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Greenhouse evapotranspiration and crop factor of *Amaranthus cruentus* grown in weighing lysimeters

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Actual evapotranspiration and crop coefficient (K_c) of *Amaranthus cruentus* grown in weighing lysimeter was determined under a screen house. The weighing lysimeter was made of a cylindrical plastic of circular cross-sectional area of 0.076 m^2 and diameter 0.3 m. Climatic variables such as solar radiation, relative humidity, air temperature and wind speed were collected for the estimation of reference evapotranspiration (ET_r) using the FAO-Penman Monteith model. Actual crop evapotranspiration (ET_c) was measured directly from the daily drop in the level of water in the burette that was connected to the lysimeter. Crop factor (K_c) was estimated from the ratio of ET_c /ET_o. The ET_c of the crop rose gradually from the period of emergence (4.5 mm $week^{-1}$) during the 1 week after planting (WAP) to a maximum value of 14.3 mm $week^{-1}$ during the 7 WAP. K_c for the emergence and maturity stages of *Amaranthus cruentus* were 0.15 and 0.36, respectively. The highest leaf area index (LAI) and leaf coverage area were 11.39 and 0.866. The optimum soil moisture content for the highest K_c value (0.36) was 11.7%. The output of this research will be useful for farmers who are into vegetable production for enhanced productivity at farm levels.

Key words: Lysimeter, *Amaranthus cruentus*, crop factor, soil water content, leave area index.

INTRODUCTION

A detailed knowledge of crop evapotranspiration from the period of crop emergence to maturity is 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). Knowing the crop's evapotranspiration is very much essential in determining the crop's irrigation requirement. It helps to save water by controlling water supply through better determination of crop water requirements and development of biological and physical criteria (Katerji et al., 1997) leading to precise determinations of irrigation schedules for efficient performance of irrigation systems supplying water to field (Pereira et al., 2002; Ramirez and Harmsen, 2011); and also to improve the water use efficiency of species and plant varieties that are cultivated. Knowing the ET helps to understand the magnitude of gas interchanges between the eco and agro systems with the atmosphere (Ramirez et al., 2011).

Evapotranspiration is directly measured using weighing

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lysimeters (Howell et al., 1991). Lysimeter measurements are adopted for hydrological balances of crops as it provides a convenient and a practical way of monitoring soil water content and the soil water balance under controlled environments of which ET is a component (da Silva et al., 2005; Liu et al., 2007, Ceccon et al., 2008), or to determine crop coefficient (K_c) values (Tyagi et al., 2000). Recent studies around the world have been reported on the use of lysimeters to develop crop-coefficient for a variety of crops, such as pulse crops in India (Pandey and Pandev, 2011), Corn in Spain (Martinez, 2008), Rice and Sunflower in India (Tyagi et al., 2000), wheat and maize in China (Liu and Luo, 2010), and Cotton and Wheat in the USA (Ko et al., 2009).

Leafy Amaranth (*Amaranthus cruentus*) has so many health and nutritional benefits. *A. cruentus* is high in protein, lysine, calcium, iron and fibre; all of which are useful as functional ingredient in cereal products. Amaranth oil is high in “squalene”, a powerful antioxidant used as a dietary supplement for diabetes and those suffering from hypertension and metabolic disorders (Makus and Davis, 1984; Pal and Khoshoo, 1974; Teutonico and Knorr, 1985). Amaranth oil has been used for strengthening immunizing function in the body, improves resistance to diseases, radioactive and x-ray irradiation, improves mental performance and memory functions, helps to regulate the conversion of fats, especially cholesterol and also helps to fight against bacteria, fungi, herpes and other viruses, and improve auto-immune disorders (Fasinmirin, 2007). The vegetable is very rich in vitamin A and it contributes to a balance diet a significant amount of bet-carotene and ascorbic acid (Vitamin C), iron and calcium (Early, 1997). Efforts to improve the production of this very important crop have been hampered by inadequate knowledge on how best to manage the increasingly scarce water resource, especially during dry season (Fasinmirin et al., 2009). Therefore, efforts should not be spared at quantifying the actual water need of *A. cruentus*, so as to effectively manage the scarce resource for optimum production of the crop. Despite these breakthroughs, limited data is available on the water requirement of *A. cruentus* from the period of its establishment to maturity in order to prevent water stress or over irrigation of the crop on the field. Therefore, this research was aimed at determining the actual evapotranspiration and crop coefficient for *A. cruentus* grown in weighing lysimeters.

MATERIALS AND METHODS

Study site

The study was conducted in a screen house at the Department of Agricultural Engineering, Federal university of technology, Akure, Ondo state, Nigeria. Akure is in the south-western part of Nigeria (latitude 7°14'N and longitude 5°08'E) and is located within the humid region of Nigeria. Akure lies in the rain forest zone with a mean annual rainfall of between 1300 and 1600 mm and with an average temperature of 27.5°C. The relative humidity ranges between 85 and 100% during the rainy season and less than 60% during the dry season period. Akure is about 351 m above the mean sea level (Fasinmirin et al., 2009) (Figure 1).

The screen house was made of galvanized iron pipes, 51 mm in diameter and 4 m high. Transparent ethylene (nylon) was used as cover for the entire screen house to aid the reception of solar radiation and to prevent rain water and dew from getting to the crop. Circular perforations of about 6 mm in diameter were made at the sides of the screen and below the platform where lysimeter containing the growing crop was placed, in order to allow for convectional movement of air into and outside the screen house.

Lysimeter configuration and water application

The lysimeter was made of a cylindrical plastic bucket, having a circular cross-sectional area of 0.076 m^2 and a diameter of 0.3 m. The thickness and depth of the lysimeter were 0.003 and 0.3 m, respectively. The lysimeter depth was enough to permit normal root development. The plastic material of which the lysimeter was made helped to minimize heat conduction down the lysimeter walls (Pruitt and Angus, 1960).

Soil was collected from a nearby, previously cultivated field at depths of 0 - 200, 200 - 400 and 400 - 600 mm. The soil was carefully collected and placed into the lysimeter to minimize disturbance. Gravel was first placed at the bottom of the lysimeter, followed by the soil obtained from soil depth of between 400 - 600 mm, then the soil at 200 - 400 mm and finally the soil at 0 - 200 mm (the top soil). The weighing mechanism comprised of a water filled float, which was connected to a calibrated burette (0.1 mm accuracy) via a mercury filled manometer. The burette was also filled to the zero point with water. The change in water level in the burette was taken as the ET for the day. A hose pipe was used to connect the water-filled tube to one end of the manometer, while another hose connected the burette to the other end of the manometer. This system measures changes in weight of the lysimeter system.

A. cruentus seeds obtained from the National Institute of Horticulture (NIHORT), Ibadan, Nigeria were mixed with dry sand, such that the sand to seed ratio was 80:20. The mixture was broadcasted on the top soil in the lysimeter. The germinating plants were prunned down to two viable stands after the 1 week after planting (1 WAP). The quantity of water added to the crop was measured using a measuring cylinder. The time to irrigate the crop was determined by a tensiometer that was installed at the 15 cm depth of soil in the lysimeter. The soil in the lysimeter was irrigated to field capacity based on the tensiometer reading (40 centibars) (James, 1994).

Measurements

Reference and actual crop evapotranspiration

Climate parameters such as daily maximum and minimum air temperature and daily maximum and minimum relative humidity, wind speed, solar radiation, sunshine hours and rainfall were collected at the Meteorological station of the Federal University of Technology, Akure, Nigeria, located some 120 m away from the site of experiment. The data collected were used to estimate the reference evapotranspiration using the FAO-Penman Monteith model as defined by Allen et al. (1998) and Fasinmirin et al. (2009) as:

$$ET_o = \frac{0.408\Delta(R_n - g) + 900\gamma u_2 (e_s - e_a)/(t+273)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

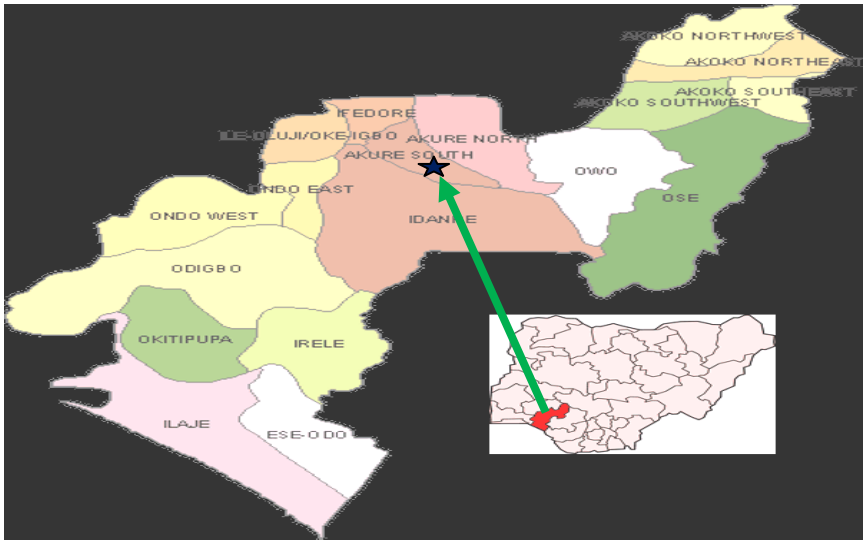

Figure 1. Maps showing the location of the experiment.

where: ET_o = Reference evapotranspiration [mm day^{-1}]; R_n = Net radiation [MJ m^{-2} day^{-1}]; G = Soil heat flux density [MJ m^{-2} day^{-1}] = 0 (In general G is negligible in the daily calculation of reference ET because g is small on daily basis (Allen et al., 1998)); t = Mean daily air temperature at 2 m height [°C]; u_2 = Wind speed at 2 m height [m s^{-1}]; e_s = Saturation vapour pressure [kPa]; e_a = Actual vapour pressure [kPa]; e_s-e_a = Saturation vapour pressure deficit [kPa]; Δ = Slope of the vapour pressure curve [kPa $°C^{-1}$], and γ = Psychrometric constant [kPa $°C^{-1}$].

The daily evapotranspiration of the crop (ET_C) was measured by determining the daily drop in water level of the burette. The amount of water lost from the lysimeter through evapotranspiration causes a drop in water level in the burette. The initial and final readings were recorded and the difference between the two gave the crop evapotranspiration on daily basis. The crop coefficient (K_c) of the crop was determined using equation 2 as stated in Fasinmirin et al. (2009).

$$K_c = \frac{crop\ evapotranspiration}{reference\ evapotranspiration} \quad \frac{ET_C}{ET_O} \qquad (2)$$

Soil parameters such as soil water content was determined weekly at a depth of 20 cm using a digital soil moisture meter on weekly basis.

Percentage soil water content was recorded during infiltration using a hand-held digital soil moisture meter-Lutron PMS - 714, IP - 65 for soil moisture ranging from 0 to 50%. The meter recorded the soil moisture content on wet basis. The soil bulk density ($g.cm^{-3}$) was determined by the core method using a 5 cm long by 4 cm diameter cylindrical metal core. The corer was rammed into the soil to ensure little soil disturbance and to ensure nearly insitu soil condition was maintained. Samples were dried at 105°C for 24 h in a forced air oven, weighed and density calculated as sample dry weight (g) divided by sample volume (cm^3) as described by Blake and Hartge (1986).

Measured agronomic parameters include number of leaves of *A. cruentus,* which was counted on a weekly basis from the 1 WAP to the 9 WAP. The leaf area (m^2) was determined using graphical (approximate) method. The leaf area was recorded weekly from the 2 WAP to crop maturity. Leaf area index according to Gong et al. (1995) was estimated from the relationship (Equation 3):

$$Leaf\ area\ index\ (LAI) = \frac{Area\ of\ leaf\ coverage\ per\ plant}{Area\ of\ soil\ covered\ per\ plant} \qquad (3)$$

The Leaf coverage area (LCA) was calculated using the Equation 4:

Leaf coverage area =

$$(Total\ number\ of\ leaves\ per\ plot) \times \frac{Leaf\ area}{Plot\ size} \qquad (4)$$

The plant height was measured using a metre rule from the soil surface to the apex leaf on the plant before the growth of flowers and to the flower tip when flowers started to appear on the crop. This was recorded on a weekly basis and error due to parallax was well avoided by taking the readings at eye level. The root depth was recorded weekly by carefully removing the soil by a hand trowel and measuring the root depth using a steel rule.

Statistical analysis

Soil and crop data were subjected to statistical analysis such as mean and standard deviation. Also, graphical analysis of the climate parameters, soil water content, evapotranspiration and crop factor were presented to enhance interpretation of trends and characteristics of the data collected.

RESULTS AND DISCUSSION

Micro-climate of the screen house

The mean weekly temperature during the 10 week The mean weekly temperature during the 10 week period of the experiment is shown in Figure 2 The highest temperature value was recorded in the 1 Week after Planting (1 WAP) with value 26.7°C (± 0.63), while the lowest temperature figures was recorded during the 10

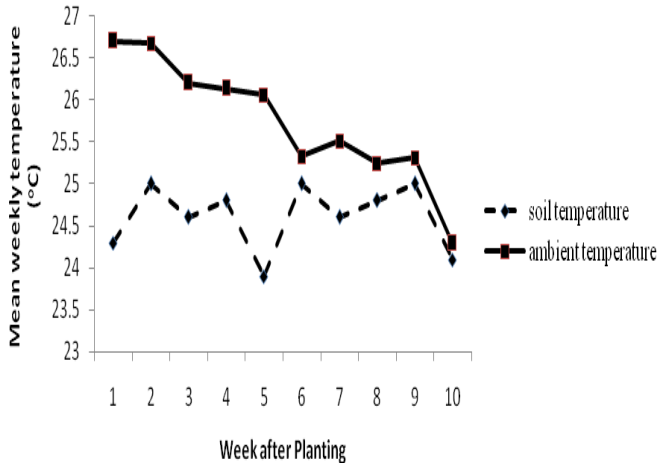

Figure 2. Mean weekly ambient and soil temperature during the research period.

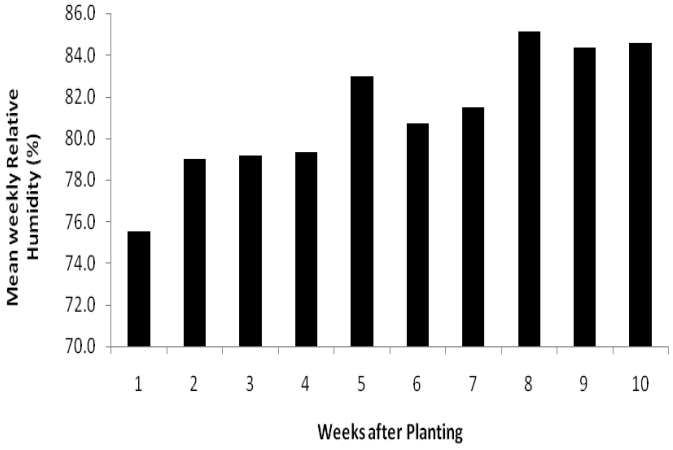

Figure 3. Ambient Relative humidity of the site during the research period.

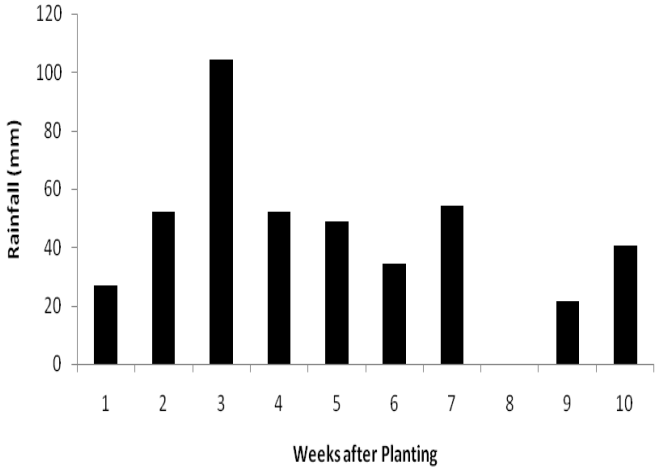

Figure 4. Average weekly rainfall during the period of the experiment.

WAP, with mean weekly temperature of 24.3°C (± 0.49). The measured soil temperature values were lower comparatively with ambient temperature and this could be as a result of the presence of the screen which shields the soil from direct solar radiation. Even at the highest ambient temperature of 26.7°C (± 0.63), the corresponding mean weekly soil temperature was 24.5°C (± 0.12). The Figure shows a steady decline in average weekly temperatures from the 1 to the 10 WAP. The decline in weekly temperature must have been caused by gradual rise in the frequency of rainfall.

Akure is known to have high relative humidity values. Throughout the course of the research (April to June), the relative humidity had a minimum value of 75.5% (± 4.73) which was recorded in the 1 WAP and highest relative humidity was recorded in the 8 WAP with a value of 85.1% (± 2.47) (Figure 3). Analysis of the rainfall data during the experiment period shows a gradual increase from 26.7 mm in the 1 WAP to a peak of 104.1 mm in the 3 WAP. A steady decline in rainfall occurred from the 4 to 6 WAP and increased again in the 7 WAP. Zero value of rainfall was recorded during the 8 WAP as a result of temporal cessation of precipitation (Figure 4).

The wind speed data is shown in Figure 5. The total weekly values of the wind speed rose from 2 ms^{-1} (± 0.39) during the 1 WAP to 2.4 ms^{-1} (± 0.21) in the 3 WAP. It declined in the 4 WAP to 2 ms^{-1}(± 0.34) and rose to a peak, 2.6 ms^{-1} (± 0.26) in the 9 WAP and declined again in the 10 WAP.

Reference evapotranspiration

Figure 6 shows the weekly reference evapotranspiration during the period of the growing season of *A. cruentus*. There was a sharp rise in the ET_o value from the 1 WAP to the 2 WAP, after which there was a gradual decline in reference evapotranspiration up to the 10 WAP. The highest ET_o value of 37.79 $mm.wk^{-1}$ occurred in the 3 WAP, an indication of highest value of 5.40 $mm.day^{-1}$ and the lowest value of 25.69 $mm.week^{-1}$ (3.67 $mm.day^{-1}$) occurred during the 10 WAP. Statistical analyses of the reference crop evapotranspiration (ET_o) values obtained from the Penman – Monteith model showed a high correlation coefficient (r = 0.81). Rise in ET_o was observed during the month of March (1 to 2WAP), which was in the dry season. The ET_o took a gradual downward trend from the month of April to May, which was in the wet season of the year. The rise in ET_o observed in March must have been caused by high solar radiation, which was accompanied by high temperature that often results in quick evaporation of water from soil and water surfaces (Fasinmirin et al., 2009).

Soil water content and crop evapotranspiration

Result of percentage soil water content at depths of 10

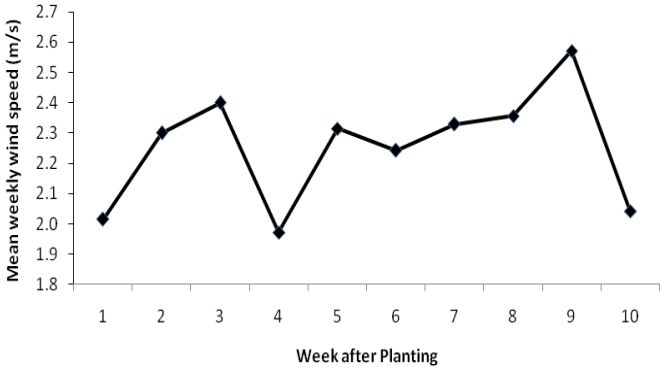

Figure 5. Mean weekly wind speed during the research period.

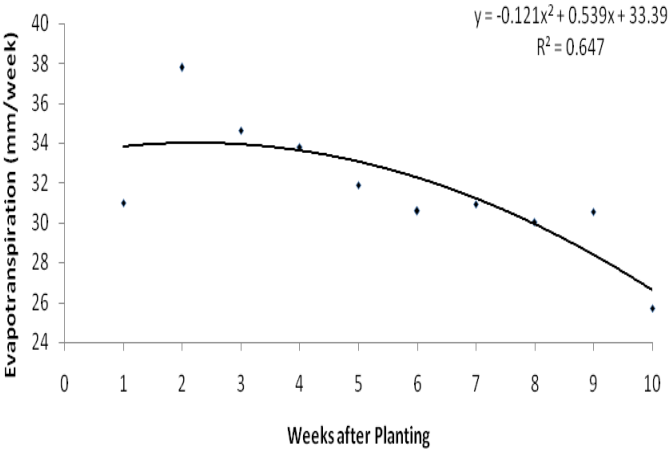

Figure 6. Reference evapotranspiration (ET_o).

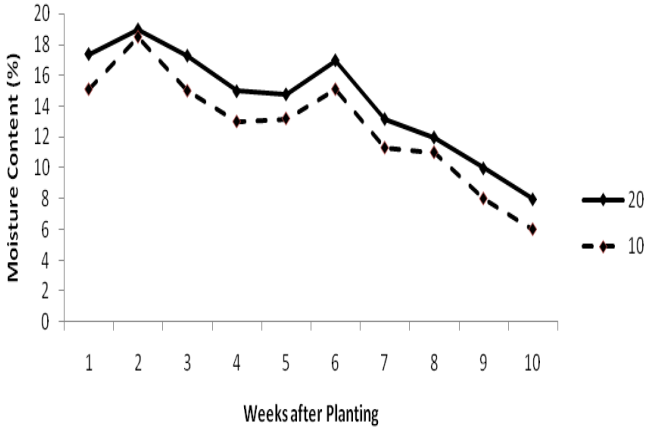

Figure 7. Percentage soil water content against weeks after planting**.**

and 20 cm is presented in Figure 7. Higher moisture was observed at the 20 cm soil layer when compared to the 10 cm soil layer throughout the period of the experiment. This could be attributed to gravitational pull of water from the soil superficial layer to the root zone depth of the crop, where the moisture was optimally utilized. At the early growth stage (emergence stage) of *A. cruentus*, moisture removal was largely due to evaporation from the soil surface. Advances in crop growth (vegetative stage) and root development led to increase in moisture loss through evaporation from soil surface and transpiration from plant surface. The increase in leaf coverage area during the crop vegetative and flowering stages lead to rapid moisture loss from the soil and thus, the decline in the trend of percentage soil water content.

Figure 8 shows the crop evapotranspiration (ET_c) in mm.week^{-1} throughout the growing season of the crop. The weekly ET_c value of evapotranspiration during the emergence stage of the crop, that is, 1 WAP was 4.5 mm, that is, 0.6 mm.day^{-1} (± 0.24)). The ET_c rose gradually from the 2 WAP with value of 6.5 mm.week^{-1}, that is, 0.9 mm.day^{-1} (± 0.19)) to the maximum at the 7 WAP with value 14.3 mm.wk^{-1} is 2.0 mm.day^{-1} (± 0.51)). The highest ET_c at the 7 WAP had corresponding high values of LAI and LCA, which were 10.65 and 0.81, respectively. The lowest ET_c value of 5 mm. week^{-1} (0.7 mm.day^{-1} ± 0.27), which was observed during the 10 WAP with corresponding decline in LCA and LAI implies that the crop water use was highest during the vegetative growth stage of the crop. Amaranth inflorescence development implies the crop passed through a significant change in its physiological stage, which were accentuated in the pattern of water use.

The lower ET_c values observed during maturity and senescence stages of the crop must have been caused by leave drops and a reduction in LCA and LAI. This agrees with the findings of Fasinmirin et al. (2009). They documented an increase in evapotranspiration of *A. cruentus* during the flowering/fruiting stage of the crop using the water balance method. However the ET values obtained from the lysimeter experiment was significantly lower than the ET values obtained from field experiment. This observation was also reported by Montero et al. (1985) and Rosenberg et al. (1989), who stated that usually, evapotranspiration inside a greenhouse/screen house is around 60 to 80% of that verified outside. The polynomial correlation between the ET_c and WAP was high (r = 0.92), an indication of a normal trend of crop behaviour during its growth stages.

Crop coefficient

The average K_c value for the emergence, vegetative, maturity and senescence growth stages are 0.15, 0.26, 0.36 and 0.19, respectively over the duration of the experiment (Figure 9). The crop factor K_c appears to be constant at the early stage of crop growth but rose sharply during the vegetative and flowering stages of the crop. At late season when the crop reaches senescence, the crop factor K_c declined. Similar observation was made

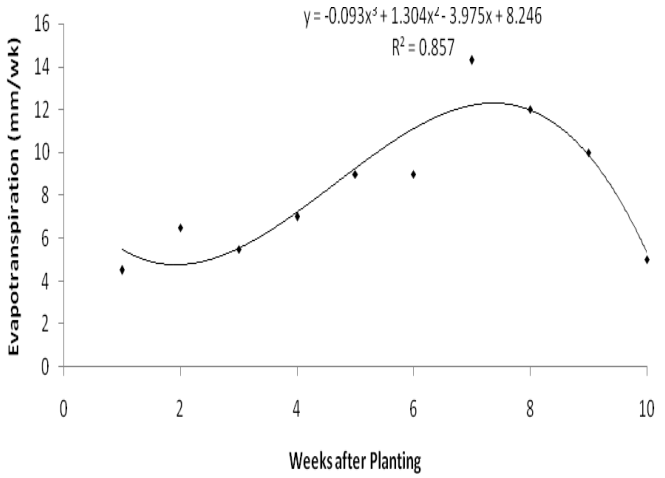

Figure 8. Crop evapotranspiration (ET_c) against weeks after planting.

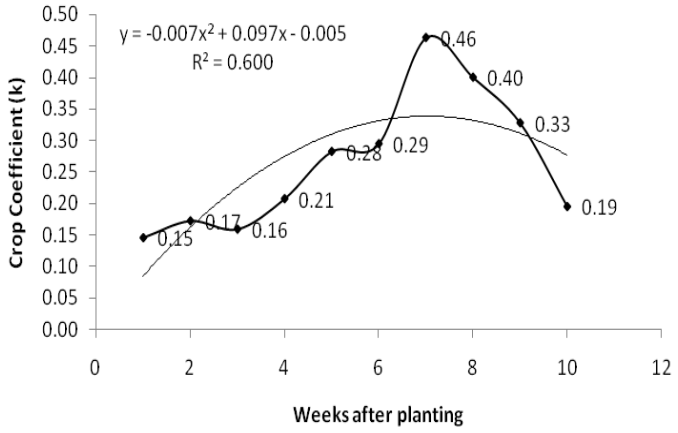

Figure 9. Variation of crop coefficient with weeks after planting.

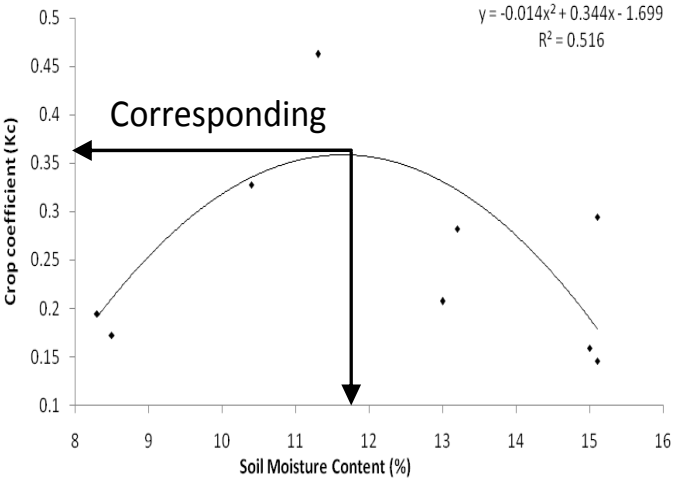

Figure 10. Relationship between crop coefficient and soil water content.

by Faust (1989) who stated in his work on pears that declining K_c values during fall might be due to reduced sensitivity of the stomata as leaves begin to senescence or due to water stress due to reducing rainfall/irrigation. The sharp rise observed during the vegetative/flowering stage is an indication that the crop requires water than other stages of its development. The high LAI (11.39 and 10.48) and LCA (0.866 and 0.797) values obtained during 8 WAP and 9 WAP respectively must have been responsible for the corresponding increase in K_c value during maturity. Same observation was made by Tyagi et al. (2000) who reported that highest K_c values occurred in sunflower during the vegetative and maturity growth stages with corresponding high mean LAI value. Also, Ayars et al. (2003) observed that K_c was a linear function of the amount of light intercepted by the leaves of peach (*Prunus persica L*.) trees. It could be assumed that as leaf area increases so would the amount of solar radiation intercepted and the amount of ET_c. A polynomial regression correlation (r = 0.77) was obtained from the plot of K_c against WAP and an expression was derived between Kc and WAP, that is, $y = -0.007x^2 + 0.097x - 0.005$.

The relationship between crop factor (K_c) and percentage soil water content (MC) is presented in Figure 10. The optimum percentage of soil water content of 11.7% was obtained from the relationship and the corresponding K_c value of 0.36 was derived for *A. cruentus* from the lysimeter experiment. Percentage water content above this optimum value will lead to decreased K_c, and consequently a decrease in crop ET. The coefficient of correlation between the crop coefficient and the percentage soil water content (r = 0.72) is sufficiently high for adoption in the study area and for soils of similar physical characteristics.

Yield parameters of *A. cruentus*

Figure 11 shows the weekly number of leaves throughout the period of the experiment. The number of leaves on the plant rose to its highest value of 21 during the 7 WAP (vegetative stage of *A. cruentus*). The polynomial correlation of regression between the number of leaves and the Weeks after Planting was high (r = 0.93).

The plant height increased throughout the period of the experiment (Figure 12). Increases in plant height were however greatest in the vegetative and maturity stage. It however tended to flatten out at crop senescence. The crop rooting depth data is shown in the Figure 13. It was observed that the root depth was shallow and had buttress and tap root formations. This could have been due to the screen house preventing enough sunlight from getting to the plant and as such causing the plant to have buttress root and shallow tap root formations. The root depth increased well from the emergence into the flowering/fruiting stage. Little change in the root depth

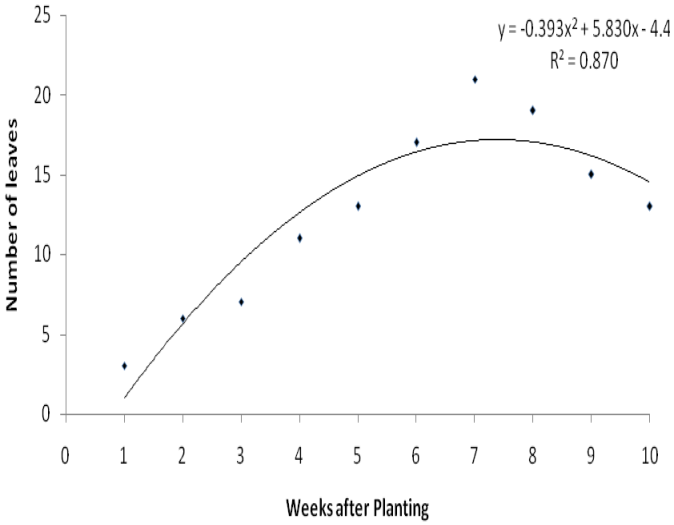

Figure 11. Number of leaves against weeks after planting.

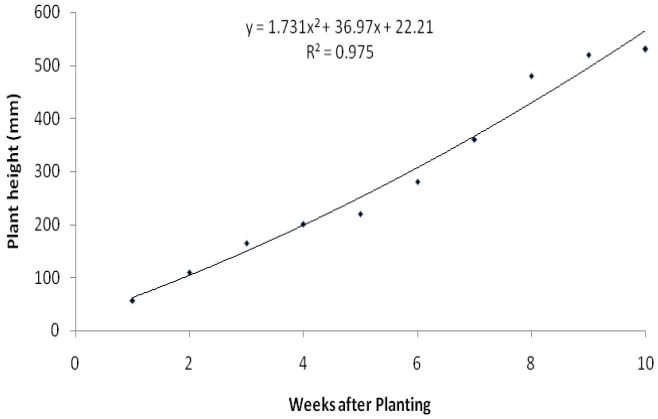

Figure 12. Plant height against weeks after planting.

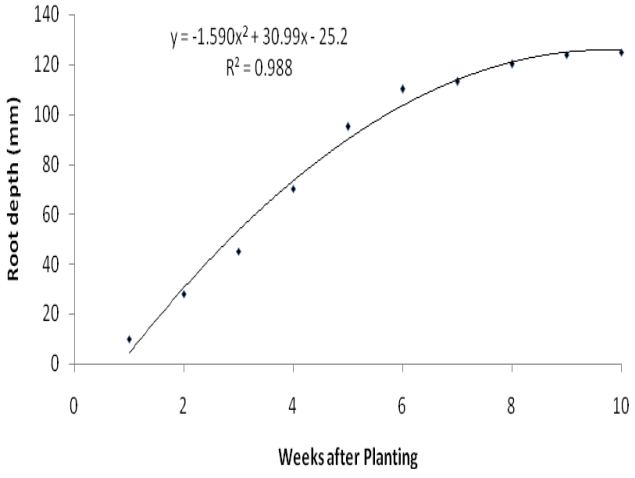

Figure 13. Variation of root depth with weeks after planting.

Table 1. Leaf area, leaf coverage area and leaf area index.

WAP	NOL	PS (m^2)	LA (m^2)	LCA	LAI
2	6	0.076	0.00046	0.036	0.48
3	7	0.076	0.00087	0.080	1.05
4	11	0.076	0.00095	0.137	1.81
5	13	0.076	0.00104	0.178	2.34
6	17	0.076	0.00242	0.541	7.12
7	21	0.076	0.00293	0.810	10.65
8	19	0.076	0.00346	0.866	11.39
9	15	0.076	0.00404	0.797	10.48
10	13	0.076	0.00411	0.703	9.25

WAP, Week after planting; NOL, Number of leaves; LA, leaf area, PS, plot size.

was observed during the maturity and senescence stages of the crop.

Leaf coverage area and leaf area index

Table 1 shows the leaf area, leaf area index (LAI) and the leaf coverage area (LCA) of *A. cruentus* throughout the period of experiment. Steady increase in LAI was observed during the vegetative stage of the crop, that is, 2 to 7 WAP with corresponding values of 0.48 and 10.65, respectively. Similarly, LCA values of 0.036 and 0.810 were recorded during the 2 and 7 WAP, respectively. However, the peak values of LAI and LCA were recorded during the 8 and 9 WAP and thereafter declined during crop senescence. Similar observation was reported by Fasinmirin et al. (2009). These researchers reported that leaf droppings at crop full maturity affects significantly the leaf area index.

Conclusion

This study shows the crop evapotranspiration (ET_c) and the crop coefficient (K_c) of *Amaranthus cruentus* growing in a lysimeter placed in a screen house. Results obtained showed that the ET_c increases rapidly during the vegetative and flowering stages, indicating that crop water requirement was highest during this crop growth stages. The ET_c values varied from 0.6 $mm.day^{-1}$ in the emergence stage to peak values of 2.0 $mm.day^{-1}$ during the vegetative and flowering stages. Also, crop coefficient (K_c) values obtained shows that *A. cruentus* requires much more application of water during the vegetative and flowering stages than at emergence and senescence. Also, the optimum percentage soil water content (11.7%) required to obtain maximum K_c value was derived from the experiment. The results obtained presents local farmers in the study area the opportunity to grow *A. cruentus* all year round, especially in areas of water scarcity, thus saving water to obtaining optimum yield, which is realizable with half the crop water requirement.

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