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Effect of Varying Water Applications on Evapotranspiration and Yield of Cowpea under Sprinkler Irrigation System

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ABSTRACT: Cowpea (*Vigna unguiculata, L. walp*) was subjected to varying water applications under sprinkler irrigation system. The experiment was conducted between January and April of 2013 and 2014 at Teaching and Research Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure under four levels of water management. In this study, evapotranspiration and Crop coefficient (k_c) of Cowpea were determined using drainage lysimeter. Meteorological data during the growing season were obtained from a meteorological station located within the site of the experiment for the determination of reference evapotranspiration (ETr). Soil samples were collected to determine the soil physical properties such as bulk density and moisture content. The highest reference evapotranspiration (ET_r) value of 5.17mm/day occurred during 4WAP and lowest value 4.20mm/day occurred at crop maturity (9 WAP). The mean crop coefficient (K_c) values for emergence, vegetative, flowering/fruiting and maturity stages were 0.37, 0.74, 0.88 and 0.84 respectively. The highest ET was recorded in the treatment block that received the highest amount of irrigation water. There was significant difference in the grain yield and biomass yield among treatments at 5% level significance ($p = 0.023$). The highest grain yield and biomass yield of 1.06 tons/ha and 6.95 tons/ha were observed with fully irrigation, while the lowest grain yield and biomass yield of 0.71 tons/ha and 3.48 tons/ha were observed in the lowest irrigation treatment as a result of moisture availability that contributed to the yield. Therefore, the grain yield and biomass yield increase progressively with water application. The findings from the research could serve as useful guide in the irrigation of cowpea in similar soil and climate.
Keywords: Reference evapotranspiration; Crop coefficient; Cowpea yield; Moisture availability; drainage lysimeter

INTRODUCTION

Cowpea is one of the most widely adapted, versatile, and nutritious of all the cultivated grain legumes. They are mainly grown in the warm climates since they require warm soil temperatures between 27°c and 35^{o}c for good establishment (Dugje *et al*., 2009). They are adapted to a wide variety of soils from heavy to light textured and from the humid tropics to the semi-arid tropics. Despite the nutritional and medicinal importance of the crop, its production, especially in the humid and sub-humid regions of the tropical countries is largely limited to the rainy season of the year. However, with the increasing need of this crop, it is necessary to accelerate and expand its production all year round. This could mean making an effort to grow the crop under irrigation so as to have more than one cropping season in a year which would increase its production. Since cowpea is a row crop, it is best suited to sprinkler, border or furrow. Since the primary objective of any irrigation system is to have a good water application uniformity so as to improve soil moisture uniformity which would in turn contribute to increase in crop yield when there is water scarcity.

Considering the effective management of water as scarce resources, there is a need to determine water use of crop from planting to harvest. The water balance method provides a simple but robust means of continous measuremnt of evapotranspiration from different species of vegetation (Granier et al., 1990; Gholipoor, 2007). The estimation of crop water requirement requirement of crop can be done by using the direct method of measuring ET using drainage Lysimeter, which measure soil water balance component such as runoff, deep percolation and change in storage. The appropriate estimation of evapotranspiration is necessary for climatic condition of a particular region. Singh et al.(1991), Al-Jamal et al. (1999), Imtiyaz et al.(2000), Camposeo and Robino (2003), Mermoud et al.(2005), Sun et al. (2006), Nazeer (2009), Ayana (2011), Quanqi et al. (2012) reported that the response of crop yields and water use to varying water applications is climate specific. Kang et al. (2002) also reported that crop yields and water use varied considerably due to differences in soil water content. Few researches have been focused on the water requirement of cowpea from establishment to harvest and its response to yield and growth parameters. Thus, there is a need to determine its water requirement from establishment to harvest and its response or effect on the yield components so as to prevent stress of the crop under irrigated condition. The objective of the present investigation was to evaluate the actual water consumption of cowpea at each stage of growth and to investigate the effect of irrigation on the crop evapotranspiration (water requirement) and yield components of cowpea under sprinkler irrigation system.

MATERIALS AND METHOD

Description of the Study Area

The field experiments were conducted during dry season of 2013 and 2014 (January - April) at Teaching and Research Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure. Akure is located within the humid region of Nigeria at latitude 7°16'N; longitude 5°13'N. Akure has a land area of about 2,303 km^2 and is situated within the Western upland area. The area has a general elevation of between 300 and 700 meters above the mean seas level and mean annual rainfall ranges between 1300 mm to 1500 mm.

Design of the Drainage Lysimeter

The lysimeter was made of a cylindrical bucket, having a circular cross-sectional area of 0.071m^2 and a diameter of 300mm. The depth of the lysimeter is 360mm. The depth is enough to permit root development. The lysimeter was made of plastic in order to minimize heat conduction down the lysimeter walls. Soil was collected from an excavated pit, in which the lysimeter was installed. Soil was collected from the field at depths of 0 – 200 mm, 200 – 400 mm, and 400 – 600 mm. The soil was carefully collected and placed into the lysimeter to minimize disturbance. Gravel filters collected at depth of 400 – 600 mm was first placed at the bottom of the lysimeter, followed by the soil attained at depth of 200 – 400 mm and finally the soil at 0 – 200 mm (the top soil).

Measurement Procedures

The estimation of the evapotranspiration requires the collection of some important meteorological data. Meteorological data such as daily relative humidity, wind speed, minimum and maximum temperature and solar radiation during the experiment were collected from the meteorological station located within the site of the experiment. The growth parameters (plant height, number of leaves, leaf area and leaf area index) were measured.

Estimation of Reference Evapotranspiration

Reference evapotranspiration was determined using the penman-monteith ET model (Allen et al., 1998). The equation used in estimating evapotranspiration is shown in Eq. 1

$$ET_o = \frac{\Delta\,(R_a - G) + 86.4\rho cp\,(e_a - e_d)/r_a}{\lambda\left[\Delta + \alpha\,(1 + r_c / r_a)\right]} \qquad (1)$$

where ET_o is the ET of the reference crop in mm d^{-1}, Δ is the slope of the saturated vapour pressure-temperature curve (δe/δT) in KPa $^oC^{-1}$, R_a is net radiation in MJ m^{-2} d^{-1}, G is sensible heat flux into the soil in MJ m^{-2} d^{-1}, ρ is air density in kgm^{-3}, Cp is specific heat of moist air (1.013 KJ kg^{-1} $^oC^{-1}$) e_a is the mean saturated vapour pressure in kPa, e_d is mean ambient vapour pressure in kPa, r_a is aerodynamic resistance in s m^{-1}, r_e is the surface resistance to evaporation in sm^{-1}, λ is the latent heat of vapourization in MJ kg^{-1}, and α is the psychrometric constant in kPa $^oC^{-1}$.

Crop factor (K_c) was determined from the relationship below;

$$K_c = \frac{ET_C}{ET_O} \qquad (2)$$

Where

ET_c = Crop evapotranspiration

ET_o = Reference evapotranspiration

Treatments and Experimental Procedures

The land was ploughed and harrowed and an area of 13x13 m^2 was marked out into four blocks, each subdivided into four (4x4) m plots separated by 1 m paths. The second experiment consisted of four treatments. Irrigation water was applied at each irrigation level for duration of 1h, 0.8h, 0.6h and 0.4h at treatments (T - 100), (T – 80), (T – 60) and (T – 40) respectively. Cowpea (*Vigna unguiculata, L Walp*) variety ife brown was planted at the recommended spacing of 30 cm on rows, 60 cm apart. The plots were planted with Cowpea (*Vigna unguiculata, L. Walp*) with a spacing of 0.6 m inter row by 0.3 m intra row. Weeds and insect pests were controlled as necessary using standard procedures. Seeds were planted and thinning was first done two (2) weeks after planting to reduce the crop to two per stand.

Two sprinklers each were arranged diagonally at the corner of each irrigation level to form a part circle irrigation water coverage pattern in each treatment block. A total of 8sprinkler heads were used to irrigate the crop field. The sprinklers were set to throw water at an angle of 90^0 in each irrigation level (treatment). The sprinklers produced a wetted radius of approximately 6meters to irrigate cowpea in each of the irrigation level at an approximate operational pressure of 250Kpa and average discharge per sprinkler was $0.49m^3/hr$. Control valves were connected to the risers at each irrigation level to stop and regulate the flow of water application at the specified time. Two uniform irrigations were applied to bring the soil to field capacity before planting to encourage seedling establishment. Irrigation depths applied at each irrigation level was predetermined at each irrigation level before sowing cowpea. The irrigation depths were measured using catch cans arranged in each irrigation level. There were twenty (20) cans per irrigation level and the average was estimated over the total area considered (Irrigation level). Irrigation was scheduled at 4days between successive irrigation events in all the irrigation levels. The soil moisture content at depths 0 - 10, 10 - 20 and 20 – 30 cm were determined from each plot in each of the treatment at the effective rooting depth of cowpea. The soil moisture contents were measured from each plot bi-weekly (before and after irrigation) by using the gravimetric method (Lascano, 2000). The Soil bulk density (g/cm^3) was determined by the core method (Blake and Hartage, 1986) using a 10.0cm long by 8.3cm diameter cylindrical metal core. Runoff and deep percolation were measured using a drainage lysimeter installed in each of the treatment block. The drainage lysimeter consisted of drainage and run off system (Igbadun, 2012). Rain gauges were installed within the experimental field to measure precipitation during the experiment. Crop ET from sowing to harvest was estimated using soil water balance equation (Hillel, 1998).

$$ET = I + P \pm \Delta S \pm D \pm R \qquad 3$$

where ET is the crop evapotranspiration (mm), I is applied irrigation (mm), P is the precipitation during the period of experiment (mm), ΔS is the change in soil moisture storage (mm), D is the excess moisture drained from soil (mm) and R is the runoff from soil surface (mm).

Regression analysis were performed to determine the relationship between yield and total amount of water applied.

Analysis of variance was carried out to determine the effect of water application depths on the yield of cowpea (*ife brown*) under varyinging water applications.

RESULTS AND DISCUSSION

Climatic Condition during the Experiment

Fig. 1 shows the mean temperature variation of the study area with Julian day during the period of experiment. Highest mean temperatures of 28.84°c was recorded at 4 WAP(weeks after planting) and lowest mean temperature of 26.31°c was observed at 10 WAP (weeks after planting). The highest and lowest mean air temperature was observed during the months of February and April, of the experiment respectively. The highest temperature recorded in February may be due to sparse or little rainfall recorded during this period and the lowest temperature obtained in April may be due to the onset of rainfall. There was steady decline in average temperature towards the end of the experiment. This may be as a result of gradual rise in the frequency of rainfall. The minimum relative humidity recorded was 55.89% at 3WAP and the highest value of relative humidity recorded was 76.08% at 10 WAP. These results are consistent the range of lowest temperature and highest temperature recorded during the experiment. Analysis of the rainfall data during the experiment period shows that there was precipitation temporal cessation in the month of February (Fig. 3) because there was little or no rainfall recorded during this period. There were low rainfall in March and it rise to a peak of 76.51mm in April. The wind speed data is presented in Fig. 4. The lowest and highest wind speed were recorded at 3 WAP and 9 WAP. The graph of the wind speed is sinusoidal; It was rising and falling.

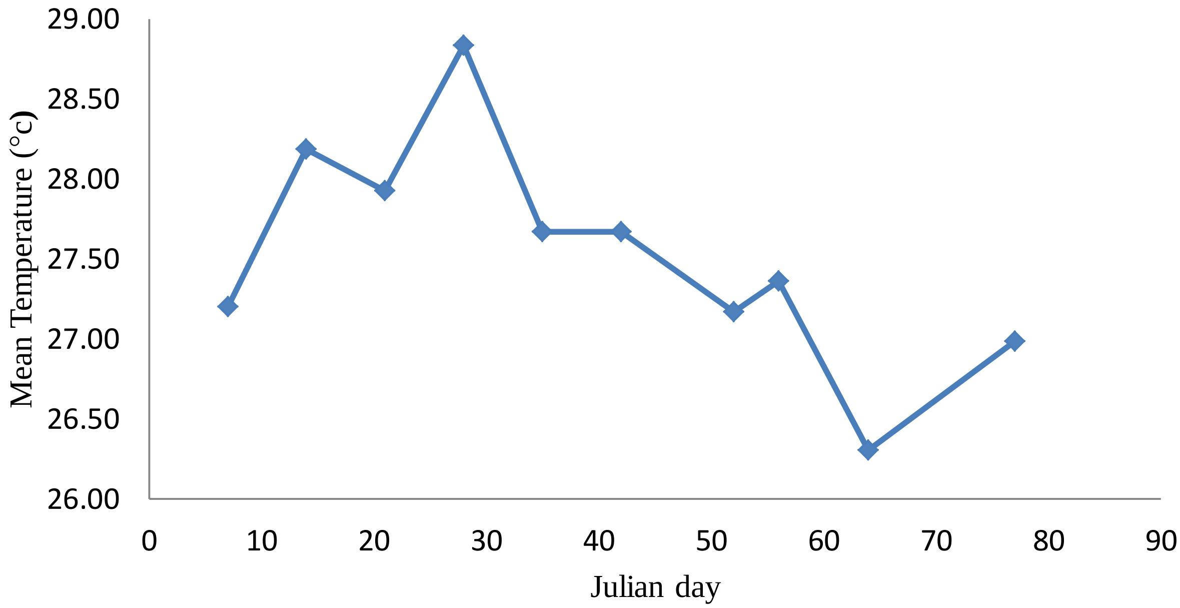

Figure1. Mean weekly temperature during the period of the research

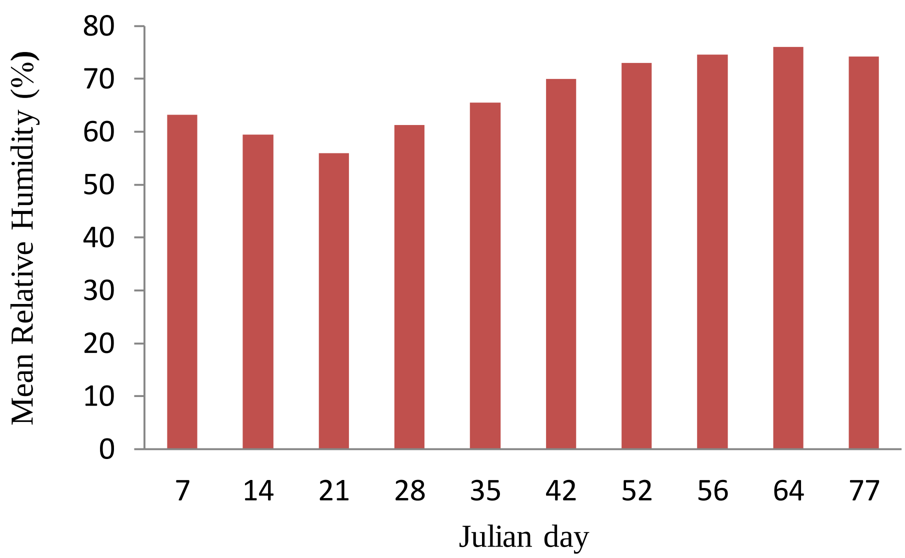

Figure 2. Mean weekly relative humidity during the period of the research

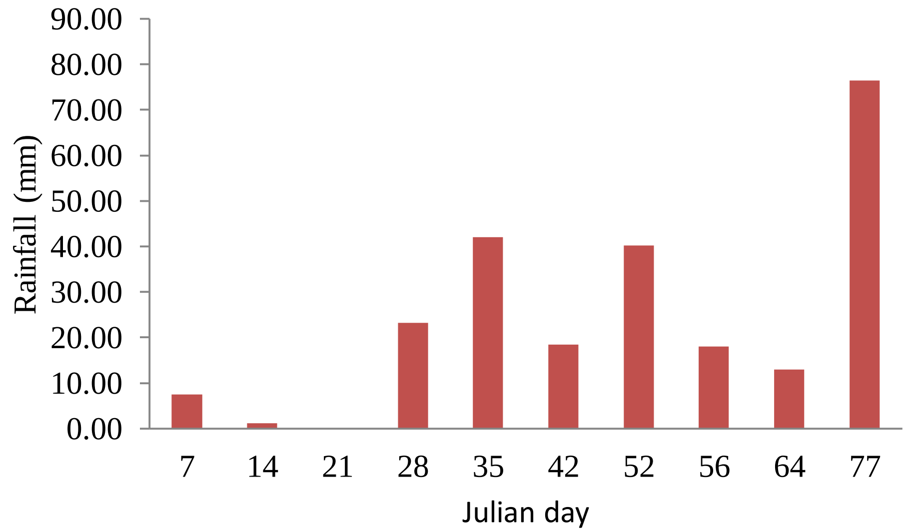

Figure 3. Mean weekly rainfall during the period of the research

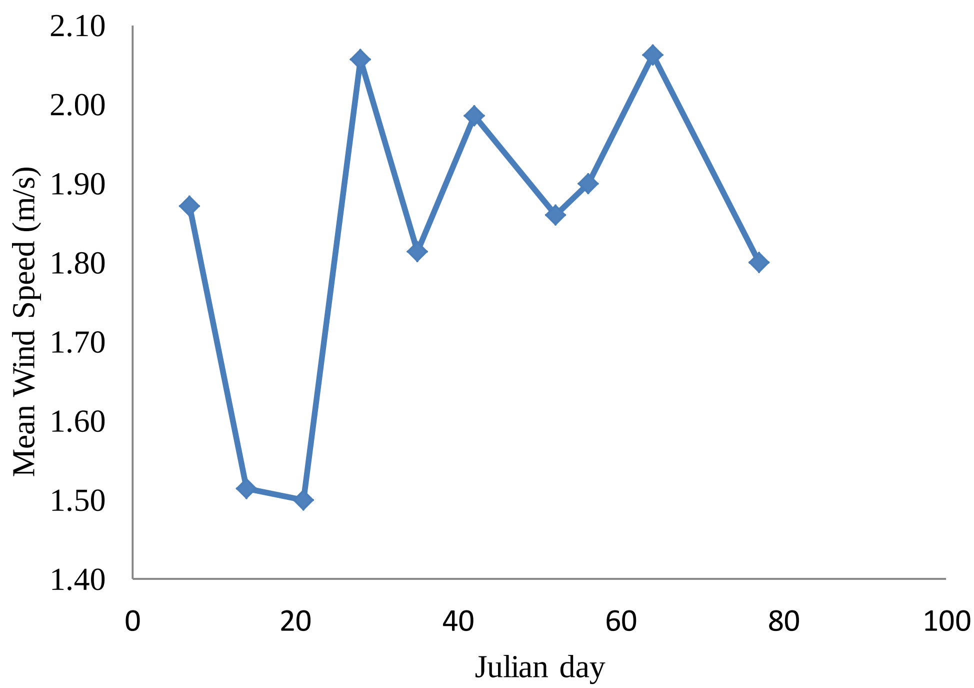

Figure 4. Mean weekly wind speed during the period of the research

Reference Evapotranspiration

Fig. 5 shows the reference evapotranspiration rate (ET_o) of the study site from 1 WAP –11 WAP, during the period of experiment using the Penman-Monteith model. High values of ETo was observed in the month of February as result of rainfall cessation which led to high solar radiation and decline in the month of March when little and sparse rainfall occurred and took a gradual downturn from the month of February to April which forms the wet season. The rise in ET_o observed in February must have been caused by high solar radiation which is accompanied by high temperature that often results in quick evaporation of water from soil and water surface.

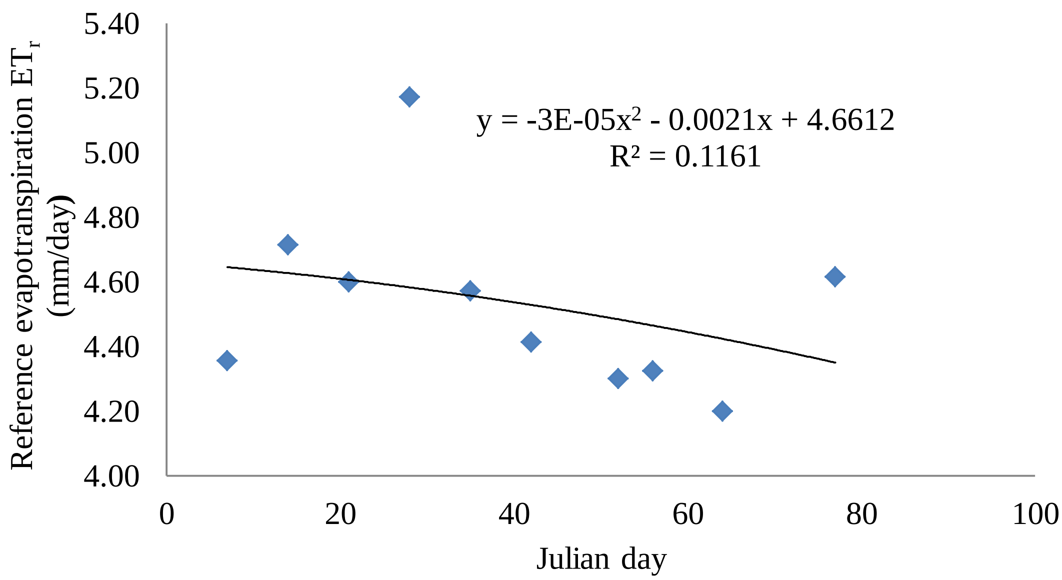

Figure 5. Reference crop evapotranspiration during the experiment

Soil Moisture Content

The soil moisture content in the various treatments; T-100, T- 80, T-60 and T- 40 from 0 – 91 days after planting (DAP) at soil layer 0 -10 cm. 10-20cm and 20 – 30cm (effective root depth) are shown in Fig. 6a, 6b, 6c and 6d. The stored moisture in the soil profile was observed to increase down the soil profile as shown in Fig. 6a, 6b, 6c and 6d. They show the relationship between the variation of soil moisture content stored under sprinkler irrigation system as a function of Julian day in each treatment block at the depth of 0 - 10, 10 - 20 and 20 - 30cm respectively and in each of the treatment block and their replicates. There was general rise and fall in soil moisture content with respect to Julian day. This observation confirmed that the soil moisture content was taken before and after each irrigation event.

The highest mean value for the soil moisture stored on depth basis was observed at 30 days after planting (DAP). This observation was preceded by two heavy rainfall events towards the end of the month of February. There was a sharp increase in depth of soil moisture stored from 45.23±2.15 to 66.09±1.10mm, 40.97±2.71 to 63.43±1.15mm, 37.65±2.14 to 64.80±1.17mm and 33.27±0.64 to 64.80±1.13mm under the full irrigation treatment (T - 100), treatment B (T - 80), treatment C (T - 60) and treatment D (T - 40) respectively during crop (cowpea) development in February.

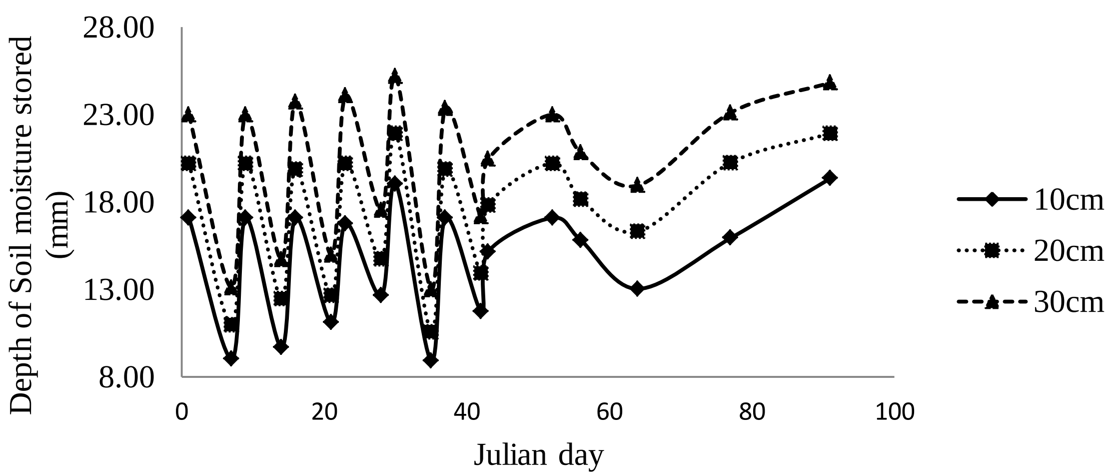

Figure 6a. Mean depth of soil moisture content in treatment (T-100) irrigated under sprinkler irrigation system

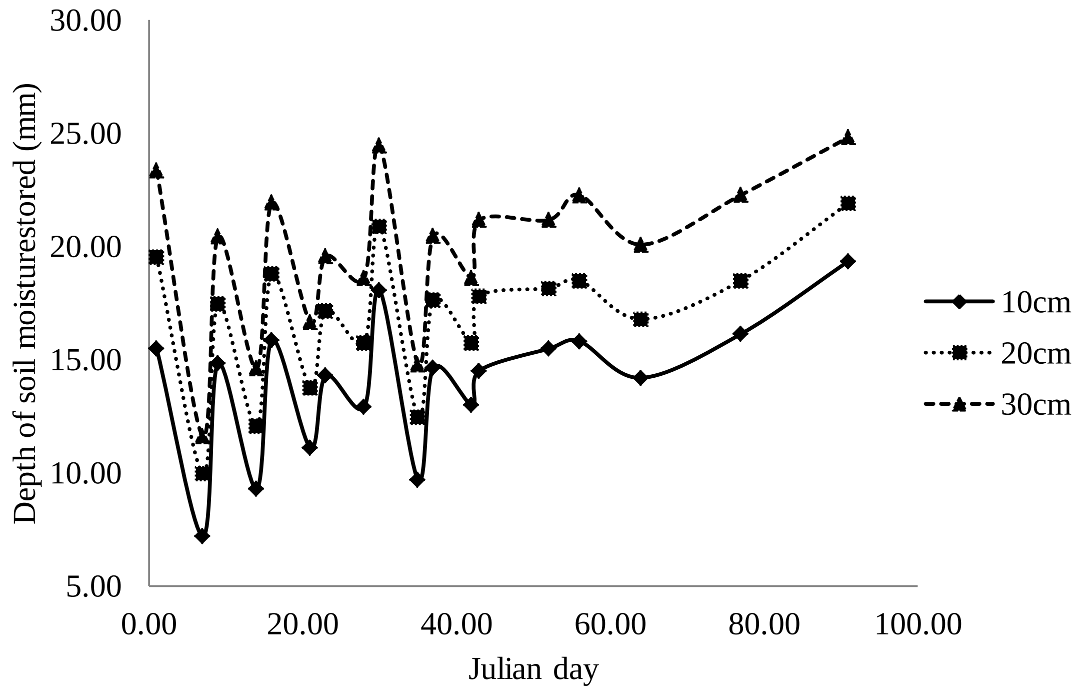

Figure 6b. Mean depth of soil moisture content in treatment B (T - 80) irrigated under sprinkler irrigation system

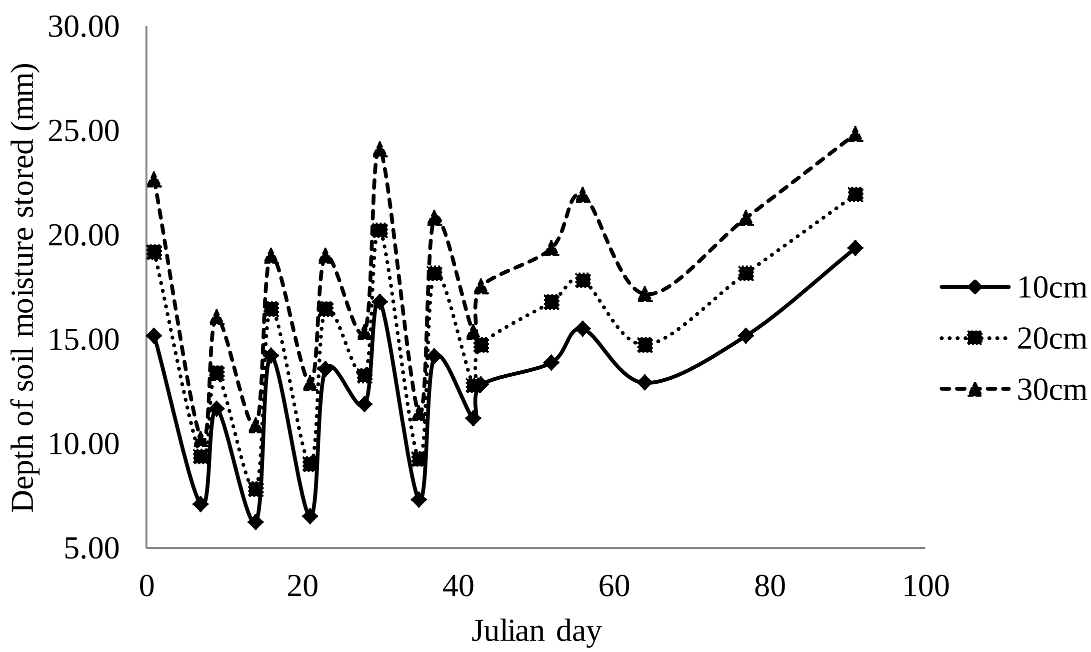

Figure 6c. Mean depth of soil moisture content in treatment C (T - 60) irrigated under sprinkler irrigation system

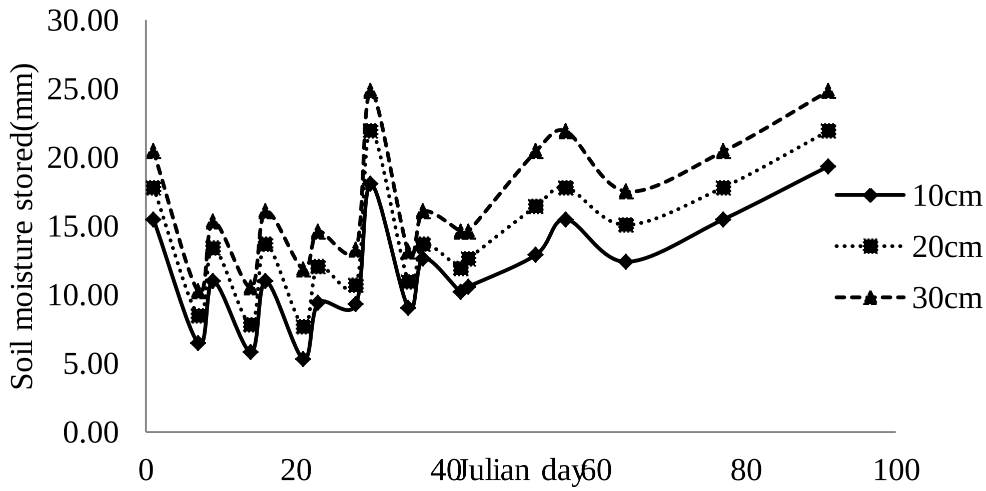

Figure 6d. Mean depth of soil moisture content in treatment D (T - 40) irrigated under sprinkler irrigation system

Actual Seasonal Evapotranspiration

The crop evapotranspiration (ET) expressed on function of Julian days is presented in Fig. 7 – Fig. 10. The highest and lowest ET values under full irrigation treatment during the experiment were 6.03 and 1.66 mm.day^{-1} respectively. Also, the highest and lowest ET values under full irrigation during the 2000 experiment were 11.8 and 2.0 mm.day-1. The evapotranspiration at full irrigation is about 7 percent higher than ET at T-80, 16% higher than ET at T-60 and 26% higher than ET at T-40 treatment. It was observed that significant proportion of total water applied was consumed at the fruiting stage of the crop during the experiment while ET was lowest at the initial stage of the crop, irrespective of the irrigation treatment during the experiment. The difference in ET in April, was not significant at P = 0.05. This is an indication of frequent precipitation during this period. The highest ET obtained show that Cowpea needs much more application of water during the fruiting stage than at emergence (initial stage) and senescence. Similar observation was reported by (Aboamera, 2010; Souza et al., 2005). He reported an increase in evapotranspiration of cowpea, during the fruiting (mid season stage) using the water balance method. Fig. 7 – Fig. 10 show the results of ET_c obtained under the four irrigation management imposed on the crop during the experiment. The polynomial curve of each graph represents the trend of evapotranspiration during the period of the experiment. Lysimeter 1 had the lowest regression correlation coefficient, r = 0.48, while Lysimeter 4 had the highest correlation coefficient, r = 0.85

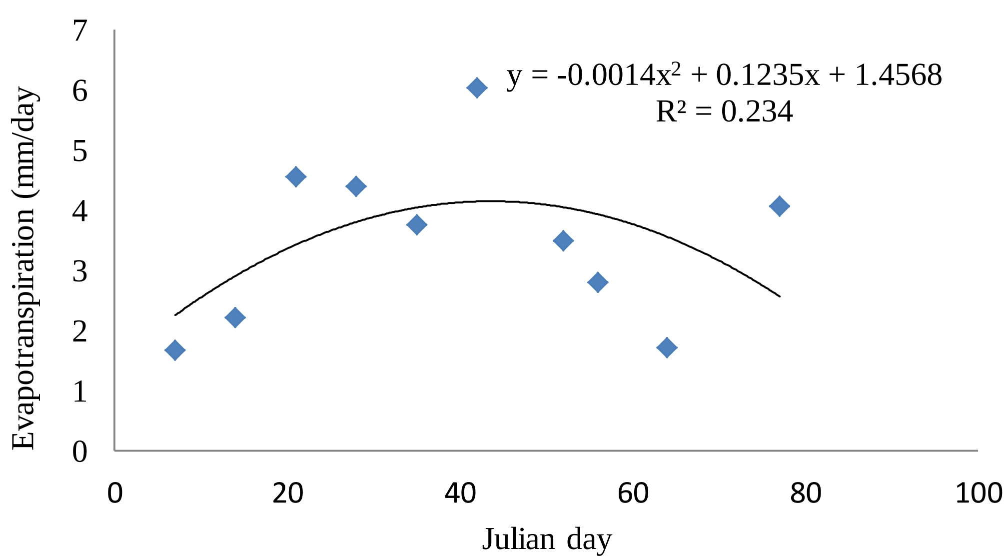

Figure 7. Evapotranspiration for lysimeter 1 during the experiment

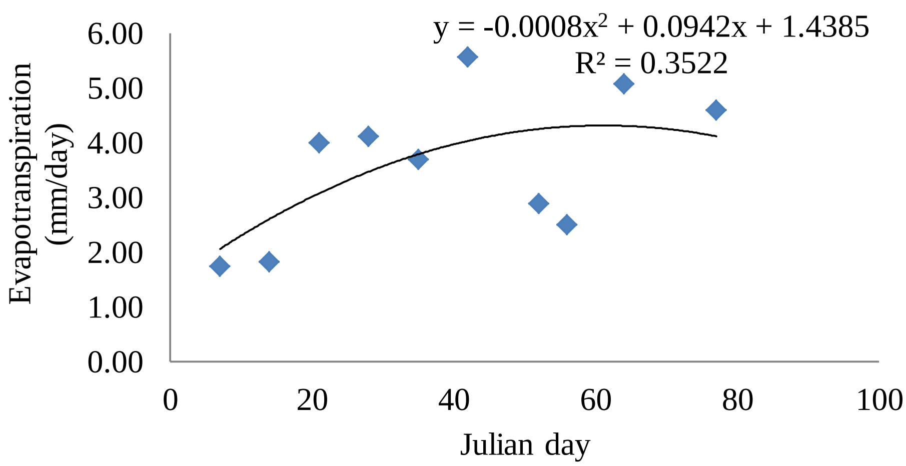

Figure 8. Evapotranspiration for lysimeter 2 during the experiment

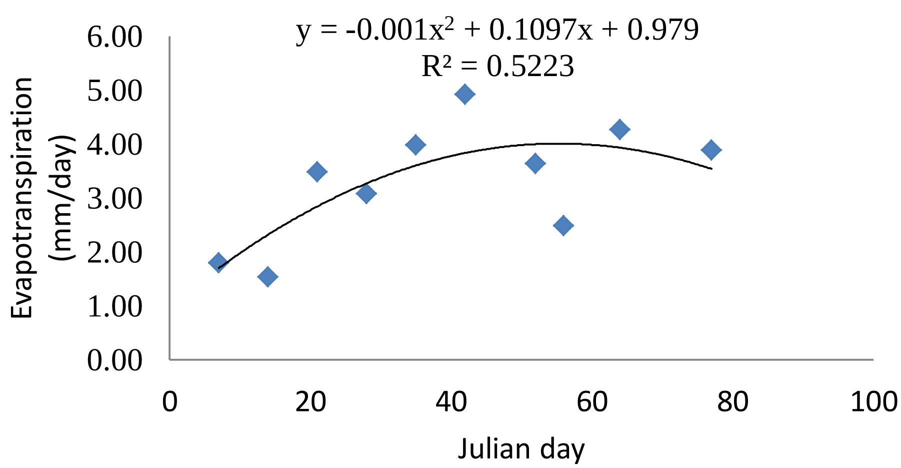

Figure 9. Evapotranspiration for lysimeter 3 during the experiment

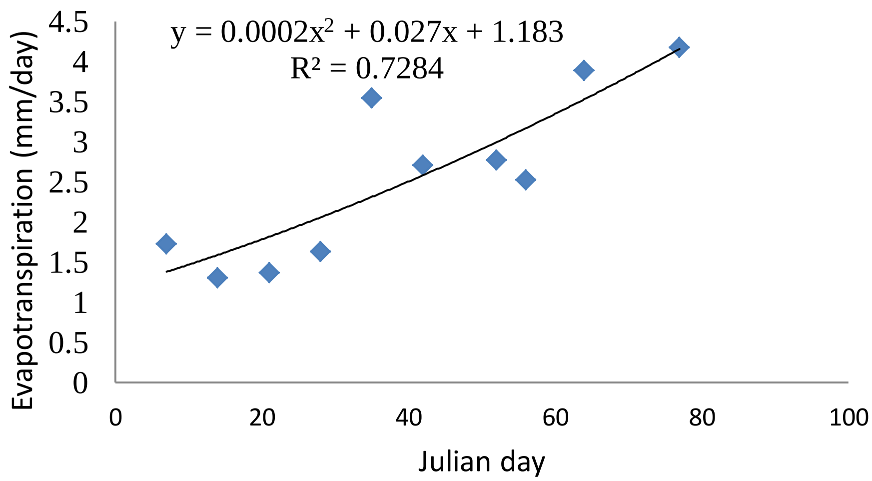

Figure 10. Evapotranspiration for lysimeter 4 during the experiment

Crop Coefficient

The trend of crop factor for cowpea during the different phonological stages at full irrigation treatment is presented in Fig. 11. The K_c value shows a curve which peaks during the flowering/fruiting (mid season) of the crop. The K_c values for emergence (initial stage), Vegetative, Mid season (flowering and pod formation) and senescence (late season) were 0.37, 0.74, 0.88, and 0.84. Declining K_c values during maturity stage might be due to reduced sensitivity of the stomata as leaves begin to senescence (Fraust, 1989). The K_c result shows that the highest water requirement occur at flowering and pod formation (mid season) stage.

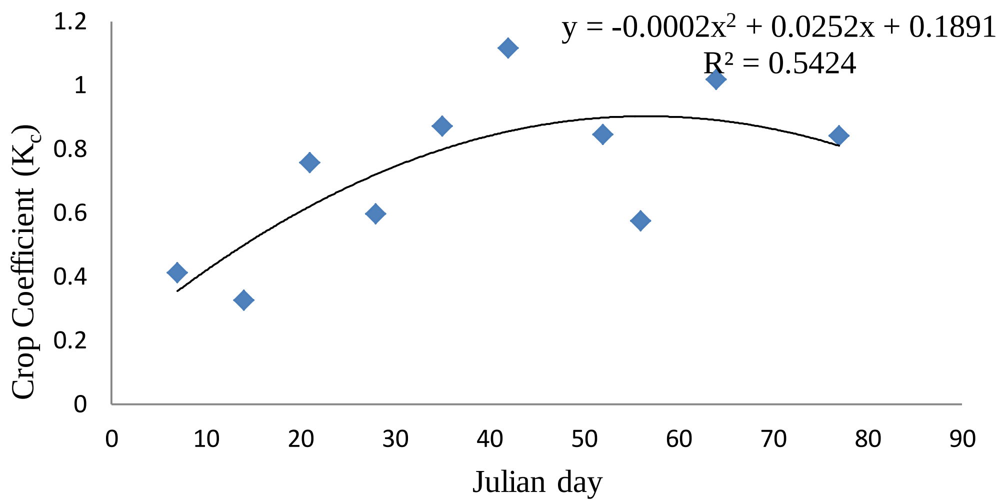

Figure 11. Crop coefficient as a function of Julian day during the experiment for lysimeter 1 (Full irrigation treatment)

Effect of irrigation on the cowpea seasonal actual evapotranspiration

Tab.1 shows the irrigation amount, actual evapotranspiration, grain yield and the biomass production of cowpea obtained during the experiment. The crop seasonal actual evapotranspiration for cowpea was highest in treatment (T – 100) with a value of 397.52mm and were 371.76, 335.38 and 295.96mm in treatment B (T – 80), C (T – 60) and (T – 40) respectively. Therefore, the crop seasonal evapotranspiration of cowpea estimated at the study area ranged from 295.96 – 397.52mm. This range of values are much higher than those seasonal ET range of 131 to 255mm and 159.5 to 262.5mm reported by Moroke *et al*.,(2011) and Adekalu, (2006) respectively and a much lower value than the result of 457.70mm reported by Hashim *et al*. (2012). These higher values of actual seasonal evapotranspiration (ET) measured from the study area may be as a result of high and frequent rainfalls that accompany the irrigation events during the late season of the growing season when the crop does not need much water and this period serves as the onset of raining season. A total of 5 irrigation events were recorded during this period. Thus, it leads to an increase in the crop (cowpea) evapotranspiration.

There was a strong linear increase in the seasonal actual evapotranspiration (Eta) with increasing irrigation amounts (r^2=0.99) for all treatments as presented in Fig. 12. The relationship accounts for varying stress levels of cowpea that occurred at various growth stages, as the relationship includes different levels of the crop (cowpea) evapotranspiration observed from different treatments that had various levels of soil moisture availability which imparted the cowpea yield. Therefore, the curves represent a wide range of irrigation regimes; treatments A (T – 100), B (T – 80), C (T – 60), and D (T – 40) at the experimental site. The relationship in study explained by a curve-linear function in Fig. 12 shows that data distribution does not plateau off at the highest irrigation level, indicating that there was no excessive irrigation applied to the fully irrigated treatment throughout the growing season.

Table 1. Descriptive statistics of the cowpea biomass yield (tons/ha)

Irrigation Amount (mm)	Evapotranspiration (mm)	Grain yield (tons/ha)	Biomass yield (tons/ha)
463.16	397.52	1.06±0.26a	6.95±1.02a
433.9	371.76	0.95±0.06a	6.62±1.32a
381.44	335.38	0.89±0.11a	4.54±2.21a
345.71	295.96	0.71±0.19c	3.48±1.39b

Means in each column bearing the same letter are not significantly different at the 5 % level of probability by Tukey's test.

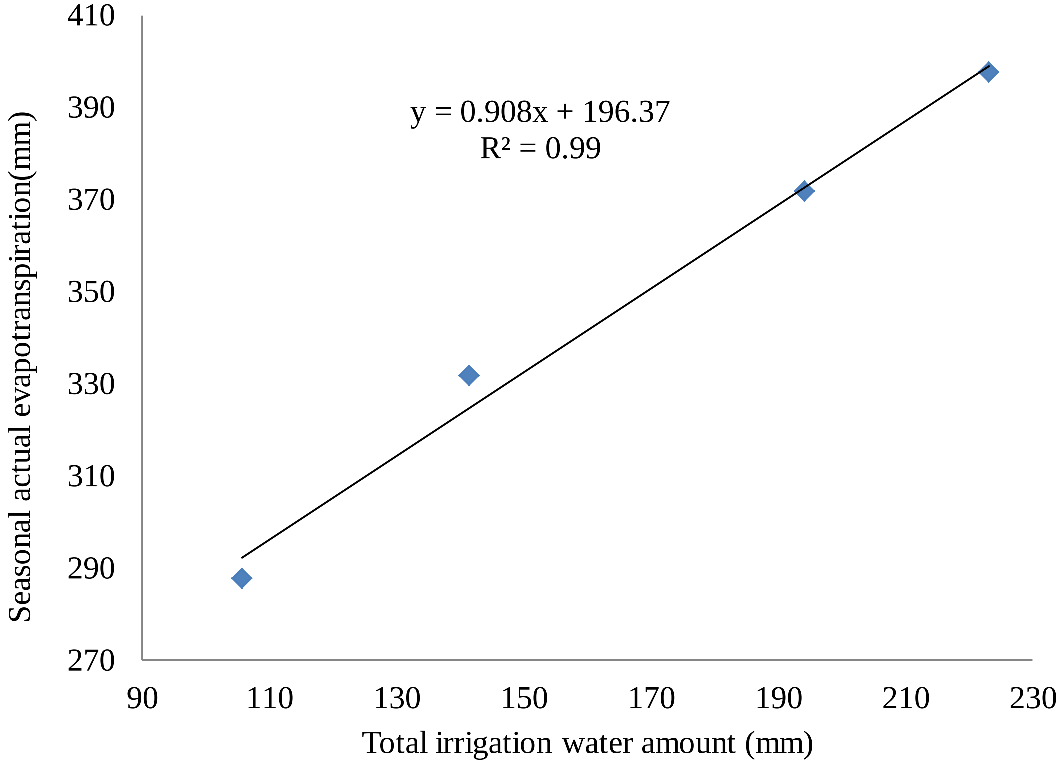

Figure 12. Seasonal actual evapotranspiration as a function of total irrigation water amount

The cowpea grain yield harvested from treatment A (T – 100), B (T – 80) C(T – 60) and treatment D (T – 40) at the experimental site ranged from 0.62 – 1.27 tons/ha. This compares favourably to the range of 0.38 to 1.88 tons/ha reported by Adekalu and Okunade (2006) under for *ife brown* cowpea variety. There was general increasing trend in the yield with increasing irrigation amounts. All irrigated treatments had yields significantly different at the 5% significance level (α=0.05). In general, the fully irrigated treatment had the greatest numerical yield than all other treatments during the experiment. Its mean yield obtained at full irrigation treatment was same as yields for the T – 80 and T - 60, but significantly higher than the yield of T-40 at 5% level of significance. Similar relationship was obtained for the biomass yield. The biomass was impacted by the irrigation amounts. This is in line with the submission of Eck (1986), Bryant et al., (1992), Payero et al., (2008), Seghatoleslami et al., (2008), and Payero et al., (2009) who reported that drought stress can significantly affect the total biomass produced of crops and that water stress can reduce crop yield by reducing CO_2 assimilation area and leaf number and total leaf area (Jones et al, 1986; Golombek and Al-Ramamneh, 2002) and net assimilation rate (Eck, 1986; Singh and Singh, 199; Seghatolesami et al., 2008 and Oktem, 2008), resulting in reduction in biomass production. There was a strong linear correlation between the two variables (crop evapotranspiration versus grain yield and crop evapotranspiration versus total biomass yield) with coefficient of correlation equal to 0.97 and 0.96 respectively. The grain yield and the total biomass also increased linearly with seasonal actual evapotranspiration (Fig. 13 and Fig. 14). Similar results were reported by Eck (1986), Soler et al. (2007), Payero et al. (2008), Payero et al. (2009), and Kapanigowda et al. (2010). While most researchers found linear and strong relationships between yield, biomass and and actual evapotranspiration (Eta) or irrigation, the slope of the line between the studies varied considerably due to differences in precipitations patterns, soil and crop characteristics and other climatic and management conditions.

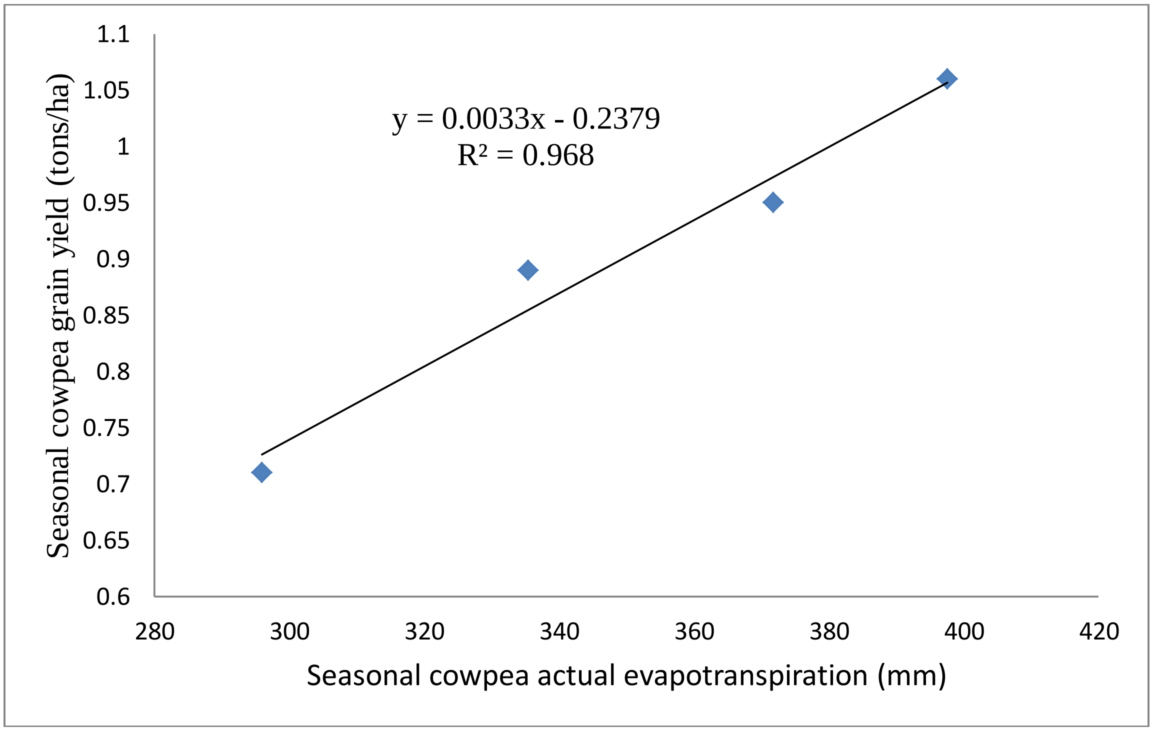

Figure 13. Seasonal cowpea grain yield as a function of seasonal actual evapotranspiration

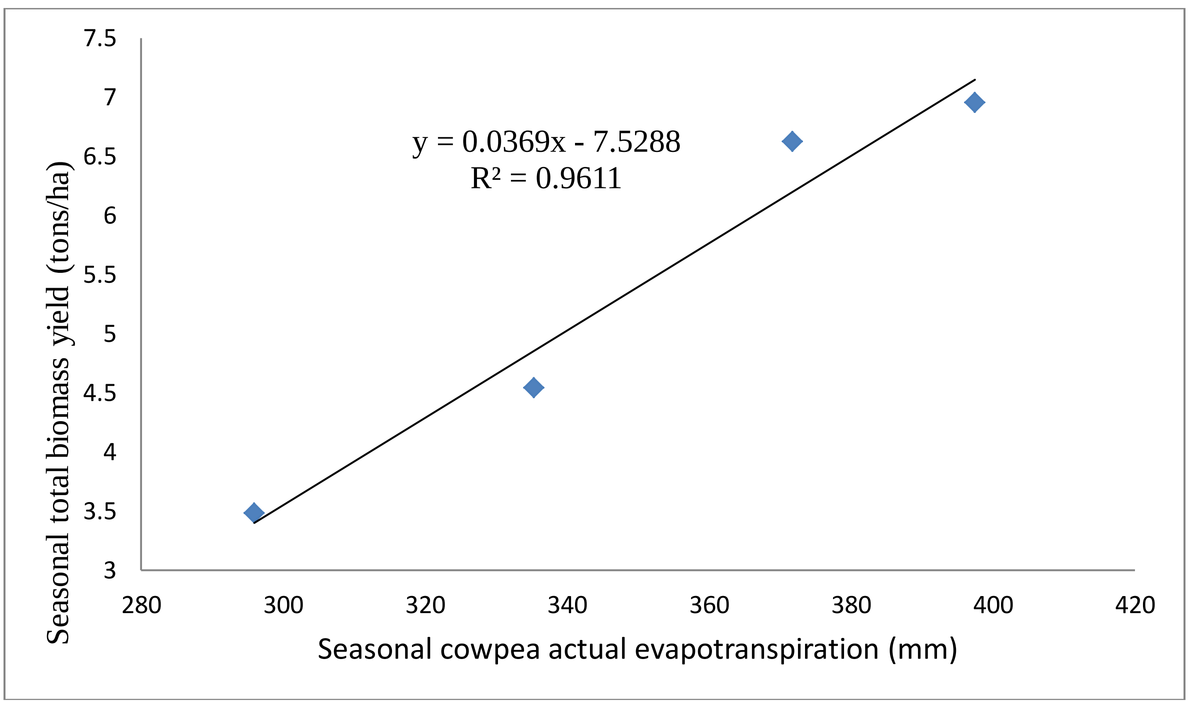

Figure 14. Seasonal cowpea biomass yield as a function of seasonal actual evapotranspiration

CONCLUSION

The study estimates the Evapotranspiration (ET) and the crop coefficient (K_c) of cowpea planted inside lysimeter. The evapotranspiration of the crop shows that the crop water requirement is highest during the flowering/fruiting stage and lowest during the emergence stage.

Cowpea actual evapotranspiration (Eta), biomass production and grain yield were significantly affected by the irrigation regimes under sprinkler irrigation. Yield and the total biomass were impacted by the irrigation regimes. The highest value of yield parameters were obtained at the treatment that received the highest amount of water as a result adequate moisture availability for the crop (cowpea) which in turn resulted to the high yield obtained during the experiment.

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