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Heavy metal uptake and growth characteristics of *Amaranthus caudatus* L. under five different soils in a controlled environment

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Abstract

This study investigated the influence of soil types on morphological growth characteristics in *Amaranthus caudatus*. Seeds of *A. caudatus* were sown in soils formulated using USDA soil triangle technique and after germination, variabilities in the mean leaf area, shoot height, girth, mean number of branches and leaves per representative stand on different soils were measured. Also, heavy metal uptake characteristics of the plant were examined by comparing the concentrations of trace metals in the soil before and after planting with amount retained in the plant shoot. The results of soil mineral analysis indicated variabilities in the mineral content of the soil before and after planting. While some trace element concentrations got depleted after planting, some appreciated considerably. In addition, variabilities observed in the mean leaf area, shoot height, girth, mean number of branches and leaves per representative plant on different soils suggested the critical role of minerals present in each soil type in plant development. Some essential minerals such as calcium and magnesium were returned to the soil in three-fold of their initial concentrations. This suggested that the plant could serve as a phytoremediator of such minerals, particularly in mineral deficient areas. Also, reduced acidity of the post-harvest soils further showed the plant's capacity to mop up high acidity in an environment, thus; a good candidate for phytoremediation. For optimal yield in afore-mentioned growth parameters in a regulated environment, loam and silty clayey loam soils are recommended for cultivation of *Amaranthus caudatus*.

Keywords: *Amaranthus caudatus*; morphological growth characteristics; phytoremediator; silty clayey loam; soil types

Introduction

Growth and development of a plant are attuned to the environment based on some complex hormonal and other signals facilitated by feedforward responses of a plant root to soil conditions (Benvenuti, 2003). The shoot growth may be inhibited in a physiological manner similar to high soil strength occasioned by limitation arising from space or volume of soil available to its growth; this inhibitory effect is termed bonsai effect (Passioura, 2002). A number of indicators such as macroporosity, microporosity, pores connectivity and pore distances as determined by soil structure or texture have been identified as relevant tools used in assessing soil

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functions to essentially characterize plant-soil water relation (Jalota *et al*., 2010; Stolf *et al*., 2011; Karimi and Mohseni Fard, 2017).

Both sand and clay contents of the soil have been reported to inhibit germination in different manners. For clay, germination inhibition was found to be directly proportional to sowing depth and inversely proportional in soil with prominent sand textures (Prasad and Power, 1997; Benvenuti, 2003). One major factor affecting the cultivation of crops is environmental variability which may affect soil moisture and its mineral content. Any limitation to soil moisture in a planting season portends danger to the survival of plants and yield (Ufoegbune and Eruola, 2016).

Amaranthus caudatus, an important staple crop in Africa and pre-Columbian America is cultivated for grains production, leafy vegetable and ornaments. It is drought tolerant, typically resistant to hot climate and may be grown alone or intercropped with other food crops such as legumes and cereals for family feeding and market (Resio *et al*., 2006). The plant is patronized for its high nutritive value and adaptability to a wide range of environmental conditions which makes its cultivation very easy (Venskutonis and Kraujalis, 2013; Jimoh *et al*., 2018). It is one of the few annual herbaceous dicotyledonous C_4 pseudocereals that dominated the old civilization of the South American Andes (Jimenez *et al., 2013)*. The C_4 photosynthetic pathway enables the plant to survive adverse environmental conditions such as low water availability, extreme temperatures and high solar radiation due to its carbon dioxide and water use efficiency (Vargas-Ortiz *et al*., 2013).

Compared to other cereals, the seeds of *A. caudatus* are known for the high composition of antimicrobial peptides and gluten-free protein rich in nutritionally balanced amino-acid content as found in other grain amaranths (Broekaert *et al*., 1992; Belton and Taylor, 2002; Jimoh *et al*., 2019a). In addition, the rising demand for safe, affordable and efficient drugs from natural sources needed to combat diseases such as hypertension, cardiovascular disorders, cancer, diabetes, helminthic infections, microbial syndromes and malnutrition has redirected focus on health-promoting nutraceutical plants such as *A. caudatus* (Peter and Gandhi, 2017; Jimoh *et al*., 2019a).

This research, therefore, focused on certain morphological growth parameters such as leaf area, number of leaves, stem girth, number of branches, and shoot height as a measure of performance of *A. caudatus* in different soil types used for cultivation to understand the interaction between plant growth and soil environment. Also, the relationship between mineral nutrients in various soils and trends in growth performance was studied to investigate how the soil types have influenced variations in the yield.

Materials and Methods

Experimental soil formulation

A heap of topsoil collected from the University of Fort Hare's Research Farm was air dried under shade for 4 weeks. The dried soil was later sifted into different particle sizes of clay, sand and silt using iron sieves of designated mesh ranging from 0.25 - 2 mm. Four experimental soil types were formulated by mixing sieved soil particles in relative proportions recommended by the United States Department of Agriculture's soil texture triangle (Table 1) and used for cultivation alongside with the control soil.

Plant material and experimental design

Viable seeds of *A. caudatus* were cultivated in summer (between October 2017 and January 2018) in pots filled to the near brim. The pot experiment was conducted and organized in three replicates in a Completely Randomized Design (CRD) inside the controlled glass house of Botany Department, University of Fort Hare, South Africa. Plants were irrigated twice daily (morning and evening).

Table 1. Experimental soil formulation in proportions proposed by USDA soil texture triangle technique (Groenendyk *et al.*, 2015)

S/N	Soil types	% Sand	% Silt	% Clay
1	Control soil (SF_1)	Unfractionated	Unfractionated	Unfractionated
2	Sandy Clay Loam (SF_2)	66	13	21
3	Silty Clay Loam (SF_3)	10	60	30
4	Clayey Loam (SF_4)	36	30	34
5	Loam (SF_5)	40	40	20

Growth parameters

Leaf area

Leaf area was evaluated by measuring the length of the leaf from petiole base to the apex and the width from the median position. (Mendoza-de Gyves *et al.*, 2008) the linear model equation was used to estimate leaf area taking cognizance of the Mendoza's constant and measured length and breadth as given below.

$A = 1.81 + 0.68\ LW$

Where A= leaf area; L = length of the leaf; W = leaf width

On a weekly basis, readings were taken from five stands of *A. caudatus* in each block consecutively for nine weeks and the mean leaf area was estimated per soil sample.

Number of leaves

This was also taken by direct counting of leaves on the same set of representative plants in each block, per soil type. The mean leaf number was taken per soil type every week.

Stem girth

Vernier calliper was used to measure stem girths of the plant to the nearest millimetre.

Number of branches

This was achieved by direct counting of branches on the sampled plants in each block, per soil type. The mean number of branches was taken per soil type every week.

Shoot height

Shoot height was measured with the aid of tape rule. The mean height of the plant was taken per soil type every week.

Mineral nutrients in various soils and trends in growth performance

Five hundred gram each of the soil samples was taken for pre and post planting analysis of mineral contents at the Analytical Laboratory of the Department of Agriculture and Rural Development, Kwa Zulu Natal Province, South Africa. The results were correlated with plant performance with respect to selected growth parameters and soil minerals.

Results

Effects of soil types on leaf area

Effects of soil types on mean leaf area are shown in Figure 1. The results obtained indicated that soil types affected leaf area in a progressive manner from week 1 to week 8. At week 9, leaf area decreases which may be an indication that senescence may have set in. Week 8 marked the peak of growth in leaf size and the leaf areas recorded and, in the order, $SF_5 > SF_3 > SF_2 > SF_1 > SF_4$.

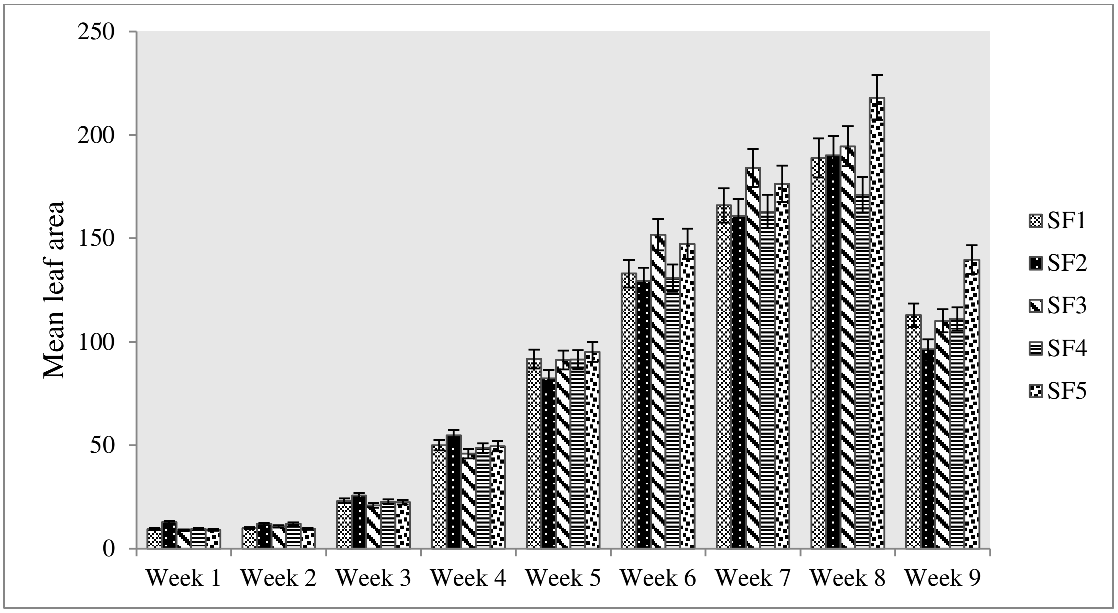

Figure 1. Effects of soil types on mean leaf area

Effects of soil types on the number of leaves

Results of this experiment also showed that soil types affect the number of leaves of the representative plants. As presented in Figure 2, most soils enhanced the increase in the number of leaves except clayey loam a sharp decline occurred at week 9. The order of increasing number of leaves in the representative plants at week 9 is $SF_4 < SF_2 < SF_1 < SF_5 < SF_3$.

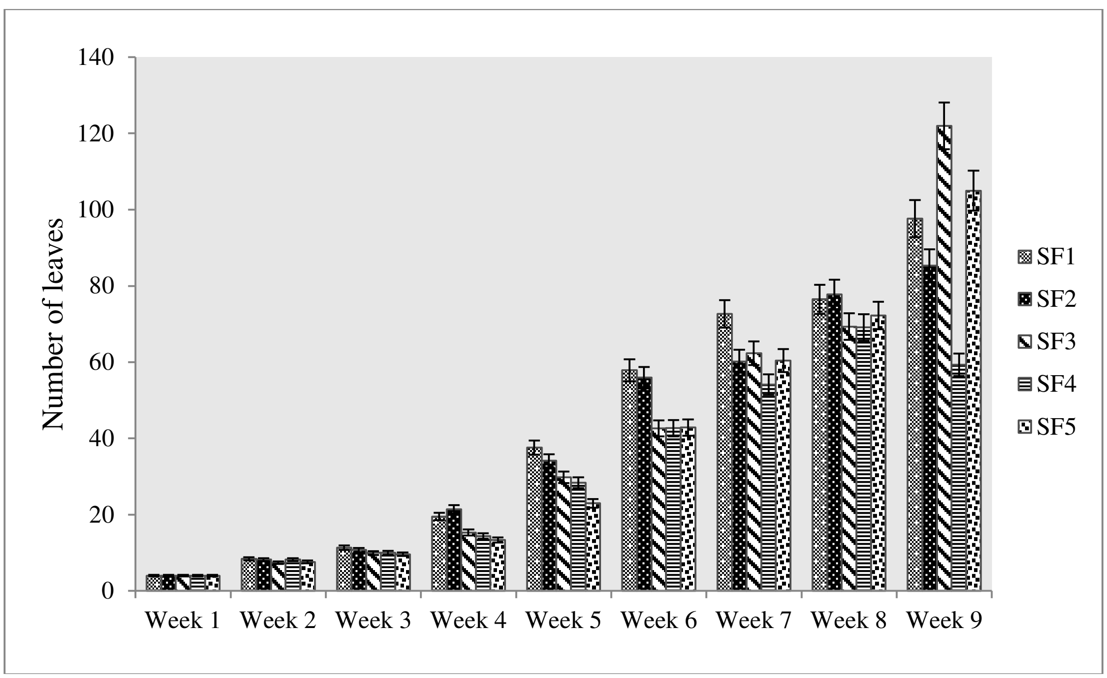

Figure 2. Effects of soil types on the number of leaves

Effects of soil types on stem girth

This is presented in Figure 3. The biggest mean stem girth was found in silty clayey loam and this was maintained consistently from week 6 to week 9. At week 9, order of decreasing stem girth was $SF_3 > SF_1 > SF_5 > SF_4 > SF_2$.

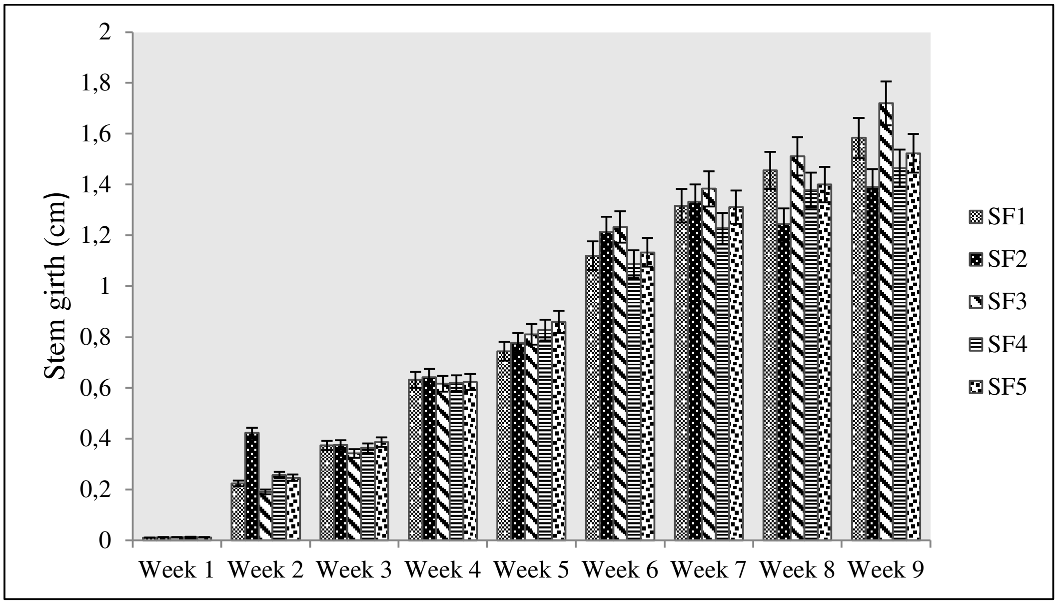

Figure 3. Effects of soil types on stem girth

Effects of soil types on the number of branches

Branches started emanating from the main stem the fourth week after transplanting (Figure 4). The number of branches increased steadily from week 4 to week 9. At the ninth week, the highest mean number of branches was recorded in the loam (SF_5) while the least was found in the clayey loam soil (SF_4).

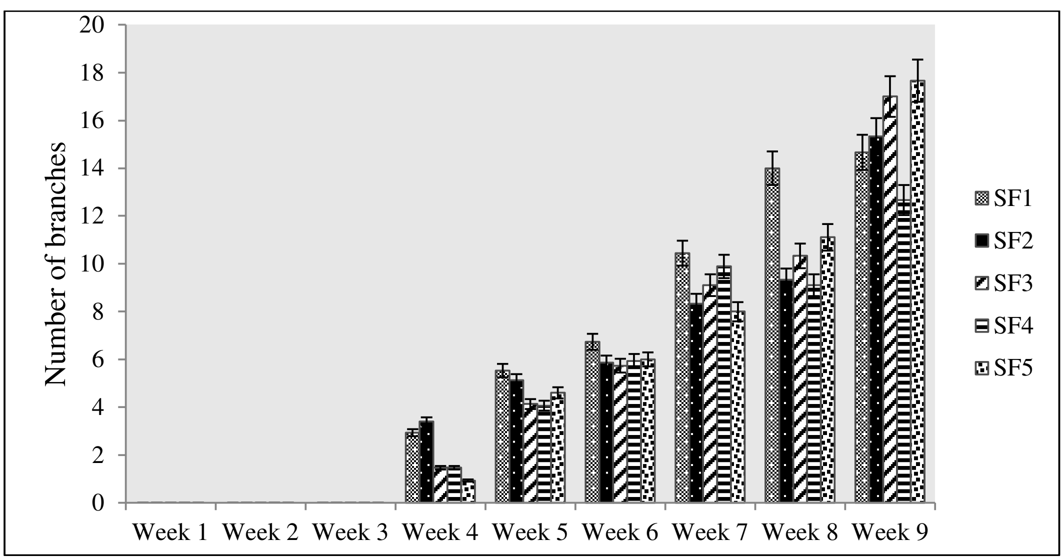

Figure 4. Effects of soil types on the number of branches

Effects of soil types on shoot height

This growth parameter increased steadily from week 1 to week 9. From week 5 to 9, silty clay loam (SF_3) maintained the tallest shoot (Figure 5) and at week 9, the shortest shoot was recorded in sandy clay loam (SF_2).

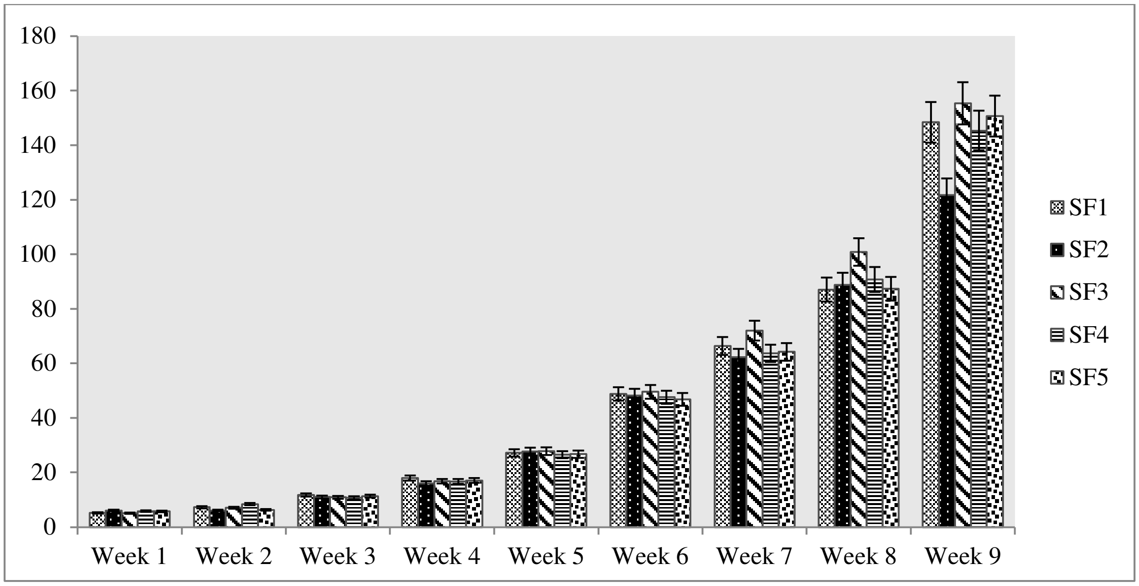

Figure 5. Effects of soil types on shoot height

Mineral nutrients in various soils and trends in growth performance

The results of soil mineral analysis indicated variabilities in the mineral content of the soil before and after planting. While some mineral concentrations in the soil got depleted after planting, some appreciated in quantity. This scenario shows that at maturity, the plant absorbed certain minerals from the soil and returned some minerals back to the soil. Minerals such as Phosphorus (P), Potassium (K), Manganese (Mn), Copper (Cu) and Zinc (Zn) got depleted in concentrations in the post-planting test, Calcium (Ca) and Magnesium (Mg) were in return, added to the soil. The exchange acidity and percentage acid saturation were also reduced in value in the post-planting soil test whereas the relative alkalinity of the soil increased after planting. There was a marked increase in total cations in the post-planting soils, an indication that the plant aided heavy metal uptake from the soils although with varying concentrations in different soil (Table 2). Reduction in bulk density of the soil was also observed in the post-harvest soil result which may be an indication that *A. caudatus* facilitates the loosening of the soil.

Table 2. Physicochemical properties of formulated soils

	Soil types	Sample density (g/mL)	P mg/mL	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Exch. Acidity (cmol/L)	Total cations (cmol/L)	Acid sat. %	pH (KCl)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)
Pre-planting	SF_1	1.2	82	806	918	281	0.09	9.04	1	6.08	7.4	55	15.8
	SF_2	1.24	82	826	1013	302	0.07	9.72	1	6.17	7.9	58	15.8
	SF_3	1.24	78	786	935	276	0.07	9.02	1	6.19	7.1	55	15
	SF_4	1.25	82	696	968	288	0.08	9.06	1	6.2	7.3	56	15.1
	SF_5	1.21	85	806	945	287	0.07	9.21	1	6.21	7.6	59	15.5
Post-planting	SF_1	1.13	32	232	3032	368	0.05	18.8	0	7.13	3.1	22	3.8
	SF_2	1.17	35	278	3126	344	0.07	19.21	0	7.14	4.1	23	4.8
	SF_3	1.16	37	211	2877	326	0.06	17.64	0	6.98	4.1	21	4.9
	SF_4	1.14	40	228	2751	315	0.06	16.95	0	6.97	12.3	23	4.8
	SF_5	1.16	41	274	2771	329	0.04	17.28	0	7.12	3.8	28	5.7

Discussion

Mineral nutrients provided by the soil plays a critical role in the plant's physiological development (Jimoh *et al*., 2019b). This was obvious in the growth parameters measured. A direct relationship has been attributed to soil phosphorus and leaf area (Rodriguez *et al*., 1998; Colomb *et al*., 2000). Phosphorus deficiency has been reported to delay the rate of leaf development, appearance and the final area depending on plant and soil type. In this study, the highest leaf area was observed in loam soil (SF_5) with the highest phosphorus composition. This is in agreement with an earlier report that increased soil phosphorus enhances leaf area expansion (Colomb *et al*., 2000). The depletion observed in post-harvest soil phosphorus showed that uptake had occurred.

Apart from phosphorus, another soil macronutrient that got depleted was potassium. This showed it was assimilated into various plant parts at different stages of development. Potassium is a vital plant nutrient that influences a number of biochemical and physiological processes that moderate plant resistance to biotic and abiotic stresses, yield and quality production (Pettigrew, 2008; Wang *et al*., 2013). Although the plant was grown under a controlled environment, a high concentration of soil potassium was among other factors responsible for the healthy condition of the plant throughout the period of study.

This study also confirmed that *A. caudatus* could act as a sink and source of certain minerals. The quantity of calcium, magnesium and total cations in the post-harvest soil was significantly higher than pre-planting soil. In this case, the plant may have acted as a duplicating channel for the minerals and at the same time, their returning agents to the soil. However, the number of heavy metals such as copper, zinc and manganese in the post-harvest soil dropped significantly. This may have been caused by leaching due to daily irrigation and retention of dissolved minerals absorbed by the root. The plant could, therefore, be said to be a refinery where heavy metals are absorbed from the soil and converted to non-toxic dosage level, that is safe for consumption (Adewuyi *et al*., 2010; Ogundola *et al*., 2018). An elevated level of Zn in the post-harvest clayey loam soil may be due to hyperaccumulation suggesting that *A. caudatus* is a good candidate for phytoremediation (Cui *et al*., 2007; Assad *et al*., 2017).

In addition, the changes observed in the relative acidity and alkalinity status of the post-harvest soils may not be unconnected with soil-water-plant interaction. Before planting, the pH of the various soil types was less acidic with a non-significant degree of acidity but after planting, the post-harvest soils turned alkaline except for silty clay loam and clayey loam soils having pH of 6.98 and 6.97 respectively (Table 2). Although it has been reported that crop production has no direct connection with soil bulk density (Rabot *et al*., 2018), the less dense post-harvest soils may have resulted from the further decomposition of organic matters in the soil and uptake by the plant roots.

Conclusions

This study confirmed that soil types influence morphological growth characteristics in *A. caudatus*. The variabilities observed in the mean leaf area, shoot height, girth, mean number of branches and leaves per representative stand on different soils indicated the critical role of soil in plant development. Some essential minerals such as Ca and Mg were returned to the soil in three-fold of their initial concentrations. This suggested that the plant could serve as a phytoremediator of such minerals, particularly in mineral deficient areas. Also, reduced acidity of the post-harvest soils further showed the plant's capacity to mop up high acidity in an environment, thus; a good candidate for phytoremediation. For optimal yield in afore-mentioned parameters in a regulated environment, loam and silty clayey loam soils are recommended for cultivation of *Amaranthus caudatus*. The plant should be domesticated for its potential in mopping up high acidity and heavy metal uptake to achieve a healthy and safe environment.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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