranspiration values might have been caused by increased canopy of the crop during flowering and fruiting stages of okra. Panigrahi and Sahu (2013) had reported a higher ETc for okra with increased water application caused by higher transpiration of crop, coupled with more evaporation from fully wetted soil surface. Variations in the crop water use of okra were also observed and these were largely due to the different irrigation schedules (low, medium and high) for all treatment plots. High values of evapotranspiration observed in T3 may have been due to high irrigation water received. Highest values of evapotranspiration obtained generally at between 28 and 32 DAP in most plots may have occurred as result occasional, but light rainfalls. The coefficient of correlation between the crop evapotranspiration and the growth stages of okra (emergence to maturity) was highest in T3 with value of 0.87, under T3.

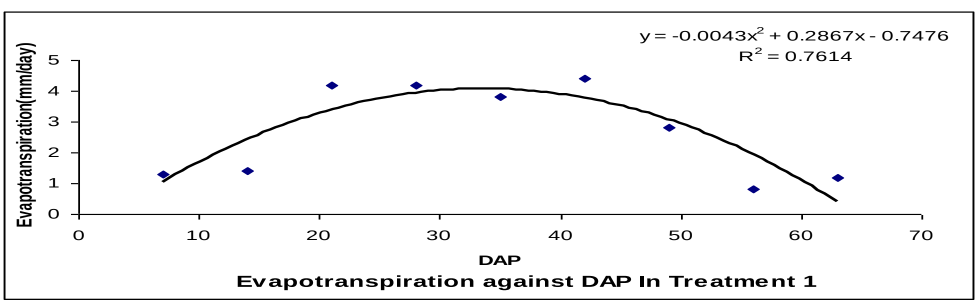

Figure 3: Variation of Evapotranspiration with DAP in T1 (Low irrigation) in 2008/2009

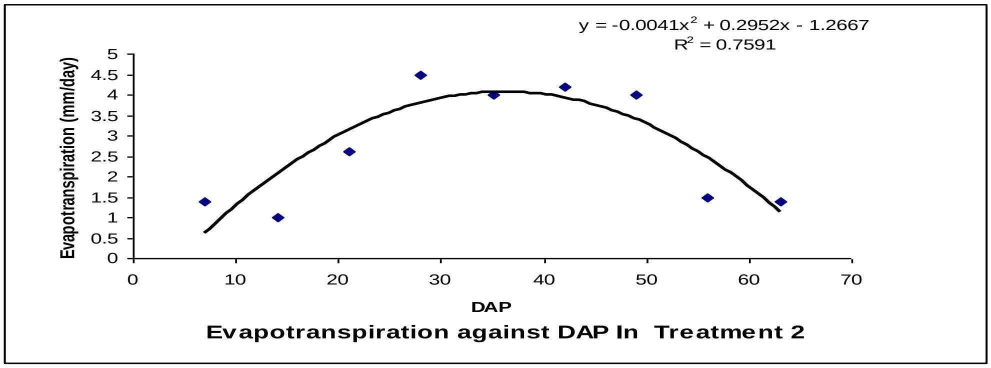

Figure 4: Variation of Evapotranspiration with DAP in T2 (Low irrigation) in 2008/2009

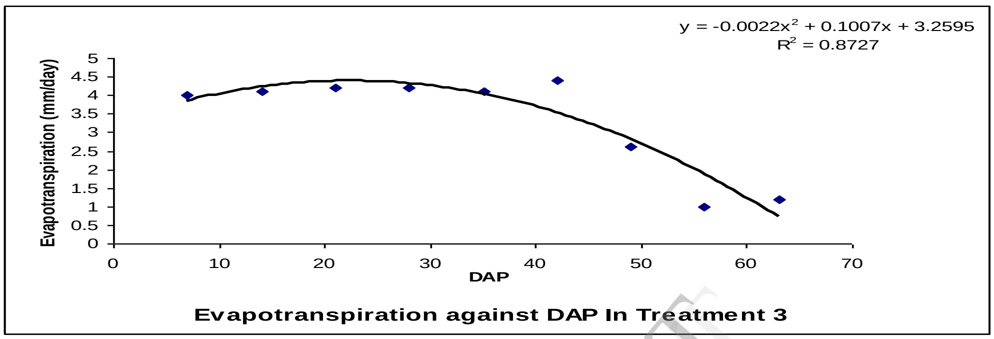

Figure 5: Variation of Evapotranspiration with DAP in T3 (Low irrigation) in 2008/2009

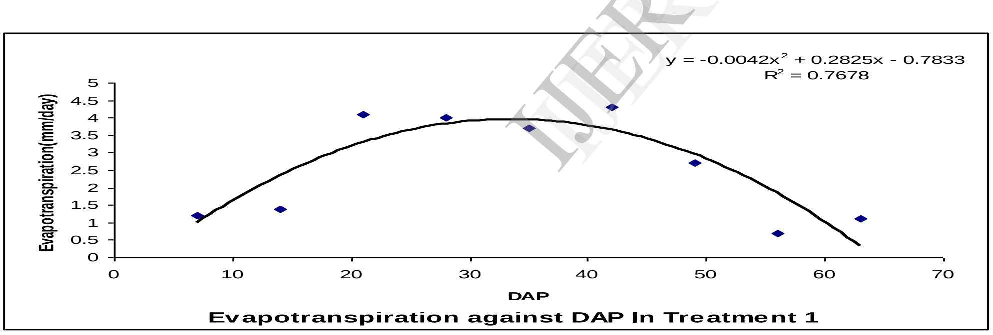

Figure 6: Variation of Evapotranspiration with DAP in T1 (Low irrigation) in 2009/2010

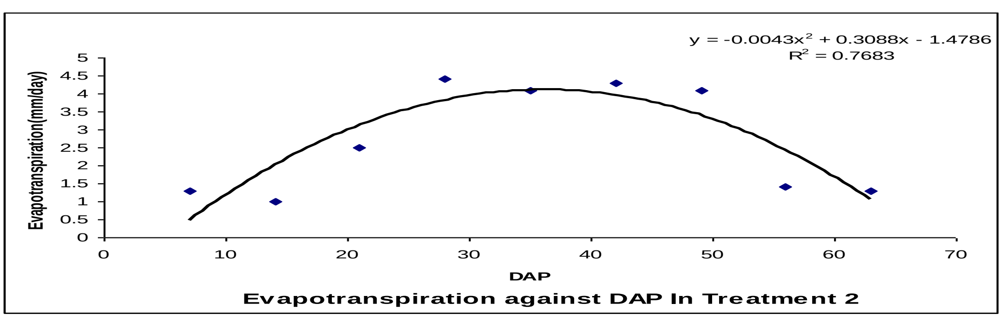

Figure 7: Variation of Evapotranspiration with DAP in T1 (Medium Irrigation) in 2009/2010

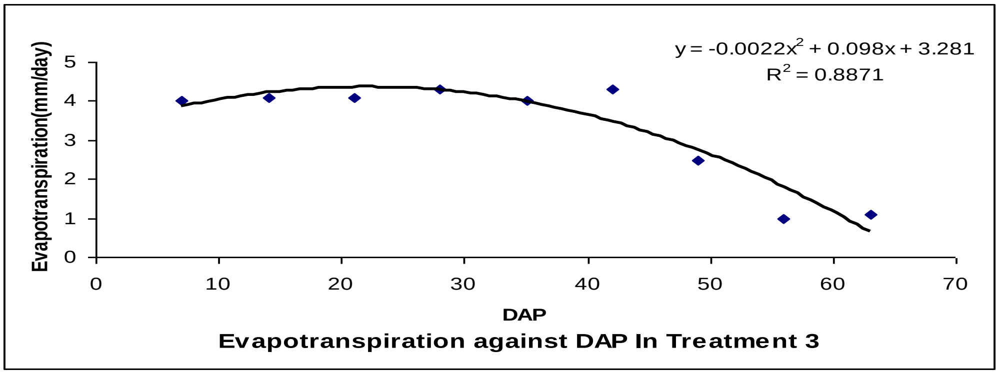

Figure 8: Variation of Evapotranspiration with DAP in T1 (High irrigation) in 2009/2010

3.3 Leaf Area Index

Leaf area index (LAI) of Okra for the 2008/2009 and 2009/2010 experiments are presented in Table 4. Leaf area index increased from emergence and reached its peak at crop maturity. However, LAI declined when crop reached senescence. This was due to leaf detachment (abscission) from sample plants when the crop reached senescence. Ahmadi et al. (2010) had earlier stated that formation of abscisic acid (ABA) in roots and its consequent translocation from root to shoot can cause reduced stomatal conductance and transpiration rate of leaves. Nevertheless, the values of LAI were found to be highest in T3 (High irrigation) and were closely followed by T2 (medium irrigation). LAI increased from 0.2088 to 4.3974 at the 7 WAP in treatment T3 at crop maturity, while it increased from 0.1564 to 3.188225 in treatment 2 during 2008/2009 experiment. The difference in LAI between T2 and T3 were not significant (P = 0.05) both at flowering and maturity stages of the crop. This must have been caused by occasional rainfalls the crop enjoyed at its later stage of development. However, the limited water supply to Okra in T1 affected the physiological development of the crop, the effect of which was highly pronounced during the maturity stage of the crop when the crop actually needed appreciable quantity of water for its water demand (evapotranspiration).

Mean and standard deviation of LAI also increased from 3WAP to 7WAPwhich showed that vegetative growth in okra responded positively to irrigation water application with weeks after planting.

Table 4: Leaf Area Index of okra under different irrigation water application

Treatment	3 WAP	4 WAP	5 WAP	6 WAP	7 WAP
T1	0.1332	0.3235	1.0395	1.6484	2.2593
T2	0.1564	0.345	1.13802	2.1632	3.18823
T3	0.2088	0.540	1.4994	2.9484	4.3974
Mean±SDEV	0.166±0.04	0.403±0.12	1.226±0.24	2.253±0.65	3.282±1.07

4.0 Conclusion

The response of Okra to three different irrigation schedules has been investigated. Evapotranspiration of crop under high irrigation (T3) was highest when compared with plots that received medium irrigation (T2) and low irrigation (T1). This observation can be due to the fact that crops grown under high irrigation has adequate moisture accumulation (reserve) in the root zone of crop, thus permitting moisture build-up at the crop root zone depth. The results also showed that the crop vegetative/fruiting stage is the most critical in term of water requirement and therefore optimum soil water must be maintained to ensure good vegetative growth and development of okra. Leaf area index of sampled crops from three irrigation treatments showed that leaf development is a function of the irrigation treatment adopted. However, there were no significant differences at $P < 0.05$ in the leaf area index of plots at high and medium irrigation. Therefore, the medium irrigation treatment is recommended most especially at the onset of rainfall in late April and May.

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