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*Full Length Research Paper*

# Soil humidity circulation blueprint in *Amaranthus cruentus* field under drip irrigation scheme

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**The status, availability and distribution of moisture distribution within a crop's root zone depths affect the yield and growth of crops. An experiment was carried out to determine the influence of three drip irrigation regimes on pattern of moisture distribution within the soil profile of *Amaranthus cruentus* field. Irrigations were carried out at 50 KPa (Low stress), 60 KPa (Medium stress) and 70 KPa (Severe stress) levels. The pattern of soil water extraction differed significantly among treatments (P<0.05). *A. cruentus* extracts water for its use depending on available moisture within depths of the root zone. The surface soil at 0.1 and 0.2 m depths, rapidly losses moisture at the peak of the dry season in treatment 70 KPa (severely stressed level). Soil hydraulic charge was high (-80.6 and -70.9 KPa) at crop emergence in the root zone of *A. cruentus* during the dry season experiment of 2005 and 2006 respectively. It however reduced to as low as -5.7 KPa at crop maturity (71 – 76 DOY) due to occasional rain showers experienced around the period of crop maturity. Relationship between soil hydraulic charge and soil moisture storage gave $r^2$ = 0.82 and standard deviation ± 1.19 at P < 0.05. The findings from this research may be useful at determining the appropriate moisture stress level at which irrigation is best carried out in vegetable field for optimum yield.**

**Keyword:** Irrigation, moisture deficit, hydraulic charge, moisture storage, root zone.

## INTRODUCTION

*Amaranthus cruentus* is a vegetable crop in the humid tropics (Grubben and Van stolen, 1981). 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). Amaranth 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 (Pal and Khoshoo, 1974; Teutonico and Knorr, 1985). Despite the nutritional and medicinal importance of the crop, efforts to improve its production have been hampered by inadequate soil water supply especially during dry seasons.

Also, leaf area growth is decreased in responses to water stress and is rapidly reversed following the release from stress (Connor et al., 1985; Irmark et al., 2000). This response limits the development of plant transpiration surface area during water deficit and keeps sink demand well balanced with plant assimilatory capacity. In the past many land surface modelers did not consider the contribution of soil moisture portion of their models to be physically based but thought of the soil moisture as more of index used for evapotranspiration and runoff calculations rather than representative of the actual mass of moisture in the soil (Oguntunde, 2004). Adequate knowledge of the distribution and linkage of soil moisture to evapotranspiration is essential to predicting the land surface processes to weather and climate (Idso, 1982). Despite this importance, global measurement and analysis of soil moisture and temperature remains an outstanding scientific problem with far-reaching significance to agriculture (Wei, 1995). Non availability of this type of data hinders research and modeling efforts in the tropical environment. The objective of this study therefore is to investigate the soil moisture distribution pattern in *A. cruentus* field under drip irrigation system.

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**Table 1.** Treatment design.

| Plots | Treatment Code | Phenological stages | | |
|---|---|---|---|---|
| | | I | II | III |
| 1 | T1 | M1 | M1 | M1 |
| 2 | T2 | M1 | M2 | M2 |
| 3 | T3 | M1 | M2 | M3 |
| 4 | T4 | M2 | M1 | M2 |
| 5 | T5 | M2 | M2 | M1 |
| 6 | T6 | M2 | M1 | M3 |
| 7 | T7 | M3 | M1 | M2 |
| 8 | T8 | M3 | M2 | M1 |
| 9 | T9 | M1 | M2 | M3 |
| 10 | T10 | M1 | M1 | M1 |
| 11 | T11 | M1 | M2 | M2 |
| 12 | T12 | M1 | M2 | M3 |
| 13 | T13 | M2 | M1 | M2 |
| 14 | T14 | M2 | M2 | M1 |
| 15 | T15 | M2 | M1 | M3 |
| 16 | T16 | M3 | M1 | M2 |
| 17 | T17 | M3 | M2 | M1 |
| 18 | T18 | M1 | M3 | M2 |

M1 – well watered; M2 – moderately stressed;
M3 – severely stressed.

## MATERIALS AND METHODS

### Description of study area

The study was conducted in Akure. Akure, humid southwestern 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 – 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 sea level.

### Treatment and experimental procedure

Field experiments were conducted from 15th January to 20th March, 2005 and from 17th January to 23rd March, 2006. Field plot, 10.0 m x 12.0 m in size was laid out using tied-ridges each 10.0 m x 0.4 m in dimension. The water application method adopted was the gravity drip irrigation system. Irrigation water was delivered to the experimental field using drip emitters spaced 1 x 1 $m^2$ apart. There were pre-irrigation of two days before planting of the crop. Thereafter, irrigation water treatments were imposed. The treatments were typified by the difference in the soil moisture stress at which irrigations were carried out as shown in Table 1. The first treatment was application of irrigation water at 50 KPa of soil moisture stress (full irrigation), the second treatment was application of irrigation water at 60 KPa of soil moisture stress (medium irrigation), the third treatment was application of irrigation water at 70 KPa soil moisture stress (severe stress level). The three distinguished stages of crop development were: (1) emergence (2) vegetative/flowering, and (3) maturity.

### Measurement procedures

Measurements of soil moisture distribution pattern ( ) and other growth parameters were carried out from 27th January to 15th March, 2005; and from 24th January to 18th March, 2006. Meteorological data such as solar radiation, Maximum and Minimum Air Temperature, Maximum and Minimum Relative Humidity, Wind Speed and Sunshine Hours during the growing season were obtained from a meteorology station located within the site of experiment site. Raingauges were installed within the experimental field to measure Precipitations during the two seasons of experiment.

Soil samples were collected from 0 – 15 cm depth at six different locations on the experimental site to determine the soil physicochemical properties such as particle size distribution (that is, sand, silt an clay contents), organic matter, soil pH, bulk density, percenttage composition of nitrogen, phosphorus, potassium, calcium and magnesium using standard procedures (Agyare, 2004). The Bouyoucos (1962) method was used to determine the particle size distribution on 2 – mm sieved air – dry soil. The Walkey Black procedure was used for the determination of organic carbon content. The organic carbon was oxidized by a known concentration of potassium dichromate (1.0 N or 0.166 M) solution added in excess. The percentage nitrogen content of the soil was determined using the digestion method described by Jackson (1962). Exchangeable potassium, calcium and magnesium were extracted using ammonium acetate (Jackson, 1962) and the individual cations of $Ca^{2+}$, $Mg^{2+}$, $K^+$ were measured by Atomic Absorption Spectrometer (AAS) and flame photometer. The soil pH was determined by suspending the soil in 0.01 M $Cacl_2$ solution a 1 - 2.5 soil to solution ratio. The suspension was stirred intermittently for 30 min. The pH was taken using a pH meter and a combined glass electrode (Thomas, 1996). Soil bulk density ($gcm^{-3}$) was determined by the core method (Blake and Hartage, 1986) using a 10.0 cm long by 8.3 cm diameter cylindrical metal core. Samples were dried at 105°C for 24 h in a forced air oven, while bulk density calculated as sample dry weight (g) divided by sample volume ($cm^3$). The soil moisture content at depths 10, 20, 30 and 40 cm from each cropbed was determined weekly using the gravimetric method (Lascano, 2000). The collected samples were placed in different containers of known weight, with a lid on to prevent evaporation. The containers and soil are weighed and then placed in an oven at 105°C, with the lid removed, until the sample dries. The containers, and dried soils were weighed again to estimate the loss in weight which is the weight of water in the original samples, and the weight of solids is final weight less the weight of the container. Hence the moisture content of the soil was determined using this relationship:

$$Soil\ moisture\ content\ (SM) = \frac{Weight\ of\ water}{Weight\ of\ solids} \quad 1$$

The bulk density was calculated using the formula below (Hillel, 1998):

$$Bulk\ Density\ (BD) = \frac{Mass\ of\ oven\ dried\ soil}{Volume\ of\ soil} \quad 2$$

$$Dry\ Density\ (DD) = \frac{Bulk\ density}{1 + Moisture\ content\ \%} \quad 3$$

The soil moisture stress was monitored up to a depth of 0.5 m at an interval of 0.1 m using mercury tensiometer. Data collected during experimental trials were subjected to statistical analysis such as

**Table 2.** Descriptive statistics of soil properties of the site of experiment during 2005.

| Sample | Sand (%) | Clay (%) | Silt (%) | Organic carbon | N (%) | P (mg/kg) | K (meq/100g | Ca (meq/100g | Mg (meq/100g | Na (meq/100g) |
|---|---|---|---|---|---|---|---|---|---|---|
| Min | 60 | 22 | 8 | 0.86 | 0.12 | 6.29 | 0.46 | 2.90 | 2.00 | 0.19 |
| Max | 69 | 28 | 15 | 1.52 | 0.21 | 10.18 | 0.61 | 8.10 | 5.0 | 0.31 |
| Mean | 63.2 | 24.7 | 12.1 | 1.30 | 0.2 | 8.97 | 0.5 | 5.30 | 3.50 | 0.20 |
| STD | 224 | 1.49 | 1.76 | 0.22 | 0.03 | 1.13 | 0.05 | 1.74 | 0.95 | 0.04 |
| Skewness | 0.78 | 0.42 | 0.25 | -1.84 | -1.30 | -2.71 | -3.28 | -0.04 | -0.44 | -1.33 |
| Kurtosis | 1.29 | 0.23 | 0.22 | -0.02 | -0.91 | 1.59 | -1.29 | -0.86 | -101 | 1.68 |

**Table 3.** Descriptive statistics of soil properties of the site of experiment during 2006.

| Sample | Sand (%) | Clay (%) | Silt (%) | Organic carbon | N (%) | P (mg/kg) | K (meq/100g) | Ca (meq/100g) | Mg (meq/100g) | Na (meq/100g) |
|---|---|---|---|---|---|---|---|---|---|---|
| Min | 67 | 19 | 7 | 0.89 | 0.13 | 7.55 | 0.38 | 3.60 | 2.45 | 0.16 |
| Max | 70 | 24 | 13 | 1.40 | 0.18 | 10.00 | 0.62 | 7.66 | 4.50 | 0.35 |
| Mean | 68.6 | 21.1 | 10.4 | 1.14 | 0.2 | 8.92 | 0.50 | 5.70 | 3.40 | 0.20 |
| STD | 1.10 | 1.39 | 1.46 | 0.15 | 0.02 | 0.85 | 0.07 | 1.27 | 0.57 | 0.06 |
| Skewness | -4.65 | 0.48 | -0.52 | -0.17 | -3.11 | -3.33 | -2.14 | -0.70 | -1.49 | -0.19 |
| Kurtosis | 1.21 | 0.31 | 0.72 | -0.86 | -1.06 | -1.21 | -0.36 | -0.93 | -0.02 | 0.17 |

Analysis of variance (ANOVA). Least significant difference and linear regressions were carried out using softwares such as SPSS and MS Excel.

## RESULTS AND DISCUSSIONS

### Weather condition of the site of study

The weather variables of the site of study are presented in Figures 1 - 4. Trends in rainfall distribution at site of the study during amaranthus growth (1995 and 2004, and the 2005 and 2006) showed that the rainfall is characterized by gradual rise from the month of January until it reaches the peak in the month of June. Thereafter, it declined in the month of July and August when a little break in rainfall is experienced. However, the months of September and October are characterized by heavy but infrequent rainfalls and this is the second modal rainfall. November marks the unset of the dry season. Relative humidity of the study site is very high, more than 90% during the night and early morning falling to between 60 and 80% in the afternoon) . Minimum relative humidity of between 37 and 77% was observed on the site during the period of experiment (January to March) while maximum relative humidity ranged between 93 and 100%. Solar radiation ranges between 14.21 and 15.16 MJ/m²/day. Wind speed ranged between 3.2 and 5.71 Km/hr.

### Soil properties at the experimental site

Presented in Tables 2 and 3 are the results of soil properties at the experimental site. The soil of the site has a mean soil texture (USDA method) of sandy clay loam in the top soil which forms mainly the agricultural layer required for the cultivation of most vegetables. Minimum and maximum organic carbon content of 0.86 and 1.52% respectively were observed within the top 0.3 m depth of soil. The top soil average carbon content falls within the range (0.6 - 1.2%) given by Young (1976) as desirable for tropical crop production. The high organic carbon content may be due to the fact that the sampled points were not frequently cultivated and primary carbon production is high. The organic matter accumulation may also be due to continuous plant growth in and around the site of experiment. This is in agreement with the work done by Nelson et al., (1994). The soil pH varies from acidic to neutral on the surface soil (5.7 - 7.1). The mean of the pH falls within the slightly acidic range (6.4) and is below the average value of 6.5 which was considered ideal for good availability of plant nutrients in the mineral soils (Foth and Ellis, 1997). The bulk density of the experimental site ranges from 1.20 – 1.50 gcm$^{-3}$ within the first 0.3 m depth of soil. This is below the critical value of 2.1 gcm$^{-3}$, be-

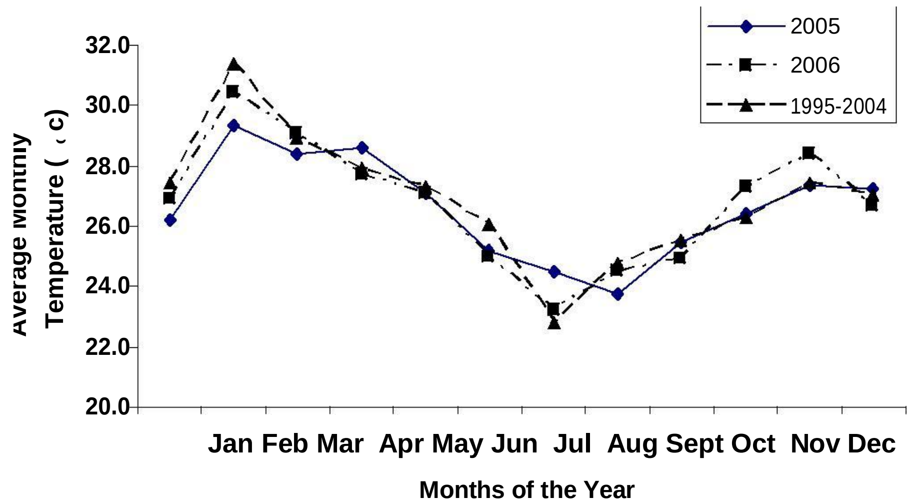


**Figure 1.** Mean monthly temperature of Akure between 1995-2004, 2005 and 2006.

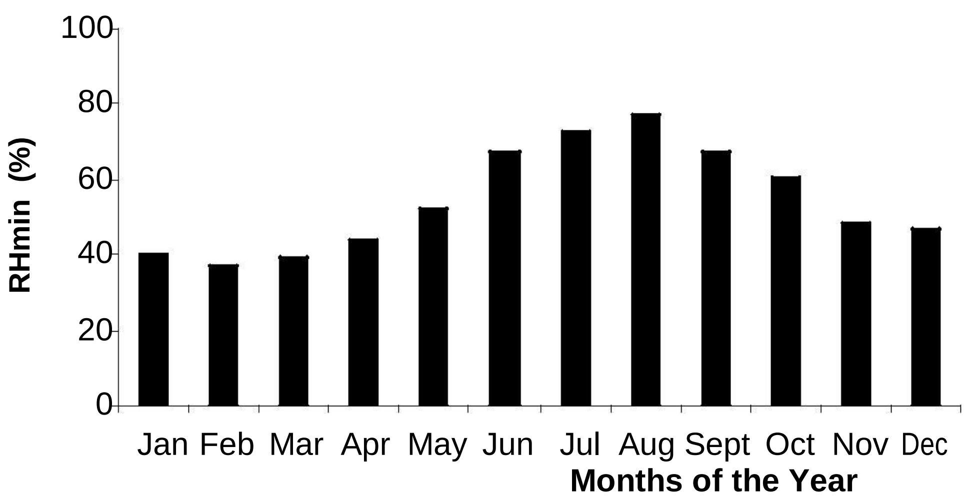


**Figure 2.** Minimum relative humidity of the site during 2005.

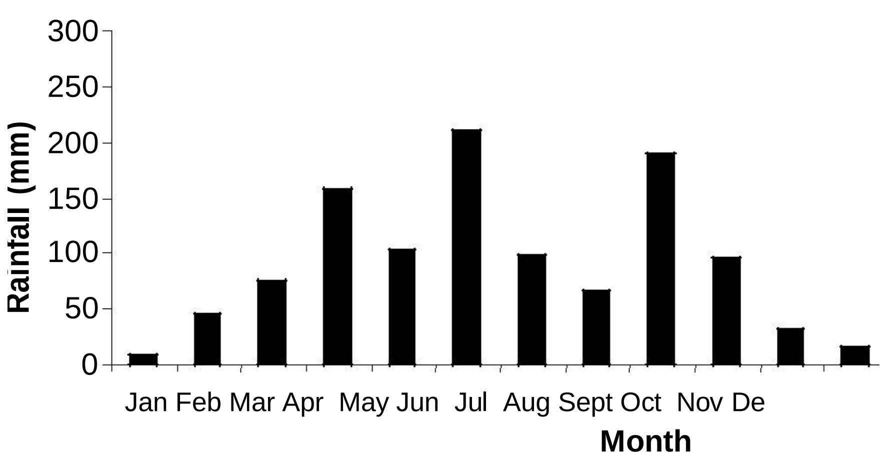


**Figure 3.** Monthly rainfall regime in the year 2005 at FUTA, Nigeria

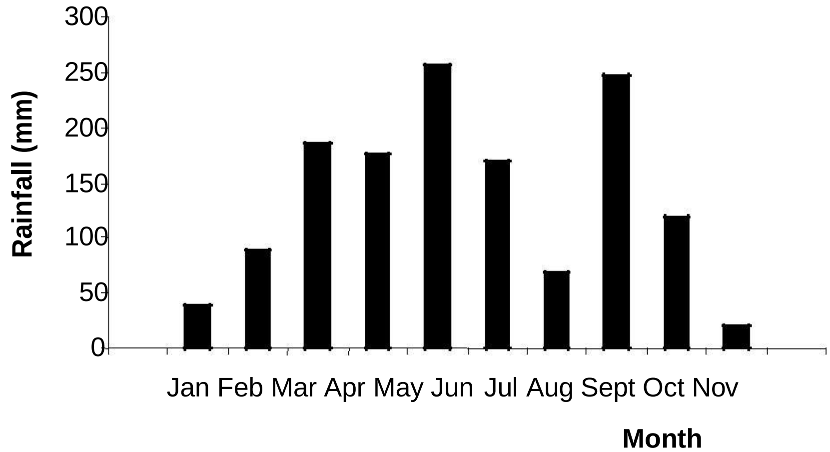


**Figure 4.** Monthly rainfall regime in the year 2006 at FUTA, Nigeria.

yond which plant growth is severely limited.

## Soil hydraulic charge

The variations of the soil moisture tension for the period of experiment are presented in Figures 5- 10. The soil moisture tension within 0.1 m depth of soil was found to be highest when compared with other measured values, an indication that moisture tension decreases down the soil profile. Variations in soil moisture tension at the different soil profile were significant at 5% level.

The moisture tension at the 0.1 m depth of soil during the dry season experiment of 2005 ranges between -80.6 and -42.6 KPa at depths 0.1 and 0.5 m respectively at crop emergence (18DOY). However, soil hydraulic charge reduced to -43.5 and -5.7 KPa at depths 0.1 and 0.5 m respectively at crop maturity (71 – 76DOY). This observation might have been occasioned by scanty rainfalls experienced during this period of the year. Soil hydraulic charge was found to be - 70.9 and -27.6 KPa at depths 0.1 and 0.5 m respectively during the dry season experiment of 2006. The decreased soil moisture stress at the root zone of *Amaranthus* must have been caused by moisture depletion due to plant low/few canopy which decreased direct evaporation from bare soil but increased the crop transpiration.

## Moisture storage in the soil profile

The variations in the volumetric soil moisture content in the *Amaranthus* field up to a depth of 0.6 m are shown in Figures 11. The stored moisture in the soil profile was observed to increase down the soil profile. However, the moisture regime in the Treatment T1 was highest among all treatments. The soil column refill in treatment T1 must have been facilitated by the daily application of irrigation water to the plot from the Mid- season (Flowering stage) to crop maturity. The sequence of moisture depletion and replenishment agrees with the findings of Allen et al. (1999). As the crop reaches maturity, soil moisture stoage for all the treatments took a down turn. Leaf detachment around this period resulted into soil exposure to direct solar radiation and hence increased evaporation from bare soil surface.

However, moisture stored in treatment T1 was highest (13.86 cm) at the 71DOY. 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 topsoil. A general rise in stored soil moisture was observed within the first six (6) – seven (7) weeks after planting until it reaches its peak during the eight week after planting.

Result of regression analysis of soil moisture storage is presented in Figure 12. The regression statistics of soil moisture storage against soil moisture tension showed that $r^2$ = 0.82 and standard error of ± 1.19. The difference between the statistically predicted soil moisture storage and the field measured soil moisture storage is not significant at P 0.05.

## Conclusion

An investigation of the moisture distribution pattern in a *Amaranthus cruentus* field grown under drip irrigation system was carried out in a typical sandy clay loam soil of Akure. Our results showed that the relation of soil moisture tension is positive with respect to soil moisture storage. Moisture depletion decreases down the soil profile, hence, low soil moisture tensions were observed at the root zone depth of *A. cruentus*. Significant increase in soil moisture storage at the root zone depth of the crop was caused by increased accumulation of soil moisture from the series of irrigations carried out. Lowest soil moisture tension of - 11.2 KPa brought about the highest moisture storage of 13.86 cm in soil during the dry season experiment of 2005. On the other hand, the high-

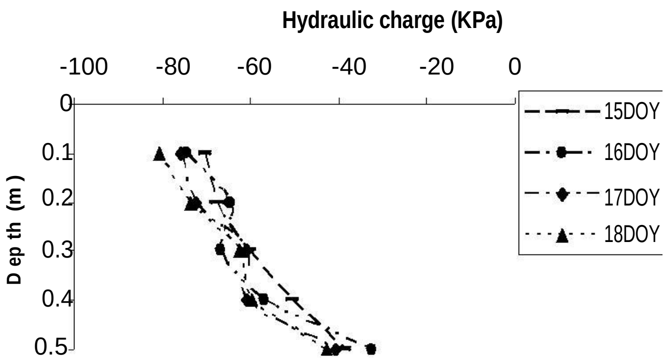


**Figure 5.** Soil hydraulic charge at the emergence stage of *A. cruentus* during the 2005 experiment.

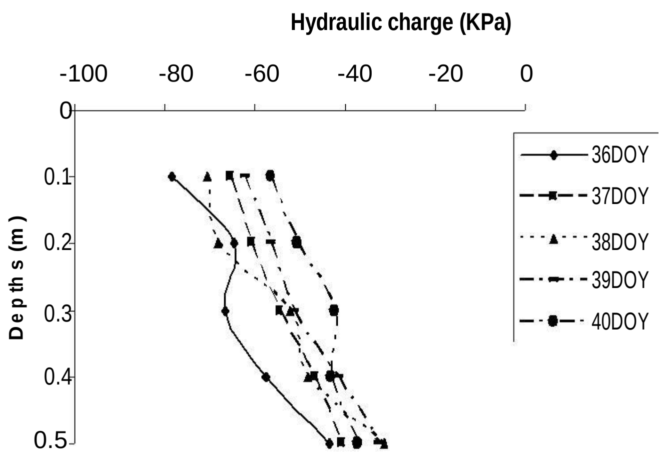


**Figure 6.** Soil hydraulic charge at the vegetative stage of *A. cruentus* during the 2005 experiment

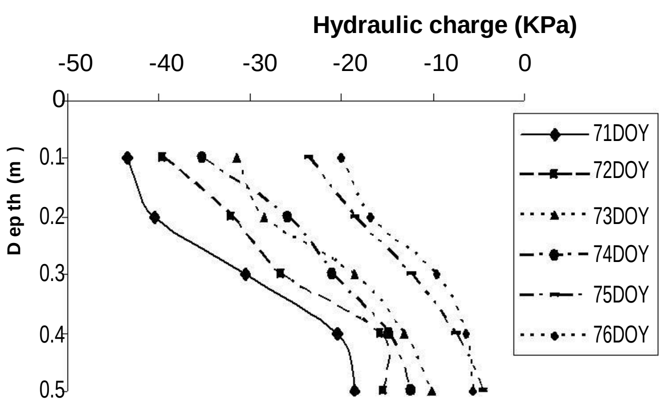


**Figure 7.** Soil hydraulic charge at the maturity stage of *A. cruentus* during the 2005 experiment.

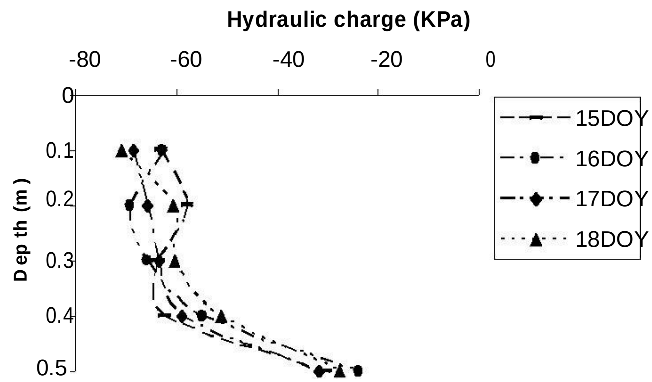


**Figure 8.** Soil hydraulic charge at the emergence stage of *A. cruentus* during the 2006 experiment.

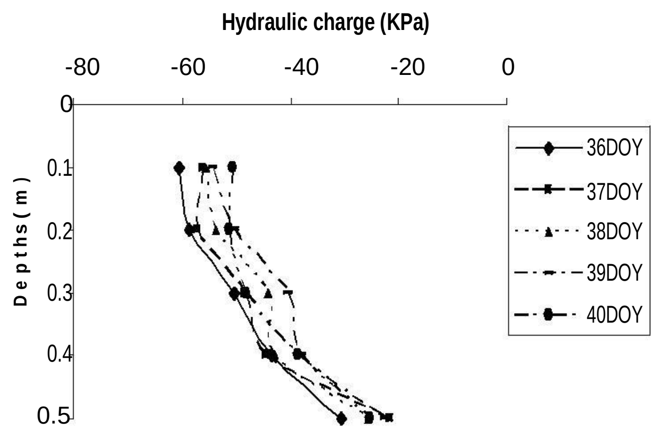


**Figure 9.** Soil hydraulic charge at the vegetative stage of *A. cruentus* during the 2006 experiment.

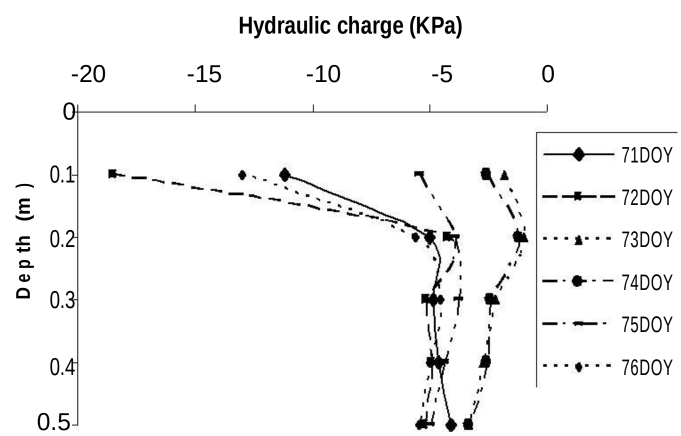


**Figure 10.** Soil hydraulic charge at the maturity stage of *A. cruentus* During the 2006 experiment.

highest soil moisture tension (-80.3 KPa) caused least soil moisture storage (7.76 cm). Therefore, keeping the soil moisture tension at its least by the use of full irragation treatment (Irrigation at 50 KPa) especially at the peak of the dry season is encouraged to ensure adequate moisture balance within the soil for crop uptake.

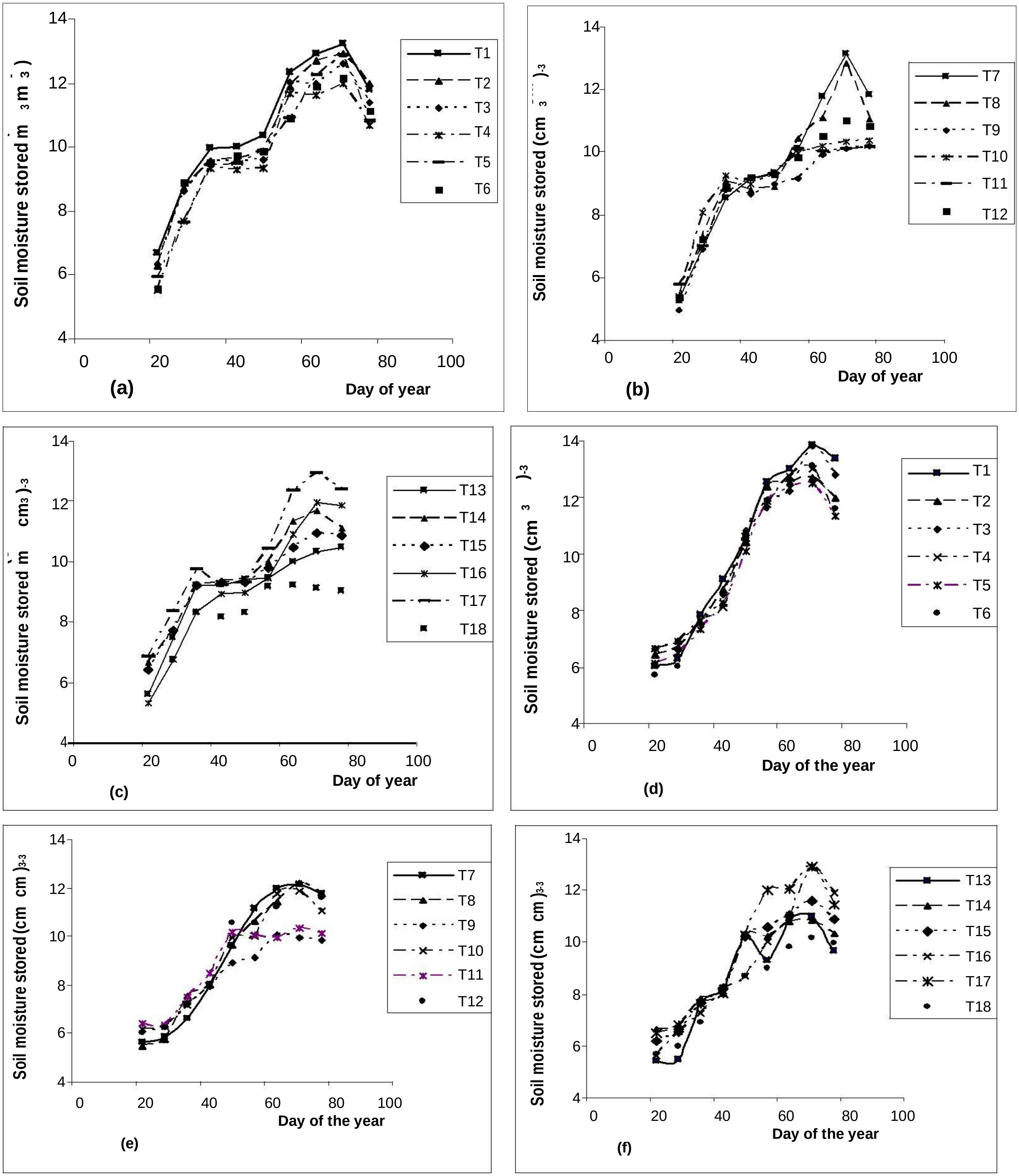


**Figure 11**a, b, c. Soil moisture storage during the 2005 experiment, (d, e, f) Soil moisture storage during the 2006 experiment

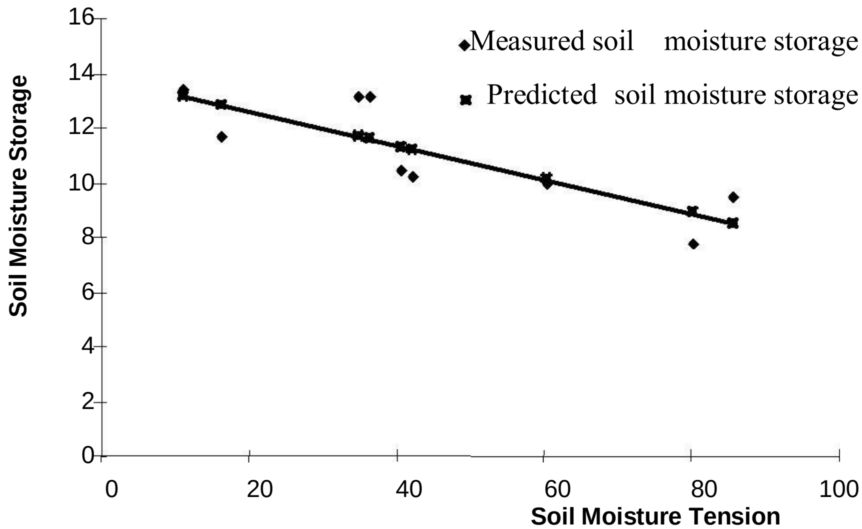


**Figure 12.** Linear regression of soil moisture storage function of soil moisture tension.

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