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Fagbayide Samuel Dare
The Federal Polytechnic, Ilaro

Temitayo Abayomi Ewemoje
University of Ibadan

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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EXPERIMENTAL DETERMINATION OF GROWTH-STAGE-SPECIFIC CROP COEFFICIENT OF *JATROPHA CURCAS* IN SUB-HUMID REGION OF NIGERIA

*Fagbayide S. D.[1, 2], Ewemoje T. A.[2] and Oluwasemire K. O.[3]

[1]Agricultural and Bio-Environmental Engineering Department, Federal Polytechnic Ilaro, Ogun State, Nigeria

[2]Agricultural and Environmental Engineering Department, University of Ibadan, Nigeria

[3]Agronomy Department, University of Ibadan, Nigeria

*E-mail: fsamueldare@gmail.com, Tel: +2347037360435

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ABSTRACT. *Information on actual evapotranspiration and crop coefficient (Kc) of* Jatropha curcas *whether under rain fed and/or irrigated agriculture has not been documented in humid sub-tropical regions in any FAO repository documents. Field experiments were conducted at Akure, Ondo State and Ilaro, Ogun State, Nigeria during 2015 and 2016 cropping seasons to determine growth-stage-specific crop coefficient (Kc) and crop water use for* Jatropha curcas. *Five lysimters were standardized and used for this study. Jatropha was grown in each lysimeter made of cylindrical drum of circular cross-sectional area of 2460.0 cm^2, 56.0 cm diameter and 100.0 cm depth filled with undisturbed sandy-loam soil. Irrigation frequencies in these lysimeters consist of daily; four times weekly; thrice weekly; twice weekly and zero water application (control). The water application was two litres per plant per irrigation using drip pressure compensating emitter that discharged at 4 litres per hour. Climatic variables were obtained for the determination of ET_o using the FAO-Penman Monteith model. Crop coefficient (K_c) was computed on a weekly basis with reference to crop development stages. Average crop coefficient (K_c) values obtained for Jatropha in Akure at different growth stages were 0.57, 0.90, 1.23 and 0.74; in Ilaro were 0.65, 0.90, 1.34 and 0.75 for the initial, development, mid-season and late season respectively. Average ET_c obtained in Akure and Ilaro for the initial, development, mid-season and late season were 67.9, 187.4, 116.1 and 240.6; and 106.03, 255.30, 164.57 and 282.60 mm/week respectively. The results obtained will assist in designing appropriate irrigation schedule for optimum production of Jatropha in sub-tropical regions of Nigeria.*

Keywords. *Actual evapotranspiration, Crop coefficient, drip irrigation, Irrigation schedule Jatropha and Lysimeter.*

1.0 INTRODUCTION

Water is a key input in crop production. Almost 70 per cent of universal water withdrawals today are used for Agriculture. Effective use of irrigation water would play a major role in meeting the ever growing demand for basic agricultural needs in many developing countries of the world. In other to help saving water by controlling water supply, the rightful estimations of crop water requirements are very important (Fasinmirin *et al.,* 2014). This will enhance optimization and efficiency of applied water and subsequently helpful determining irrigation water requirements and scheduling.

Information about the exact quantity of water to needed by different crops in a particular climatic environments is very important in the planning of irrigation scheme, irrigation scheduling, and for management and effective design of irrigation system (Egbuikwem and Obiechefu, 2017; Babu *et al.,* 2015; Pandey *et al.,* 2014 and Kiwi *et al.,* 2013). Crops should get adequate water at various stages of growth for optimum productivity (Fagbayide *et al.,* 2018). Through inadequate water, plants become stressed and fruitless, and eventually die. The decision on when next to irrigate and the amount of water to apply varies from one agro-ecological zone to the other particularly in sub-Sahara Africa where extensive range of disparity is observed within a specified region (Fagbayide *et al.,* 2018; Raphael *et al.,* 2018).

Many researchers have studied crop ET using lysimeters (Khan *et al.*, 1992; Islam and Hossain, 2010). A lysimeter is a container that isolates soil and water from its surroundings. Two categories of lysimeters in existence are weighing and drainage type. Weighing type was classified as mechanical and hydraulic (Igbadun and Agomo, 2014). The water balance involves computing all the water inputs and outputs in and out of the lysimeter and the change in storage (soil moisture) over a stipulated period of time. Measurements of lysimeters are adopted for hydrological balances of crops. It provides a convenient and a practical way of monitoring soil water content and the soil water balance under controlled environments (Fasinmirin *et al.,* 2014). According to Sanjay *et al.,* (2007) and Howell *et al.*, (1991), lysimeter provides sustainable estimates of ETc for longer periods such as weekly or monthly. Latest researches all over the world have acknowledged the use of lysimeters in developing crop coefficient for a variety of crops, such as Rice and Sunflower in India (Tyagi *et al.*, 2000), Corn in Spain (Martinez, 2008), Cotton and Wheat in the USA (Ko *et al.,* 2009), Wheat and Maize in China (Liu and Luo, 2010), Pulse crops in India (Pandey and Pandev, 2011) and *Amaranthus cruentus* in Nigeria (Fasinmirin, *et al.,* 2014).

Jatropha (Jatropha curcas L.) is a soft-woody oil-seed bearing plant of the Euphorbiaceae family. It is a potential source of biodiesel native to tropical America but now cultivated in different parts of the world including Nigeria because of its adaptation to wide range of agro-climatic conditions (Openshaw, 2000; Fairless, 2007; Arun *et al.,* 2014). Jatropha has been designated as drought tolerant and capable of growing in marginal and poor soils (Helena *et al.*, 2013). Jatropha grows well in low-rainfall conditions (200 mm) but respond better to higher rainfall complement with irrigation up to 1200 mm, particularly in hot climatic conditions (Ewemoje *et al.,* 2018). Jatropha has received special attention in many countries and is one of the main crops to be promoted for growing in marginal lands for biodiesel production (Niu *et al*., 2012). A typical Jatropha is shown in Plate 1.

Efforts to intensify and improve the production of Jatropha on large commercial scale have been hampered by inadequate knowledge on how best to manage the increasingly limited water resource, particularly during parched season (Fasinmirin *et al.*, 2014). Hence, efforts should not be spared at estimating the actual water need of *Jatropha*, so as to effectively manage the scarce resource for its optimum production. Despite these discoveries, information on actual evapotranspiration and crop coefficient (Kc) of *Jatropha curcas* whether under rain fed and/or irrigated agriculture from the period of its establishment to maturity has not been documented in humid sub-tropical regions in any FAO repository documents. Therefore, the research was aimed at determining growth-stage specific crop coefficient and consumptive use for Jatropha curcas grown in drainage lysimeters in the south western, Nigeria.

Plate 1: Young Jatropha of about Four-weeks – old under drip irrigation system.

2.0 MATERIALS AND METHODS

2.1 Study Areas

The studies were carried out in the Research Farm of Federal College of Agriculture Akure, Ondo State and Agricultural and Bio-Environmental Engineering Research Farm of Federal Polytechnic, Ilaro Ogun State, Nigeria. Akure site was situated on latitude 7°15’9.2’’ N and longitude 5°11’35.2’’ E and on elevation 353 m above sea level while the Ilaro site was located on latitude 6°53'11.5" N and longitude 3°1'13.8" E and at altitude of 89 m above sea level. The climates of the two locations were characterized as humid tropic, with two distinct seasons. Rainy season commences in both locations around April and ends in late October or early November while dry season starts from late October to March. Average annual rainfall in Akure and Ilaro are 1745 and 1257 mm respectively. Average temperature during wet and dry seasons in Akure site are 20.2 and 36.3 °C respectively while in Ilaro, the average temperature during wet and dry seasons are 23.6 and 34.2 °C. Soils in Akure and Ilaro were characterized as sandy loam and fine sandy clay loam respectively.

2.2 Experimental treatments description and water application

The frequencies of irrigation in these lysimeters consist of daily (N_D); four times weekly (N_4); thrice weekly (N_3); twice weekly (N_2) and zero (N_C) water application (control). The water application was two litres per plant per irrigation using drip pressure compensating emitter that discharged at 4 litres per hour. 22.5 × 4.5 m plot size was used for the study with a spacing distance of

1.5 m × 1.5 m and having 4,444 plants/ha. One lysimeter was installed at the center of each plot, contained one plant and bounded by Jatropha plants (to maintain a similar environment) spaced 1.5 m by 1.5 m apart. The sources of irrigation water for Akure site was Dug Well while Bore hole was used in Ilaro site.

Jatropha seeds were sourced from Agricultural Develpoment Project office, Ondo State, Nigeria and planting was carried done on June 30th, 2015 and July 4th, 2016 in the study locations. There was no chemical fertilizers application throughout experimentation. However, both manual and chemical methods of weed control were adopted in management of the weeds. The qualities of water used for irrigation in Akure and Ilaro were determined (Table 1).

Table 1: Physical and chemical properties of irrigatied water at the studied sites

pH	EC dS/m at 25°C	SAR	ESP	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	Colour	Odour	Conductivity
				(meq/l)								
Akure												
5.9	0.27	16.2	18.1	11.3	1.8	60.1	64.0	0.05	3.9	Colour-less	Odou-rless	$1.25x10^2$
Ilaro												
5.6	0.19	19.2	23.3	15.4	26.7	83.0	61.0	0.14	7.2	Colour-less	Odou-rless	$2.50x10^2$

2.3 Jatropha crop evapotranspiration (ETc)

Soil moisture contents were measured before applying irrigation with calibrated digital moisture meter PMS-714. Change in storage was accounted for by the change in soil water storage (SWS) in the whole lysimeter for a specified period. 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 values in mm. Crop evapotranspiration for the specified period was gives as:

$$ETc = P + I - Ro - Do \pm \Delta SM \quad (1)$$

Where ETc = Crop evapotranspiration, P = Rainfall (mm), I= Irrigation (mm), Do = Drainage (mm), Ro = Runoff (mm) and ΔSWS = Change in soil water storage (mm).

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:

$$S_i = \{\theta_{0-20} + \theta_{20-40} + \theta_{40-60} + \theta_{60-80} + \theta_{80-100}\}*d \quad (2)$$

Where θ is soil water content and S_i is soil water storage, mm for days I. $\theta_{0-20}, \theta_{20-40}, \theta_{40-60}, \theta_{60-80}$ *and* θ_{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. The difference between two consecutive days gives the change in soil water storage as:

$$\Delta SWS = S_{i+1} - S_i \quad (3)$$

However, change in storage soil moisture at time instants t and t-1, is:

$$\Delta SM = SM_t - SM_{t-i} \quad (4)$$

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

2.4 The crop coefficient (Kc)

The crop coefficient (Kc) of Jatropha was determined using the equation as determined by Fasinmirin *et at.*, (2009) and Fagbayide *et al.*, (2018). The crop coefficient (KC) of the crop was determined using equation 4 as stated in Fasinmirin et al. (2009). Kc values were calculated on daily basis. The values obtained were expressed as average of the crop four growth stages according to Igbadun and Agomo, 2014.

$$K_c = \frac{Crop\ Evappotranspiration\ (ET_C)}{Reference\ Evapotranspiration\ (ET_O)} \quad (5)$$

3.0 RESULTS AND DISCUSSION

3.1 Growth and yield parameters of Jatropha

Results indicated that Jatropha response favourably to adequate soil moisture. The varying water application significantly influenced both growth and yield attributes of Jatropha in all treatments at Akure and Ilaro locations. However, for the growth parameters of Akure, treatment N_D (daily irrigation) produced the highest plant height (215.0 cm) and number of leaves (167.0) while treatment N_C (zero irrigation) had the minimum plant height (105.0 cm) and number of leaves (61.0). As observed in the Table 3, there were no significance difference in the plant height for treatments N_D and N_4, while there were significance difference in treatments N_3, N_2, N_C at 0.05 probability, using Turkey Test. Soil moisture situation in treatment N_D permit favourable growing conditions for Jatropha throughout the cropping season.

Similarly, in Ilaro, it was observed that treatment N_D (daily irrigation) produced the highest plant height (107.0 cm) and number of leaves (179.0) while treatment N_C (zero irrigation) had the minimum plant height (62.0 cm) and number of leaves (65.0). Although, in case of plant height (Table 2), there were no significance difference in treatments N_D and N_3, while there were significance differences with other treatments N_4, N_2, N_C at 0.05 probability, using Turkey Test. Response of Jatropha to water application during crop growing seasons might due to prevailing soil condition mostly sandy soil at the top 20 cm layer of the site which allowed easy percolation and aeration without side effects on crop. Response of Jatropha to water was visible in treatment N_C. The findings of Azza *et al.*, (2010); Sarhan *et al.*, (2010) and Anil *et al.*, (2017) were in agreement with this study that Jatropha response favourably to adequate soil moisture.

Yield parameters in Ilaro showed that treatment N_D (daily irrigation) gave statistically superior number of fruits, highest number of seeds and fruit yield (t/ha) while treatment N_2 (twice weekly water application) gave the least statistical values number of fruits, number of seeds and fruit yield (t/ha). Treatment N_D (daily irrigation) produced the highest number of fruits (98.0), fruits yield (0.85 t/ha) and number of seeds (294.0) while treatment N_2 (twice weekly water application) had the minimum number of fruits (26.0), fruit yield (0.23 t/ha) and number of seed (78.0). In Akure, treatment N_D (daily irrigation) has highest statistical numbers of fruits, number of seeds and fruit yield (t/ha) while treatment N_C (zero irrigation) gave the least statistical values number of fruits, number of seeds and fruit yield (t/ha). Treatment N_D (daily irrigation) produced the highest number of fruits (113.0), fruits yield (0.778 t/ha) and number of seeds (309.0) while treatment N_C (zero irrigation) had the minimum number of fruits (23.0), fruit yield (0.25 t/ha) and number of seed (58.0). This is in agreement with Anil *et al.*, (2017) and Azza *et al.*, (2010) findings that Jatropha responded very well to irrigation in terms of yield.

Table 2: Effect of variables water application on growth and yield parameters of Jatropha

Treatments	Plant per lysimeter	No. of leaves	Plant height (cm)	No. of seeds	No. of fruits	Jatropha fruit yield (t/ha)
Akure						
N_D	1	167.0a	215.0a	309.0a	113.0a	0.778a
N_4	1	146.0b	211.0a	212.0b	82.0b	0.562b
N_3	1	127.0c	199.0b	141.0c	51.0c	0.459c
N_2	1	99.0d	132.0c	92.0d	35.0d	0.360d
N_C	1	61.0e	105.0d	58.0e	23.0e	0.250e
Ilaro						
N_D	1	179.0a	107.0a	294.0a	98.0a	0.85a
N_4	1	164.0b	93.0b	213.0b	71.0b	0.62b
N_3	1	146.0c	101.0a	189.0c	63.0c	0.55c
N_2	1	103.0d	86.0b	78.0e	26.0e	0.23d
N_C	1	65.0e	62.0c	108.0d	36.0d	0.31d

Mean in the same column followed by the same letter(s) are not significantly different at 0.05 probability, using Turkey Test.

3.2 Determination of crop evapotranspiration (ETc)

Treatment with daily water application (N_D) performed the best in term of growth and yield. Maximum crop coefficients at various growth stages are endorsed to determine from the growing plants having highest yields (Doorenbos and Pruitt, 1977; Islam and Hossain, 2010). This condition is expected to apply only to crops that are grown under optimum soil moisture. Hence, all calculations for Kc and ETc were based on the performance of N_D treatment (Table 3).

Table 3: Determination of crop evapotranspiration (ETc) used by the treatment N_D

Duration (WAP)	Durations (DAP)	Applied water (mm)	Effective rainfall (mm)	Change in soil water storage (mm)	Percolation / Drainage (mm)	Runoff (mm)	Crop ET (mm)
Akure							
5	35	142.44	88.6	-75.24	95	6	54.8
10	70	84	210	12	201.7	21.8	82.5
15	105	84	340.8	32.3	270.5	68.6	118
20	140	116	112	41.3	104.8	18.7	145.8
25	175	140	9.6	32.4	59.8	0	122.2
30	210	56	0	73.8	41.1	0	88.7
Ilaro							
5	35	142.44	74.9	-78.64	50.7	6.3	81.7
10	70	84	161.3	51.8	149.2	22.7	125.2
15	105	84	194.2	91.1	180.6	24.1	164.6
20	140	116	103	85.2	107.7	6.1	190.4
25	175	140	6.6	56.1	59.8	0	142.9
30	210	56	11.4	77.4	41.1	0	103.7

Jatropha seeds were planted directly and it took 7 days to emerge. In both study locations, the crop was uniformly irrigated for 3 weeks for crop establishment. First irrigation was administered within 35 Day After Planting (DAP) as seen in Table 3 while last irrigation was applied at 206 DAP. Final crop harvesting was done on 208 DAP and crop cycle was 208 days. Negative sign in column 5, Table 3 showed that Jatropha plant was depleted of water from initial soil moisture content. Cumulative crop ET was plotted against the days after sowing (Figure 1).

Growth cycle of Jatropha crop is 208 DAP. Crop coefficients are estimated based on the crop growth stages. General acceptable crop growth stages are: initial, development, mid-season, and late-season. The length of growing season of a particular crop and climate determined the duration of each growing stage (Doorenbos and Pruitt, 1977; Smith et al., 1992). Table 4 shows the stage wise of crop co-efficient estimated for Jatropha during crop growing season. It shows the values of reference evapotranspiration (ETo), crop evapotranspiration (ETc) and the crop coefficient (Kc) at different growth stages of the crop.

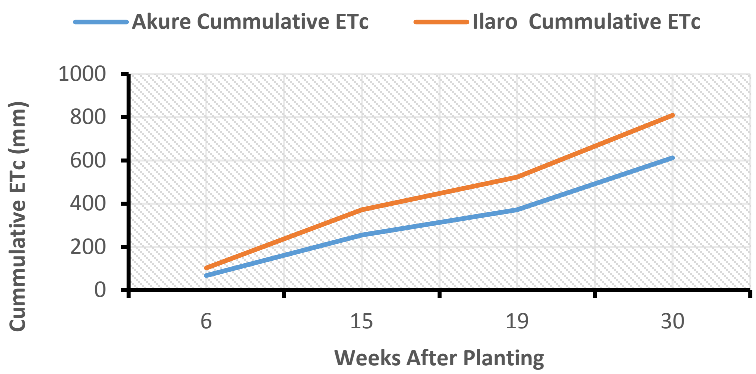


Figure 1: Relationship between cumulative ET and weeks after sowing

Table 4: Stage wise of crop co-efficient estimated for Jatropha during crop growing season.

Growth Stage	Time periods (weeks)	Crop ET (ETc) (mm)	Reference ET (ETo) (mm)	Average Crop coefficient (Kc)
Akure				
Initial season	6 (43 days)	67.9	119.4	0.57
Development	8 (60 days)	187.4	207.2	0.90
Mid-Season	4 (30 days)	116.1	94.7	1.23
Late season	11 (75 days)	240.6	327.2	0.74
Total	30 (208 days)	612.00	748.50	
Ilaro				
Initial season	6 (43 days)	102.90	158.00	0.65
Development	8 (60 days)	233.00	238.00	0.98
Mid-Season	4 (30 days)	155.10	126.30	1.34
Late season	11 (75 days)	317.5	422.20	0.75
Total	30 (208 days)	808.5	944.5	

3.3 Crop evapotranspiration (ETc)

Jatropha average ETc daily values in Akure ranged from 1.37 to 4.59 mm/day while the average ETc daily values in Ilaro ranged from 1.83 to 5.93 mm/day. The ETc values obtained in the two locations increases rapidly during the vegetative and flowering stages, indicating that crop water requirement was highest during this crop growth stages. Daily mean values of ETo in Akure ranged from 2.76 to 4.64 mm/day while the mean ETo daily values in Ilaro ranged from 3.44 to 5.80 mm/day. Mean values of ETc recorded were higher at the mid-season stage in both Akure and Ilaro compared to other stages of crop development.

There were variations in the average values of ETc during the cropping season and this change was due to crop development and climatic change. Table 5 show the computed values of growth stages

ETc and ETo values for the Jatropha crop during the growing season. The values ETc obtained in Akure and Ilaro during the initial, development, mid- and late-season stages were: 67.9, 187.4, 116.1 and 240.6; and 102.9, 233.0, 155.1 and 317.5 respectively. Total water use during the cropping seasons were 612 mm and 808.5 mm in Akure and Ilaro respectively.

3.4 Crop coefficient (Kc)

The trend of Kc obtained for the treatments are shown in Figure 2. The curve was used in denoting the changes that occurred in the values of Kc over the length of the growing season. The curve shape indicated changes in the vegetation and ground cover during crop development and maturation that affect the ratio of ETc to ETo. The Kc increased from the initial to development stages and reached its highest at the mid-season stage. Thereafter, values of Kc declined rapidly during the late season stage. Similar comment was made by Faust (1989) who indicated in his work on pears that decreasing Kc values during fall might be due to reduced sensitivity of the stomata as leaves begin to senescence or due to water stress.

The values of Kc for initial, development, mid- and late-season growth stages of Jatropha curcas were: 0.57, 0.90, 1.23, 0.74 and 0.65, 0.98, 1.34, 0.75 in Akure and Ilaro respectively. The crop coefficient (K) values obtained indicated that Jatropha requires much more application of water during the vegetative and flowering stages than at emergence and senescence. However, the Kc values obtained in this study were higher than those developed by Garg *et al*., 2014. Figure 2 below show the polynomial relationship that was obtained. A polynomial regression correlation (r = 0.97) and (r = 0.92) were obtained for Akure and Ilaro respectively from the plot of Kc against week after planting with the Kc curves.

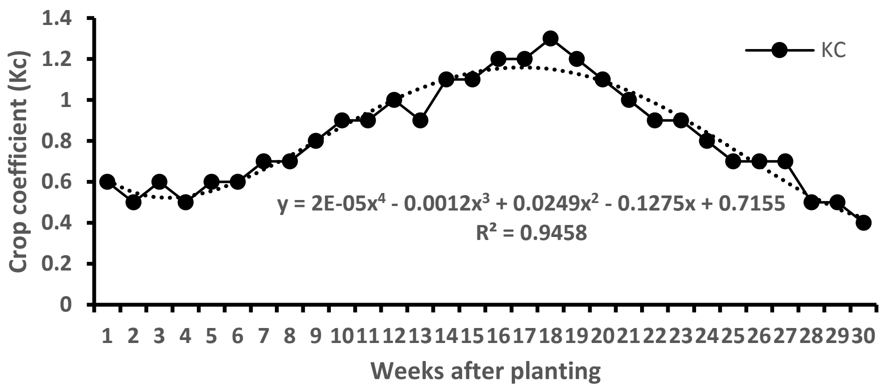


Figure 2a: Lysimetric Kc curve for Jatropha in Akure

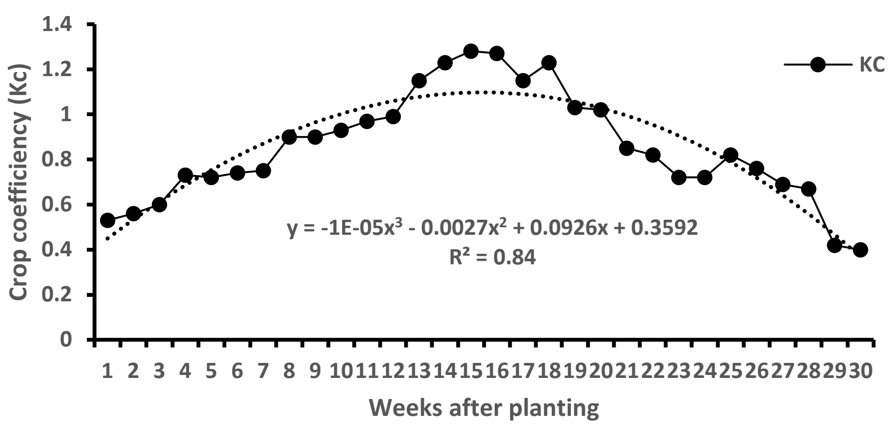


Figure 2b: Lysimetric Kc curve for Jatropha in Ilaro

3.5 Yield and Crop Evapotranspiration

Figure 3 showed the relationship between the yield and crop evepotranspiration. Negative intercepts observed for this relationship reflect the non-growth-related evaporation component of ETc that displaces the yield versus ETc function along the x-axis (Rodney and Ted 2011).

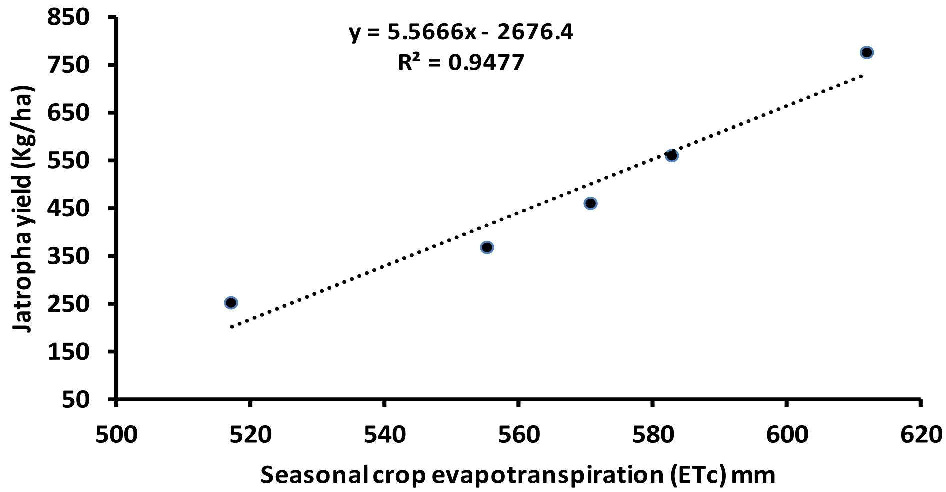


Figure 3a: Jatropha yield and ETa during 2015/16 cropping season in Akure

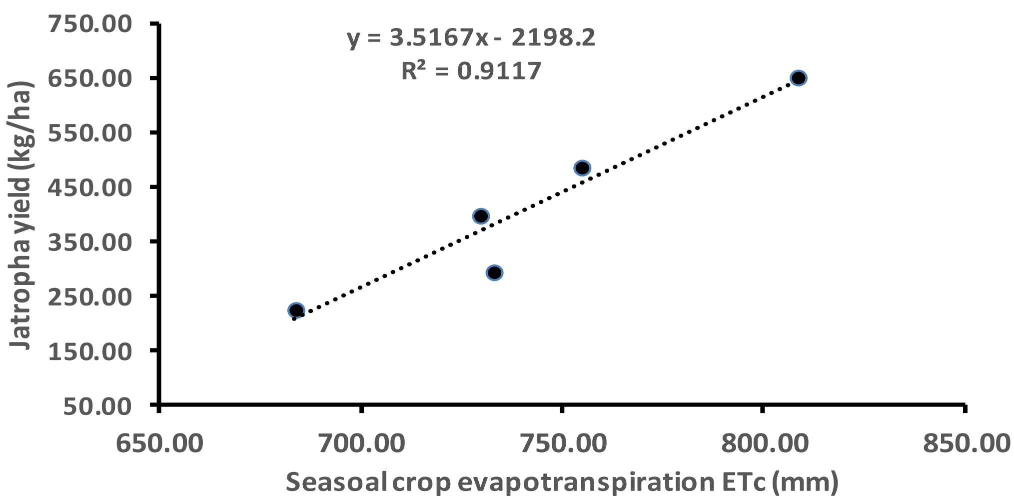
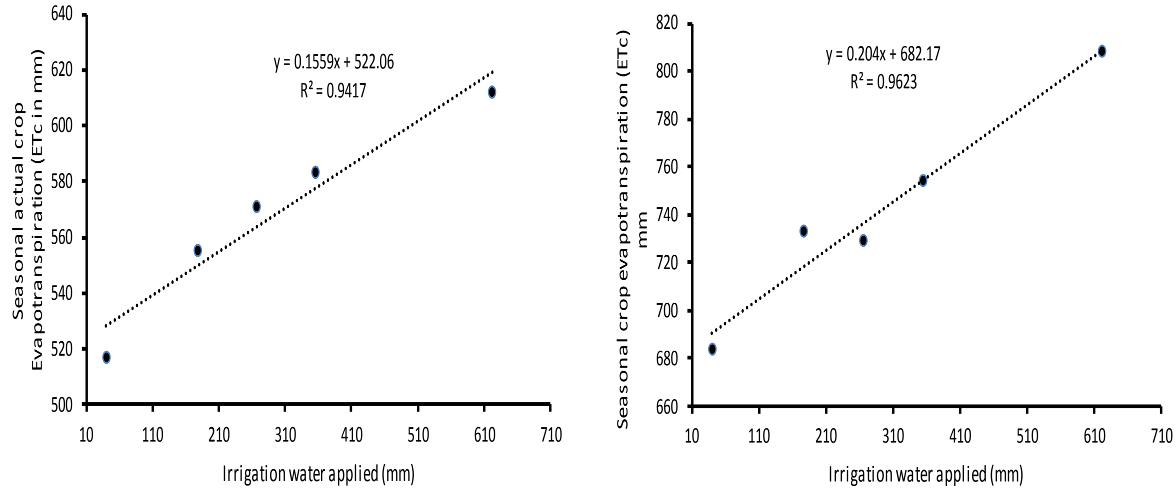


Figure 3b: Jatropha yield and ETa during 2015/16 cropping season in Ilaro

3.4 Total irrigation water applied and seasonal crop evapotranspiration (ETa)

Figure 4 shows the relationship between the total irrigation water applied and seasonal crop evapotranspiration (ETa).



Figures 4a and 4b: Total irrigation water applied against seasonal ETa in Akure and Ilaro.

4.0 Conclusion

The crop evapotranspiration (ETa) and the crop coefficient (Kc) of Jatropha curcas L. have been developed. The ETc values varied in Akure and Ilaro from 1.37 mm.day and 1.83 mm/day in the emergence stage to peak values of 4.59 mm.day and 5.93 mm/day during the vegetative and flowering stages. Also, crop coefficient (Kc) values obtained indicated that Jatropha requires much more application of water during the crop development and mid-season growth stages (vegetative and flowering stages) than at initial-, development- and late-seasons stages.

This study provided the local farmers in the study area the opportunity to grow Jatropha round the year under crop water management practices. It will also be a valuable reference for the researchers in the region in absent of Kc values in the FAO repository for the Jatropha carcass L. crop in the region.

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