Proceedings of the 2017 Annual Conference of the School of Engineering & Engineering Technology, FUTA, 11-13 July, 2017

SEET 17 F010

LYSIMETER DETERMINATION OF CROP COEFFICIENT OF DRIP IRRIGATED YOUNG *JATROPHA CURCAS*

Ewemoje T. A.[1] and *Fagbayide S. D.[2]
[1]Agricultural and Environmental Engineering Department, University of Ibadan, Nigeria.
[2]Agricultural and Bio-Environmental Engineering Department, Federal Polytechnic Ilaro, Ogun State, Nigeria.
*E-mail: fsamueldare@gmail.com

ABSTRACT

The study was designed to examine the actual evapotranspiration and crop coefficient (Kc) of young *Jatropha curcas* grown in mini-drainage lysimeter with a cylindrical drum of circular cross-sectional area of 0.246 m^2, diameter 0.56 m and 1.0 m depth. Investigation was conducted with drip irrigation system using five mini lysimeters. Each lysimeter contained one pressure compensating emitter of 4L/hr. Climatic variables were obtained for the determination of reference evapotranspiration (ETo) using the FAO-Penman Monteith model. The value for the crop evapotranspiration (ETc) was determined from the lysimeter using the soil water balance method on daily basis and the crop factor (Kc) was estimated from the ratio of ETc / ETo. The ETo estimated from weather data for the crop growing season ranged from 19.3 to 33.1 mm/day. The average crop coefficient (Kc) values at different growth stages were 0.6, 0.9, 1.2 and 0.8 for the initial, development, mid-season and late season respectively. The research output will enhance the productivity of farmers with optimum water management on large scale Jatropha cultivation.

Key words: Mini-drainage lysimeter, soil water balance, Jatropha crop coefficient and drip irrigation.

1.0 INTRODUCTION

The conflict of water problem being experienced today is not about having too little water to satisfy our needs especially in agriculture but consequence of proper management (Akinbile and Sangodoyin, 2011). Rightful application of water to a crop is very important especially during drought. Irrigated agriculture helps in stabilizing agricultural produce in many countries of the world and the contribution of irrigation to increase food production worldwide has been enormous especially with drip system that applied right quantity of water needed for increasing crop yield and quality (Ewemoje *et al.*, 2006). However, information on crop water use and crop coefficient (Kc) are very vital when planning, designing, scheduling and managing irrigation system (Igbadun and Agomo, 2014).

Crop water use can be estimated as sum of water that goes into the atmosphere from the soil surface through evaporation process, water that goes through the plant leaves into the atmosphere through the process of transpiration, plus the fraction used in metabolic activities by the plants (Igbadun and Agomo, 2014). The percentage of water used in metabolic activities by plant is negligible so crop water use is directly related to (ET) evapotranspiration (Ted, 2001; Larry, 1998). Crop coefficient (Kc) on the other hand is essential as this will help in the irrigation management and also provides precise water applications for a region. It is defined as the ratio of crop evapotranspiration (ETc) and reference evapotranspiration (ETo) (Ted, 2001).

When Kc value is known for a given crop, then ETc can be calculated from ETo. Detailed knowledge of crop evapotranspiration from the period of crop emergence to maturity is very essential for the assessment of water resources and storage requirements, the capacity of irrigation systems, optimal allocation of water to crops and for the decision making in agriculture (Oguntunde, 2004).

One method of direct estimation of ETc in order to develop Kc is by using lysimeters (Clark *et al.,* 1996; Haman *et al.,* 1997; Simon *et. al,* 1998). Two types of lysimeters available are weighing and non weighing otherwise called drainage type. In weighing type which is also classified as mechanical and hydraulic (Igbadun and Agomo, 2014) the changes in the total weight of the soil sample are measured. The crop water use is calculated from the changes in weight of the lysimeter tank and this changes is adjusted to account for weight changes caused by factors other than crop water use such as drainage or runoff and water input (Malone *et al.*, 2002; Igbadun and Agomo, 2014).

In non-weighing or drainage lysimeters, estimation of ET is done by computing the water balance. The water balance involves measuring all the water inputs and outputs to and from the lysimeter and the change in storage (soil moisture) over a stipulated period of time. These lysimeters provide viable estimates of ETc for longer periods such as weekly or monthly (Sanjay *et al.*, 2007). The dimension of lysimeter is very vital in controlling the accuracy of a lysimeter. According to Clark and Reddell (1990) the lysimeter surface area and its depth must be large enough to minimize plant root restrictions. Sanjay *et al.*, (2007) reported that accuracy of lysimeters increases with an increase in their surface area. These researchers also emphasized the need to surround lysimeters by a buffer area of the same crop that is of the same age, growth stage, and density for reliable estimates of crop water use.

Findings have shown that Kc for the same crop may vary from place to place based on factors such as climate and soil evaporation (Allen *et al.*, 1998 and Kang *et al.*, 2003). Also Doorenboss and Pruitt (1977), Kang *et al*., (2003) and Sanjay *et al.*, (2007) had agitated for the need to develop regional Kc for accurate estimation of water use, under a specific climatic condition. Some researchers over the years have developed Kc for Jatropha using literatures for validation (Arisoa *et al*., 2012, Gush *et al.*, 2007, Garg *et al.*, 2014). However, regional crop coefficient (Kc) values for Jatropha Curcas still need to be developed. Hence, the study was designed to evaluate regional crop coefficient (Kc) data for accurate estimation of Jatropha water use in south west region of Nigeria.

2.0 METHODOLOGY

2.1 Description of the Experiment site

Experimentation was carried out at Federal College of Agriculture, Akure, Ondo State located on latitude $7^0$15’58.4’’N, longitude $5^0$14’17.2’’E and on elevation 352.4 m above sea level. The site was relatively flat with slope of about 1.0%. The soil is sandy clay loam. The site had been used for the cultivation of yam, maize and cassava for the past eight years and under fallow for two years before the commencement of the study. The rainy season commences around April and ends in late October or early November with an annual rainfall amount of approximately 1300 mm and it is well distributed throughout the year with peak rainfall experienced in July. Mean minimum and maximum temperatures are about 20 and 36^{o}C, respectively.

Relative humidity is generally high, ranging between 80 and 100% in the mornings and during precipitations, while in the afternoon it values range between 60 and 80%. Akure is affected by two air masses in the course of a year. The air masses are the Tropical Continental (TC), which is hot, dry and dusty. However, during the Harmattan haze spells of November to February, relative humidity values of 40 to 50% are possible especially after mid-day. Temperature begins to subside at this time while relative humidity increases to attain higher values in the range of 60 to 80%. The weather data during the crop period was collected from the Akure Airport Meteorological Station which was very close about 950 metres to the experimental field except rainfall data which was obtained from a locally fabricated Rainguage installed directly on the field. The weather data are presented in Figs.1– 3.

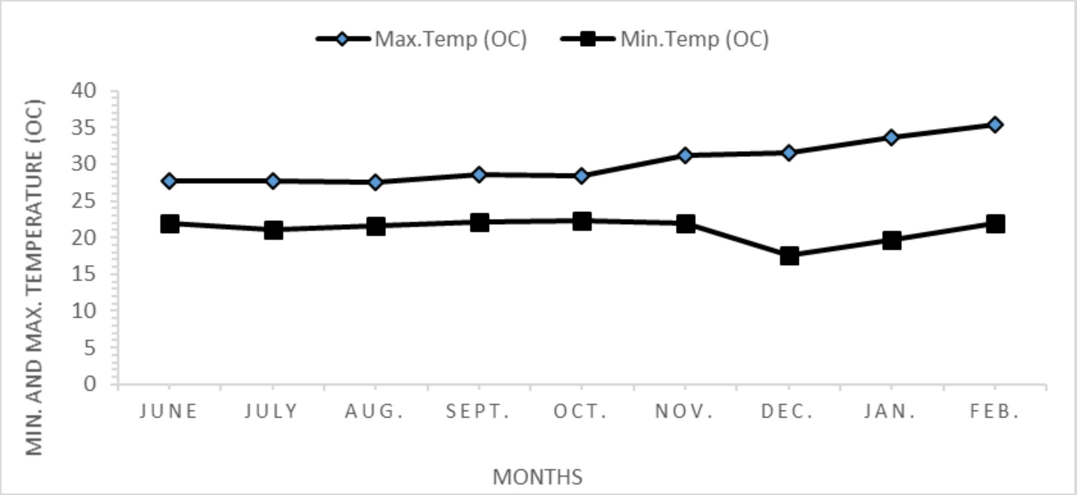

Fig. 1. Monthly maximum and minimum air temperatures during 2015-2016 crop cycle.

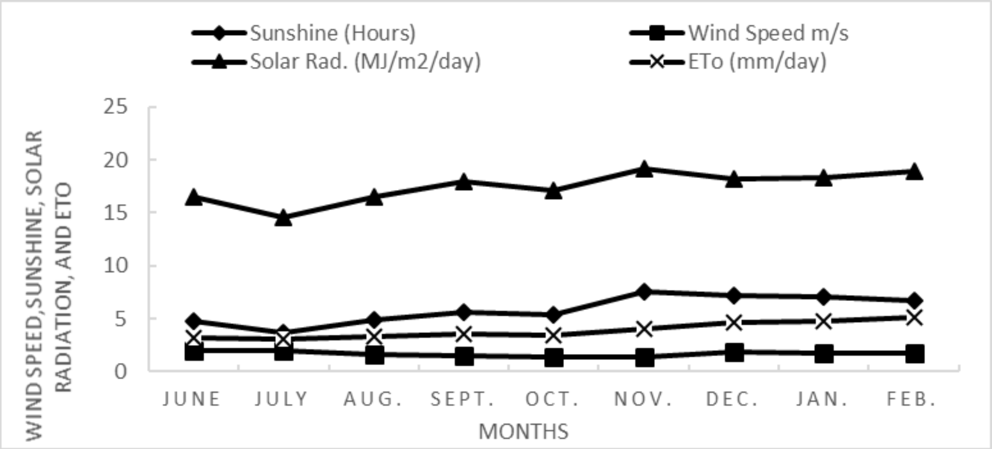

Fig. 2. Monthly wind speed, sunshine hours, ETo during 2015-2016 crop cycle.

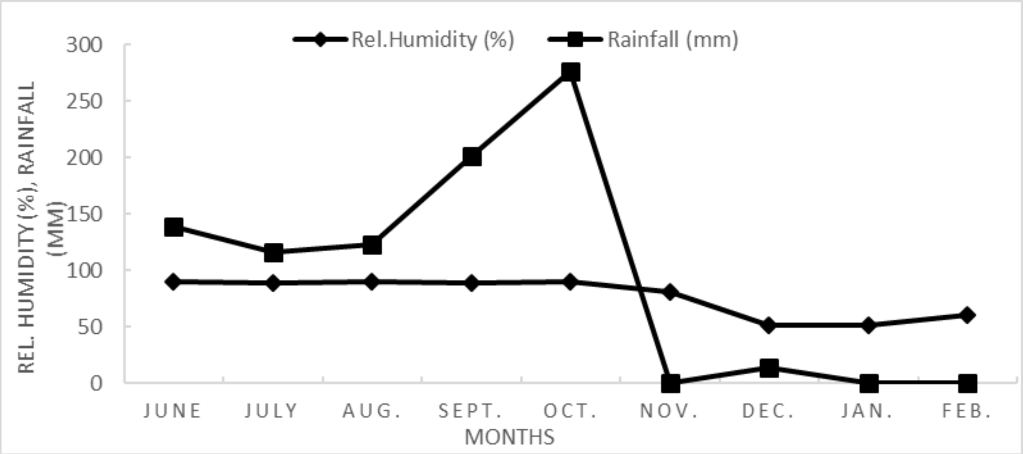

Fig. 3. Monthly relative humidity, rainfall during 2015-2016 crop cycle.

2.2 Lysimeters Design and Experimental Setup

Five mini-drainage lysimeters were constructed and used for this study. Each set of mini lysimeters consisted of cylindrical drum, slightly tapered at the bottom to allow good drainage of water. A drum of 56 cm diameter and 110 cm deep served as the lysimeter tank where the crop (Jatropha*)* 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 of each of the 0-20, 20-40, 40-60, 60-80 and 80-100 cm layers. 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 (25 litres bucket) placed underneath the lysimeter. The heights of the lysimeter rims are maintained near the ground level to minimize the boundary layer effect in and around the lysimeter.

However, the rims of lysimeter were protruded 20 cm above the soil surface so that no surface runoff water enters into the lysimeter. Another vessel (25 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 container that collected water underneath the lysimeter using graduated bucket likewise was the runoff water. Plants in lysimeters were irrigated in the same way (i.e., drip irrigation) as those plants in the surrounding areas to maintain a favorable moisture regime in the root zone.

2.3 Experimental Set up and Lysimeter Soil Moisture Monitoring System

Five irrigation treatment blocks were adopted for the five mini-drainage lysimeters constructed and used for this study. Water applications in the blocks were based on fractions of available water (AW) as presented in Table 1. The sizes of each treatment block were 4.5 m x 22.5 m. It consisted of three laterals. One lysimeter was installed at the center of each block, contained one plant and surrounded by Jatropha plants (to maintain a similar atmosphere) spaced 1.5 m by 1.5 m apart. Plants in lysimeters were irrigated in the same way (i.e., surface drip irrigation) as those plants in the surrounding areas to maintain a favorable moisture regime in the root zone.

The surface drip irrigation consisted of the following: an electrical operated submersible pump of 5 horse power to pump water from open well to storage tank of capacity 40 m^3, screen filter, pressure gauge, main line of 32 mm diameter (high density polyethylene) pipe, sub-main line of 25 mm diameter PVC pipeline, lateral pipe of 16 mm (low density polyethylene plastic) pipe, flow meter, control valves, 4litre/hour pressure compensating drippers inserted into the 16 mm lateral at a space of 150 cm apart. Efficiency parameters based on drip system efficiency and emission uniformity were taken into consideration however this ranged between 94% and 90% based on the actual discharge rate of 4.0 L h^{-1} along the drip lines.

Table 1: Experimental treatment descriptions

Treatments No.	Treatments Codes	Description

1	T_D	Daily water application
2	T_4	Four times weekly water application
3	T_3	Thrice weekly water application
4	T_2	Twice weekly water application
5	T_C	Control (rain-fed as practiced by local farmers)

The crop was irrigated in accordance to the design of the treatments (Table 1). The amounts of water were measured by flow meters, which were fixed to the sub main lines, and Jatropha were daily-irrigated using one emitter with a water volume determined by the emitter discharge, time of application and plot area. Flow control valves were used to control the amount of water delivered to the laterals. Jatropha curcas (Locally sourced) seeds were planted on June 30th and a pre-irrigation of 25 mm was applied in the field for proper seed germination and plant establishment. The crop was harvested between 6th of December, 2015 to 23rd January, 2016.

2.4 Determination of crop evapotranspiration (ETc)

In other to estimate the value of crop evapotranspiration (ETc), daily average water balance was computed for the lysimeters using equation 1 shown below.

$$ETc = P + I - Do - Ro \pm \Delta SM$$

……... (1)

The components of water balance equation for the lysimeter are Rainfall (P), Irrigation (I), Drainage (Do), Runoff (Ro), and Change in Soil Moisture (ΔSM). Where change in storage is accounted for by the change in soil water storage (SWS) in the entire lysimeter for a given period of time. No further replication of the treatments was done for estimating ETc. since the lysimeter was a controlled structure from surrounding soil (Islam and Hossain, 2010).

Daily volumes of water inputs and outputs to the lysimeters were totaled and average values were obtained to compute the daily input and output volumes (expressed in mm). The soil water storage (SWS) was computed using daily soil moisture reading (θ) obtained using the digital moisture meter PMS -714 developed in Australia. The moisture meter was calibrated against gravimetric method before inserted into lysimeter's wall. The average absolute error (percent difference between the Lutron PMS – 714 and gravimetric) was 15%. The readings obtained from the PMS – 714 meter were converted to volumetric soil water content (θv) which was determined by 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 (d) by (θv ×d) (Foroud *et al*., 1993; Mehmet *et al*., 2005; Stone *et al*., 1987). Plasticines were used in covering the perforated holes after daily measurements to prevent moisture loss.

The SWS was computed for every 20 cm increment up to depth of 100 cm. The difference between two consecutive days gives the change in soil water storage as:

$$S_i = \{\theta_{0-20} + \theta_{20-40} + \theta_{40-60} + \theta_{60-80} + \theta_{80-100}\}*d \qquad \text{……...}$$

(2)

Where θ is soil water content and S_i is soil water storage, mm for weeks I; $\theta_{0-20}, \theta_{20-40}, \theta_{40-60}, \theta_{60-80}\ and\ \theta_{80-100}$ are the volumetric soil water contents of the different soil layers $cm^3\ cm^{-3}$ and the d is the depth of each soil layer in mm.

$$\Delta S = S_{i+1} - S_i$$

$$\Delta SM = SM_t - SM_{t-i} \qquad \text{……... (3)}$$

Where SM_t and SM_{t-i} are the storage soil moisture at time instants t and t-1, respectively.

2.5 Reference crop evapotranspiration (ETo)

The reference evapotranspiration (ETo, mm $week^{-1}$) was computed following the FAO Penman Monteith method given as FAO 56 (Allen *et al.*, 1998).

$$ET_0 = \frac{0.408\Delta(R_n - \gamma\frac{900}{T-273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \qquad \text{…………………… 4}$$

Where ETo = reference evapotranspiration (mm /day),
Rn = net radiation at the crop surface (MJ m^{-2} day^{-1}),
G = soil heat flux density (MJ m^{-2} day^{-1}),
T = mean daily air temperature at 2 m height (°C),
u2 = wind speed at 2 m height (m s^{-1}),
es = saturation vapour pressure (kPa),
ea = actual vapour pressure (kPa),
es-ea = saturation vapour pressure deficit (kPa),
Δ = slope vapour pressure curve (kPa $°C^{-1}$),
γ = psychrometric constant (kPa $°C^{-1}$).

2.6 Determination of the Crop Coefficient (Kc)

The growing period (208 days) was divided into four distinct growth stages: initial (43 days), development (60 days), mid-season (30 days) and late-season (75 days). The crop coefficient (Kc) was determined by dividing the estimated crop evapotranspiration (ETc) by a weather-based reference evapotranspiration (ETo), using equation (5) as stated in Fasinmirin *et al.*, (2009) and Allen *et al.*, (1998).

$$K_c = \frac{Crop\ Evapotranspiration\ (ETc)}{Reference\ Evapotranspiration\ (ETo)}$$

……… (5)

The Kc values were computed on daily basis and later expressed as average of the four growth stages of the Jatropha (Doorenbos and Pruitt, 1977; Igbadun and Agomo 2014). The stages are: initial, development, mid and late season.

At 208 days after sowing, the data on plant height were recorded from each lysimeter. The fruit yield and yield contributing data such as number of seed/plant) were collected during harvest.

3.0 RESULTS AND DISCUSSION

3.1 Growth and Yield Parameters of Jatropha

The growth and yield parameters of Jatropha are presented in Table 2. It was observed that both growth and yield attributes of Jatropha were influenced by irrigation application. In all the parameters treatment T_D were found highest. Treatment T_D (daily irrigation) produced the highest plant height (215.0 cm) and number of leaves (167.0) while treatment T_C (zero irrigation) had the minimum plant height (105.0 cm) and number of leaves (61.0). Also, treatment T_D (daily irrigation) produced the highest fruit yield (1.34 t/ha) while treatment T_C had the least value of 0.27 t/ha. The reason was that the treatment T_D got the most favorable soil moisture conditions to produce healthy plants as seen from the data of both growth and yield parameters. For the calculation of the crop coefficient values for different growth stages in a crop, Doorenbos and Pruitt (1977) recommended that the best growing plants producing the highest yields should be selected and adopted. Treatment T_D was therefore selected for determining the crop coefficient values of Jatropha in this study.

Table 2. Effect of irrigation on growth and yield parameters of Jatropha

Treatments	Plant height (cm)	No. of leaves	No. of fruits	Jatropha fruit yield (t/ha)	No. of seeds
T_D	215.0	167.0	113.0	1.34	309.0
T_4	211.0	146.0	82.0	0.93	212.0
T_3	199.0	127.0	51.0	0.61	141.0
T_2	132.0	99.0	35.0	0.42	92.0
T_C	105.0	61.0	23.0	0.27	58.0

3.2 Crop evapotranspiration (ETc)

Figure 4 shows the results of the daily ETc and ETo values for the Jatropha crop during the growing season. The Jatropha ETc daily values ranged from 9.6 to 32.1 mm and ETo daily values ranged from 19.3 to 33.1 mm. Higher ETc values were recorded between 84 to 154 days after planting which corresponds to mid - season growth stages as compared to the values obtained in other parts of the crop life cycle or growth stages. Changes occurred in the ETc throughout the season and this was likely due to change in the crop development and daily changes in weather parameters such as wind speed, radiation, temperature and humidity during the cropping season. Also, from the computation shown in Table 3 below, the water requirement of Jatropha from the study varied throughout the crop development and it is a function of the crop growth stages. The values obtained during the initial, development, mid-season and late season stages were 67.9 mm, 187.4 mm, 116.1mm and 240.6 mm, respectively.

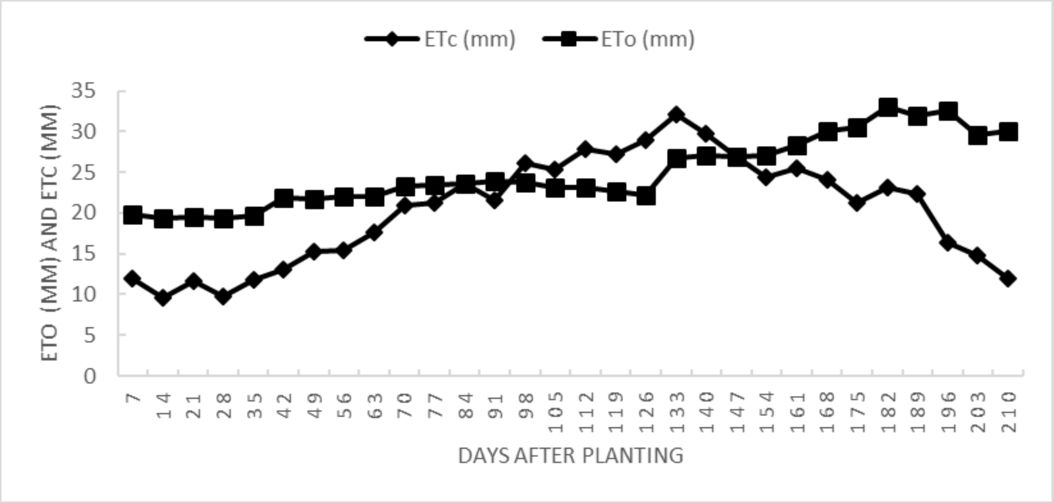

Fig. 4. Crop evapotranspiration (ETc) and potential evapotranspiration (ETo) of Jatropha during the growing season.

3.3 Reference Evapotranspiration (ETo)

The reference evapotranspiration values varied with the time period (Table 3), depending on the atmospheric temperature and other climatic parameters. Minimum values of ETo were obtained during the initial crop growth stage and this could be attributed to cooler weather resulting from the increased rainfall, decreases in intensity of solar radiation and temperature drops during the period. This could result in lower evaporative demand and high relative humidity of the atmosphere as indicated in the above (Figure 4). Gradual increase in ETo started after 35 DAP and decreased from 98 DAP to 126 DAP and thereafter increased. The increased in ETo from 126 DAP to 210 DAP was due to lack of rainfall which resulted in increased sunshine hours and the intensity of radiation during the growing season. The fluctuating trend was attributed to the variability of climatologically factors during the growing season.

Table 3. Estimation of crop coefficient of Jatropha.

Growth Stage	Time periods (days)	Crop ET (ETc) (mm)	Reference ET (ETo) (mm)	Average Crop coefficient (Kc)
Initial season	43	67.9	119.4	0.6
Development	60	187.4	207.2	0.9
Mid-Season	30	116.1	94.7	1.2
Late season	75	240.6	327.2	0.7
Total	208			

3.4 Determination of crop coefficient

According to Doorenbos and Pruitt, (1977); Smith *et al.*, (1992) and Akanda *et al.*, (2017), the length of growing season of a particular crop and climate determined the duration of crop growth stage. The total duration of the Jatropha growth stages was 208 days and from table 3, the maximum values of ETc and ETo were noted in the flowering stages (mid-season).

The trend of crop factor for Jatropha during the different phonological stages at full irrigation was shown in figure 5. The shape of the curve represents the changes in the vegetation and ground cover during plant development and maturation that affect the ratio of ETc to ETo. The Kc curve for Jatropha developed in this study followed the trend of a classic Kc curve, where Kc is small at the beginning of the season and increases as the plant grows until it reaches a maximum value at crop maturity (Allen et al., 1998). The Kc value shows a curve with peaks during the flowering/fruiting (mid-season) of the crop. The Kc values for emergence (initial stage), Vegetative, Mid-season (flowering and pod formation) and senescence (late season) were 0.6, 0.9, 1.2, and 0.7. These values are far from those reported in literature by Garg *et al.*, 2014 but in close range to the values reported by Wani *et al*. (2014) in the studies they conducted in some States of India. However, variations in Kc values could be attributed to environmental conditions and different planting date.

The trend in figure 5 showed that crop coefficients decreased from about 0.6 to about 0.5 just after planting. The relatively high initial coefficients were probably caused by rainfall several days before planting. The initial values of Kc obtained during 0 - 35 DAP (Kc > 0.60) for Jatropha developed in this study was a little higher than values reported by Garg *et al.*, (2014). Between 42 DAP and 126 DAP, crop coefficients increased rapidly with time to values between 0.6 and 1.2. Thereafter, there were fluctuations in between 84 – 96 DAP which were likely due to the effect of rainfall and drainage (Steele *et al.*, 1996). The increased Kc from 42 DAP to 126 DAP could be as results of increased evaporation (Ea) as the soil remained wet from rainfall or irrigation (Allen *et al.*, (1998). While, high Kc during 112 – 133 DAP could also be as a result of crop maturity or increased evaporation (Ea) due to rainfall and irrigation. Declining Kc values during maturity stage (140 – 210 DAP) might be due to reduced sensitivity of the stomata as leaves begin to senescence (Fraust, 1989). The Kc result showed that the highest water requirement occur at flowering and pod formation which was (mid-season) stage.

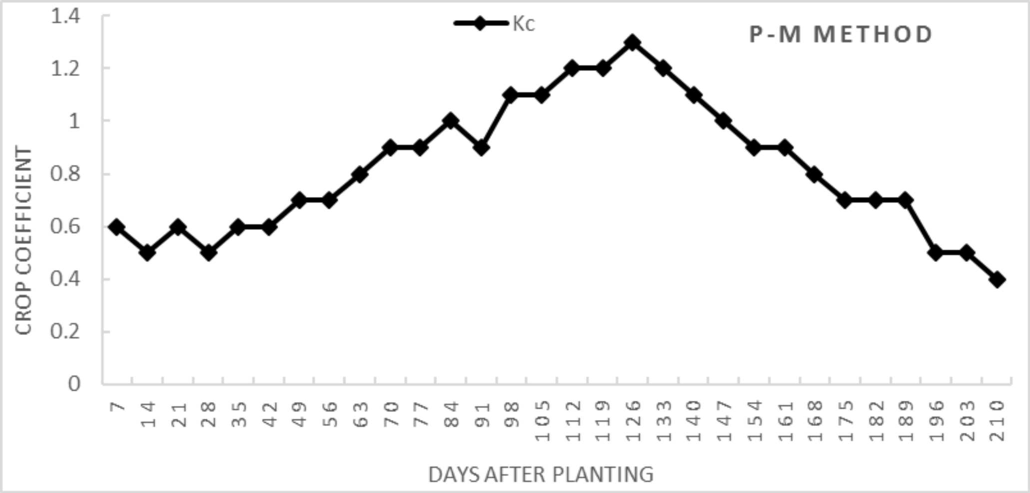

Fig. 5. Crop coefficient values of Jatropha during the growing season.

4.0 CONCLUSION

The study estimates crop evapotranspiration (ETc) and crop coefficients (Kc) of Jatropha grown inside a mini-lysimeter in an open field. Results obtained showed that the ETc increases rapidly during the vegetative and flowering stages, indicating that crop water requirement was highest during this crop growth stages. The seasonal Kc values varied from 0.6 mm day^{-1} in the emergence stage to peak values of 1.2 mm day^{-1} during the vegetative and flowering stages. Also, crop coefficient (Kc) values obtained indicated that *Jatropha curcas L.* requires much more application of water during the vegetative and flowering stages than at emergence and senescence. The results presented that Kc values can be different from one region to the other. It is assumed that the different environmental conditions between regions allow variation in variety selection and crop developmental stage which affect Kc (Allen *et al.*, 1998). The Kc results obtained may help in irrigation management of Jatropha and also help in providing precise water applications in area where high irrigation efficiencies are required for the establishment of large scale commercial cultivation of *Jatropha curcas*.

5.0 REFERENCE

Akinbile, C. O., and Sangodoyin, A.Y. (2011). Crop Water Use Responses of Upland Rice to Differential Water Distribution under Sprinkler Irrigation System. *The Pacific Journal of Science and Technology*. Vol. 12, No.1

Akanda, A. R., Rahman, M. S., Islam, , M. S. and Mila, A. J. (2017). Crop Coefficient of a Popular Potato Variety in Bangladesh. Bangladesh Journal of Agricultural Res. Vol. 42(1): 67-76.

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. Irrigation and Drainage Paper 56. Rome, IT: Food and Agriculture Organization (FAO 56).

Arisoa, M. R., Nele, S., and Folkard, A. (2012). Potential of Waste Water Use for Jatropha Cultivation in Arid Environments. Date Accessed 20/12/2013.

Boyoucos, G.J. (1962). Hydrometer method improved for making particle size analysis of soil. Agron. J. 54: 464 -465.

Clark, G. A., and Reddell D. L. (1990) Construction Details on Modifications of a Permanent Rain Sheltered Lysimeters. *ASAE*, Vol. 33, No. 6, pp.1813-1832.

Clark, G.A., Albergts, E. E., Stanley, C.D., Smajstrala, A.G., and Zazueta, F.S. (1996). Water Requirements and Crop Coefficients of Drip-irrigated Strawberry Plants. *Transactions of ASAE*, Vol. 39, No. 3, pp.905-913.

Doorenbos, J., and Pruitt, W.O., (1977). Crop Water Requirements. FAO Irrigation and Drainage Paper 24; Food and Agriculture Organization of United Nations, Rome Italy

Ewemoje, T. A., Lateef, S. A., and Afolayan S. O. (2006). Performance Evaluation of Drip Irrigation System Using Sweet Corn under Variable Water Application. *Journal of Applied Science, Engineering and Technology,* Vol. 6,No.1, pp. 16- 21.

Faust M. 1989. Physiology of temperature zone fruit trees, Wiley, New York. pp l52.

Foroud, N., Mundel, H. H., Saidon, G., and Entz, T. (1993). Effect of level and timing of moisture stress on soybean plant development and yield components. *Irrigation. Sci*. Vol.13, pp.149–155.

Fasinmirin, J. T., and Adesigbin, A. J. (2012). Degree of compaction and compression strength of Nigerian Alfisol under tilled condition and different machinery traffic passes. *Int J Agric & Biol Eng*. Vol. 5, No.2. DOI: 10.3965/j.ijabe.20120502.005

Fasinmirin, J. T., Olufayo, A. A, Oguntunde, G. P., and Oguntuase, M. A. (2009). Parametrizing Simple Model between Yield and Evapotranspiration for *Amaranthus cruentus* under Drip and Sprinkler Irrigations. *Int. J. Plant Prod*. Vol. 3, No. 1, pp. 1735-8043.

Garg, K. K., Wani S. P., Principal Scientist, and Kesava Rao, A. V. R (2014). Crop coefficients of Jatropha (Jatropha curcas) and Pongamia

(Pongamia pinnata) using water balance approach. Wiley Interdisciplinary Reviews: Energy and Environment.

DOI: http://dx.doi.org/10.1002/wene.88. Date Accessed: 20/10/2016.

Gush, M. B., and Moodley, M. (2007). Water use assessment of Jatropha curcas. In: Jatropha curcas in South Africa: an assessment of its water use and bio-physical potential. Report No. 1497/1/07. pp. 58–103. (Chapter 4). Retrieved from: http://jatropha.pro/PDF%20bestanden/JatrophaWater%20South%20Africa.pdf Date Accessed: 02/03/2014

Haman, D. Z. Pritchard, R. T., Smajstria, A.G., Zazueta, F.S., and Lyrene, P.M. (1997). Evapotranspiration and crop coefficients for young blueberries in Florida. *Applied Engineering in Agriculture*, Vol. 13, No. 2, pp. 209-216.

Igbadun, H. E., and Agomo. (2014). Estimation of Water Use and Crop Coefficient (Kc) of Irrigated Cabbage (*Brassica oleracea*) Using Mini- Lysineter. Proceedings of the 2014 International Conference of the Nigerian Institution of Agricultural Engineering held at FUTA

Islam M. S., M. A. Hossain. 2010. Determination of crop co-efficient of hybrid maize by lysimeter study. Bangladesh Journal of Agricultural Research. 35(1):77-82

Kang, S., Gu, B., Du, T., and Zhang, J. (2003). Crop Coefficient and Ratio of Transpiration to Evapotranspiration of Winter Wheat and Maize in a Semi Humid Region. *Agricultural Water Management*, Vol. 59, No. 1, pp. 239-254.

Larry, G. J. (1998). Principle of Farm Irrigation System Design. John Wiley and Sons, Inc. USA

Oguntunde, P.G. (2004). Evapotranspiration and Complimentary Relations in the Water Balance of the Volta Basin: Field Measurement and GIS – Based Regional Estimate. *Ecol. Dev. Ser*. Vol. 22, pp. 16-91.

Malone, R. W., Bonta, J. V., Stewardson, D. J., and Nelsen, T. (2002). Error Analysis and Quality Improvement of the Cosheton Weighing Lysimeters. *Trans ASAE*. Vol. 31, pp. 477-484.

Mehmet, S., Tahsin. T., Murat K., Nuray. C. and Zeki, D. (2005). The Effects of Different Irrigation Regimes on Cucumber (*Cucumbis sativus L.*) Yield and Yield Characteristics under Open Field Conditions. *Agricultural Water Management*, Vol. 73, pp. 73–191.

Sanjay, S., Fouad, J., Saurabh S., and James K. (2007). Water Use Crop Coefficient for Water Watermelon in Southwest Florida. Final Report No. WRP-LY-0009. Submitted to: Southwest Florida Water Management District Brooksville, Florida. Pp70. Retrieved from: http://www.swfwmd.state.fl.us/files/database/site_file_sets/42/crop_wateruse_watermelon.pdf . Date Accessed: 14/02/2015.

Shenkut, A., Tesfaye, K., Abegaz, F. and Hordofa, T. (2013). Determination of Water Requirement and Crop Coefficient for Sorghum (*Sorghum bicolor L.*) at Melkassa, Ethiopia. *East African Journal of Sciences*, Vol. 7, No.1, pp 41-50.

Simon, C. M., Ekue, E. I., Gumbs, F. A., and Narayan, C. V. (1998). Evapotranspiration and Crop coefficients of Irrigated Maize (*Zea mays L.*) in Trinidad. *Journal of Tropical Agriculture*. Vol. 75, No. 3, pp. 342-346.

Smith, M., Allen, R., Monteith, J. L., Perrier, A., Santos Pereira, L., Sageren, A. (1992). Expert consultation on revision of FAO methodologies for crop water requirements. Food and Agricultural Organization of the United Nations, Land and Water Development Division, Rome, Italy, Pp: 60.

Steele, D. D., Sajid, A. H., and Prunty. L. D. (1996). New corn evapotranspiration crop curves for southeastern North Dakota. Transactions of ASAE Vol. 39, No. 2, pp 931-936.

Stone, L. R., Gwin Jr., R. E., Gallagher, P. J., and Hattendorf, M. J. (1987). Dormant-season Irrigation: Grain Yield, Water Use, and Water Loss. *Agron. J.*, Vol. 79, pp. 632–636.

Ted, V. G. (2001). Crop Coefficients for Use in Irrigation Scheduling: Water Conservation Factsheet. British Columbia, Ministry of Agriculture, Food and Fisheries. Order No.577.100-5, Agdex 561.

Wani, S. P. Garg, K. K. and Rao, A.V.R. K. (2014), Crop coefficients of *Jatropha* (*Jatropha curcas*) and *Pongamia* (*Pongamia pinnata*) using water balance approach. *WIREs Energy Environ.*, Vol. 3, pp.301–309. http://dx.doi.org/10.1002/wene.88: Date Accessed: 20/12/2015.