Effects of Varying Manganese Concentrations on Growth Performance and Proximate Composition of *Amaranthus hybridus* L.

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Abstract

Amaranthus hybridus is an important leafy vegetable consumed daily in many Nigerian households because of its high nutritional content and adaptability to local soils. Its ability to bioaccumulate metals, including manganese, presents both an advantage and a risk. While sufficient Mn promotes biomass accumulation, chlorophyll synthesis, and crop quality, excess Mn can reduce productivity and lead to undesirable accumulation in edible tissues, which may affect consumer health. This study investigated the impacts of varying manganese (Mn) concentrations on the growth and development of *Amaranthus hybridus* seeds (variety NGAC-00-3) obtained from the National Horticultural Research Institute (NIHORT), Ibadan. Loamy-sand soil was collected at coordinates 6°27”33.16'N 4°45'53.86°'E and fortified with Mn to desired concentrations designated as treatments S_1(0.13g), S_2 (0.10g), S_3 (0.07g), and S_4 (control- untreated), each replicated three times and arranged in Randomised Complete Block Design (RCBD). Growth characters, including leaf length, leaf width, petiole length, stem length, and stem width, were measured. Plant proximate analysis was carried out using a standard procedure as described by AOAC (2005. Data obtained was analysed using SPSS version 16, while mean separation was carried out using Duncan's Multiple Range Test at $p \leq 0.05$.

Control (S4: 6.41 ± 0.33 cm) showed the highest leaf length, while the highest Mn stress (S1: 5.90 ± 0.30 cm) was observed, implying that excessive Mn inhibits leaf elongation. Highest leaf width S4 (6.41 + 0.33 cm), petiole length S4 (5.19 ± 0.16 cm) and stem width S4 (1.24 + 0.06 cm) were observed while Mn-stressed plants exhibited reduced radial growth, which implies Mn toxicity limits both vertical and radial stem expansion. These findings highlight the importance of regulating Mn levels in soils to optimise the growth and biomass production of leafy vegetables.

The data provide critical insights for nutrient management and sustainable cultivation practices of *Amaranthus hybridus* in Mn-prone soils.

1.0 Introduction

Manganese (Mn) is one of the essential micronutrients required by plants in small quantities but plays a disproportionately large role in plant physiology. It functions as a cofactor for several enzymes, including those involved in respiration, photosynthesis, and nitrogen metabolism (Alejandro et al., 2020). In the photosynthetic process, Mn is a critical component of the oxygen-evolving complex of Photosystem II, which splits water molecules and releases oxygen (Millaleo et al., 2010). Despite its importance, manganese has a narrow optimal range in soil. Deficiency is common in calcareous or alkaline soils where Mn is oxidised to insoluble forms, leading to symptoms such as interveinal chlorosis, reduced photosynthetic efficiency, and stunted growth (Fernando *et al*., 2023). Conversely, acidic soils often increase Mn solubility to toxic levels, which can damage cellular structures, cause leaf crinkling and necrosis, and interfere with the uptake of other nutrients (Millaleo et al., 2010). These dual effects make Mn availability a critical factor in sustainable crop production.

Amaranthus hybridus, widely cultivated in Nigeria and other parts of West Africa, is an important leafy vegetable with high nutritional and economic value (Odiyi et al., 2019). It has the potential to accumulate significant amounts of mineral elements, including manganese. The crop, among other species, is an efficient accumulator of mineral elements, including manganese (Yusoff and Rahman, 2022). While moderate Mn supply may enhance biomass production and chlorophyll content, excess accumulation poses risks to plant productivity and consumer health when the leaves are consumed (Yusoff and Rahman, 2022). Therefore, understanding the influence of manganese stress, particularly at moderate levels, on the growth and bioaccumulation capacity of *Amaranthus hybridus* is essential. This knowledge will provide insights into nutrient management strategies that sustain crop yield while ensuring food safety in Mn-variable soils.

This research aims to evaluate the effect of manganese at varying concentrations on the growth and development of *Amaranthus hybridus*.

2.0 Materials and Methods

2.1 Collection and Preparation of Experimental Materials

Seeds of *Amaranthus hybridus* (variety NGAC-00-3, original name ED82/1019B) were obtained from the National Horticultural Research Institute (NIHORT), Jericho Dugbe, Ibadan, Oyo State, Nigeria. These seeds were second-generation (2nd gen.), selectively bred for desirable traits such as high yield, disease resistance, and adaptability to specific climates and had a percentage purity of 96%.

Soil samples were collected from the back of the former E-library, Olusegun Agagu University of Science and Technology (OAUSTECH), Okitipupa, Nigeria. The soil samples were air-dried, sieved, and sent to the laboratory for physicochemical analysis to determine baseline soil properties before use.

2.2 Experimental Design

The study was conducted at N 6^0 27.55’ E 4^0 45.90’, using a Randomised Complete Block Design (RCBD) with four manganese (Mn) treatment levels designated as S_1, S_2, S_3, and S_4 (control), treated with an equivalent amount of water in three replicates. Manganese treatments were prepared as aqueous solutions and applied at the designated concentrations: 0.13g of Mn dissolved in 1000ml of water (S_1), 0.10g of Mn dissolved in 1000ml of water (S_2), 0.07g of Mn dissolved in 1000ml of water (S_3), while S_4 received no Mn treatment. Applications were done at 9 WAP (week after planting), and plants were monitored for three weeks, post-application, to observe the effect of Mn on growth.

2.3 Germination and Transplanting

Seeds were sown in twenty perforated polythene bags filled with the collected soil and watered regularly to maintain adequate soil moisture. At 2 weeks after planting (2 WAP), uniform seedlings were carefully transplanted into sixteen perforated plastic pots, each containing 10 kg of soil. Pots were labelled according to the Mn treatments (S_1, S_2, S_3, and S_4) in three replications per treatment. Agronomic parameters such as the leaf length, leaf width and plant height using a meter rule and stem width using a micrometre screw gauge were measured two times weekly for 12 weeks after planting (WAP). At 12 WAP, plants were harvested for laboratory analysis. Plant proximate analysis was carried out using a standard procedure as described by AOAC (2005. Data collected were subjected to Analysis of Variance (ANOVA), and mean separation was done using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$.

3.0 Results and Discussion

Table 3.1 shows the physicochemical properties of the soil before and after the experiment. The initial soil analysis revealed a slightly acidic loamy sand (pH 6.5), suitable for nutrient uptake. Following Mn application, the soil exhibited elevated electrical conductivity (EC) and heavy metals such as Pb, Cr, Cd, and As. Similar reports by Kabata-Pendias (2010) and Broadley et al. (2012) indicate that Mn addition can alter soil ionic balance, thereby mobilising trace elements. The observed decline in organic carbon and total nitrogen after cultivation aligns with nutrient uptake by plants and accelerated microbial decomposition under pot conditions (Hajiboland, 2012). Interestingly, phosphorus concentrations increased across treatments, suggesting interactions between Mn and phosphorus availability, emphasising that Mn stress can indirectly influence phosphorus dynamics in cropping systems (Fageria, 2001). Growth analysis revealed that control plants (0% Mn) consistently outperformed Mn-treated plants in leaf length, stem width, and petiole development. This confirms the dual nature of Mn: essential at low levels but toxic in excess. Mn toxicity reduces photosynthetic efficiency, restricts cell expansion, and induces oxidative stress (Millaleo et al. 2010; Marschner, 2012).

Leaf length increased progressively in all treatments up to 8 WAP at $p \leq 0.05$. (Fig. 3.1). The control (S_4) showed the highest significant values, reaching a peak of 6.41 ± 0.33 cm at 8 WAP. In contrast, the high-stress group (S_1) had the lowest values, with a maximum of 5.90 ± 0.30 cm at the same point. The measured growth parameter increased steadily from 1 to 8 WAP across all treatments, indicating vigorous vegetative development during the early growth stages. Treatment S_4 consistently produced the highest values from 4 to 12 WAP, closely followed by S_2, whereas S_3 recorded the lowest values throughout the study period.

Peak growth was attained at 8 WAP, where S_4 (6.41 ± 0.33^a cm), S_3 (6.01 ± 0.31^a cm) and S_2 (6.10 ± 0.32^a cm) were statistically the same but significantly higher than S_1 (5.90 ± 0.30^b cm), implying that low-dose Mn supplementation enhances growth but not beyond the control. After this, a slight decline or stabilisation was observed, suggesting a transition from active vegetative growth to maturity. The superior performance of S_2 and S_4 indicates that these treatments enhanced nutrient utilisation and biomass accumulation more effectively than S_1 and S_3. The observed growth pattern agrees with reports that adequate micronutrient availability promotes cell division, chlorophyll synthesis, and photosynthetic efficiency, resulting in improved plant growth and productivity (Marschner, 2012; Broadley et al., 2012; Taiz et al., 2015).

Table 3.1
Physicochemical properties of soil before and after the experiment

Parameter	**S_1**	**S_2**	**S_3**	**S_4 After Experiment**	**S_4 Before Experiment**
PH	6.35	6.45	6.50	7.07	6.50
EC	96	204	120	228	108
Exch. Acidity.	0.48	0.30	0.55	0.28	0.50
Exch. H	0.30	0.30	0.50	0.30	0.40
Exch. Al (cmol/kg)	0.18	0.08	0.05	0.08	0.10
Ca (cmol/kg)	2.83	2.31	2.09	2.12	2.63
Mg (cmol/kg)	0.74	0.81	0.67	0.90	1.03
K (cmol/kg)	0.31	0.38	0.28	0.26	0.28
Mn (mg/kg)	48.0	l53.0	67.0	52.0	48.00
Fe (mg/kg)	118.0	101.0	126.0	121.0	103.00
Cu (mg/kg)	1.84	1.84	1.36	1.16	1.35
Zn (mg/kg)	2.64	2.37	2.40	2.61	2.24
Co (mg/kg)	1.41	1.06	1.68	1.83	1.03
Cr (mg/kg)	3.06	2.11	3.84	2.22	0.65
Pb (mg/kg)	4.06	7.57	8.56	7.30	1.61
Cd (mg/kg)	1.22	1.53	1.11	1.41	0.66
As (mg/kg)	1.11	1.21	1.46	1.26	0.39
Se (mg/kg)	0.8	1.5	0.8	0.6	0.70
Nitrate (mg/kg)	0.062	0.038	0.037	0.048	0.035
Phosphate (mg/kg)	296.7	224.0	261.0	291.8	124.0
Ammonium (mg/kg)	0.070	0.053	0.043	0.055	0.042
CEC (cmol/kg)	4.59	4.07	3.81	3.84	4.68
Available P (mg/kg)	22.16	10.20	10.96	21.04	33.36
% Sand	85	83	82	83	83
% Silt	10	10	12	11	12
% Clay	5	7	6	6	5.0

Parameter	S_1	S_2	S_3	S_4 After Experiment	S_4 Before Experiment
% Organic carbon	2.58	2.28	1.63	2.01	4.10
% Total Nitrogen	0.28	.20	0.17	0.22	0.40
Texture	Loamy	Loamy	Loamy	Loamy	Loamy

mg/kg = milligram per kilogram, cmol/kg = centimole per kilogram, EC = Electric conductivity

The proximate and mineral composition of *Amaranthus hybridus* varied among plant parts following manganese treatment, with leaves consistently recording the highest concentrations of most nutrients (Fig. 3.3). Leaf tissues contained greater levels of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, copper, and zinc than stems and roots, indicating preferential nutrient translocation and accumulation in photosynthetically active organs. Treatment S1 generally produced the highest nutrient concentrations, while S4 showed comparatively lower values for several minerals. Potassium and phosphorus were the most abundant macronutrients across all plant parts, whereas iron and manganese were the dominant micronutrients.

The elevated nutrient levels in leaves highlight their superior nutritional value and suitability for human consumption. Similar preferential accumulation of N, P, K, Ca, Mg, Mn, Cu, and Zn in amaranth leaves has been reported previously (Olivares and Peña, 2009; Yaméogo and Garanet, 2023). Furthermore, enhanced mineral uptake and accumulation in *Amaranthus hybridus* have been associated with improved nutrient uptake efficiency (Ngoroyemoto et al., 2020).

Appendix 1 shows the vegetative structure of *Amaranthus hybridus* before and after transplanting. The proximate analysis demonstrated that nutrient accumulation was highest in leaves, followed by stems and roots. This distribution reflects the metabolic role of leaves as primary sites of photosynthesis, consistent with (Alegbejo, 2013) and (Grubben and Denton, 2004), who emphasised the nutritional superiority of amaranth leaves. However, Mn accumulation was also highest in leaves, raising concerns for food safety. (Gupta et al. 2018) highlighted that high Mn levels in edible tissues could threaten consumer health, particularly in regions where leafy vegetables form dietary staples. This outcome corroborates findings in rice (Fageria, 2001) and spinach (Yusoff et al., 2022), where Mn toxicity reduced both biomass and nutrient quality.

4. 0 Conclusion

The study concludes that while *Amaranthus hybridus* can tolerate moderate manganese levels, excessive Mn stress negatively affects growth, potentially reducing yield and biomass production. Treatments, S_2 (100mg/L) and S_3 (70mg/L) showed optimal growth rate. The highest Mn accumulation in leaves is a major concern for food safety if consumed chronically. The leaf Mn (33.3mg/kg) observed has not exceeded the safe dietary limit of less than 1000mg/kg. Manganese application at moderate levels to ensure optimal growth and regular soil testing to monitor manganese content before fertiliser application among farmers is encouraged.

Declarations

4.1 Acknowledgments

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18. Before, After

Figures

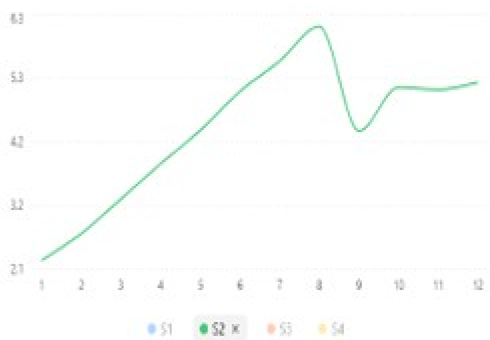

Figure 1

Fig. 3.1: Showing Effect of treatments on leaf length from 1–12 WAP

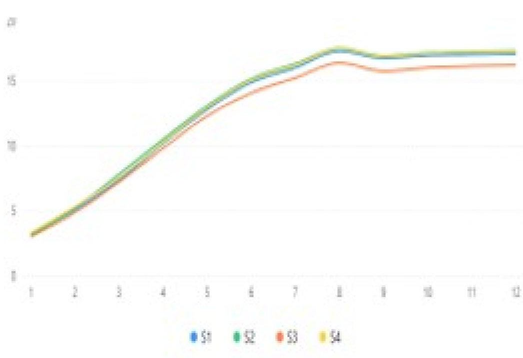

Figure 2

Figure 3.2: Effect of treatments on plant height, from 1–12 WAP

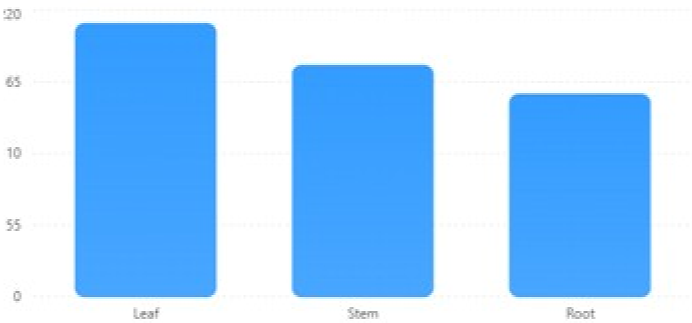

Figure 3

Fig. 3.3: Mean Nutrient Concentration of *Amaranthus hybridus* Plant Parts across Manganese Treatments

Supplementary Files

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- Appendix1.docx