CROP COEFFICIENTS AND WATER REQUIREMENT OF ONE YEAR OLD *JATROPHA CURCAS* L. IN ILARO, SUB-HUMID REGION OF NIGERIA

*__Samuel Oluwagbayide and Ademola Adenigba__
Agricultural and Bio-Environmental Engineering Department,
Federal Polytechnic, Ilaro, Ogun State, Nigeria.
*****samuel.oluwagbayide@federalpolyilaro.edu.ng; ademola.adenigba@federalpolyilaro.edu.ng

Abstract

The information on Crop coefficient (K_C) and crop evapotranspiration (ET_C) is very vital in planning and managing the irrigation of any crop. This study aimed at determining the crop evapotranspiration and crop coefficient of Jatropha at its various developmental stages. This research was carried out in Agricultural Research Farm of Federal Polytechnic, Ilaro between June 2019 and February 2020 by appraising two different irrigation treatments consisting of drip irrigation and no irrigation (rainfed). The *ETc* was determined with a drainage lysimeter made from cylindrical drum of circular cross-sectional area 5003.6 cm^2, diameter 70.0 cm and depth 130.0 cm. The lysimeter was filled with undisturbed sandy-loam soil and a Jatropha was grown in it. The grass-reference evapotranspiration (ET_0) was estimated using the Penman-Monteith equation from the climatic data obtained from a nearby weather station. The values of K_C were computed as the ratio between the ET_C and ET_0 for the irrigated treatments. The results show that, average values of ET_C ranged from 1.4 to 5.6mmday^{-1} for drip irrigation and from 1.1 to 5.3mmday^{-1} for no irrigation. Average crop coefficient (K_C) values determined for Jatropha in drip irrigation at different four growth stages were 0.5, 0.9, 1.2 and 0.7; while in no irrigation (rainfed), 0.4, 1.0, 1.1 and 0.6 were obtained for the initial, development, mid-season and late season growth stages respectively. The highest K_C values of 1.2 and 1.1 were obtained at mid-season (from late November to mid-December), during the season, for the drip irrigation and no irrigation treatments, respectively.

Keywords: Jatropha ***curcas***, Drainage lysimeter, Crop coefficient, Irrigation schedule and Crop evapotranspiration.

Introduction

Jatropha curcas Linnaeus generally known as Jatropha is an important biodiesel crop cultivated in many parts of the world including Nigeria because of its easy adoption to a wide agro-climatic condition (Arun *et al.*, 2014). The crop has an increasing potential in the world because of its usefulness in terms of biodiesel production, soil stabilization and other domestic uses such as fertilizer production, oil-soap production and pharmaceuticals (Achten *et al*., 2010). Recently, Jatropha has attracted interest from governments and private investors worldwide because of the shift in energy sources being envisioned to reduce dependence on fossil fuels, cut down greenhouse gas (GHG) emissions, and the need to relieve national economies from the ever-escalating prices of fossil fuels. Great hopes have been pinned on the oil-bearing, “drought resistant” non-edible tree called *Jatropha* to help alleviate energy demands (Arun *et al.*, 2014), restore degraded ecosystem services in drylands (Garg *et al.*, 2011), combat climate change (Arun *et al.*, 2014) and to generate income in rural areas of developing countries (Achten *et al*., 2010).

Jatropha develops very well in low rainfall conditions of 200mm but higher rainfall enhanced with irrigation up to 1200 mm promote the yield of crop especially in hot climatic conditions (Ewemoje *et al.*, 2018). One well-known and established method for attaining high efficiencies of water application is drip irrigation. The system involves application of water to only a restricted part of the root zone therefore, contributes to the sustainable use of water resources for agriculture (Oluwagbayide *et al;* 2020).

However, despite the global promotion of Jatropha as source of biodiesel production, there is surprisingly limited information about its crop coefficient (K_C) and actual crop evapotranspiration (ET_C). Information on actual evapotranspiration and crop coefficient (K_C) 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 (Fagbayide *et al;* 2018). There is limited or no data on K_C and ET_C of Jatropha to assist in designing appropriate irrigation schedule for optimum production of this important crop.

Crop coefficient (K_C) is essential in the irrigation management as its help in providing precise water applications for a given region. It is defined as the ratio of crop evapotranspiration (ET_C) and reference crop evapotranspiration (ET_0 (Ted, 2001). Allen *et al.* (1998) listed the factors affecting K_C as crop type, crop growth stage, climate and soil evaporation. K_C is commonly expressed as a function of time (Clark *et al.,* 1996; Haman *et al.*, 1997). Likewise, ET_0 is a climatic parameters and value can be estimated from weather data (Ted, 2001) while the actual crop evapotranspiration (ET_C) can also be obtained from lysimeter. Lysimeters have long been used in research for the direct measurement of evapotranspiration of a crop, varying in form and scale (MAREK et al., 2006). Lysimeters provide viable estimates of ET_C for longer periods such as weekly or monthly (Sanjay *et al.*, 2007). Two classifications of lysimeters in existence are weighing and non- weighing otherwise called drainage type (Islam and Hossain, 2010). In weighing type, the crop water use is calculated from the changes in weight of the lysimeter tank and this change 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). However, for 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 (Islam and Hossain, 2010).

Therefore, the research was aimed at determining the crop coefficient (K_C) and actual crop evapotranspiration (ET_C) for Jatropha grown in drainage lysimeters under drip irrigation and no irrigation (rain-fed) conditions in Ilaro, South western, Nigeria.

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

2.0 Materials and methods

2.1 Details of the experimental area

The study was conducted in the Research Farm of Agricultural and Bio-Environmental Engineering Department, Federal Polytechnic, Ilaro, Ogun State, Nigeria between June 2019 and February 2020. In Ilaro, the 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 climate of the location was characterized as humid tropic, with two distinctive seasons' namely rainy and dry seasons. The Rainy season starts around April and ends in late October or early November while dry season commences from late October to March. The mean annual rainfall in Ilaro is 1257 mm while the mean temperatures during wet and dry seasons are 23.6 and 34.2 °C. The soil in study site in laro was categorized as fine sandy clay loam.

2.2 Experimental treatments description and water application

Two different irrigation treatments consisting of no irrigation (rainfed) and drip irrigation were appraised. For the drip irrigation treatment which was conducted under control environment (green house), water was applied four times weekly at two litres per plant per irrigation using pressure compensating emitter that discharged at 3 litres per hour.

Moreover, the plot size used for the study (the two treatments) was 20.0 m × 4.0 m with a planting distance of 2.0 m × 2.0 m and consisting of 2,500 plants/ha. A drainage lysimeter was installed at the center of each treatment plot, contained one plant and surrounded by Jatropha plants (to ensure similar environment). The drainage lysimeter of circular cross-sectional area, 5003.6 cm^2, diameter 70.0 cm and depth 130.0 cm was made from cylindrical drum. The lysimeter was filled with undisturbed sandy-loam soil on which a Jatropha was grown.

The source of irrigation water for the project was Bore hole located 250 m away from the study site. Seeds of Jatropha were obtained from Nigeria Institute of Horticultural Research (NIHORT), Jericho, Ibadan, Oyo State, Nigeria. The crop was raised in the nursery for one month in June 2019 and later transplanted to the study site on July 5th, 2019. There was no chemical fertilizers application throughout the period of the investigation. However, for the weed control, both chemical and manual methods were adopted in management of the weeds. Find below the physical and chemical properties of water used for the irrigation in (Table 1). Table 2 also shows the physical and chemical properties of soil in the studied site as evaluated before the commencement of the experiment. The mean bulk density is 1.38 Mg/m^3, while the bulk density decreases from the top to lowest layers. The soil texture of the experimental site varied from sand at the upper layer (1 – 20 cm) to clay in the lowest layer (80 – 100 cm).

Table 1: Physical and chemical properties of irrigated water at the studied area

pH	EC dS/m at 25°C	SAR	ESP	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	Colour	Odour	Conductivity
				(meq/l)								
5.6	0.19	19.2	23.3	15.4	26.7	83.0	61.0	0.14	7.2	Colour-less	Odou-rless	$2.50x10^2$

Source: Field data, (2019)

Table 2: Physical and Chemical properties of soil in the studied area

Soil Texture	**Soil Depth** (cm^3)	K_{sat} (mm/hr)	**Bulk Density** (Mg/m^3)	**FC**	**WP**	**TP**	**Mi**	**TAW**
				m^3/m^3				
Sand	0 – 20	64.20	1.32	0.35	0.19	0.41	0.32	28.10
Loam	20 – 40	35.60	1.35	0.39	0.21	0.42	0.34	27.50
Clay loam	40 - 60	24.80	1.39	0.47	0.23	0.45	0.34	25.30
Clay	60 – 80	19.70	1.41	0.48	0.20	0.44	0.39	25.70
Clay	80- 100	12.40	1.45	0.57	0.25	0.48	0.34	20.10
Mean values		31.34	1.38	0.45	0.22	0.44	0.35	25.34

Source: Field data, (2019)

2.3 Determination of actual crop evapotranspiration (ET_C)

Calibrated digital PMS-714 soil moisture meter was used in determining the soil moisture inside the lysimeter before the irrigation was applied. Changes in the soil water storage (SWS) in the entire lysimeter system were determined for a specified time (Islam and Hossain, 2010).

The crop evapotranspiration (ETc) was obtained using water balance approach of measuring the difference between daily volumes of water inputs and outputs from the lysimeter. Soil moisture inside the lysimeter was measured before irrigation. Irrigation was made to maintain soil humidity close to field capacity, monitored with calibrated digital PMS-714 soil moisture meter installed at 0.25 and 0.5 m deep on the lysimeters (Edson *et al.*, 2012), Changes in the soil water storage (SWS) in the entire lysimeter system were determined every twenty-four hours (Islam and Hossain, 2010).

Daily crop evapotranspiration (ETc) values in millimeters were computed using the equation given below.

$$ET_C = R + I - R_U - D_R \pm \Delta SW \quad (1)$$

Where ET_C = Crop evapotranspiration, R = Rainfall (mm), I= Irrigation (mm), R_U = Runoff (mm), D_R = Drainage (mm) and ΔSW = Change in soil water storage (mm).

The changes in the soil water storage were computed for every 25 cm increment up to depth of 100 cm. The variation between two consecutive days provides the change in soil water storage as:

$$S_t = \{\alpha_{0-25} + \alpha_{26-50} + \alpha_{50-75} + \alpha_{75-100}\} * d \quad (2)$$

Where α is soil water content and S_t is soil water storage, mm for days P.

$\alpha_{0-25}, \alpha_{25-50}, \alpha_{50-75}$ *and* α_{75-100} are the volumetric soil water contents at different layers $cm^3\ cm^{-3}$ of the soil and the d stand for the depth (25 mm) of each soil layer in mm. The difference between two consecutive days gives the change in soil water storage as:

$$\Delta SW = S_{P+1} - S_P \quad (3)$$

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

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

In which case, SM_t and SM_{t-i} are the soil moisture storage at instants time t and t-1, respectively. The values of daily crop evapotranspiration (ETc) were obtained till 208 days after planting (DAP) marking the Jatropha crop cycle.

2.4 The crop coefficient (K_C)

(ET_0) was estimated from the climatic data obtained from a nearby weather station using the Penman-Monteith equation according to Allen *et al.* (1998). Climatic data used include temperature, relative humidity, solar radiation and wind speed. The crop coefficients (Kc) were calculated for each day of the cycle according to equation stated below by Fagbayide *et al.*, (2018).

$$K_c = \frac{Crop\ Evappotranspiration\ (ET_C)}{Reference\ Evapotranspiration\ (ET_0)} \quad (5)$$

Mean values of ET_C and K_C were expressed into the growing stages as proposed by Allen *et al.* (1998): These stages are: (i) initial phase: planting up to 10% of ground cover; (ii) development phase: from the end of the initial stage up to 80% of ground cover; (iii) mid-season phase: from 80% of ground cover to the beginning of fruit maturation and (iv) late season phase: from the beginning of maturation until harvest.

3.0 Results and discussion

Climatic conditions during the study show highest mean temperature of 35.4 °C (February) and the lowest mean of 27.50 °C (July). The average relative humidity in Ilaro was very high; it ranged between 50.66 and 89.60 % during the cropping season. Minimum relative humidity of 50.66 % was observed in December while maximum relative humidity of 89.60 % was recorded in October (Figure 1 and 2). The average rainfall of 761.00 mm was recorded throughout the cropping season for rainfed between 30th of June 2019 and 16th of February 2020. The mean monthly temperatures and other climatic parameters fall within acceptable limits considered good for Jatropha cultivation (Abobatta, 2019). In general, the climatic conditions were highly favorable to the development of culture, resulting in 208 days from planting to harvest.

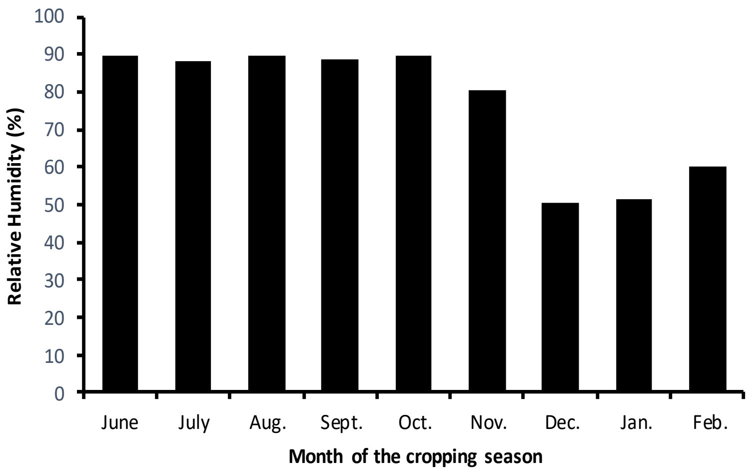

Figure 1: Mean relative humidity during cropping season 2019/20

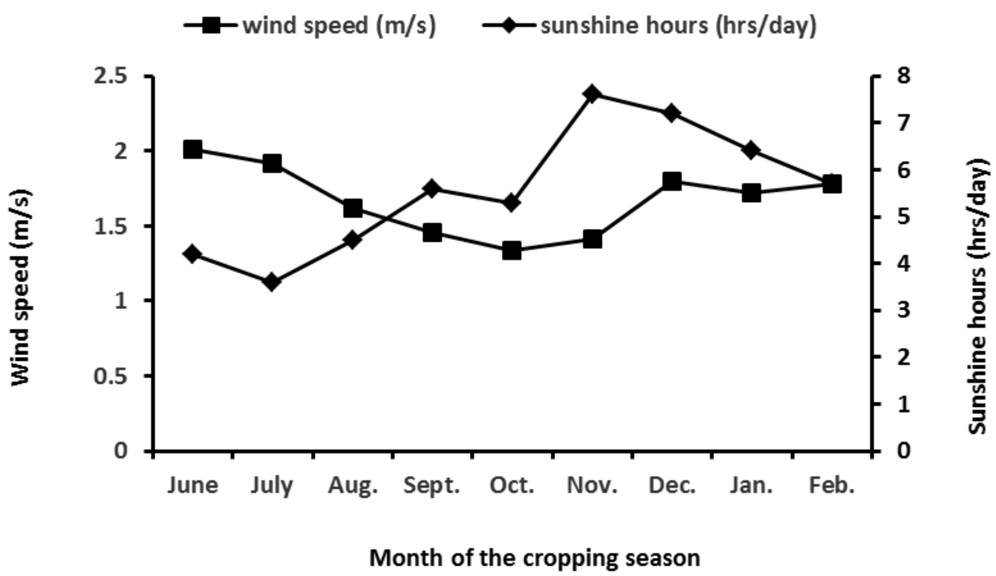

Figure 2: Average sunshine and wind speed during cropping season 2019/20

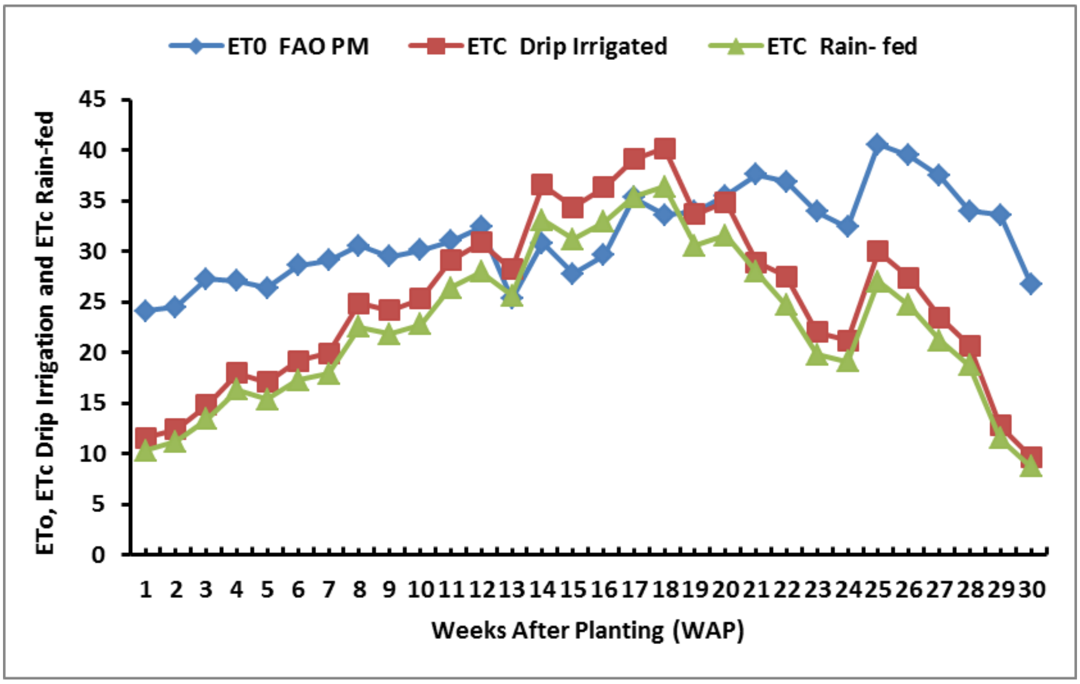

Figure 3: Relationship between WAP, Actual Crop evapotranspiration (ET_C) for Drip Irrigated and Rain-Fed treatments and the Reference evapotranspiration ($ET_{0\ FAO\ PMM}$),

Crop evapotranspiration (ET_C)

Jatropha seeds were planted and nursed for one month (30 days) before it was transplanted to the study locations. In both study locations, the crop was uniformly irrigated for 3 weeks after planting for crop establishment. First irrigation was administered within 31 Days After Planting (DAP) on the study's field as seen in Table 3 for drip irrigation treatment while last irrigation was applied at 207 DAP. Final crop harvesting was done on 208 DAP in both treatments as the crop cycle was 208 days. Negative sign in the 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 planting (Figure 3).

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 (Doorenbos and Pruitt, 1977; Smith et al., 1992).

The mean daily values of Jatropha crop evapotranspiration (ET_C) in Drip irrigated varied from 1.4 to 5.6 mm/day while the mean Jatropha crop evapotranspiration (ET_C) in Rainfed varied from 1.1 to 5.3 mm/day. It was observed that ET_C values recorded in the two treatments rises rapidly during the vegetative and flowering phases. This shows that crop water requirement was at maximum during this growth stages. Daily mean values of ET_0 in Drip irrigated ranged from 2.7 to 4.6 mm/day while the mean daily ET_0 values in Rainfed ranged from 3.4 to 5.8 mm/day. Mean values of ET_C recorded were higher at the mid-season stage in both Drip irrigated and Rainfed compared to other stages of crop development.
There were variations in the average values of ET_C during the crop growing season and this variation was due to crop development and climatic change. Table 4 show the computed values of growth stages ET_C and ET_0 values for the Jatropha during the growing season. The values ET_C obtained in Drip irrigated and Rainfed during the initial, development, mid- and late-season stages were: 54.3, 149.9, 92.9 and 192.5; and 42.3, 146.4, 94.1 and 197.0 respectively. Total water use during the cropping seasons were 612 mm and 808.5 mm in Drip irrigated and Rainfed respectively.

Table 3: Estimation of water balance for crop evapotranspiration (ET_C)

Duration (WAP)	Durations (DAP)	Applied water (mm)	Effective rainfall (mm)	Change in soil water storage (mm)	Percolation / Drainage (mm)	Runoff (mm)	Crop ET (mm)
Drip Irrigation							
5	35	140.2	0	-15.4	75	6	43.8
10	70	277.5	0	12	201.7	21.8	66.0
15	105	401.2	0	32.3	270.5	68.6	94.4
20	140	198.8	0	41.3	104.8	18.7	116.6
25	175	125.2	0	32.4	59.8	0	97.8
30	210	38.3	0	73.8	41.1	0	71.0
Rain-Fed							
5	35	0.00	76.2	-25.8	4.7	1.3	44.4
10	70	0.00	191.9	11.4	112.2	26.7	64.4
15	105	0.00	315.3	26.4	204.3	44.9	92.5
20	140	0.00	170.5	-25.2	29.3	2.1	113.9
25	175	0.00	28.3	-47.1	0	0	75.4
30	210	0.00	0	-89.3	0	0	89.3

Table 4: Jatropha crop evapotranspiration (ET_C) in each crop development stage under Drip Irrigated and Rain-fed treatments.

Phonological Phase	Time periods (days)	Crop ET (ET_C) (mm)	Reference ($ET_{0\ FAO\ PMM}$) (mm)	Average Crop coefficient (K_C)
Drip Irrigation				
Initial season	43 (6 wks)	54.32	95.52	0.5
Development	60 (8 wks)	149.92	165.76	0.9
Mid-Season	30 (4 wks)	92.88	75.76	1.2
Late season	75 (11 wks)	192.48	261.76	0.7
Total	208 (30 wks)	489.60	598.80	

Rain-Fed				
Initial season	43 (6 wks)	42.32	86.40	0.4
Development	60 (8 wks)	146.40	150.40	1.0
Mid-Season	30 (4 wks)	94.08	87.04	1.1
Late season	75 (11 wks)	197.00	357.76	0.6
Total	208 (30 wks)	479.80	681.60	

Crop coefficient

The trend of Crop coefficient (K_C) derived for the two treatments are shown in Figure 4. The curve was used in denoting the changes that emerged in the values of Crop coefficient (K_C) over the length of the cropping season. The curve shape indicated changes in the vegetation and ground cover during crop development and maturation that affect the ratio of ET_C to ET_0. The K_C increased from the initial to development stages and reached its highest at the mid-season stage.

The K_C increased from the initial to development stages and reached its highest at the mid-season stage. Thereafter, values of K_C declined rapidly during the late season stage. Similar comment was made by Faust (1989) who indicated in his work on pears that decreasing K_C values during fall might be due to reduced sensitivity of the stomata as leaves begin to senescence or due to water stress. During the initial stage, the value of K_C was 0.5 for Rainfed and 0.4 for drip irrigated. At the initial stage, K_C values were minimal. The crop is not fully covered and more evaporation takes place in the soil than transpiration because the plants have little leaf area (Allen et al., 1998).

The K_C values for initial, development, mid- and late-season growth stages of Jatropha curcas were: 0.5, 0.90, 1.2, 0.7 and 0.4, 1.0, 1.1, 0.6 in Drip irrigated and Rainfed respectively. The crop coefficient (K) values obtained in Drip irrigated indicated that Jatropha requires more water application during the vegetative and flowering stages than at emergence and senescence.

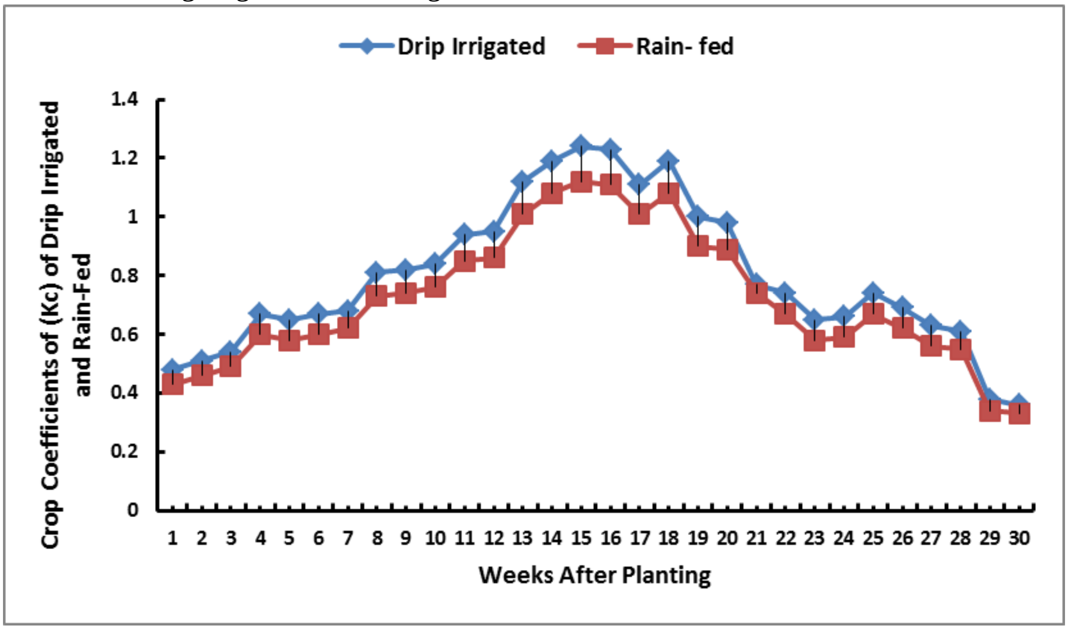

Figure 4: Relationship between WAP and Crop Coefficient (K_C) under Drip Irrigated and Rain-fed treatments.

4.0 Conclusion

The crop coefficient (K_C) and the actual crop evapotranspiration (ET_C) of *Jatropha curcas L.* have been computed. The average daily ET_C values during the emergence stage to peak / flowering stage ranged from

1.4 to 5.6 mm day−1 for drip irrigation and from 1.1 to 5.3 mm day−1 for no irrigation. Maximum values are obtained during the vegetative and flowering stages.

The values of crop coefficient (K_C) obtained from the treatments shows that more water needs to be supplied to the crop during the crop development and mid-season growth stages (vegetative and flowering stages) than at initial-, development- and late-seasons stages. For maximum production of Jatropha crop round the year by the local farmers in the study area, supplementary irrigation will be required in addition to rain-fed.

Finally, the information derived from this study will be a valuable reference for future researchers in the region in absent of Jatropha's K_C values in the FAO repository.

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