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Response of *Amaranthus cruenthus* to Different Aeration Methods and Varying Irrigation Levels

I. B. Sadiku[1&2], K. O. Yusuf[2], and A. O. Ogunlela[2]

[1,2]*Department of Computer Science, Faculty of Applied Sciences, Gateway Polytechnic Saapade, Ogun State, Nigeria*
[2]*Department of Agricultural and Bio-systems Engineering, Faculty of Engineering and Engineering Technology, University of Ilorin, Ilorin, Nigeria*

Abstract. Response of *Amaranthus cruenthus* to varying aeration methods (aeration of irrigation water (A_1), air injection to crop root zone in soil before irrigation (A_2), air injection to crop root zone in soil after irrigation (A_3), and non aeration treatment (A_0)) and irrigation levels (100% field capacity (FC) (W_0), 75% FC (W_1), 65% FC (W_2) and 55 % FC (W_3) were investigated. The results showed that varying irrigation as well as aeration levels had significant effects on the height of *A. cruenthus* while no significant difference was obtained in number of leaves across the field capacities during the growing period. The findings of this work showed that *A. cruenthus* was not sensitive to air treatment as expected. This is because lower number of leaves were obtained when air was either injected into the soil before or after irrigation as well as when air was injected into irrigation water at 4 and 7 weeks after planting. Plant height was maximum when no air was introduced to the plant at 4 Weeks After Planting. However, the number of leaves were highest at 65% FC throughout the growing period. The shoot, root and whole plant fresh weight were all significantly influenced by the aeration treatments but not FC except the root fresh weight. The edible yield (shoot fresh weight) was highest (48.55g) at 100% FC (W_0). Also, when the irrigation water was injected with air (A_1), the highest edible yield of 57.33 g was obtained. The highest Water Use Efficiency was exhibited at 100% FC (W_0) while aeration of irrigation water (A_1) gave the highest (26.06) Air Use Efficiency. 65% field capacity is best for planting *A. cruenthus* without negatively affecting the yield.

Keywords: African spinach, available water, AUE, edible yield, wilting point, WUE

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1. Introduction

Aeration is addition of air to irrigation water or soil. The method of supplying oxygen to the crop root zone through the subsurface drip irrigation delivery system has been termed 'oxygation' [1] or airjection irrigation [2]. Oxygation has led to significant enhancement in growth parameters for a number of crop species [3] – [5]. However, oxygen deprivation may cause severe injury, reduction of chlorophyll content, stomatal conductance, photosynthesis and transpiration rate of leaves [6] – [7] in most crop plants. Declining trends in yields of some

*Corresponding author at: Department of Computer Science, Faculty of Applied Sciences, Gateway Polytechnic Saapade, 121116, Ishara, Ogun State, Nigeria

E-mail address: sibsadiku@gmail.com

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crops have been attributed to variation in the supply of oxygen to the roots via the air delivery system. Flooding and oxygen depletion can cause root injury if soil is not drained within one or two days, particularly for susceptible species such as cotton and tomato [8]. Lack of soil oxygen content in the crop root-zone leads to damage to the root tissue, altering the growth and development of vegetative and reproductive organs of plants [9] – [11]. Adequate root-zone oxygation provides oxygen for aerobic metabolism of microorganisms [9], [12] - 13]. In addition, aeration helps in nutrient availability, improve water use efficiency and ultimately yield of crops [13].

Various methods of aerated irrigation have been identified and practiced and all been reported to have have significant impact on the growth and yield of plants [14]. Their is ventilation after irrigation which involves injecting pure oxygen or compressed air into the root zone of soil after the application of irrigation water [8]; simultaneously injecting air and irrigation water into the root zone [15]; using chemical materials (such as urea, calcium peroxide as fertilizer as well as addition of low concentration of hydrogen peroxide (H_2O_2) to the irrigation water) to increase oxygen content of the soil [16] – [17]; mixing gases with irrigation water as well as using underground air layer to penetrate and replenish soil air [16]. Ventilation after irrigation has been reported to increase the anti-clogging ability of dripper thereby extending the service life of drip irrigation belts [18]. However, the method results into insufficient soil water for topsoil because emitters are usually submerged at certain depth and this has been reported to hinders seed germination and seedling emergence [8]. Injection of air alone is expensive and the injected air moves away from the root zone [1, 19] and the amount of air cannot be accurately controlled under this method. According to Parameshwarareddy and Dhage [8], using chemical material such as H_20_2 to increase oxygen content of the soil has been limited in its use mainly due to its potential hazards for crop, soil structure and soil organisms among others [20].

Quite a number of researches have pointed out the advantages of aerated irrigation to plant growth and productivity. Niu et al. [21] reported that post-irrigation aeration enhanced greenhouse cucumber plant height and stem diameter under both furrow irrigation and sub-surface drip irrigation (SSD). Bhattarai et al. [13] reported higher root weight, root diameter and root length, highest WUE for Air injection treatment compared to either hydrogen peroxide and control treatment. Similarly, Bhattarai et al. [3] and Dhungel et al. [22] reported higher WUE for air injection treatment of irrigation water as compared to control treatment in soybean and pineapple respectively. Shahien et al. [23] reported that air injection with subsurface trickle irrigation treatment recorded higher chlorophyll content, total carbohydrates, soluble sugar and insoluble sugar as compared to surface trickle irrigation and subsurface trickle irrigation in potato. They also recorded significantly lower irrigation water amount, plant water consumption and higher yield and WUE in potato with air injection with subsurface trickle irrigation treatments compared to surface trickle irrigation and subsurface trickle irrigation. Pendergast et al. [24] reported that, significantly greater total root mass per plant was recorded with oxygation treatment compared to the control treatment which was without oxygation supply. Vivek et al. [25] reported that Radish yield obtained in air injection irrigation plot was higher (2.47 t/ha) against control drip irrigated plot (2.24 t/ha). According to Wang et al. [14] tomatoes fruit yield was 21% higher under aerated water irrigation than the control. Aerated irrigation improved the reproductive performance of tomatoes through early flowering and fruiting [14]. oxygenated brackish water irrigation was also reported to improve the germination rate, germination potential, germination index, vigor index, and plant height of wheat were significantly higher than those of brackish water treatment [14]. Bhattarai et al. [3] reported higher total marketable yield (8.86 and 89 t/ha in watermelon and pumpkin respectively) with oxygation as compared to control. Torabi [26] observed the response of four vegetable species to oxygation. He reported the Soil Plant Analysis Development (SPAD) value of onion (57), bean (37) and beet root (36) was higher in aerated treatment as compared to non-aerated. Vitamin C content, soluble protein, soluble sugar and soluble solids in post-irrigation aeration of cucumber fruits harvested under both furrow irrigation (FI) and sub-surface drip irrigation (SSD) were reported by Niu et al. [21] while Bhattarai [3] revealed that increased total soluble sugar content by 19 % and 4% in watermelon and pumpkin, respectively compared to control treatments.

In this study, we investigated the response of *Amaranthus cruenthus* (African spinach) to 4 different aeration methods (by injection of air to the soil before or after irrigation or to the irrigation water) and deficit irrigation levels. To date, there is little or no reports in the literature specifically examining the sensitivity of *A. cruenthus* to different aeration methods. It was expected that varying the volume of air pumped into the root zone would result in an improved soil air environment in the root zone, promote nutrient uptake and thus promote the growth and yield of *A. cruenthus*.

2. Materials and Methods

2.1. Experimental Site and Soil Details

The experiments were conducted in a screen house at The Gateway Polytechnic, Saapade, Ogun State, Nigeria (latitude 6° 59’ 0 N and longitude 3° 41’ 0 E). Saapade is characterized with annual rainfall between 1,400 and 1,500 mm and average daily temperature of 26.5 °C. The experimental soil was taken from the top soil that is rich in organic matter within the study area and the soil was thoroughly mixed together to have a homogeneous soil fertility. Soil type, physical and chemical properties were determined and recorded. 13 kg of the experimental soil was put in each pot to 235 mm depth to anchor, provide support and supply nutrients to the plant during the vegetative and flowering growth stages.

2.2. Experimental Design and Layout

Amaranthus cruethus seed with accession number NHAC3 was purchased from National Horticultural Research Institute (NIHORT) Ibadan, Oyo State, Nigeria. The seeds were sown in the pots of 240 mm depth and 255 mm diameter having 5 holes of diameter 10 mm drilled at the bottom for drainage water so as to have total control of the quantity of water applied to the crop during the study and to prevent underground water from flowing into the crop. The germination of the seeds was observed and recorded after 5 days and the seedlings were watered regularly based on the quantity of water for each treatment. At week 2, seedlings were thinned to two seedlings per pot.

The experimental design was two factors factorial (Field Capacity x Aeration) experiment at four levels each arranged in completely randomized design with three replicates as shown in Table 1. Factor W was the water applied based on 100 %, 75 %, 65 % and 55 % of field capacity which were designated W_0, W_1, W_2 and W_3, respectively. Factor A was aeration treatment based on: air injection of irrigation water (A_1), air injection to crop root zone in soil before irrigation (A_2), air injection to crop root zone in soil after irrigation (A_3) and non aeration treatment (A_0). The influence of the two factors on the growth and yield of African spinach were monitored and recorded. The research was carried out in a screen house to prevent rain water from getting into the plant so as to have a total control of water for the plant, for proper monitoring and to avoid intrusion of animals that could destroy the plants.

Table 1. Experimental Layout of the Aeration and Irrigation of *A. cruenthus*

Replicate 1				Replicate 2				Replicate 3			
A_0W_0	A_1W_0	A_2W_0	A_3W_0	A_0W_0	A_1W_0	A_2W_0	A_3W_0	A_0W_0	A_1W_0	A_2W_0	A_3W_0
A_0W_1	A_1W_1	A_2W_1	A_3W_1	A_0W_1	A_1W_1	A_2W_1	A_3W_1	A_0W_1	A_1W_1	A_2W_1	A_3W_1
A_0W_2	A_1W_2	A_2W_2	A_3W_2	A_0W_2	A_1W_2	A_2W_2	A_3W_2	A_0W_2	A_1W_2	A_2W_2	A_3W_2
A_0W_3	A_1W_3	A_2W_3	A_3W_3	A_0W_3	A_1W_3	A_2W_3	A_3W_3	A_0W_3	A_1W_3	A_2W_3	A_3W_3

W_0 = 100 % FC, W_1 = 75 % FC, W_2 = 65 % FC, W_3 = 55 % FC; A_0 = non aerated water, A_1 = aerated-water, A_2 = aerated soil after irrigation and A_3 = aerated soil before irrigation

2.3. Determination of Quantity of Water for Irrigation

The quantity of water that was applied to the African spinach was computed based on different percentage requirements of the field capacity (FC) applied on the soil. Available water in the experimental pot (W_a), Wilting point (W_p), net depth of irrigation (d_a), crop evapotranspiration (ET_c), irrigation interval (I_{in}) and area of pot (P_a) as well as volume of water that was required for irrigation (I_v) were determined using Equations 1. 2, 3, 4, 5, 6 and 7 respectively.

$$W_a = B_d \frac{\rho_b}{\rho_w} \times \frac{(FC_c - W_p)}{100} \qquad \text{(i)}$$

$$W_p = \frac{FC}{F} \quad \text{(ii)}$$

$$d_n = W_a \times P_n \quad \text{(iii)}$$

$$ET_c = k_c \times ET_o \quad \text{(iv)}$$

$$I_{in} = \frac{d_n}{ET_c} \quad \text{(v)}$$

$$P_a = \pi \frac{d^2}{4} \quad \text{(vi)}$$

$$I_v = P_a \times ET_c \quad \text{(vii)}$$

where B_d is the dept of the pot (cm), ρ_b is bulk density of the soil (g/cm3), ρ_w is density of water (g/cm3), FC is the field capacity of the soil (%) or water holding capacity of the soil (%), W_p is the wilting point of the soil (%), F is a soil factor ranging from 2 to 2.4 depending on the level of silt in the soil [27] – [28], d is the average diameter of the pot used, d_n is net dept of irrigation water in the soil (cm), P_n is the percentage of available water in the soil at which irrigation must be done (30 % at initial growth stage and 60 % at vegetative growth stage were used), ET_c is the crop evapo-transpiration of the crop (mm/day), k_c is the crop coefficient of African spinach and ET_o is the reference evapo-transpiration (mm/day) [29] – [31].

ET_o for Ogun State area for the month of April and May where and when the study was conducted were taken as 4.63 mm/day during the initial growth and 4.28 mm/day during the vegetative growth stage respectively [32]. The k_c value for African spinawch for the initial, vegetative and maturity growth stages were 0.810, 0.809 and 0.919 respectively [32].

For two plants per pot for three days irrigation interval, volume of water required to have enough available water in the soil for the period was determined using equation 8. The irrigation water was discharged near the crop root zone.

$$V_{dp} = I_{in} \times P_a \times FC \times ET_c \times Plant_{number} \quad \text{(viii)}$$

where V_{dp} is volume of water applied

2.4. Aeration Treatment

Oxygation unit for the aeration experiment consists of air flow meter, air pump (Sphygmomanometer C42) capable of running on 3 to 12 direct current voltage (V). An emitter was buried each in the crop root zone. The other end of the emitter was connected to pump through a hose. Fine bubble air stone (ASW-10108) of carborundum material (108 x 19 x 5 mm) with gas output of 4 L/min was used as a diffuser which was inserted into the irrigation water. Air flow meter was installed to measure the mean air flow rate (L/min) at 3.5V, 5.02V, 7.5V, 11.1V, and 12.5 V supplied through the variable voltage power supply. Water aeration treatment was calculated based on the aeration time flow rate of air injection into water or crop root zone.

2.5. Determination of Quantity of Aeration Required in the Crop Root Zone

Aeration treatments based on irrigation without aeration (A_0), irrigation with aerated-water (A_1), soil aeration after irrigation (A_2) and soil aeration before irrigation (A_3). Aeration volume (V_a), porosity, and aeration time were determined using Equations 9, 10, 11 and 12. L is the mean length of the plant root. 2.65 (g/cm3) was used for particle density (ρs) of the soil which is commonly used for most soil [33].

$$V_a = A_P L\left(1 - \frac{\rho_b}{\rho_d}\right) - FC \quad \text{(ix)}$$

$$Porosity = \left(1 - \frac{\rho_b}{\rho_d}\right) \quad \text{(x)}$$

$$Porosity = \left(1 - \frac{1.426}{2.65}\right) = 0.46 \equiv 46\% \quad \text{(xi)}$$

Total porosity was estimated from bulk density and particle density (assuming, particle density = 2.65 gcm −3). Hence, total porosity (%) = (1 − Bulk density/Particle density) * 100 [34].
At constant $A_P L$, aeration is expressed as:

$$Aeration = porosity - FC \quad \text{(xii)}$$

Aeration = 0.46 – 0.2695 = 0.1824 = 18.24%

Aeration volume is given as:

$$V_a = A_p L(Aeration) \quad \text{(xiii)}$$

while aeration time is given as:

$$t = \frac{V_a}{Q} \quad \text{(xiv)}$$

Aeration volume based on crop evapotranspiration (ET_c) was determined using Equation

$$V_a = A_p \times ET_c \times Aeration \quad \text{(xv)}$$

At 3 days irrigation interval for 2 plants per pot and aeration treatment with respect to ET_c at a particular water level applied W_i (where i = 0, 1, 2, 3) based on the above Equations, the aeration time (A_t) in seconds was expressed as

$$A_t = \frac{A_p \times ET_c \times Aeration \times plant_{numbet} \times FC \times I_{in} x60}{flowrate} \quad \text{(xvi)}$$

where flow rate is in L/min.

2.6. Measurement of Agronomic Parameter

To observe the dynamic change of plant growth and development, plant heights of the *A. cruenthus* were measured using a steel ruler. The number of leaves of the spinach were also counted.

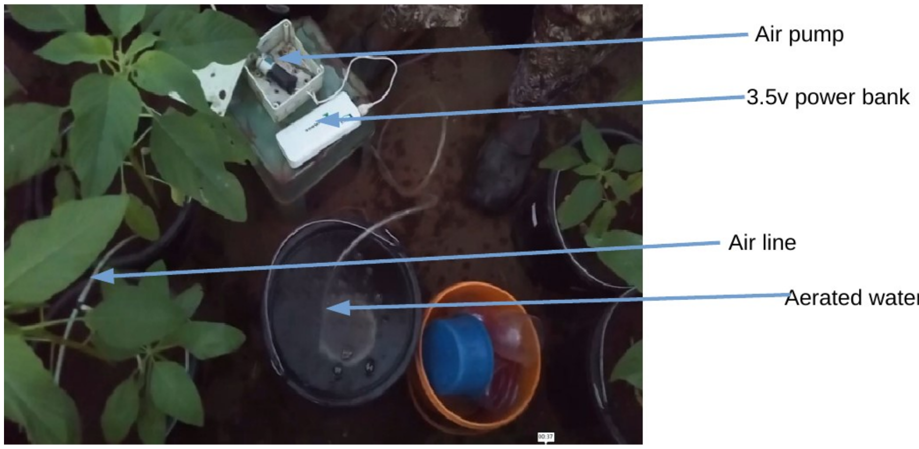
2.7. Calculation of Water and Air Productivity

Irrigation water use efficiency (WUE, g/litre) is defined as the ratio of fresh yield (g) to the amount of irrigation water applied per pot. The total irrigation volume for each treatment was estimated as the total irrigation water volume divided by the number of weeks. The observed fresh weight of the harvested spinach from each treatment for a given treatment was summed to obtain the total yield. This was calculated as the WUE = (Y/W), where WUE = water use efficiency; Y = total yield (g) and W = amount of applied water (Litres) for each treatment.

The air-use efficiency (AUE g/litre) was calculated as AUE = (Y/A), where AUE = air use efficiency; Y= total yield (g) and A = amount of air that was injected into each pot for each of the treatments.

Figure 3. Growth of *A. Cruenthus* Under Varying Aeration and Soil Moisture Content at 5 Weeks After Planting

A = irrigation of plant without aeration (A_0); B = irrigation of plant with aerated-water (A_1); C = aerated plant root zone after irrigation (A_2); D = aerated plant root zone before irrigation (A_3)



2.8. Statistical Analysis

Weekly experimental data on the plant agronomic parameters (plant height, number of leaves) as well as WUE and AUE were subjected to statistical analysis using 'R Package DoE.base', 'R Commander' and 'R: A Language and Environment for Statistical Computing' (Fox and Bouchet-Valat, 2018, 2020). All the data were analyzed using two-way ANOVA to determine the significant differences among the means. Difference in means were compared using the Least Significant Difference test. Correlation analysis was carried out to examine the linear relationship between each of the treatments factors and the agronomic parameters, WUE and AUE.

3. Results and Discussion

3.1. Total Volume of Air and Irrigation water Applied

Volume of water and aeration applied from week 4 to 7 is shown in Table 2. The results revealed that W_0 applied the largest total volume of water (30.42 litre) while W_3 gave the lowest volume of 16.71 litres throughout the 4weeks growing period. The total volume of air applied through out the growing period was 2.51 litres.

Table 2. Volume (in liter) of Water and Aeration Applied During Aeration Experiment

Treatments	**Levels**	**Weeks after Planting**				**Total Volume Applied (Litres)**
		4	**5**	**6**	**7**	
Quantity of Water (litr)	W_0	4.85	7.47	10.17	7.93	30.42
	W_1	3.59	5.60	7.63	5.95	22.77
	W_2	3.10	4.85	6.60	5.16	19.71
	W_3	2.64	4.11	5.6	4.36	16.71
Quantity of air (litr)	A_0	0.40	0.62	0.84	0.65	2.51

W_0 = 100 % FC, W_1 = 75 % FC, W_2 = 65 % FC, and W_3 = 55 % FC

The volume of irrigation water applied increased with increasing field capacity. Generally, applied water and air increased weekly from week 4 to 7 (Table 2).

3.2. Growth Characteristics of *A. cruenthus*

The cumulative vegetative growth parameters of *A. cruenthus* height and number of leaves at 4, 5, 6 and 7 weeks after planting for 4 aeration and irrigation levels are presented in Table 3. The results showed that varying irrigation as well as aeration levels had significant effects on the plant height and number of leaves during the growing period. The ANOVA P-value showed that aeration and field capacity (FC) were unable to influence the plant height at 4 weeks after planting (WAP). However, interaction of Aeration*FC significantly influence the plant height at 4 weeks after planting. At 5weeks, only the interaction of Aeration and FC was significant. Only aeration significantly influence the plant height at 6WAP. However, all the factors as well as their interaction significantly influence the plant height at & WAP (Table 3). For the number of leaves, only aeration had influence on the number of leaves at week 4 and 7, while the FC as well as interaction of aeration*FC had no significant influence on the number of leaves at 4 weeks after planting. At week 5 and 6 week after planting, none of the variables had influence on the number of leaves of *A. cruenthus*.

Table 3. Analysis of Variance Showing the P-values ($p \leq 0.05$) on the Plant Height and Number of Leaves of *A. cruenthus* as Influenced by Varying Aeration and Irrigation Levels

Agronomic Parameters	Source of Variation	df	Weeks after Planting			
			4	5	6	7
Plant height	Aeration	3	0.890 ns	2.487 ns	3.414 *	11.917 *
	Field capacity	3	0.046 ns	0.036 ns	2.110 ns	8.280 *
	Aeration*Field capacity	9	2.478 *	3.046 *	1.254 ns	2.515 *
Number of leaves	Aeration	3	7.738 *	2.677 ns	1.197 ns	3.843 *
	Field capacity	3	0.743 ns	0.164 ns	0.858 ns	2.697 ns
	Aeration*Field capacity	9	1.982 ns	1.003 ns	0.648 ns	1.162 ns

* = significant at $p \leq 0.05$; ns = not significant at $p \leq 0.05$

At week 4 and 5, all the FC and aeration levels had similar effect on the plant height (Table 4). However, similar effects of FC were exhibited on the plant height at 6WAP. W_1 (75% FC) had the greatest positive effect on the plant height at 4 and 5 WAP as it recorded the height height of 14.26 cm and 24.18 cm respectively. At 6 and 7WAP, W_2 had the highest plant height. Although, W_1 and W_2 were statistically similar likewise W_0 and W_3 at 7 WAP. The influence of aeration treatment showed that A_0 and A_2 gave similar plant height at 6WAP. At 6 and 7WAP, A_1 gave the highest height of 41.38 cm and 52.46cm respectively.

Table 4. Result of Mean Separation on the Influence of Varying Levels of Field Capacity and Aeration on the Plant Height as Revealed by LSD

Source of Variation	Levels	Weeks After Planting			
		WK4	**WK5**	**WK6**	**WK7**
Field capacity (%)	W_0	14.53 ± 3.32^a	23.70 ± 4.34^a	8.18 ± 4.34^a	44.29 ± 8.79^a
	W_1	14.26 ± 3.49^a	24.18 ± 5.66^a	39.04 ± 6.56^a	49.75 ± 5.57^b
	W_2	14.18 ± 2.48^a	23.90 ± 4.99^a	39.80 ± 6.48^a	50.61 ± 7.43^b
	W_3	14.25 ± 1.59^a	24.04 ± 2.99^a	34.36 ± 7.61^a	42.71 ± 4.49^a
Aeration (%)	A_0	14.87 ± 2.95^a	24.66 ± 4.09^a	35.64 ± 7.89^{ab}	41.53 ± 7.83^a
	A_1	14.78 ± 2.51^a	25.98 ± 3.63^a	41.38 ± 5.17^b	52.46 ± 7.17^c
	A_2	13.39 ± 2.81^a	23.00 ± 4.94^a	39.52 ± 6.16^{ab}	48.51 ± 5.17^{bc}
	A_3	14.20 ± 2.75^a	22.18 ± 4.60^a	34.94 ± 4.79^a	44.86 ± 4.68^{ab}

Means with the same letter vertically are not significantly different at ($p \leq 0.05$)

The least plant height (34.36 cm) at 6WAP could be attributed to the non-availability of adequate moisture, which has a significant impact on the vegetative growth of the vegetable because plant under stress tend to experience difficulty in absorbing essential nutrients and hence growth and development is negatively affected [35].

For the number of leaves of *A. cruenthus,* all the FC levels showed similar number of leaves at 4, 5 and 6 WAP while the aeration treatments had similar effects at 5 and 6 WAP (Table 5). At 4 and 7 WAP, 65% FC (W_2) gave the highest number of leaves through out the growing period (Table 5). Air injection to crop root zone in soil before and after irrigation had similar influence on the number of leaves at 4 and 7 WAP respectively. Likewise, aeration of irrigation water recorded the highest number of leaves of 14 and 20 at 5 and 7 WAP respectively. W_0 and W_1 gave similar number of leaves at 4 and 7WAP respectively. In the same vein, none of the aeration treatments was able to influence the number of leaves at 5 and 6WAP.

Table 5. Result of Mean Separation on the Influence of Varying Levels of Field Capacity and Aeration on the No of Leaves as Revealed by LSD

Source of Variation	Levels	Weeks After Planting			
		4	**5**	**6**	**7**
Field capacity (%)	W_0	9.00 ± 1.76^a	12.00 ± 1.78^a	17.00 ± 1.66^a	19.00 ± 1.87^{ab}
	W_1	9.00 ± 1.91^a	13.00 ± 2.22^a	16.00 ± 1.67^a	19.00 ± 1.25^{ab}
	W_2	10.00 ± 1.11^a	13.00 ± 2.03^a	17.00 ± 2.07^a	20.00 ± 1.38^b
	W_3	9.00 ± 0.65^a	13.00 ± 1.34^a	16.00 ± 1.44^a	18.00 ± 2.06^a
Aeration (%)	A_0	11.00 ± 1.07^b	13.00 ± 1.56^a	16.00 ± 1.74^a	18.00 ± 1.09^a
	A_1	10.00 ± 0.80^{ab}	14.00 ± 1.67^a	17.00 ± 1.61^a	20.00 ± 1.79^b
	A_2	9.00 ± 1.71^a	13.00 ± 2.03^a	17.00 ± 1.98^a	19.00 ± 1.76^{ab}
	A_3	9.00 ± 1.14^a	12.00 ± 1.54^a	16.00 ± 1.32^a	18.00 ± 1.80^{ab}

Means with the same letter vertically are not significantly different at ($p \leq 0.05$)

Generally, no significant difference was obtained in number of leaves across the varying field capacities (Table 3). The findings of this work showed that *A. cruenthus* was not sensitive to air treatment as expected. This is because lower number of leaves were obtained when air was either injected into the soil before or after irrigation as well as when air was injected into irrigation water at 4 and 7 WAP. However, the number of leaves tend to increase when air was injected into the irrigation water at 7WAP. Plant height was maximum when no air was introduced to the plant at 4WAP.

It was expected that the number of leaves will reduce with reducing available water content. However, the number of leaves were highest at 65% field capacity through out the growing period. This implied that at 65% field capacity, the water deficit was not sufficiently high to affect the vegetative growth of *A. cruenthus*. This clearly showed that the growth rate of the vegetables were not reduced. Likewise, the plants cell division and enlargement on which the growth rate depends were not affected [36]. Although some studies reported reduction in leaf area of egg plants with reduced irrigation water [37]. However, the results clearly showed that 65% field capacity was probably optimum for *A. cruenthus*. Therefore, *A. cruenthus* could be grown through sustainable irrigation management to avoid high yield losses in future climate scenarios [38].

3.3. The Effect of Different Aeration and Water Treatments on the Yield Components of *A. cruenthus*

The result of the analysis of variance on all the yield components (shoot, root, whole plant fresh weight and shoot to root ratio) showed that they were all significantly influenced by the aeration treatments. However, only root fresh weight was not influenced by the available water content (Table 6). The interaction if the two variables did not significantly influence all the yield components.

Table 6. Analysis of Variance Showing the P-values ($p \leq 0.05$) on the Yield Components of *A. cruenthus* as Influenced by Varying Aeration and Irrigation Levels

Source of Variation	P-values		
	Shoot Fresh Weight (g)	Root Fresh Weight (g)	Whole Plant Fresh Weight (g)
Aeration	5.788 *	3.260 *	5.739 *
Field capacity	1.127 ns	3.591 *	1.394 ns
Aeration*Field capacity	1.356 ns	1.951 ns	1.410 ns

* = significant at $p \leq 0.05$; ns = not significant at $p \leq 0.05$

The highest yield (whole plant fresh weight) of 65.42g was obtained when *A. cruenthus* was planted under 75% field capacity and when irrigated with non aerated water (A_0) (Fig 1a-c). Although, the edible yield (shoot fresh weight) was highest (48.55g) when the field capacity was 100% (W_0). Also, when the air was injected into the irrigation water (A_1), the highest edible yield of 57.33 g was obtained. Generally, injecting air into the irrigation water gave the best edible yield at 100% field capacity.

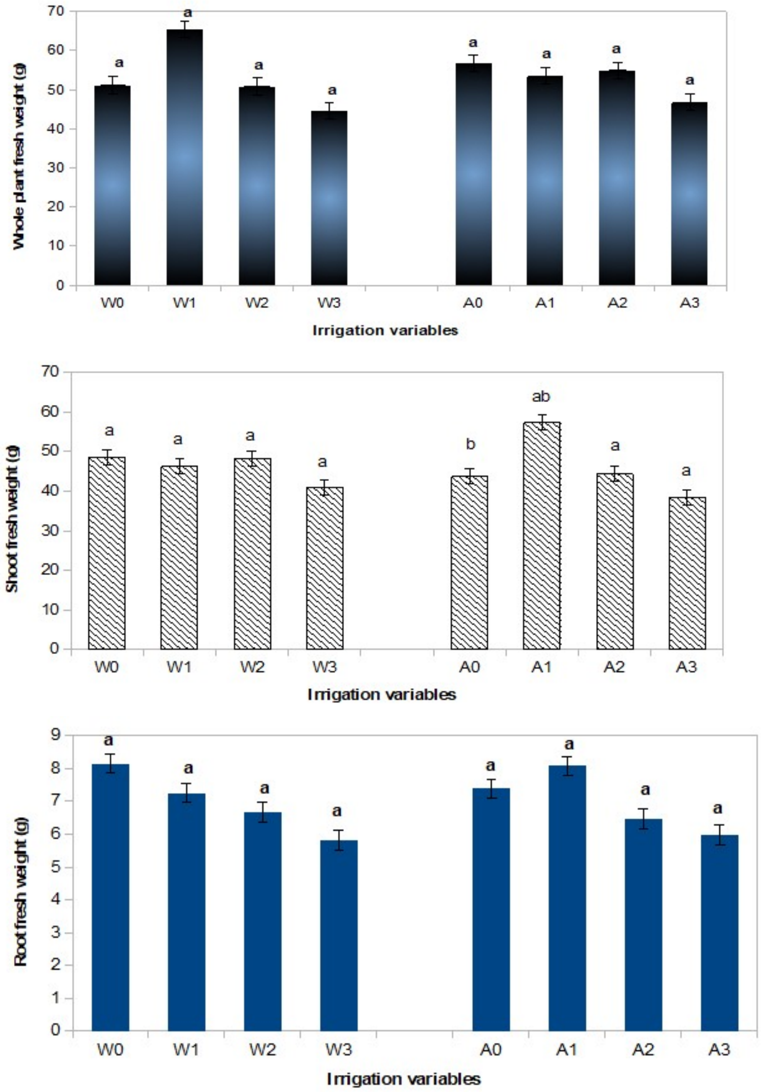


Figure 1. Influence of Irrigation Variables on (a) Whole Plant Fresh Weight; (b) Shoot Fresh Weight; (c) Root Fresh Weight of *A. cruenthus*

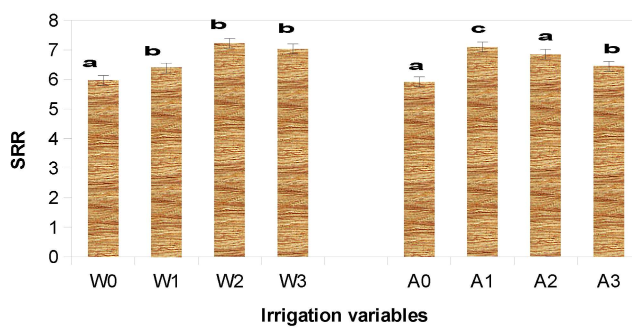


Figure 2. Influence of Irrigation Variables on the Shoot/Root Ratio of *A. cruenthus*

Considering the influence of the two variables on the shoot to root ratio (SRR), the best SRR of 5.96 and 5.92 were gotten at 100% field capacity and when non aerated irrigation water was used respectively (Fig. 2). This implied that the highest leafy content which is the edible part was gotten when the vegetable was given full irrigation amount and when air was not injected into the irrigation water. Although there were no significant differences in all the yield components across all the varying field capacity (Table 6). The root and whole plant fresh weights were statistically similar across all the irrigation and aeration treatments. However, the shoot fresh weight as well as the SRR vary significantly across all the aeration treatments. Shoot fresh weights and SRR were similar for vegetables that were aerated before irrigation (A_2) as well as after irrigation (A_3). Similarly, SRR were similar for W_0 and W_1 and W_2 and W_3 respectively (Fig. 2).

Since there were no statistical difference in the shoot fresh weight which is the edible part, there is a potential to save water by reducing irrigation rates without negatively impacting the shoot fresh yields. Although the results indicated that 65% field capacity gave the second highest yield of 48.22 g which was very close to the highest yield of 48.55g (Fig 1b). So, their is no point wasting water if the yield of the vegetable will not be negatively affected even when irrigating at lower field capacity such as 65%. Senyigit et al. [39] got similar finding, they reported that highest yield was obtained from full irrigation treatment as well as 10% reduction of full irrigation amount. So, irrigating at 65% field capacity (which is 35% reduction of full irrigation amount) is recommended to maximize *A. cruenthus* yield while conserving water.

In the same vain, not aerating the irrigation water was the best. So there is no point wasting money on air injection equipment before the maximum yield could be obtained for *A. cruenthus.* So, irrigation without air injection (A_0) was best for growing *A. cruenthus* to achieve the maximum yield. These findings showed that *A. cruenthus* may tolerate mild water stress, because the yield was similar irrespective of the level of water given to it. Diaz-Perez and Eaton [40] reported similar scenario for eggplant where plants irrigated at 20-30 % reduction of ETc produced fruit yields similar to those of plants irrigated at 100% ETc.

3.4. The Effect of Different Treatments on the AUE and WUE of *A. cruenthus*

Results of data on water use efficiency (WUE) and air use efficiency (AUE) of A. cruenthus as influenced by the different levels of aeration and field capacity is presented in Table 7. Analysis of variance on the effect of deficit irrigation on WUE and AUE of *A. cruenthus* showed that aeration and field capacity significantly influence WUE while only aeration was able to influence the AUE (Table 7). The interaction of aeration and field capacity were not significant on both WUE and AUE

Table 7. Analysis of Variance Showing the P-values (p≤ 0.05) on the WUE and AUE of *A. cruenthus* as Influenced by Varying Aeration and Irrigation Levels

Source of Variation	P-values	
	WUE (g/litr)	AUE (g/litr)
Aeration	6.005 *	5.739 *
Field capacity	5.206 *	1.394 ns
Aeration*Field capacity	0.659 ns	1.410 ns

* = significant at p ≤ 0.05; ns = not significant at p ≤ 0.05

Generally, there were significant variations in the AUE of *A. cruenthus.* However, the WUE were statistically similar. The highest WUE and AUE were exhibited by *A. cruenthus* at 100% FC (W_0) even though there were no statistical difference across all the field capacity. *A. cruenthus* planted under aeration of irrigation water (A_1) gave the highest (26.06) AUE (Fig. 2).

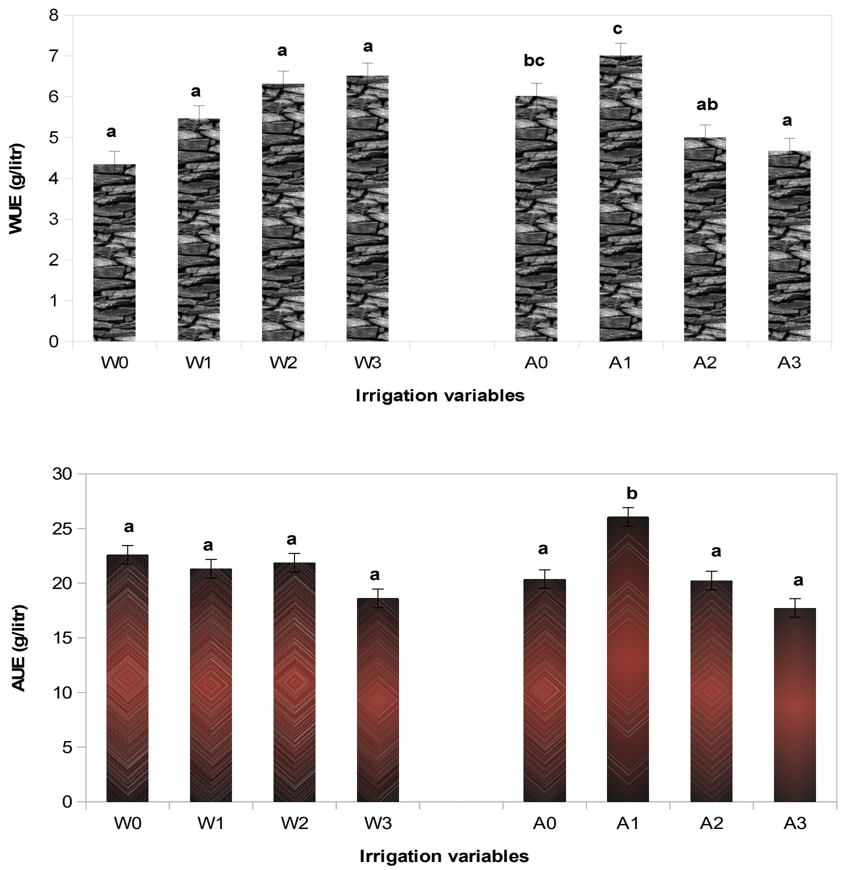


Figure 3. Influence of Irrigation Variables on (a) WUE and (b) AUE of *A. cruenthus*

When considering the influence of field capacity on AUE, 100% (W_0) gave the best AUE while the poorest AUE was recorded at 55% (W_3) field capacity. Likewise, *A. cruenthus* efficiently use water most when air was injected into the irrigation water (A_1) and least when air was injected to the root zone after irrigation (A_3). These findings go contrary to that of Senyigit et al., [39]; Serhat [41] and Darko et al. [42] who reported lowest water use efficiency at 100% Etc for eggplant. This shows that the response of plants to water stress differs from plant to plant. Their findings indicated that WUE decreased with increasing irrigation water. However, this study showed that WUE increased as the available water content increased. The phenomena where lower available water gives the higher WUE indicates that as the crops are exposed to water stress there is high dry matter accumulation [42] – [43].

4. Conclusion

The root and whole plant fresh weights were statistically similar across all the irrigation and aeration treatments. However, the shoot fresh weight as well as the shoot/root ratio vary significantly across all the aeration treatments. *A. cruenthus* efficiently use water most when air was injected into the irrigation water. WUE increased as the available water content increased. Injecting air into the irrigation water gave the best edible yield at 100% field capacity. *A. cruenthus* may tolerate mild water stress, because the yield were similar irrespective of the level of water given to it.

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