International Journal of Research and Innovations in Earth Science
Volume 2, Issue 6, ISSN (Online) : 2394-1375

Growth Changes of Seven Amaranthus (*spp*) During the Vegetative and Reproductive Stages of Development as Influenced by Variations in Soil Water Deficit

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Abstract – **Soil water deficit is a principal a biotic factor that limits plant growth and development in dry areas. Insufficient moisture contributes to soil water deficit and some negative effects on Amaranthus (*spp*) such as reduced growth and altered biomass allocation. Differences in soil water deficit responses of plants may be a consequence of different morphological adaptations during their developmental growth stages. In arid and semi-arid areas, water shortage is becoming an increasing problem because of the unreliable and limited rainfall and it significantly contributes to food shortage especially in Kenya. During the vegetative stage amaranth leaves are harvested while during the reproductive stage their seeds are harvested this makes its growth stages critical. Despite this obvious advantages, and besides it being the most popular and widely consumed micronutrient rich African indigenous Leafy Vegetables in Kenya, published information is limited concerning the growth stages of amaranth species in response to soil water deficit. These research was therefore designed to evaluate the seven widely cultivated amaranth species in Kenya:- *Amaranthus blitum* (L), *Amaranthus retroflexus* (L), *Amaranthus Spinosus* (L), *Amaranthus albus* (L), *Amaranthus cruentus* (L), *Amaranthus hypochondriacus* (L) and *Amaranthus tricolor* (L). to soil water deficit in relation to their growth. The experiment was carried out at Kenya Agricultural and Livestock Research Organisation, Kisii Centre. The experiment was laid out as completely randomized design, consisting of four treatments, seven species and three replications. The treatments were: 100%, 75%, 50% and 25% available water capacity. Growth parameters measured included; plant height and the stem diameter using a meter rule and a veneer calliper respectively, and by counting the number of leaves. The root to shoot ratio was determined at the end of the experiment. Soil moisture content was determined gravimetrically. Data was subjected to analysis of variance and separation of means using the Least Significant Difference at 5% level. Results showed that the seven species of amaranth were significantly ($p \leq 0.05$) affected by soil water deficit. Growth parameters during the vegetative and reproductive stages decreased with increase in water deficit and reduced significantly ($p \leq 0.05$) with further increase in water deficit. The root to shoot ratio increased with increase in soil water deficit. From the results obtained, it can be concluded that among the seven species of amaranthus evaluated, *A albus*, had the highest growth to soil water deficit and therefore can be recommended to be grown in water deficient regions followed by *A. hypochondriacus*, *A. cruentus*, *A. retroflexus*, *A. blitum*, *A. Spinosus*, and *A. tricolor* respectively. The results of this study can also be used to recommend better management plant strategies to drought, as it considered the effects of soil water deficit on both the vegetative and reproductive stages of growth.**

Keywords – **Amaranth, Available Water Capacity, Soil Water Deficit.**

I. Introduction

Soil water deficit is the major environmental factor limiting agricultural production. It is a major problem in low rainfall areas of Kenya and by extension it is a worldwide problem affecting plant growth, to varying degrees (Oniang'o, 2001). Whereas global climatic change has made the situation dire for agricultural production (Pan *et al*., 1996), the use of the commonly cultivated drought tolerant Amaranth vegetables such as *Amaranthus blitum* (L), *Amaranthus retroflexus* (L), *Amaranthus Spinosus* (L), *Amaranthus albus* (L), *Amaranthus cruentus* (L), *Amaranthus hypochondriacus* (L) and *Amaranthus tricolor* (L), might be a solution to this global problem (Vorster *et al.,* 2005). According to Schippers, (2002) indigenous crops may be having a strong tendency to tolerate soil water deficit, however, the tolerance level in relation to their developmental stages is not clear and this therefore formed the basis for this research. In leafy vegetables the critical growth stage (s) is depended on the kind of crop grown and the purpose of growing such a crop. The vegetative stage is the critical stage and according to Ma *et al.*, (2006), soil water deficit occurring during the vegetative growth stage has been shown to have little effect on yield as compared to water deficit occurring during the reproductive stage. This however is not the case with amaranth because it is considered as a pseudo cereal crop and the effects of water deficit might not be depended on its growth stage. The occurrence of water deficit at the vegetative stage will definitely reduce leaf area and dry matter as a result of reduced leaf expansion. These effects of water deficit at the vegetative stage will inhibit shoot height resulting in reduced leaf area, dry weight, leaf number and stem diameter.

Sikuku *et al.* (2010) confirmed a reduction in whole plant yield with an increase in water deficit in rice. Similar results were observed by Pattanagul and Thitisaksakul, (2011) where water deficit caused a significant reduction in yield of rice. Cengiz *et al*. (2006) observed that water deficit reduces yield and the total plant dry weight, but affects shoots more than roots causing a larger root : shoot ratio. There is little information on the extend of yield reduction on amaranth under water deficit conditions. However, investigations on two African nightshade species by Jomo *et al.* (2014) a similar leafy vegetable revealed growth reduction, and ascribed this to avoidance mechanisms aimed at reducing plant water consumption hence conserving water during periods of drought, which could similarly be the case with amaranth.

Soil water deficit according to Jomo, (2013), directly and physically reduces plant growth through reduction of cell turgor. Netondo, (1999) noted that the growth rate of cereal leaves is very sensitive to plant water status, since a small reduction in water potential of the root medium was able to limit the growth rate of maize and barley immediately. Amaranthus (*spp*) investigated are however classified as pseudo cereals which might be limited in their growth even further, considering the various water deficit levels. Water deficit during the vegetative stage has been found to reduce plant height, and plant leaf area. However the effects during this stage vary with the severity of stress and age of the crop. Long duration species suffer less yield damage than short duration species as long vegetative period could help the plant to recover when stress is relieved (Jones and Flowers, 1989). Thobile *et al.* (2010), while studying wild mustard leafy vegetables revealed that the critical growth stage is the vegetative stage, hence need for sufficient soil water to meet plant demand for vegetative growth but noted that leaf expansion during this vegetative stage is very sensitive to water deficit and that cell enlargement requires turgor to extend the cell wall and a gradient in water potential to bring water into the enlarging cell. The occurrence of early stages of moisture stress leads to poor crop establishment and increased seedling mortality in the rice (Jose *et al.*, 2004). Plants under water deficit have shown reductions in leaf area and number as a mechanism to reduce water loss through transpiration, and through the inhibition of leaf expansion. Whereas according to Muthomi and Musyimi, (2009) moderate water deficit reduces leaf area in African nightshades (*Solanum scabrum*, Mill) seedlings, and that leaf area reduction was a drought avoidance mechanism in plants subjected to water stress. Liu and Xu (2004) reported that root length increased significantly in wheat (*Triticum aestivum*) cultivars in response to drought stress. These studies by Muthomi and Musyimi, (2009) and Uku and Bjorkman, (2005), did not address important growth attributes in the plant developmental stages including their root to shoot ratio, which this research sought to find out among the seven amaranth species.

II. Materials and Methods

2.1 Soil Moisture Content Determination

The soil moisture content was determined gravimetrically, whereby samples were scooped from the topsoil, ten cm from the top using an auger between 10.00 a.m. and 11.00 a.m. During soil extraction care was taken to minimize root destruction. The scooped samples were immediately placed in polythene tubes (non-perforated) to avoid any moisture loss. The fresh weights (W_1) were taken using an electronic weighing balance. Samples were then dried in an oven for 48 hours at 72^0C and the dry weight (W_2) obtained. The measurements were done at every 13^{th} day after initiation of treatments and the average values obtained. The percentage water content (W) was calculated according to Nguyen *et al.* (2013).

$$W = \frac{w_1 - w_2}{w_1} \times 100 \qquad (1)$$

Where;
W_1 = fresh weight
W_2 = dry weight
W = percentage soil moisture content

The treatments were: 100% available water capacity (no water stress/control), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low), according to (Vanassche *et al.* 1989 and Neluheni 2007), where 25% was the lowest water level applied for plant survival.

The determination of field capacity was done gravimetrically. The upper limit of field capacity was determined by watering soil thoroughly to drainage and then allowed to drain for 24 - 48 hours then soil samples were collected at 10 cm. The scooped samples were immediately placed in polythene tubes (non-perforated) to avoid any moisture loss. The fresh weights (W_1) were taken using an electronic weighing balance. Samples were then dried in an oven for 48 hours at 72^oC and the dry weight (W1) obtained, and the percentage water content (W) was calculated as shown in equation (1) below. The lower limit for plant water extraction (permanent wilting point) was determined by growing plants to flowering without limiting water intake, after which water intake was limited by stopping irrigation until permanent wilting was achieved. The percentage water content by mass was calculated at the permanent wilting point. The levels of moisture deficit imposition for each treatment in terms of percentage was calculated according to Nguyen *et al.* (2013).

$$AWC = FC - WP \qquad (2)$$

$$\text{Water Deficit} = \frac{FC - T_1}{AWC} \times 100 \qquad (3)$$

Where;
AWC = available water content
WP = wilting point
FC = field capacity
T_1 = treatments

Before initiating treatments plants were irrigated with normal tap water using a hand sprinkler to full saturation for two weeks in order to improve root development (Imana *et al.*, 2010). After which 500 ml of water was applied to each pot and this was able to wet the soil to full saturation.

2.2 Shoot height

Shoot height was measured using a meter rule, from the stem base up to the shoot apex. This was done during the vegetative and reproductive stages of development.

2.3 Stem diameter

The diameter of each seedling was measured by use of a vernier calliper at a height of 10 cm from the stem base. Measurements were done during the vegetative and reproductive stages of development.

2.4 Leaf number

The number of fully expanded fresh leaves per plant on the main stem and branches were counted and recorded during the vegetative and reproductive stages of development.

2.5 Root : shoot ratio determination

These were calculated at the end of the experiment. The plants were carefully uprooted after loosening the soil and rinsed under tap water. The root masses that were embedded in the soil were carefully removed by soaking the rooting media in water and sieving out all the root segments. The plants were then separated into shoot and root, dried in an oven at 70 ^{o}C for 48 hrs and then weighed using an electronic weighing balance (Denver Instrument Model XL-31000, Germany). The ratio of root : shoot biomass was computed as a percentage according to Jomo *et al.* (2014).

$$\text{Root : Shoot Ration} = \frac{\text{Root dry weight}}{\text{Shoot dry weight}} \times 100 \qquad (4)$$

2.6 Statistical analysis of data

Data were analyzed using the statistical program (SAS, 2003). Differences between soil water deficit treatments and Amaranthus (*spp*) were tested by a two-way analysis of variance (ANOVA). Treatment means were separated using Fisher's protected t-test Least Significant Difference (LSD) test at 5% significance level (Snedecor and Cochran, 1980).

III. Results

3.1 Soil moisture content

There was a significant difference in soil moisture content ($p \leq 0.05$) among all soil water deficit treatment means and among amaranth species means. There was a significant difference ($p \leq 0.05$) between the vegetative and reproductive growth stages. The highest reduction in soil moisture content was observed in 25%, followed by 50%, 75% and 100% as indicated in tables 1 and 2. There was no significant interaction between soil water deficit treatments and amaranth species (P=0.001).

3.1.1 Soil moisture content during the vegetative stage

Amaranth spinosus, had the highest soil moisture content followed by *A. hypochondriacus*, *A. albus A. tricolor*, *A. blitum*, *A. retroflexus* and *A. cruentus* respectively. The reduction in soil moisture content at 25% soil water deficit treatment was 38% of the control treatment for *Amaranthus blitum*, 34% for *A. retroflexus*, 36% for *A. spinosus*, 35% for *A. albus*, 32% for *A. cruentus*, 36% for *A. hypochondriacus* and 37% for *A. tricolor.*

Table 1: Soil moisture content for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the vegetative stage.

Amaranthus (*spp*)	Soil moisture content by weight (%) under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**29.1±0.19a**	**21.8±0.45b**	**17.0±0.22 c**	**10.9±0.38d**	19.7±2.01**a**	5
A. retroflexus	**29.6±0.38a**	**22.1±0.38b**	**16.8±0.25c**	**10.0±0.28d**	19.6±2.17**b**	6
A. spinosus	**30.2±0.77a**	**22.4±0.74b**	**16. 5±0.79c**	**11.0±0.44d**	20.0±2.17**c**	1
A. albus	**30.0±0.68a**	**22.6±0.22b**	**16.1±0.38c**	**10.4±0.51d**	19.8±2.21**d**	3
A. cruentus	**29.4±0.59a**	**21.9±0.60b**	**16.8±0.42c**	**9.4±0.14d**	19.4±2.21**e**	7
A. hypochondriacus	**30.5±0.57a**	**22.7±0.39b**	**15.2±0.39c**	**10.9±0.38d**	19.8±2.26**f**	2
A. tricolor	**30.1±0.27a**	**22.1±0.70b**	**16.0±0.47c**	**11.1±0.31d**	19.8±2.15**g**	4
Overall treatments mean	**31.3±1.89a**	**22.2±1.91b**	**16.3±1.96c**	**10.5±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 48 days period. Means with the same letter are not significantly different.

3.1.2 Soil moisture content during the reproductive stage

Amaranth spinosus, had the highest soil moisture content followed by *A. albus*, *A. retroflexus*, *A. blitum*, *A. tricolor*, *A. cruentus* and *A. hypochondriacus* respectively. The reduction in soil moisture content at 25% soil water deficit treatment was 36% of the control treatment for *Amaranthus blitum*, 37% for *A. retroflexus*, 37% for *A. spinosus*, 33% for *A. albus*, 35% for *A. cruentus*, 33% for *A. hypochondriacus* and 37% for *A. tricolor.*

Table 2: Soil moisture content for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the reproductive stage.

Amaranthus (*spp*)	Soil moisture content by weight (%) under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**29.0±0.13a**	**22.0±0.09b**	**17.0±0.36 c**	**10.5±0.40d**	19.6±2.05**a**	4
A. retroflexus	**29.7±0.32a**	**22.1±0.23b**	**16.2±0.32c**	**11.0±0.17d**	19.75±2.10**b**	3
A. spinosus	**30.9±0.61a**	**23.3±0.10b**	**16. 3±0.79c**	**11.3±0.33d**	20.4±2.23**c**	1
A. albus	**30.4±0.99a**	**22.8±0.22b**	**16.7±0.17c**	**10.1±0.46d**	20.0±2.27**d**	2
A. cruentus	**29.3±0.96a**	**22.3±0.27b**	**16.3±0.47c**	**10.2±0.75d**	19.5±2.16**e**	6
A. hypochondriacus	**29.0±0.53a**	**21.4±0.52b**	**15.8±0.38c**	**9.6±0.31d**	19.0±2.16**f**	7
A. tricolor	**29.4±0.39a**	**21.3±0.27b**	**16.7±0.72c**	**11.0±0.69d**	19.6±2.04**g**	5
Overall treatments mean	**29.6±1.89a**	**22.2±1.91b**	**16.4±1.96c**	**10.4±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 96 days period. Means with the same letter are not significantly different.

3.2 Shoot height

Soil water deficit significantly reduced shoot height of all the amaranth species. There were significant differences in shoot height (p≤0.05) among soil water deficit treatments and among amaranth species as observed in tables 3 and 4. There were significant differences (p≤0.05) between the vegetative and reproductive growth stages. The highest reduction in shoot height was observed in 25%, followed by 50%, 75% and 100% respectively, as indicated in tables 3 and 4. There was no significant interaction between soil water deficit treatments and amaranth species (P=0.5702).

3.2.1 Shoot height during the vegetative stage

Amaranthus albus, had the highest shoot height followed by *A. hypochondriacus*, *A. cruentus*. *A. retroflexus*, *A. blitum*, *A. spinosus* and *A. tricolor* respectively. The reduction in shoot height at 25% soil water deficit treatment was 85% of the control treatment for *Amaranthus blitum*, 87% for *A. retroflexus*, 85% for *A. spinosus*, 85% for *A. albus*, 87% for *A. cruentus*, 85% for *A. hypochondriacus* and 85% for *A. tricolor*.

Table 3: Shoot height for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the vegetative stage.

Amaranthus (*spp*)	Shoot height (cm) under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**56.0±0.58a**	**52.7±0.33b**	**49.7±0.33 c**	**47.7±0.88d**	51.5±0.98**a**	5
A. retroflexus	**60.0±0.57a**	**56.7±0.33b**	**53.7±0.33c**	**52.0±0.58d**	55.6±0.94**b**	4
A. spinosus	**53.7±0.33a**	**50.7±0.33b**	**47. 7±0.33c**	**45.7±0.88d**	49.4±0.94**c**	6
A. albus	**67.0±0.58a**	**64.0±0.58b**	**60.7±0.33c**	**57.0±0.58d**	62.2±1.15**d**	1
A. cruentus	**63.0±0.58a**	**59.7±0.33b**	**56.7±0.33c**	**55.0±0.58d**	58.6±0.94**e**	3
A. hypochondriacus	**65.0±0.58a**	**61.7±0.33b**	**58.7±0.33 c**	**55.0±0.58d**	60.1±1.13**f**	2
A. tricolor	**52.7±0.33a**	**49.7±0.33b**	**46.7±0.33c**	**44.7±0.88d**	48.4±0.94**g**	7
Overall treatments mean	**59.6±1.89a**	**56.5±1.91b**	**53.4±1.96c**	**51.0±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 48 days period. Means with the same letter are not significantly different.

3.2.2 Shoot height during the reproductive stage

Amaranthus albus, had the highest shoot height followed by *A. hypochondriacus*, *A. cruentus*. *A. retroflexus*, *A. blitum*, *A. spinosus* and *A. tricolor* respectively. The reduction in shoot height at 25% soil water deficit treatment was 94% of the control treatment for *Amaranthus blitum*, 94% for *A. retroflexus*, 95% for *A. spinosus*, 94% for *A. albus*, 94% for *A. cruentus*, 94% for *A. hypochondriacus* and 96% for *A. tricolor*.

Table 4: Shoot height for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the reproductive stage.

Amaranthus (*spp*)	Shoot height (cm) under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**96.0±0.58a**	**93.3±0.67b**	**92.3±0.33c**	**90.0±0.58d**	92.9±0.69**a**	5
A. retroflexus	**97.0±0.58a**	**95.0±0.58b**	**94.0±0.58c**	**91.0±0.58d**	94.3±0.70**b**	4
A. spinosus	**94.0±0.58a**	**91.3±0.67b**	**90.3±0.33c**	**89.0±0.58d**	91.2±0.60**c**	6
A. albus	**101.0±0.58a**	**99.0±0.58b**	**98.0±0.58c**	**95.0±0.58d**	98.3±0.70**d**	1
A. cruentus	**98.0±0.58a**	**96.0±0.58b**	**95.0±0.58c**	**92.0±0.58d**	95.3±0.70**e**	3
A. hypochondriacus	**100.0±0.58a**	**98.0±0.58b**	**97.0±0.58c**	**94.0±0.58d**	97.3±0.70**f**	2
A. tricolor	**92.0±0.58a**	**90.3±0.67b**	**89.3±0.33c**	**88.0±0.58d**	89.9±0.50**g**	7
Overall treatments mean	**96.9±1.89a**	**94.7±1.91b**	**93.7±1.96c**	**78.4±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 96 days period. Means with the same letter are not significantly different.

3.3 Stem diameter

Soil water deficit significantly reduced stem diameter of the amaranth species. There were significant differences in stem diameter ($p \leq 0.05$) among soil water deficit treatments and among amaranth species. There were significant differences in stem diameter ($p \leq 0.05$) at the vegetative and reproductive growth stages. The highest reduction in stem diameter was observed in 25%, followed by 50%, 75% and 100% respectively as indicated in tables 4 and 5. There was a significant interaction between soil water deficit treatments and amaranth species (P=0.1042).

Table 5: Stem diameter for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the vegetative stage.

3.3.1 Stem diameter during the vegetative stage

Amaranthus albus, had the highest stem diameter followed by *A. hypochondriacus*, *A. cruentus*. *A. retroflexus*, *A. blitum*, *A. spinosus* and *A. tricolor* respectively. The reduction in stem diameter at 25% soil water deficit treatment was 95% of the control treatment for *Amaranthus blitum*, 95% for *A. retroflexus*, 96% for *A. spinosus*, 96% for *A. albus*, 96% for *A. cruentus*, 96% for *A. hypochondriacus* and 96% for *A. tricolor.*

Table 5

Amaranthus (*spp*)	Stem diameter (cm) under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**4.19±0.003a**	**4.12±0.006b**	**4.07±0.006c**	**4.02±0.003d**	4.10±0.019**a**	5
A. retroflexus	**4.20±0.003a**	**4.13±0.006b**	**4.08±0.006c**	**4.03±0.003d**	4.11±0.019**b**	4
A. spinosus	**4.17±0.006a**	**4.10±0.006b**	**4.05±0.006c**	**4.01±0.003d**	4.08±0.018**c**	6
A. albus	**4.25±0.003a**	**4.19±0.006b**	**4.13±0.006c**	**4.08±0.003d**	4.16±0.019**d**	1
A. cruentus	**4.21±0.003a**	**4.16±0.006b**	**4.10±0.006c**	**4.05±0.003d**	4.13±0.018**e**	3
A. hypochondriacus	**4.23±0.003a**	**4.18±0.006b**	**4.11±0.006c**	**4.07±0.003d**	4.15±0.019**f**	2
A. tricolor	**4.15±0.006a**	**4.09±0.006b**	**4.02±0.006c**	**4.00±0.000d**	4.07±0.018**g**	7
Overall treatments mean	**4.20±1.89a**	**4.14±1.91b**	**28.6±1.96c**	**4.04±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 48 days period. Means with the same letter are not significantly different.

Table 6: Stem diameter for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the reproductive stage.

Amaranthus (*spp*)	Stem diameter (cm) under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**5.81±0.019a**	**5.68±0.012b**	**5.56±0.006c**	**5.44±0.003d**	5.62±0.042**a**	5
A. retroflexus	**5.82±0.019a**	**5.70±0.012b**	**5.60±0.006c**	**5.46±0.003d**	5.65±0.040**b**	4
A. spinosus	**5.79±0.019a**	**5.63±0.012b**	**5.54±0.006c**	**5.41±0.003d**	5.59±0.042**c**	6
A. albus	**5.91±0.006a**	**5.73±0.012b**	**5.67±0.006c**	**5.52±0.006d**	5.71±0.042**d**	1
A. cruentus	**5.86±0.006a**	**5.71±0.012b**	**5.62±0.006c**	**5.47±0.003d**	5.67±0.042**e**	3
A. hypochondriacus	**5.89±0.006a**	**5.72±0.012b**	**5.66±0.006c**	**5.50±0.006d**	5.69±0.042**f**	2
A. tricolor	**5.78±0.19a**	**5.62±0.012b**	**5.51±0.012c**	**5.38±0.003d**	5.57±0.045**g**	7
Overall treatments mean	**5.84±1.89a**	**5.68±1.91b**	**5.59±1.96c**	**5.45±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 96 days period. Means with the same letter are not significantly different.

3.3.2 Stem diameter during the reproductive stage

Amaranthus albus, had the highest stem diameter followed by *A. hypochondriacus*, *A. cruentus*. *A. retroflexus*, *A. blitum*, *A. spinosus* and *A. tricolor* respectively The reduction in stem diameter at 25% soil water deficit treatment was 94% of the control treatment for *Amaranthus blitum*, 93% for *A. retroflexus*, 93% for *A. spinosus*, 93% for *A. albus*, 93% for *A. cruentus*, 93% for *A. hypochondriacus* and 93% for *A. tricolor*.

Soil water deficit significantly reduced the leaf numbers of the amaranth species. There were significant differences ($p \leq 0.05$) in leaf numbers among soil water deficit treatments and among amaranth species. The highest reduction in leaf numbers was observed in 25%, followed by 50%, 75% and 100% respectively as indicated in tables 7 and 8. There were significant differences in leaf numbers ($p \leq 0.05$) at the vegetative and reproductive growth stages. There was a significant interaction between soil water deficit treatments and amaranth species (P=0.0001).

3.4 Leaf number

Table 7: Leaf numbers for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the vegetative stage.

Amaranthus (*spp*)	Leaf numbers under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall species mean**	**Species Rank**
A. blitum	**79.7±1.20a**	**73.0±0.58b**	**66.7±0.88c**	**60.3±0.67d**	69.9±2.20**a**	5
A. retroflexus	**81.3±0.88a**	**75.0±0.58b**	**68.7±0.88c**	**62.0±0.58d**	71.8±2.19**b**	4
A. spinosus	**77.7±1.20a**	**71.0±0.58b**	**64.7±0.88c**	**59.3±0.67d**	68.2±2.10**c**	6
A. albus	**86.3±0.88a**	**79.0±0.58b**	**73.0±1.15c**	**67.7±0.88d**	76.5±2.13**d**	1
A. cruentus	**83.3±0.88a**	**76.0±0.58b**	**70.0±1.15c**	**64.7±0.88d**	73.5±2.13**e**	3
A. hypochondriacus	**85.3±0.88a**	**78.0±0.58b**	**72.0±1.15c**	**66.7±0.88d**	75.5±2.13**f**	2
A. tricolor	**76.7±1.20a**	**70.0±0.58b**	**63.7±0.88c**	**55.3±0.67d**	66.4±2.40**g**	7
Overall treatments mean	**81.5±1.89a**	**74.6±1.91b**	**68.4±1.96c**	**62.3±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 48 days period. Means with the same letter are not significantly different.

3.4.1 Leaf numbers during the vegetative stage

Amaranthus albus, had the highest leaf numbers followed by *A. hypochondriacus*, *A. cruentus*. *A. retroflexus*, *A. blitum*, *A. spinosus* and *A. tricolor* respectively The reduction in leaf numbers at 25% soil water deficit was 76% of the control treatment for *Amaranthus blitum*, 76% for *A. retroflexus*, 76% for *A. spinosus*, 78% for *A. albus*, 78% for *A. cruentus*, 78% for *A. hypochondriacus* and 72% for *A. tricolor.*

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Volume 2, Issue 6, ISSN (Online) : 2394-1375

Table 8: Leaf numbers for seven Amaranthus (*spp*) grown under four levels of water application; 100% available water capacity (no water stress), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low) during the reproductive stage.

Amaranthus (*spp*)	Leaf numbers under four soil water deficit treatments					
	100 % (Control)	**75 %**	**50 %**	**25 %**	**Overall Species Mean**	**Species Rank**
A. blitum	**107.7±0.33a**	**99.0±0.00b**	**80.0±0.58c**	**73.3±0.88d**	90.0±4.19**a**	5
A. retroflexus	**109.7±0.33a**	**100.0±0.00b**	**82.0±0.58c**	**74.3±0.88d**	91.5±4.24**b**	4
A. spinosus	**104.7±0.33a**	**97.3±0.33b**	**78.0±0.58c**	**72.3±0.88d**	88.1±4.03**c**	6
A. albus	**116.0±0.58a**	**106.0±0.00b**	**95.0±1.00c**	**81.3±1.33d**	99.6±3.91**d**	1
A. cruentus	**112.7±0.33a**	**103.0±0.00b**	**85.3±1.45c**	**76.3±0.88d**	94.3±4.32**e**	3
A. hypochondriacus	**115.0±0.58a**	**104.0±0.58b**	**90.0±0.00c**	**79.0±0.58d**	97.0±4.12**f**	2
A. tricolor	**102.7±0.33a**	**94.7±0.33b**	**75.7±0.33c**	**67.3±0.88d**	85.1±4.28**g**	7
Overall treatments mean	**109.8±1.89a**	**100.6±1.91b**	**83.7±1.96c**	**74.8±2.01d**		
CV (%) 1.755946						
LSD (P = 0.05) Species (S) **0.2954**						
LSD (P = 0.05) water level (T) **0.2233**						

Values represent means of three replicates ± SE, in a 96 days period. Means with the same letter are not significantly different.

3.4.2 Leaf numbers during the reproductive stage

Amaranthus albus, had the highest leaf numbers followed by *A. hypochondriacus*, *A. cruentus*. *A. retroflexus*, *A. blitum*, *A. spinosus* and *A. tricolor* respectively The reduction in leaf numbers at 25% soil water deficit was 68% of the control treatment for *Amaranthus blitum*, 68% for *A. retroflexus*, 69% for *A. spinosus*, 70 % for *A. albus*, 68% for *A. cruentus*, 69% for *A. hypochondriacus* and 66% for *A. tricolor.*

3.5 Root : Shoot ratio

The root : shoot ratio increased with increase in soil water deficit in all the amaranth species from 100%, 75%, 50% and 25% respectively. There were significant differences in root : shoot ratio (p≤0.05) among soil water deficit treatments and among amaranth species (Fig 1). There was no significant interaction between soil water deficit treatments and amaranth species (P=0.4501). The reduction in root : shoot ratio at 100% control treatment was 65% of the 25% soil water deficit treatment for *Amaranthus blitum*, 59% for *A. retroflexus*, 74% for *A. spinosus*, 38% for *A. albus*, 55% for *A. cruentus*, 48% for *A. hypochondriacus* and 75% for *A. tricolor.*

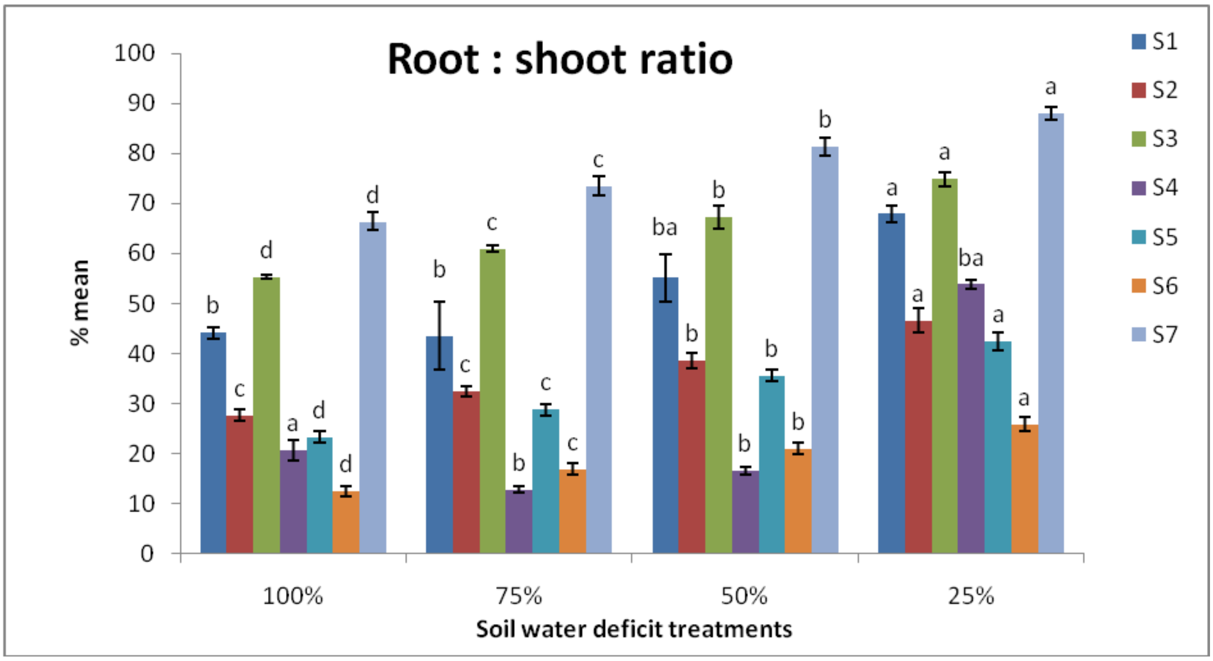

Fig1. The mean root : shoot ratio of the seven Amaranthus (*spp*) namely; S1 *A. blitum*, S2 *A. retroflexus*, S3 *A. spinosus*, S4 *A. albus*, S5 *A. cruentus*, S6 *A. hypochonriacus* S7 *A. tricolor*, grown under four watering regimes 100% available water capacity (control), 75% available water capacity (slight), 50% available water capacity (moderate) and 25% available water capacity (low). Values represent means of three replicates ± SE, in a 96 days period. Means with the same letter are not significantly different.

IV. Discussion

4.1 Soil moisture content

Soil moisture content in amaranth decreased with decreasing soil water deficit. This is in agreement with results of Martim *et al.* (2009), on grapevine and Siddique *et al.* (2000), on wheat plants. However soil moisture content was not significantly different in *A. blitum, A. retroflexus, A. cruentus,* and *A.tricolor,* species possibly because plants were adapting to their water deficit environment and an indication that when water was not limiting the species of amaranth might have had the same water absorption, utilization and water loss in sustaining their growth processes. Whereas according to Thobile *et al.*, (2010) moisture requirements for plants differ with the species, stage of development and plant age, further losses of moisture from the soil may be attributed to surface evaporation, transpiration through the leaves and water absorbed by the roots (Luvaha *et al.*, 2008). The significant differences in soil moisture contents during the vegetative and reproductive growth stages implied variations as a result of metabolism among the seven amaranth species.

4.2 Shoot height

Amaranth species depend on water and nutrients for growth and survival, however the increased water deficit might have limited nutrient uptake thereby becoming detrimental to their growth and development (Wu *et al.*, 2011). In this study, significant reductions in plant height among the seven species in all treatments, could have resulted from a reduction in plant photosynthetic efficiency as also reported by Castonguay and Markhart (1992), or a reduction in their nutrient absorption by the plants under water deficit conditions. During the initial stages of development (vegetative stage) the plants were adjusting to water deficit and therefore did not require a lot of water unlike during their last stages of development (reproductive stage). Reduction in plant height under water deficit could be due to leaf number reduction which is a result of physiological changes that occur under water deficit stress. A general decline in shoot height with increasing water deficit may further imply that growth allocation may have been diverted to other plant organs like to the roots, leaves or the stems. Similar results have been reported with rice (*Oryza sativa*) varieties (Sikuku *et al.*, 2010). Plant growth is depended on cell division, cell enlargement and differentiation processes which can be delayed by soil water deficit (Thobile *et al.*, 2010). Shoot growth, is generally more sensitive to soil water deficit than root growth. The 25% soil water deficit treatment had the lowest shoot height for all species probably due to reduced cell turgor thereby affecting cell division and expansion, and as noted by Salisbury and Ross (1992), cell enlargement requires turgor to extend the cell wall and a gradient in water potential to bring water in the enlarging cell, but water deficit suppresses cell expansion and cell growth due to low turgor pressure. The 100% (control) soil water deficit treatment, shoot height increased the highest, while the contrary was with 25% soil water deficit treatment where shoot height was limited probably due to internodal elongation, leaf initiation and expansion by inducing epinasty of leaf and petiole, leaf senescence, leaf chlorosis, and leaf abscission.

4.3 Leaf number

Water deficit increased leaves senescence in *Amaranthus tricolor*. This was also observed in wheat by Liu and Xu (2004) where wilting in mature leaves was associated with carbohydrate depletion due to mobilisation and export followed by senescence. Although leaf senescence and wilting was common in *amaranthus tricolor*, growth inhibition was still evident especially in 25% soil water deficit treatment and this might have enhanced nucleic acid destruction of the polysomal mRNAs in the zone of elongation of the hypocotyls. At the start of water deficit, changes in the leaf number were more visible, where 100% (control) soil water deficit treatment had the highest number of leaves, whereas 25% soil water deficit had the least number of leaves. Decrease in leaf number, could be attributed to reduction in cell expansion which was common at 25% soil water deficit possibly due to carbohydrate depletion as a result of mobilisation and export (Jomo, 2013). Among the seven amaranth species *amaranthus albus*, recorded the highest growth, followed by *amaranthus hypochondriacus*, *amaranthus cruentus*, *amaranthus retroflexus*, *amaranthus blitum*, *amaranthus spinosus* and *amaranthus tricolor* respectively. The highest number of leaves in *amaranthus albus* implied a higher photosynthetic rates, and a subsequently increased photosynthate allocation to other plant organs. This was in agreement with Sah and Zamora, (2005) where maize plants subjected to water deficit had significantly reduced leaf area and number. The effects of water deficit on the vegetative stage leading to reduced leaf numbers might be considered as an adaptive mechanism which helped reduce water loss from plants subjected to extreme water deficit unlike during the reproductive stage. Reduced leaf numbers in plants under water deficit stress, reduced light interception by a plant and eventually reduces biomass production (Masinde *et al.*, 2005). Shoot growth, particularly growth of leaves is generally sensitive to soil water deficit than root growth (Hopkins and Huner, 2004). The significant decrease in leaf numbers with increasing water deficit results were in concormittant with those observed in tomato by Imana *et al.*, (2010), in maize plants by Sah and Zamora (2005) where reduced leaf numbers reduced light interception by a plant and eventually reduced biomass production. *A. albus* had the highest number of leaves and this detaching of old leaves for the formation of new leaves with smaller leaf area could have been a mechanism of stress avoidance that was aimed at reducing plant water consumption and hence conserving water during water deficit.

4.4 Stem diameter

The stem diameter elongation reduced with increasing soil water deficit an observation made in tomato, by Imana *et al.*, (2010). In all treatments especially in 100% and 50% there was increased stem diameter possibly due to the fact that 100% and 75% soil water deficit could have had more oxygen deficiency further inhibiting growth, while the contrary was with 50% and 25% water levels which may have undergone leaching thereby causing soil nutrient deficiency. Reduction in stem diameter with increase in water deficit as in may have been as a result of reduced cell size and cell number as a result of lower rates of cell division and cell enlargement respectively. While the highest growth in well watered treatments (100% and 50%) could be due to resumption of stem cell division and elongation and leaf expansion (Vurayai *et al.*, 2011). Our results were in agreement with those obtained in tomato (*Lycopersicon esculentum* Mill.) where the smallest stem diameter of plants was observed in those that received the least amount of water (Imana *et al.*, 2010). However, according to Bimpong *et al.* (2011), and according to our results the stem growth of the seven species of amaranth may have been inhibited at low soil moisture content despite complete maintenance of turgor in the growing regions as a result of may be osmotic adjustment. This suggests that growth inhibition may be metabolically regulated possibly serving an adaptive role by restricting the development of the transpiring leaf in water stressed plants (Sharp, 1996). Contrary, to cell division having been reported to be less sensitive to water deficit than cell expansion or enlargement by Jomo, (2013). Turgor pressure in growing cells might have also provided the driving force for cell expansion. Hence reduced growth rate under water deficit in all treatments especially in 50% and 25% water levels can be related to reduced cell turgor and reduction in cell wall extensibility. This cell turgor might have decreased with any dehydration-induced decrease in cell water potential. Amaranth results on stem elongation are therefore in agreement with studies on sorghum and maize plants which showed to be negatively affected in their cell division and meristematic tissue enlargement Wenzel, (1997).

4.5 Root : Shoot ratio

The root : shoot ratio of the seven Amaranthus (*spp*) increased with increase in soil water deficit. The increase in root length which helped plants to grow even under extreme water deficit conditions according to Jomo *et al.* (2014), is the second line of defense after leaf number reduction. Roots tend to grow until the plants demand for water is met. In sorghum for instance, Jafar *et al.*, (2004) showed that severe drought resulted in increased root length. Amaranth genotypes subjected to water stress showed increased dry matter in root : shoot ratio. However, this is not always true because root and shoot growth are also controlled by nutrient availability, growth stages and most importantly the plant species Jomo, (2013); Jomo *et al.* (2014) and this partly led to the investigation of the seven amaranth species. The differential sensitivity of roots and shoots with root growth being less sensitive to water deficits could have led to the increase in the root to shoot ratio under water deficit conditions because increased root surface area allows more water to be absorbed from the soil. Besides differential sensitivity, the observed increase in root : shoot ratio with increase in water deficit, in the current study may be attributed to increased allocation of biomass from shoot to root, which is in agreement with previous results obtained in *M. indica* rootstock by Luvaha *et al.* (2008). Jomo, (2013) showed different response of root : shoot ratio of two African nightshades species to be increasing under soil water deficit. Root : shoot ratio of many crops and pasture species increased under water deficit condition (Wilson and Myers 1954), which may arise from relative greater decrease in shoot biomass. Masinde *et al.* (2005), reported similar results in *Cleome gynandra*, and attributed this to differential sensitivity of the root and shoot biomass production to soil water deficit, in amaranthus (Liu and Stutzel, 2004) and in wheat by Liu *et al.* (2004). Under low soil water content, the roots grow deeper in search for water. Roots therefore become the second line of defense after leaf area reduction. Water deficit usually changes the source-sink relationship thus altering assimilate partitioning, and under water stress, the roots become the stronger sink. Sharp and Davies (1985), observed a significant accumulation of solutes in the root tips of un-watered plants which resulted in the maintenance of root turgor for the duration of water deficit treatment. Higher root length at lower depth provides the ability of crop to survive under drought by acquiring more water. Many plants have developed mechanisms to cope with a restricted water supply. Plants can avoid drought stress by maximizing water uptake e.g. tapping ground water by deep roots or minimizing loss e.g. stomatal closure (Jie *et al.*, 2010). Generally plants increase root : shoot ratio under water deficit conditions (Westgate and Boyer, 1985). Water deficit causes a decline in the growing zones while increased root surface area allows more water to be absorbed from the soil and could be an adaptive response by *A. albus* to water deficit. This implies that increased root : shoot ratio during soil moisture deficit might have continued at very low water potentials which in turn inhibited the shoot growth, and a reduction in shoot growth coupled with continued root growth would result in an improved plant water status under extreme water deficit conditions (Sharp and Davies, 1985). Root growth may have been reduced by the use of pots and this might have had a negative consequence on shoot growth an argument also noted by Wenzel, (1997). Results of root to shoot ratio were also in agreement with those of Sharp and Davies, (1985) in maize seedlings where growth continued at very low water potential. According to Fig (1) *A. albus* had the highest root to shoot ratio implying that it was more tolerant to water deficit. A reduction in shoot growth coupled with continued root growth can occur as a result of improved plant water status even under extreme water deficit conditions such as 25% soil water deficit.

V. Conclusion

The growth of *amaranthus albus*, had the highest growth followed by *amaranthus hypochondriacus*, *amaranthus cruentus*, *amaranthus retroflexus*, *amaranthus blitum*, *amaranthus spinosus* and *amaranthus tricolor*. The reduction in shoot height was attributed to a reduction in plant cell turgor which affected cell division and elongation. Generally stem and leaf growth were inhibited at low water levels despite complete maintenance of turgor in the growing regions as a result of osmotic adjustment. 25% soil water deficit significantly reduced all amaranth species and in response they showed adaptive features to survive and this included:- shedding of leaves. The root : shoot ratio increased with increase in water deficit. *Amaranthus albus* had a higher root : shoot ratio, implying that it is more tolerant and well adapted to water deficient regions as compared to other amaranth species.

The increase in root : shoot ratio dry weight was as a result of differential sensitivity of the root and shoot biomass production to soil water deficit. This can be concluded to be an adaptation to soil water deficit in most plants growing in arid conditions in a bid to increase the surface area for water absorption while reducing transpiration.

Acknowledgements

The authors wish to thank Kenya Agricultural and Livestock Research Organisation, Kisii centre for creating an enabling environment for this research work.

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