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# Parametrizing Simple Model between Yield and Evapotranspiration for Amaranthus cruentus under Drip and Sprinkler Irrigations

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## Abstract

*Amaranthus cruentus,* an annual vegetable crop, is known to be highly productive under rain-fed conditions and during the dry season when supplied with water. However, for good water management, there is need to accurately quantify the water consumed by the crop. This paper investigates the water use and biomass yield of differentially irrigated *Amaranthus cruentus* at different developmental stages: emergence/vegetative, fruiting and maturity. Field experiments were conducted between January and March of 2005 and 2006. The experiment was a 2×3×3 combination of two irrigation methods (drip and sprinkler systems) three crop phenological stages (Emergence/vegetative, fruiting and maturity), and three water stress levels. A randomized complete block design (RCBD) was adopted. Soil moisture storages within the root zone depth (10-30 cm) of *Amaranthus* were highest (13.86 and 13.23 cm) on drip plots at the 71 day of year (DOY) during the 2005 and 2006 experiment respectively. This has direct influence on the evapotranspiration of the crop. The highest evapotranspiration were 12.87 and 9.96 mm day$^{-1}$ during 2005 and 2006 respectively on plots irrigated under drip system. The highest and the lowest crop yield were 13.94 and 4.2 tonha$^{-1}$, respectively in plots irrigated under drip irrigation system, and 11.16 and 3.39 tonha$^{-1}$, respectively in plots irrigated under sprinkler system. The non-linear model used for yield prediction showed good agreement with the field data with $r^2$ = 0.94 and 0.74 for *A. cruentus* grown under drip and sprinkler irrigation systems, respectively. The correlation coefficient (r) between relative yield and relative evapotranspiration were 0.78 and 0.74 for crop under drip and sprinkler irrigation systems, respectively.

***Keywords:*** Crop factor; Soil moisture; *Amaranthus cruentus*; Root zone; Water Stress; Nigeria

## Introduction

Princes feather *Amaranthus cruentus* has been valued since ancient times for its nutritional and medicinal qualities (Oke, 1983; Teutenico and Knorr, 1985). The protein content of *A. cruentus* is quite important especially for children who do not receive enough animal protein (Mc Pherson, 1982). 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 transforming the existing largely traditional or subsistent agriculture into modern agriculture through intense use of modern irrigation facilities (Smith, 2000).

Water is becoming increasingly scarce resource in the West Africa sub-region (Fasinmirin, 2007). Therefore, effective management of this scarce resource necessitates the estimation of the consumptive use of crop from the period of establishment to maturity (Oguntunde, 2007). The water balance technique provides a simple and relatively inexpensive but robust means of continuous measurement of evapotranspiration from different species of vegetation (Granier et al., 1990; Gholipoor, 2007). However, reliable research findings that could serve as useful guide in the irrigation of *A. cruentus* in the tropical environment are few. The objective of this study therefore was to use evapotranspiration measurement to parameterize simple yield model for *A. cruentus* grown under drip and sprinkler irrigation systems.

## Materials and methods

The study was carried out during the dry season of 2005 and 2006 on a typical sandy clay loam soil of Akure, Nigeria (latitude $7^o17^1$N and longitude $5^o13^1$E) (Fasinmirin and Olufayo, 2001). Akure lies within the humid region of Nigeria and the cropping season usually starts in May and last until the end of September or October when dry season begins.

The experiment was a 2×3×3 combination of two irrigation methods (drip and sprinkler systems), three crop phenological stages (I-emergence/vegetative, II-fruiting and III-maturity) and three water stress levels (M1-well watered, M2- moderately stressed and M3 – severely stressed) as shown in Table 1. Total moisture supplied ranged between 320 and 440 mm, 213 and 245 mm, and between 187 and 195 mm for the well watered, moderately stressed and severely stressed plots, respectively. A randomized complete block design (RCBD) was adopted for the two years experiment. There were a total of eighteen seed beds (micro-sprinkler plots) each 2.0 m long, 2.0 m wide and 0.15 m deep, spacing of 1.0 m was left between beds to minimize interference. There were also eighteen tied-ridges each 10.0 m x 0.4 m to from drip plots. The micro-sprinkler were connected to separate supplies (0.04 $m^3$ capacity reservoirs) placed adjacent to each of the bed and supplying water at uniform pressure head of 2 m.

Amaranth seed/cultivar '*Amaranthus cruentus*' was grown manually at a spacing of 0.2 m within rows and 0.2 m between rows with four to five seeds per hole on the $15^{th}$ of January 2005 and 2006. Urea was applied with a rate 45 kg N $ha^{-1}$ uniformly to all treatments (Russel, 1980). All weedings were carried out manually once per week during the growing period and was thinned down to two plants per stand at the 30 DOY.

Table 1. Design of the Experiment.

| Plots | Treatment Code | Phenological Stages | | |
|---|---|---|---|---|
| | | I | II | III |
| 1 | ST1/DT1 | M1 | M1 | M1 |
| 2 | ST2/DT2 | M1 | M2 | M2 |
| 3 | ST3/DT3 | M1 | M2 | M3 |
| 4 | ST4/DT4 | M2 | M1 | M2 |
| 5 | ST5/DT5 | M2 | M2 | M1 |
| 6 | ST6/DT6 | M2 | M1 | M3 |
| 7 | ST7/DT7 | M3 | M1 | M2 |
| 8 | ST8/DT8 | M3 | M2 | M1 |
| 9 | ST9/DT9 | M1 | M3 | M2 |
| 10 | ST10/DT10 | M1 | M1 | M1 |
| 11 | ST11/DT11 | M1 | M2 | M2 |
| 12 | ST12/DT12 | M1 | M2 | M2 |
| 13 | ST13/DT13 | M2 | M1 | M2 |
| 14 | ST14/DT14 | M2 | M2 | M1 |
| 15 | ST15/DT15 | M2 | M1 | M3 |
| 16 | ST16/DT16 | M3 | M1 | M2 |
| 17 | ST17DT17 | M3 | M2 | M1 |
| 18 | ST18/DT18 | M1 | M3 | M2 |

M1 – well watered, M2 – moderately stressed, M3 – severely stressed, ST – sprinkler treatment plots
DT – drip treatment plots

Soil moisture content was determined in each of the plot once a week at the effective root zone depth of the crop (0.1, 0.2, 0.3m) and at depths 0.4 and 0.5 m using EC.5 Echo-probe. Soil bulk density (g cm$^{-3}$) was determined by the core method (Blake and Hartage, 1986) using a 10.0 cm long by 8.3 cm diameter cylindrical metal core. Rainfall estimates and depth of moisture applied were made from rain gauges located on all the plots and the average estimated over the total area. Runoff measurements were made with the aid of automatic runoff meter (Fasinmirin, 2007). Darcy law was used to estimate the drainage below the root zone following the method used by Hulugalle and Lal (1986). Other meteorological parameters such as minimum and maximum relative humidity, minimum and maximum air temperature, wind speed, solar radiation and pan evaporation were obtained from an automatic weather station located within the site of experiment.

Evapotranspiration was determined from the Penman-Monteith equation (Jensen et al., 1990).

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

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 $kP_a$ $^oC^{-1}$, Ra 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, ed is mean ambient vapour pressure in kPa, ra is aerodynamic resistance in s m$^{-1}$, re 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 $^oC^{-1}$.

The water use of *A. cruentus* was determined from the various components of the soil-water balance. The method consists of assessing the incoming and outgoing water flux into the crop root zone over sometime (Hillel, 1998).

$$ET = P + I + D \pm R \pm \Delta S \quad (2)$$

Where

ET = evapotranspiration (mm)

P = precipitation i.e. rainfall (mm)

I = water applied by irrigation (mm)

D = drainage (mm)

R = runoff (mm)

$\Delta S$ = Change in soil water storage (mm)

Crop factor ($K_c$) was determined from the relationship below:

$$K_c = \frac{ET_{\max}}{ET_o} \quad (3)$$

where

$ET_{max}$ = maximum evapotranspiration (mm $day^{-1}$)

$ET_o$ = reference crop evapotranspiration (mm $day^{-1}$)

Fresh yield of *A. cruentus* were determined on weekly interval stating from the 65 DOY to 79 DOY. Representative plants in each of the treatment plots were harvested and leaves, stems and roots carefully detached for ease of measurement of fresh biomass. The weight of the harvested fresh biomass was determined from an electronic weighing device with 0.01 level of sensitivity. The weighted materials were thereafter oven-dried at 70$^o$C until a constant dry weight was achieved. ET-fresh yield functions were established from the relationship below:

$$Y = f(ET) \quad (4)$$

$$\frac{Y_{act}}{Y_{\max}} = f\left[\frac{ET_{act}}{ET_{\max}}\right] \quad (5)$$

where

Y= the yield (t $ha^{-1}$)

$ET_{max}$= maximum consumptive use of crop (mm $day^{-1}$)

$ET_{act}$= actual consumptive use of crop for different treatments (mm $day^{-}1$)

Statistical analysis such as ANOVA and regressions were performed on crop yield based on actual evapotranspiration using MS Excel and Sigma plot software packages.

The measured and predicted yields relatively to evapotranspiration were evaluated over time. The mean bias error estimate (MBE), correlation coefficient r and root mean square error (RSME) were also determined. These statistics have the form:

$$MBE = \left[\frac{\sum (Y_p - Y_m)}{n_d}\right] \quad (6)$$

$$RSME = \sqrt{\frac{Sum\ of\ errors}{n_d}} \quad (7)$$

where $Y_p$ and $Y_m$ are predicted and measured yield, respectively; $n_d$ is the number of data points. These statistics were used to quantify the degree of under/over prediction and correlation by the model.

**Results and discussion**

Figure 1 shows the mean monthly temperature of the study area over ten years data (1995 - 2004), 2005 and 2006 periods of experiment. Highest mean temperatures of 29.3°C and 30.4°C occurred during 2005 and 2006, respectively; lowest mean temperature of 23°C was observed for the two years of experiment. The highest and lowest mean air temperature was observed during the months of February and July, respectively. Minimum relative humidity of between 37 and 77% was observed on the site during the period of experiment while maximum relative humidity ranged between 93 and 100% during the wet season of the year (Figures 2 and 3). Rainfall was characterized by gradual rise from the month of January with a value 10.2 mm to its peak in June with a value of 210.4 mm during 2005. Little but frequent rainfall were experienced since and July, and heavy but short duration rainfalls were experienced in September 2005 and 2006 (Figures 4 and 5).

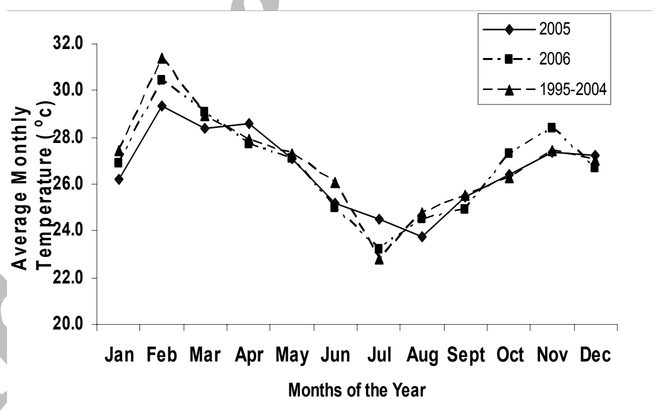



Figure 1. Mean monthly temperature of akure between 1995-2004,2005 and 2006

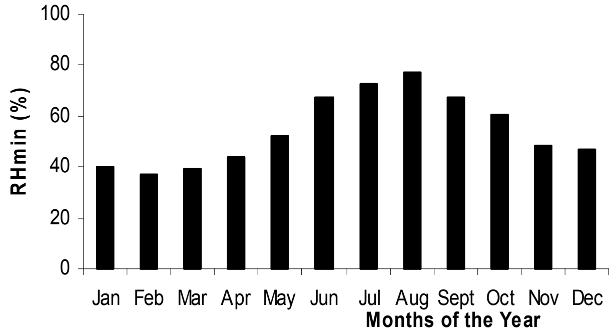



Figure 2. Minimum relative humidity of the site during 2005.

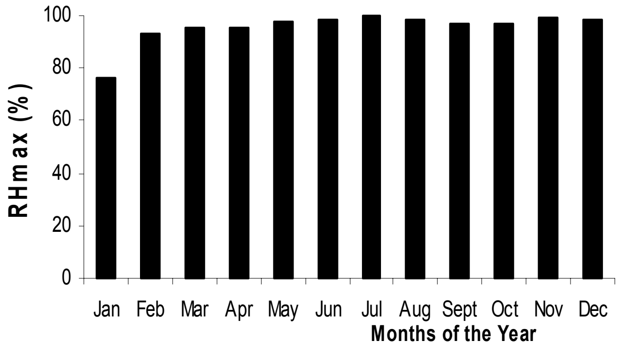



Figure 3. Mean maximum relative humidity of the site during 1995-2004.

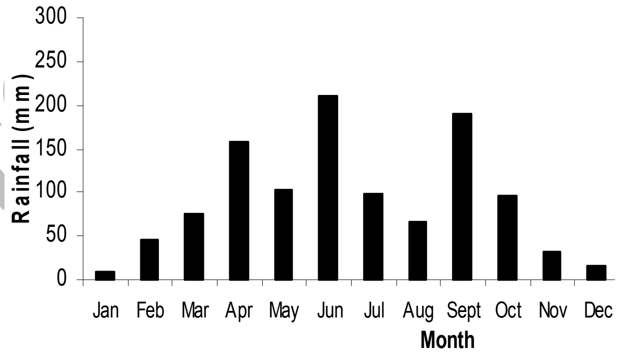



Figure 4. Monthly rainfall regime in the year 2005 at FUTA, Nigeria.

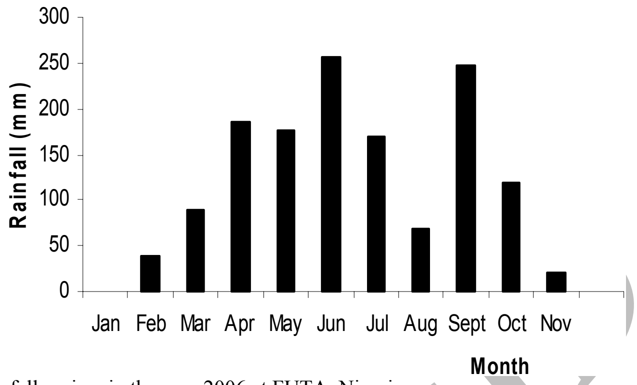



Figure 5. Monthly rainfall regime in the year 2006 at FUTA, Nigeria.

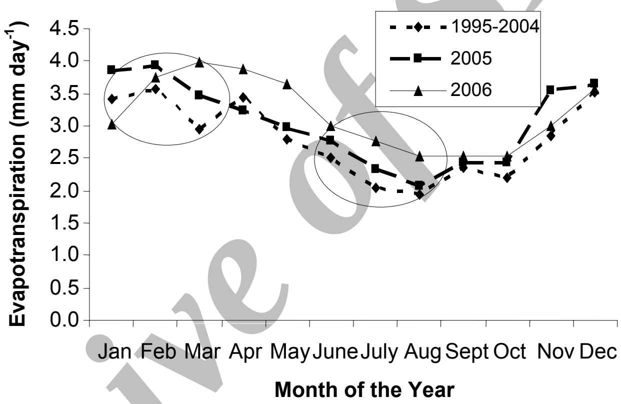
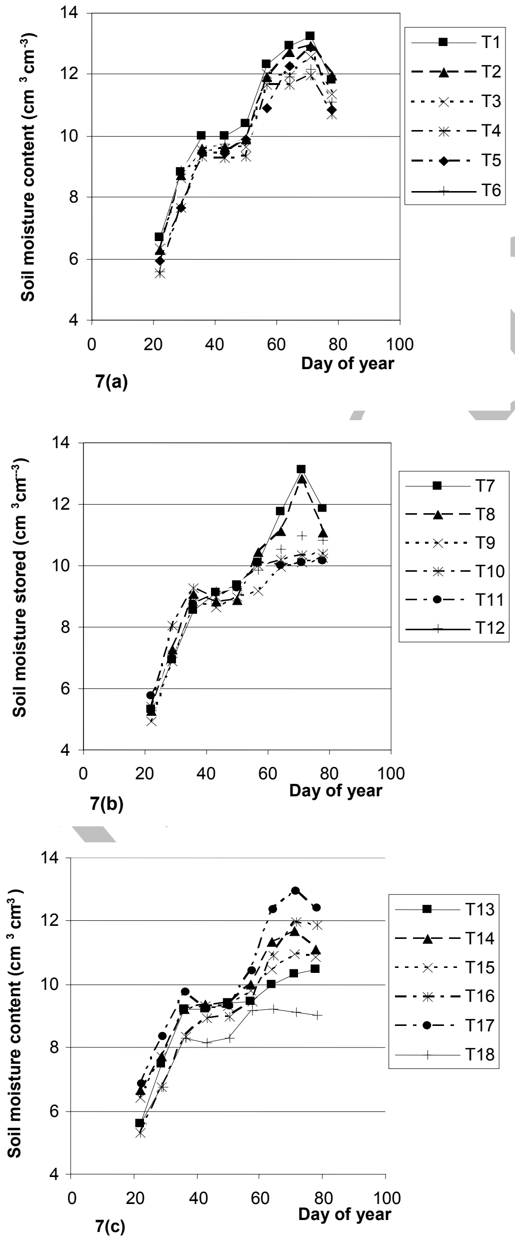


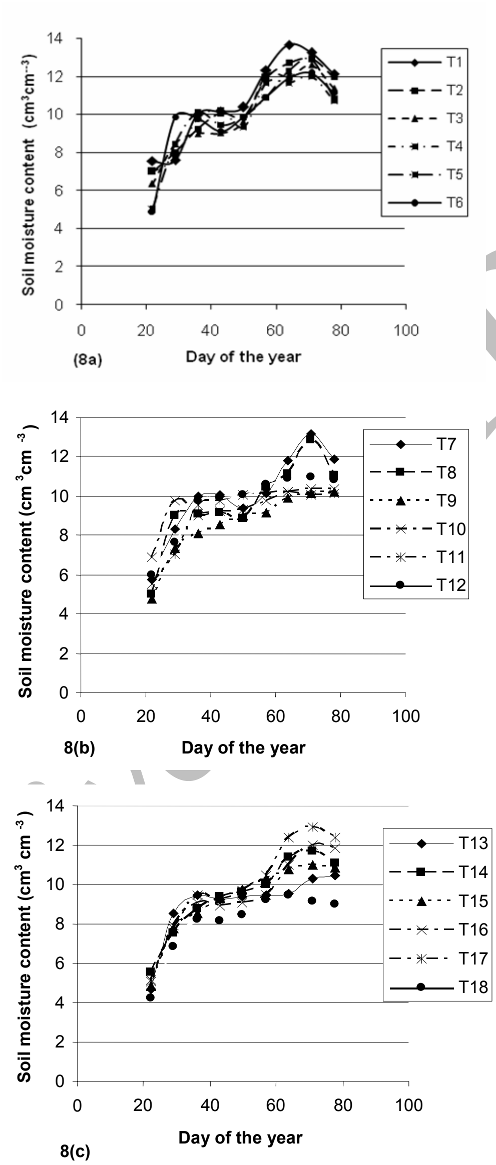

Figure 6. Potential Evapotranspiration of the Site Estimated from Pemnan-Monteith Model.

Figure 6 shows the reference evapotranspiration rate ($ET_o$) of the study site from 1995 – 2004, and in 2005 and 2006 period of experiment using the Penman-Monteith model. The encrypted areas show the period of experiment. Rise in $ET_o$ was observed from the month of November to March (dry season) and took a gradual downturn from the month of May to August which forms the wet season. The rise in $ET_o$ observed in November to March 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 surfaces.

The variations in the volumetric soil moisture content in *A. cruentus* field up to a depth of 0.6 m are shown in Figures 7a, 7b, 7c and 8a, 8b, 8c under sprinkler and drip irrigation systems, respectively. The stored moisture in the soil profile was observed to increase down the soil profile. Soil moisture content in drip treatment plot DT1 was highest (13.86 $cm^3$ $cm^{-3}$) at the 71 DOY. This was so because gentle drips of water had enough time to accumulate around the root zone of crop, thus permitting moisture build-up at the top soil.



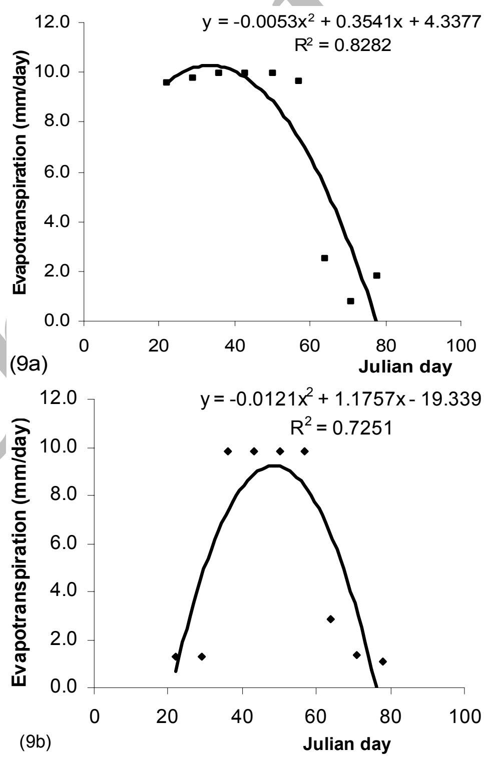

Figures 7a, 7b, 7c. Volumetric soil water content in plots irrigated under sprinkler system.



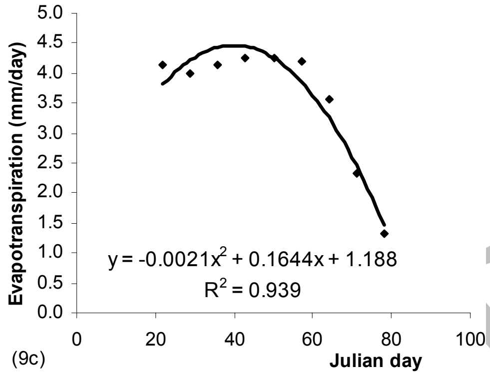

Figures 8a, 8b, 8c. Volumetric soil water content in plots irrigated under drip system.

The sequence of moisture depletion and replenishment is in agreement with the findings of Allen et al. (1999). A general rise in soil moisture content was observed within the first six to seven weeks after planting (vegetative/fruiting stage) until it reaches its peak at crop maturity. Thereafter, the soil moisture content declined due to reduction in leaf canopy that shaded the soil surface from direct solar radiation.

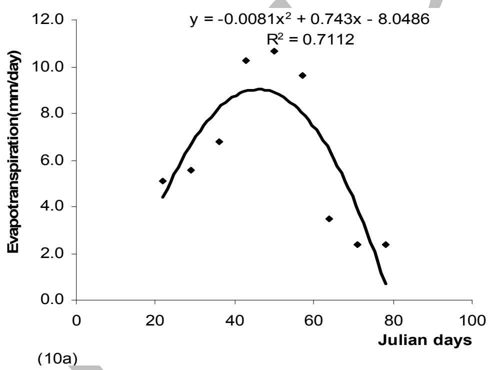
Figures 9 and 10 show the variations of mean evapotranspiration estimates under drip and sprinkler irrigation systems as a function of Julian day during the dry season of 2005 and 2006. Water use of crop was highest (9.96 mm $day^{-1}$) on drip plots DT1 and DT2 during the peak of the dry season in February (57 - 64 DOY). However, the highest evapotranspiration (10.0 mm $day^{-1}$) was observed on plot irrigated under sprinkler system ST8 at the 50 DOY. The coefficient of determination between the crop evapotranspiration and the growth stages of *A. cruentus* (emergence to maturity) was the highest in treatment plot ST6 (0.94). There were variations in the crop water use and this was due largely to the different irrigation treatments adopted for all treatment plots. Plots that received frequent irrigation have enough water to meet evapotranspiration needs i.e. evapotranspiration increases as the days between irrigation decreases because evapotranspiration is dependent on the length of time since wetting. This observation was confirmed by Hanks et al. (1971). It was also noticed that some *A. cruentus* reached maturity earlier than normal and this must have been due to water stress at the sensitive stage of crop growth which falls between the vegetative and flowering stages of the crop (50 - 57 DOY). This might have accounted for some abnormal curves of evapotranspiration that were observed on plots irrigated under sprinkler and drip irrigation systems. Statistical analysis of evapotranspiration showed that the least value of variance (7.34 mm) was observed in the month of January (22 DOY) and was highest (12.26 mm) in February (64 DOY).

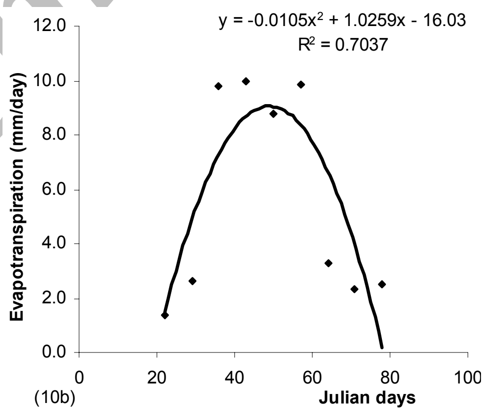



Figures 9a, 9b, 9c.

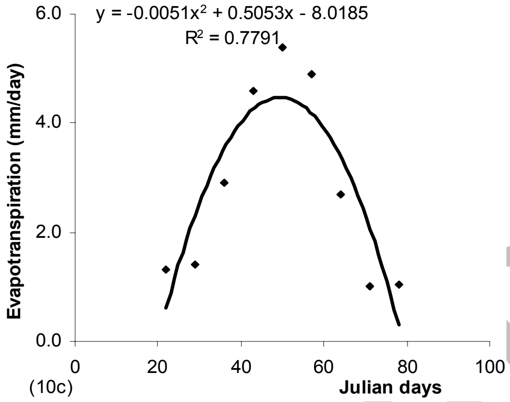



Figures 9a, 9b, 9c. Elationship between evapotranspiration and Julian day for well-watered, moderately stressed and severely stressed plots irrigated under sprinkler system



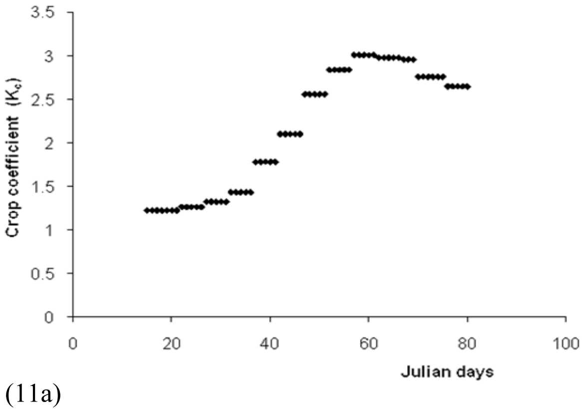

Figures 10a, 10b, 10c.




Figures 10a, 10b, 10c. Relationship between evapotranspiration and Julian day for well-watered, moderately stressed and severely stressed plots irrigated under drip system

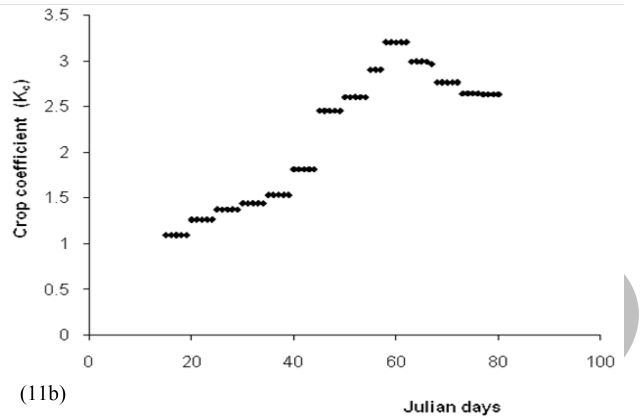
The crop coefficient $K_c$ of *A. cruentus* was plotted against days of the year as presented in Figures 11a and 11b. The crop factor appears constant at the earlier stage of crop growth but rose sharply during the productive stage of the crop. At late season when the crop reaches senescence, $K_c$ appears constant again. The sharp rise observed at mid-season is an indication that the crop evapotranspiration was higher at its vegetative stage than other stages of its development.

Linear relationship between the predicted and the measured yield is presented in Figure 12. The coefficient of determination ($R^2$) of the model output and measured value of yield was significantly high (0.94) on drip plot than on sprinkler plots (0.74). The goodness-of-fit statistics MBE and RMSE used for the comparison of model estimates and observed yield values of 2005 and 2006 dry season experiment are presented in Table 2.




(11a)

Figure 11a, b.




(11b)

Figure 11a, b. Crop coefficient as a function of day of year during the dry season experiment in 2005 and 2006, respectively.

Table 2. Mean bias error (MBE) and root mean square error (RMSE) to compare the simulated and the measured yield values.

| Phenological stage | MBE 2005 | RMSE 2005 | MBE 2006 | RMSE 2006 |
|---|---|---|---|---|
| Emergence | 0.7600 | 0.9462 | 0.6960 | 0.8454 |
| Vegetative/Fruiting stage | -0.4444 | 1.3526 | -0.5332 | 1.4372 |
| Maturity/Senescence | -0.3213 | 1.2341 | -0.2874 | 1.2876 |

The highest and the lowest crop yield obtained in treatment DT2 and DT18 were 13.94 and 4.2 $tonha^{-1}$ respectively. *A. cruentus* yield on plot ST2 and ST18 were 11.16 and 3.39 $tonha^{-1}$ respectively.

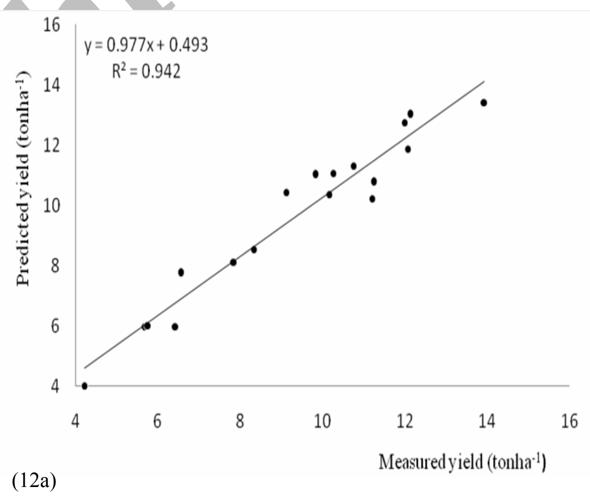
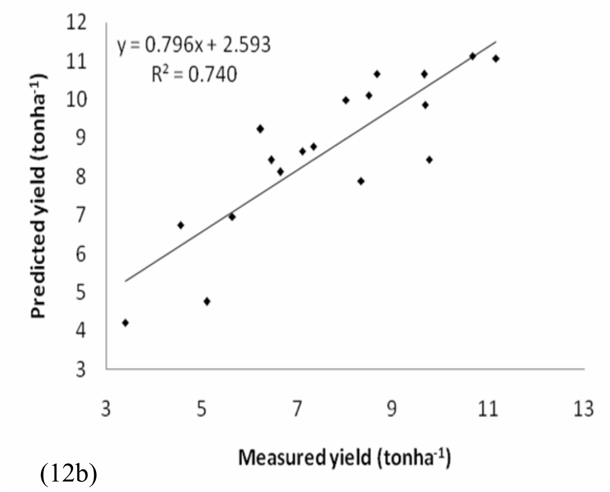



Figure 12 a,b. (12a)




(12b)

Figure 12 a,b. Relationship between Predicted and Measured Yield on Drip and Sprinkler Plots respectively.

Figures 13 and 14 show the linear regression model carried out on yield of *A. cruentus* in response to relative ET. Relationship "Yield – Evapotranspiration" for the dry season experiment of 2005 shows that *A. cruentus* differs in sensitivity to water deficit at its separate developmental stages The relationship between relative yield and relative evapotranspiration was expressed by a linear equation in relative terms (Varlev et al., 1996).

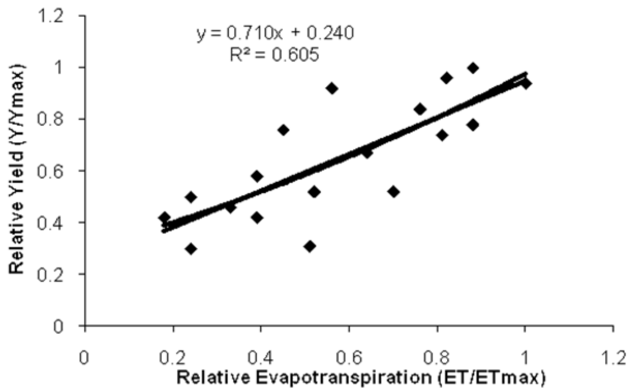



Figure 13. Relative yield against Relative evapotranspiration on drip plot during the dry season of 2005.

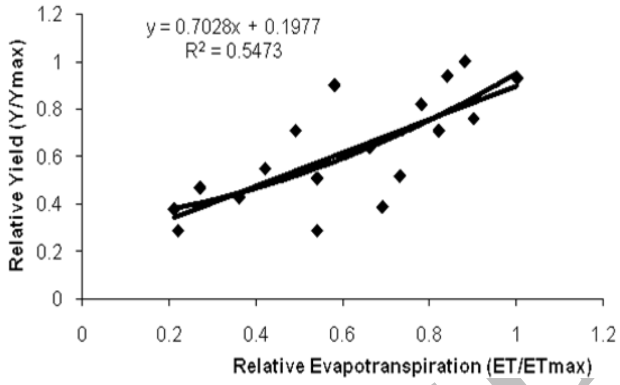



Figure 14. Relative yield against relative Evapotranspiration on sprinkler plots during the dry season of 2005.

The correlation coefficient (r) between relative yield and relative evapotranspiration are 0.78 and 0.74 for crop under drip and sprinkler irrigation systems, respectively. This result shows that there was no significant difference in the relative yield against relative evapotranspiration of *A. cruentus* for both plots irrigated under drip and sprinkler systems at $P<0.05$. It is evident from the model that experimental observations are quite satisfactory and well interpreted with the linear model. The relationship "yield - evapotranspiration with linear equation gave a good precision within the range 0.2 - 1.0 of relative yields, which include all above ground fresh yield.

## Conclusion

Based on a two-year study, the pattern of soil water extraction differed among treatments ($P<0.05$). There was a trend that the evapotranspiration of *A. cruentus* was higher on treatment plots irrigated under drip system than on sprinkler plot. The crop water use under the drip system was considerably higher because the crop had enough time to accumulate moisture around its root zone, thus permitting moisture build-up for its uptake. The relationship between yield and evapotranspiration expressed by a linear equation showed that yield-evapotranspiration with variation in water supply to crop and also to variations in rainfall. Prediction model between *A. cruentus* yield and evapotranspiration was established. The model output and measured value of yield gave $r^2 = 0.79$ at $P<0.05$.

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