ARTICLE
Saline Irrigation Water Retards Growth of Amaranthus in Coastal Kenya

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ABSTRACT
Salinity is a major biotic factor that negatively affects growth and yield of crops. Over 90% of the coastal region of Kenya is arid and semi-arid, most farmers in the region use borehole irrigation water which is saline. Amaranthus spp. is one of the main vegetables grown in coastal region. There is limited information regarding the effect of salinity on amaranthus production. The study sought to determine the effect of saline irrigation water on amaranthus growth in coastal Kenya. Two experiments were set up, one at Mivumoni Secondary School farm in Kwale County and another at Pwani University farm in Kilifi County from beginning of September 2019 to the end of January, 2020. The experiments were laid out in a randomized complete block design and replicated three times. The six treatments tested were: fresh water alone, 75% saline water alone, 100% saline water alone, fresh water + DAP, 75% saline water + DAP, 100% saline water + DAP. Crop growth data collected were: emergence rate, plant height, leaf number, leaf area, chlorophyll content, stem thickness, root density, root weight, root volume and total plant biomass. Data obtained were subjected to analysis of variance using SAS statistical package (SAS, Version 10) and treatment effects were tested for significance using F-test. Significant means at F-test was ranked using Tukey’s test at 5% level of significance. Amaranthus seeds sown in fresh water had higher emergence rate compared to seeds sown in saline water. Salinity regardless of concentration used and application of DAP, resulted in decrease in height, leaf number, leaf area, chlorophyll content, stem thickness, root density, root weight, root volume and total plant biomass. The study demonstrates that saline irrigation water in coastal Kenya has a negative effect on Amaranthus growth.

1. Introduction
Salinity is a major biotic factor that negatively affects growth and yield of crops [1]. With over 90% of the coastal region of Kenya being arid and semi-arid, most farmers in the region are forced to use borehole irrigation water which is mainly saline [2]. Saline water refers to any water that contains more than 1,000 parts per million (mg kg⁻¹) dissolved solids or one that has a specific conductance more than 1,400 µΩ/cm at 25 °C [1]. Salinity has a significant effect on crop and soil. Salinity results in deterioration in

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the physical structure of the soil like water permeability and reduction in soil aeration, and reduction in the osmotic potential of the soil solution. Salinity consequently result in the reduction of plant water availability and minerals uptake, increase in the concentration of certain mineral ions that have an inhibitory effect on plant metabolism and physiology which negatively affect growth and yields. 

Kilifi County experiences unreliable rainfall with frequent drought. Areas like Bamba, Ganze and western part of the county experience about 5-6 months of continuous dry weather. Therefore, groundwater contributes nearly 50% of the water used in the area through boreholes. Kwale County on the other hand which lies on the southern part of the Kenyan coastal line is also dry and experiences unreliable rainfall. Subsistence agricultural activities within the area are rainfed while commercial agriculture mainly relies on underground saline water to complement the few rivers around.

According to Kumar and Rao, irrigation water quality depends on the type and quantity of dissolved salts. Salinity of the soil reduces uptake of plant phosphorus causes toxicity of ions, osmotic stress and deficiency of nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), iron (Fe) and zinc (Zn) which limits plant water uptake. Elements like sodium (Na), chlorine (Cl), and boron (Bo) have specific toxic effects on plant. According to Akbarimoghaddam et al. as well as Reynolds et al., presence of salts in the soil affects interaction among physiological, morphological and biochemical processes like germination of seeds, growth of plant, nutrient and water uptake. Saline growth medium has adverse effects on plant growth; osmotic stress, salt stress, nutrition imbalance or combination of the factors. Accumulation of salts in the soil is known to cause metabolic and physiological disturbance in crop affecting, yield, growth and crop quality. Salt accumulation around the root zone prevents plant roots from withdrawing water from the surrounding soil decreasing available water for plant, causing stress to plant. Soil salinity causes flocculation which promotes soil aeration and growth of roots; however, its increase to high level is lethal to plant growth. Sodium salts accumulation in soil has an opposite effect to salinity in soil. High concentration of sodium salts causes dispersion which leads to reduced infiltration, surface crusting and reduced hydraulic conductivity. In clay soil high sodium concentration causes aggregation and swelling. High Na concentration causes osmotic stress leading to cell death.

*Amaranthus* spp. is an important crop for human diet and income generation in the coastal region. However, its yield and quality have been declining. This has been attributed to poor soil condition and irrigation water quality, especially salinity, in addition to other factors like unfavourable weather conditions leading to poor growth and poor yields. Despite the importance of salts in crops nutrient uptake, physiological and metabolic activities and the resulting yields and quality, limited research has been carried out on the effects of saline borehole water especially within the Kenyan Coast. Objective of the study was to determine the effect of saline irrigation water on *amaranthus (Amaranthus dubius Mart. ex Thell.)* growth in Coastal Kenya.

2. Materials and methods

2.1 Site of the Study

Two experiments were set up, one in Mvumoni Secondary School farm in Kwale County and another in Pwani University farm in Kilifi County, from beginning of September 2019 to the end of January, 2020. Kilifi County lies between latitude 3.63° S and longitude 39.85° E in the Coastal lowland (CL) 3-CL6. The landscape covers an area of 12,609.7 square kilometers and lies within 30 to 310 meters above sea level. It experiences average daily temperature of 21°C - 32°C and average annual rainfall of 600-1100 mm. It is dominated by sandy-loam soil which is well drained, shallow to moderately deep, dark brown to yellowish brown whose pH ranges between 4.22 - 7.80. Kwale County on the other hand lies between latitudes 4.33° S and longitudes 39.52° E in the Coastal lowlands agro-ecological zones CL3-CL5. It covers an area of 8270.2 square kilometers, altitude of between 0 - 462 meters above sea level and receives poorly distributed, unreliable annual rainfall ranging from 400 mm to 1200 mm per year and mean annual minimum and maximum temperatures are 24 °C and 27.5 °C respectively. The predominant soil in the area is sandy-clay whose pH ranges between 5.35 and 7.80.

2.2 Candidate Crop

*Amaranthus (Amaranthus dubius Mart. ex Thell.)* was procured from Amiran, Mombasa, Kenya. The vegetable was chosen because it is widely grown and consumed in the coastal region.

2.3 Experimental Design, Treatment Application and Crop Husbandry

The experiments were laid out in a randomized complete block design and replicated three times. The six treatments tested were: fresh water alone, 75% saline water alone, 100% saline water alone, fresh water + DAP, 75% saline water + DAP.
DAP, 100% saline water + DAP. Kwale county composite soils were used for Mivumoni greenhouse experiment while Kilifi county composite soil samples were used for the Pwani University greenhouse experiment trials. Four kilograms composite soil samples were measured and put in five-liter plastic pots. DAP fertilizer (250 kg/ha) was measured, incorporated in each pot that was meant for DAP treatment and mixed thoroughly. Saline water (200 ml) at 4 dS m\(^{-1}\) electrical conductivity (EC) was used for 100% saline water, fresh water of EC 0 dS m\(^{-1}\) and a mixture of the 150 ml saline water and 50 ml of the fresh water for the 75% saline water treatments were added every 2 days to compensate for evaporative losses. Twenty amaranthus seeds were then sown in each pot. Thinning was done to allow only ten seedlings per pot. Water treatments (200 ml) were applied throughout the experimental period (60 days) in the form of manual irrigation.

### 2.4 Data Collection

Three plants per pot were randomly selected from the pots in the inner rows and tagged for data collection. Crop growth data collected were:

#### 2.4.1 Emergence Rate

Number of seedling emergence per treatment per day was counted from 1\(^{st}\) day of sowing and recorded up to 10\(^{th}\) day, recorded and percent emergence computed.

#### 2.4.2 Plant Height

Plant height was established by measuring the height of the tagged plants from each pot using a meter rule. The measurements were carried out on weekly basis from one till tenth week after crop emergence. The measurements were taken from the ground level to the tip of the shoot and recorded in centimeters (cm).

#### 2.4.3 Number of Leaves

Number of leaves was determined by counting the total number of leaves on the tagged plants per pot on weekly bases two weeks after crop emergence up to tenth week after emergence.

#### 2.4.4 Leaf Area

Fully expanded leaves (third, fourth, and fifth from the shoot) of the tagged plants per pot were used to determine leaf area. The length and width of the leaf were measured using a ruler. Length and width were multiplied by a constant as in the formula: Leaf Area = Length × width × 0.75 (constant) for the triangular leaves such as amaranthus. Leaf area was measured one week after emergence and thereafter on weekly basis up to tenth week and results recorded in squared centimeters (cm\(^2\)).

#### 2.4.5 Stem Thickness

Tagged plants per pot were used to measure stem thickness using a standard vernier caliper. The jaws of vernier caliper were placed on the stem just above the ground level and readings recorded in centimeters (cm). This was done on a weekly basis until tenth week from 1\(^{st}\) week of crop emergence.

#### 2.4.6 Root Growth Characteristics

Root length: on the tenth week after emergence, the tagged plants per pot were uprooted, washed. Root length measured using a ruler and recorded in centimeters (cm). Root weight (dry): on the tenth week after emergence, the tagged plants per pot were uprooted, washed, dried and weighed on an electronic weighing balance and Weight recorded in kilograms (kg). Root volume: on the tenth week after emergence, the tagged plants per pot were uprooted, roots chopped off, washed and used to determine root volume by displacement method. Known volume of water was filled into the beaker to the brim. Clean roots were immersed then displaced water was collected. Volume of displaced water was measured and recorded in cubic centimeters (cm\(^3\)).

#### 2.4.7 Chlorophyll Content

Chlorophyll content was measured using chlorophyll meter (CCM-200, Opti-sciences, Inc. Tyngsboro, MA, USA) with a precision of ± 1.0 chlorophyll concentration index units (CCI). This was done every until the tenth week after emergence. The readings were taken from the tagged plants per pot on the third, fourth, and fifth leaves from the shoot that had fully expanded.

#### 2.4.8 Total Biomass

On the tenth week after emergence, the tagged plants per pot were uprooted, then oven dried at 75 °C until a constant weight and used to determine biomass yield. Yield was determined by weighing on an electronic weighing balance and weight recorded in kilograms (kg).

### 2.5 Data Analysis

Data obtained were subjected to analysis of variance using SAS statistical package (SAS, Version 10) and treatment effects were tested for significance using F-test. Significant means at F-test was ranked using Tukey’s test. All analysis was at 5% level of significance.

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3. Results

3.1 Seedling Emergence Rate

Significantly ($p \leq 0.05$) higher emergence rate of seedlings was observed in fresh water compared to those from saline water in Pwani University (95%) and Mivumoni (97%) respectively (Figure 1). This was followed by fresh water which had significantly higher rate of emergence compared to saline water plus DAP, 75% saline water plus DAP and 75% saline water were not significantly different. Saline water plus DAP had the lowest rate of emergence in both sites.

3.2 Plant Height

Amaranthus grown in fresh water plus DAP was significantly ($p \leq 0.05$) taller compared to the rest of the treatments, in both Pwani University and Mivumoni by 56% and 54% respectively (Table 1). This was followed by fresh water, 75% saline water plus DAP and saline water plus DAP. Plants grown in saline water plus DAP were the shortest.

3.3 Leaf Number

Plants grown in fresh water plus DAP had significantly ($p \leq 0.05$) higher number of leaves, followed by fresh water compared to the rest of the treatment in both Pwani university and Mivumoni. Amaranthus grown in saline water, saline plus DAP and 75% saline which had comparable number of leaves. Plants grown in saline water had the lowest number of leaves (Table 1).

3.4 Leaf Surface Area

Amaranthus planted in fresh water plus DAP had sign-

![Figure 1. Effect of saline borehole water on emergence of amaranthus in Pwani University (Kilifi county) and Mivumoni (Kwale county). Means followed by the same letters within a study site are not significantly different according to Tukey’s Test ($p \leq 0.05$).](image)

| Table 1. Effect of saline borehole water on growth of amaranthus in Pwani University (Kilifi county) and Mivumoni (Kwale county) |
| --- |
| Treatment | Plant height (cm) | Leaves (no./plant) | Leaf surface area (cm$^2$) | Stem thickness (cm) |
| | PU | MI | PU | MI | PU | MI | PU | MI |
| Fresh | 27.8$^a$ | 27.4$^a$ | 12.6$^a$ | 10.2$^a$ | 12.7$^{ab}$ | 13.4$^a$ | 1.2$^b$ | 1.3$^a$ |
| Saline | 13.9$^c$ | 14.1$^c$ | 4.8$^d$ | 4.0$^d$ | 4.8$^d$ | 8.7$^d$ | 0.8$^e$ | 0.7$^e$ |
| 75% saline | 18.5$^b$ | 18.6$^b$ | 7.5$^e$ | 5.3$^e$ | 8.1$^e$ | 12.0$^{bc}$ | 1.0$^e$ | 1.3$^e$ |
| Fresh + DAP | 31.7$^a$ | 28.0$^a$ | 19.3$^a$ | 17.0$^a$ | 15.7$^a$ | 17.0$^a$ | 1.4$^a$ | 1.4$^a$ |
| Saline + DAP | 13.9$^c$ | 12.9$^c$ | 4.6$^d$ | 4.0$^d$ | 5.9$^d$ | 7.2$^d$ | 1.0$^e$ | 1.0$^e$ |
| 75% saline + DAP | 16.4$^{bc}$ | 16.3$^{bc}$ | 7.4$^{a}$ | 7.0$^{a}$ | 11.9$^{c}$ | 13.2$^{bc}$ | 1.1$^{b}$ | 1.2$^{bc}$ |
| LSD (0.05) | 4.0 | 7.5 | 3.3 | 5.3 | 3.8 | 5.6 | 0.2 | 0.2 |
| CV (%) | 6.9 | 13.4 | 12.4 | 23.6 | 13.5 | 16.8 | 5.1 | 6.3 |

Means followed by the same letter(s) within a column are not significantly different according to Tukey’s Test ($p \leq 0.05$). PU = Pwani University, MI = Mivumoni.
significantly ($p \leq 0.05$) larger surface area compared to the rest of the treatment in both Pwani University and Mivumoni by 69% to 58% respectively (Table 1). This was followed by fresh water alone. Amaranthus plants in saline, saline plus DAP, 75% saline plus DAP and 75% saline had comparable leaf surface area. Plants grown in saline water plus DAP had the lowest leaf surface area.

### 3.5 Stem Thickness

Amaranthus grown in fresh water plus DAP had significantly ($p \leq 0.05$) higher stem thickness compared to the rest of the treatments in both Pwani University and Mivumoni by 42% and 25% respectively (Table 1). This was followed by fresh water. Plants planted in saline water, saline plus DAP, 75% saline plus DAP and 75% saline had comparable stem thickness. Plants planted in saline water had the least stem thickness.

### 3.6 Root Growth Characteristics

Amaranthus grown in fresh water plus DAP had significantly ($p \leq 0.05$) larger root volume compared to the rest of the treatments, in both Pwani University and Mivumoni by 84% and 82% respectively followed by fresh water alone (Table 2). Plants grown in saline, saline plus DAP, 75% saline plus DAP and 75% saline had comparable root volume. Plants grown in saline water had the lowest root volume.

Amaranthus grown in fresh water plus DAP had significantly ($p \leq 0.05$) higher root weight compared to the rest of the treatments in both Pwani University and Mivumoni by 91% and 86% respectively (Table 2). This was followed by those grown in fresh water alone. Plants grown in saline, saline plus DAP, 75% saline plus DAP and 75% saline had comparable root weight. Plants grown in saline water had the lowest root weight.

Amaranthus grown in fresh water plus DAP had significantly ($p \leq 0.05$) longer roots compared to the rest of the treatment in both Pwani University and Mivumoni by 73% and 55% respectively (Table 2). This was followed by fresh water alone. Plants grown in saline, saline plus DAP, 75% saline plus DAP and 75% saline had comparable root length.

### 3.7 Chlorophyll Content

Chlorophyll content of amaranthus plants grown in fresh water plus DAP had significantly ($p \leq 0.05$) higher chlorophyll content compared to the rest of the treatment both in Pwani University and Mivumoni by 31% and 28%. There was no significant difference in chlorophyll content in fresh water, 75% saline and 75% saline plus DAP. Plants grown in saline water had the lowest chlorophyll content (Figure 2).

### 3.8 Total Biomass

Amaranthus grown in fresh water plus DAP had significantly ($p \leq 0.05$) higher biomass compared to the rest of the treatments in both Pwani University and Mivumoni by 88% and 74% respectively. This was followed by fresh water alone. Biomass of plants grown in 75% saline and 75% saline plus DAP had comparable biomass. Plants grown in saline water and saline water plus DAP had the lowest biomass in both sites (Figure 3).

**Table 2.** Effect of saline borehole water on root growth of amaranthus in Pwani University (Kilifi county)

| Treatment             | Root volume (cm$^3$) | Root weight (g) | Root length (cm) |
|-----------------------|----------------------|-----------------|------------------|
|                       | PU       | MI     | PU       | MI     | PU       | MI     |
| Fresh                 | 9.0$^b$  | 10.0$^a$ | 1.5$^a$  | 1.4$^b$ | 14.4$^b$ | 15.6$^b$ |
| Saline                | 2.2$^e$  | 2.5$^e$ | 0.2$^e$  | 0.3$^e$ | 5.4$^e$  | 8.9$^e$ |
| 75% Saline            | 5.8$^d$  | 6.0$^a$ | 0.8$^d$  | 0.7$^b$ | 7.7$^d$  | 9.0$^b$ |
| Fresh + DAP           | 13.8$^b$ | 14.0$^a$ | 2.2$^b$  | 2.2$^b$ | 19.8$^b$ | 19.9$^b$ |
| Saline + DAP          | 5.5$^c$  | 5.2$^d$ | 0.5$^c$  | 0.4$^d$ | 7.9$^c$  | 10.6$^d$ |
| 75% Saline + DAP      | 8.2$^b$  | 7.5$^c$ | 1.1$^b$  | 1.6$^c$ | 13.1$^b$ | 13.1$^c$ |
| LSD value             | 2.2      | 2.2    | 0.8      | 1.4    | 2.9      | 1.7    |
| CV (%)                | 10.3     | 10.4   | 6.0      | 44.6   | 8.9      | 4.6    |

Means followed by the same letter(s) within a column are not significantly different according to Tukey’s Test ($p \leq 0.05$). PU = Pwani University, MI = Mivumoni.
4. Discussion

Amaranthus seedlings grown from fresh water had higher emergence rate compared to those grown in saline water. Salinity may affect germination by reducing water imbibition in seeds since activities are related to germination. Additionally, salinity may have promoted absorption of toxic ions altering hormonal or enzymatic activities \[24\]. Cuartero and Fernandez-Munoz \[25\] found that seeds required more days to germinate (50%) in medium at EC 1.4 mS/cm and 100% delayed germination in medium at EC 3.4 mS/cm. Neamatollahi et al. \[26\] reported that increasing NaCl concentration in priming treatments causes higher osmotic pressure hence reducing germination percentage on fennel seeds. Asch and Wopereis \[27\] found that salinity levels below 4 mS cm\(^{-1}\) delayed germination by 1 - 2 days, while higher salinity delayed germination by more than a week. Osborne \textit{et al.} \[28\] also observed that exposure of amaranthus to high salinity inhibits germination and reduce rate of germination. Similar findings were reported with \textit{Eriochiton sclerolaenoides}, \textit{Maireana georgei}, \textit{M. pentatropis}, \textit{M. pyramidata}, \textit{M. trichoptera} and \textit{M. triplera} species in semi-arid climate Australia \[29\].

Increasing salt concentrations resulted to decrease in height, shoot and root lengths, root volume, leaf number, leaf surface area, chlorophyll content and stem thickness. Salinity affects a number of aspects of plant growth and development like; germination, reproductive and vegetative growth. Salinity may cause reduction in water availability by decreasing osmotic potential of total soil water potential. Matric potential and osmotic potential of soil are both elements of total soil water potential and add up

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Effect of saline borehole water on chlorophyll content of amaranth leaves during production in Pwani University (Kilifi County) and Mivumoni (Kwale County). Means followed by the same letter(s) within a study site are not significantly different according to Tukey’s Test ($p \leq 0.05$).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Effect of saline borehole water on total biomass of amaranth during production in Pwani University (Kilifi county) and Mavumoni (Kwale county). Means followed by the same letter(s) within a study site are not significantly different according to Tukey’s Test ($p \leq 0.05$).}
\end{figure}
the effects on availability of water which causes decline in both yield and evapotranspiration \cite{30,31}. Abbas et al. \cite{32} found that salinity and Fe deficiency reduced chlorophyll concentration, shoot and root growth, photosynthetic, stomatal conductance and transpiration rates. Retarded growth may have been caused by osmotic inhibition of oxidative stress, water absorption and specific ions that affect crucial physiological processes in plants. Oxidative stress prevents photosynthetic performance in high saline conditions. Saline soil conditions affect stomatal aperture and reactive oxygen species that hinder activities of the enzymes and membranes related to photosynthesis \cite{5}. Saline soils reduce the uptake of plant phosphorus significantly since phosphate ions precipitates with Ca ions \cite{9}. Salinity has an effect on the absorption of some specific ions across the cell membranes which cause nutritional disturbances to crops \cite{13}. This includes uptake of NO3-, which is lowered by Cl- and K+ uptake which is reduced by Na+. When sodium accumulates in the cell wall excessively, it leads to rapid osmotic stress causing death of the cells \cite{14}.

Soil physical properties can be affected by accumulation of some salts such as sodium in the soil solution as observed in the study and the exchange phase can cause clay dispersion, especially for smectitic clays, which affect soil physical and chemical characteristics by reducing its structural stability and promoting surface crust formation; increasing bulk density and mechanical resistance resulting in poor soil tilth and soil aeration. Reduction of hydraulic conductivity and infiltration rate causes significant water management problems by increasing runoff and erosion potential due to surface sealing and poor infiltration leading to poor water and nutrient uptake hence poor crop growth \cite{35,36}.

5. Conclusions and Recommendations

Results observed indicate that salinity had effects on growth characteristics of amaranthus. Amaranthus grown in fresh water plus DAP had significantly \((p<0.05)\) higher growth characteristic than the rest of the treatments. Plants grown in saline water had the lowest growth characteristics in both sites. There was significantly higher \((p<0.05)\) emergence rate in seeds sown in fresh water compared to those from saline water in Pwani University (95%) and Mivumoni (97%) respectively. Fresh water plus DAP improved amaranthus growth compared to saline water plus DAP in both Pwani University and Mivumoni by 56% and 54% respectively. This was followed by fresh water, 75% saline water plus DAP, 75% saline water, saline water and saline water plus DAP.

Based on the research findings there is need for further studies on:

i. Effect of saline soils on physiology of vegetable crops in coastal region.

ii. Effects of saline irrigation water on various crops in the coastal region.

iii. Effects of saline irrigation water on availability and uptake of mineral elements.

Other policy recommendations include:

Farmers should adopt appropriate measures to manage salinity in irrigation. These measures could include diluting the saline water with fresh water, application of manure to supplement soil nutrients and improve soil structure, water retention capacity, soil microbial activities and buffer soil and appropriate method of irrigation water application.

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