Agricultural Science Research Journal
ISSN 2026-6073
Julius Oluwaseun A. *et al* Volume (12) Issue (3): 66 – 70 March – 2022.
RESEARCH PAPER

Growth, yield and nutrient uptake of amaranth (*Amaranthus caudatus*) as influenced by organic fertilizers on sandy loam in Ondo, Nigeria

***Julius Oluwaseun ADEGOKE.[1], Oluwaseun Anne HASSAN.[2], and Bolaji Toyin ALABI[3]**

[1]Department of Agriculture, Wesley University, Ondo, Nigeria

[2]Department of Horticulture and Landscape Technology, Federal College of Agriculture, Akure, Ondo State., Nigeria

[3]Department of Agricultural Technology, Bamidele Olumilua University of Education Science and Technology, Ikere-Ekiti, Ekiti State, Nigeria

*Corresponding Author

*** Julius Oluwaseun ADEGOKE**

[1]Department of Agriculture, Wesley University, Ondo, Nigeria

*Corresponding Author Email: juliusgoke@yahoo.com[1], Tel.: +234-8066630568

Abstract

Continuous use of mineral fertilizers on tropical soils results in soil acidity and pollution of underground environment. Organic fertilizers, such as compost, are good sources of plant nutrients for sustainable crop production and healthy underground environment. Thus, the focus of this study was to evaluate the influence of different organic fertilizers on growth, yield and nutrient uptake of amaranth (*Amaranthus caudatus*). The experiment was conducted at the experimental field of the Wesley University, Ondo, Nigeria. The study had five fertilizer treatments viz: rice bran based compost (RBC), conventional compost (CC), moringa leaf (ML), NPK 20-10-10 and the control (no soil additive). The treatments were laid out in a Randomized Completely Block Design with three replicates. The treatments were applied at the rate of 100 kg N ha^{-1} and the effects on nutrient uptake, biomass yields, plant height, number of leaves, as well as stem girth were observed. Analysis of variance (ANOVA) was carried out and significantly different means were separated using Duncan's Multiple Range Test (DMRT) at the 5 % probability level. The results of the analyses revealed that compost treatments (RBC and CC) produced similar plant height (37.2 cm and 29.5 cm), number of leaves (26.4 and 29.5 per plant) and stem girth (11.1 cm and 10.1 cm) at 8 weeks after sowing of amaranth. However, the above values were higher than those for ML and NPK (23.6 cm and 23.6 cm), (18.5 and 22.5 per plant) and (9.3 cm and 6.1 cm) with respect to plant height, number of leaves and stem girth of the crop. Also, RBC treated soils had the highest mean fresh biomass yield of amaranth plants, leaves (0.3 kg ha^{-1}), stem (0.2 kg ha^{-1}) and root (0.2 kg ha^{-1}) while ML had the lowest fresh biomass yield; leaves (0.07 kg ha^{-1}), stem (0.04 kg ha^{-1}) and root (0.04 kg ha^{-1}). In terms of nutrient uptake, N, P and K uptake of amaranth were significantly enhanced with fertilizer treatments compared to the control. Rice bran based-compost improved nutrient uptake as much as conventional compost. RBC application resulted in highest growth and yield of green amaranth. It is therefore reasonable to recommend the use of rice bran based-compost as an alternative to the recommended NPK dose for production of amaranth.

Keywords: Fertilizer materials, sandy loam, *Amaranthus caudatus*, biomass yields, nutrient uptake.

Introduction

Sustainable agriculture is, nowadays, an urgent requirement to minimize the environmental pollution that has increased as a result of unhealthy agricultural practices such as extensive use of mineral fertilizers. Mineral fertilizers are important for plant nutrition; however, they are also a potential sources of environmental pollution, particularly mineral-nitrogen (N) fertilizers. In addition, farmers are suffering from declining soil fertility and increasing soil salinization. Consequently, management of poor soil fertility in arid and semi-arid regions needs many effective solutions. The challenge of sustainable agriculture is more serious in developing countries, including Nigeria. This is due to the extensive use of mineral fertilizers, low rainfall, high evaporation rate, poor irrigation water and poor water management in these regions (Rady *et al.,* 2013).

Attention is, therefore, focused on using various forms of composts as partial substitutions to mineral fertilizers. These practices have been recommended (Ojo *et al.,* 2014; Smith *et al.,* 2015) under normal or saline conditions in arid and semi-arid regions as sources of nutrients, because these soils inherently have low organic matter and low mineralization (Adeoye *et al.,* 2005), due to high alkalinity and low rains. The beneficial effects of this practice in terms of improved crop productivity, soil fertility and sustainability, and balanced plant nutrition have been reported (Moyin-Jesu, 2015 and Semida *et al.,* 2015).

Agricultural dry residues such as rice bran residue and sunflower plant parts (i.e leaves and stems) are produced in large amounts as a by-product of crop productions in arid and semi-arid regions (Semida *et al.,* 2015). Majority of these agricultural residues are disposed by burning, mulched in crop fields, or discarded. In addition, some are used in animal feed, mulched in crop fields or are discarded. However, an attractive usage of all these residues/wastes is composting after they are mixed with some organic and mineral components, such as farm yard manure to produce organic composts (Akanbi *et al.,* 2007). Semalulu *et al.* (2011) had defined the composting as a biological process of aerobic decomposition, which degrades labile organic matter to carbon dioxide, water vapour, ammonia, inorganic nutrients and a stable organic material containing humic like substances. Compost has several advantages over mineral fertilizers, such as nutrient availability, uptake efficiency and quality of yields produced by crop. (Akanbi *et al.,* 2007).

Amaranth is one of the most popular vegetable crops grown in the Middle Eastern countries for human diet due to its rich source of proteins, carbohydrates, and nutrients. Its cultivation requires considerable amounts of nitrogen so that the crop can grow well, and leaves acquire the dark green color sought by consumers. Production usually involves the use of inorganic nitrogen fertilizers in quantities ≥150 kg N ha^{-1}, being one of the most critical elements in plant growth and quality (Rouphael *et al*., 2018). Nitrogen plays a significant role in biosynthesis of secondary plant metabolites such as phenols, ascorbate, and glutathione as well as antioxidant enzymes such as glutathione reductase (Ibrahim *et al.,* 2012; Argyropoulou *et al.,* 2015). Thus, cultivation of amaranth and other different crop plants under soil application with composts, as a partial alternative to mineral-NPK fertilizers, has the potential to increase crop production and soil sustainability (Abdelhamid *et al.,* 2004 and Smith *et al.,* 2015). This practice promotes higher plant growth and productivity while reducing mineral fertilizer use, crop production cost and indirectly increasing income.

Therefore, the objective of this study was to assess the effects of various organic fertilizer applications on the growth, yield and nutrient uptake of amaranth plants grown on sandy loam soil.

Materials and Methods

The trial was carried out at the Department of Agriculture, Wesley University, Ondo, Nigeria (Lat. 6°51‘N and Long. 3°42‘E). Ondo is located in the tropical rain forest ecological zone of Nigeria, characterized with bimodal rainfall distribution with distinct dry and rainy seasons. The zone has an average annual rainfall of 1532±227 mm over a period of 10 years (2011 to 2021), average temperature ranges of 2.2℃ (max. temp.; 27.8℃, min temp.; 25.6℃) and average relative humidity of 86.1% over the same period (NASA-Power, 2016). The vegetation is classified into two; low and top layers. The low layer vegetation is characterized with abundance of herbs, shrubs and grasses while the top layer is characterized with valuable economic trees such as *Chlorophora excelsa*, *Eucalyptus marginata*, *Khaya ivorensis* among others (Sowunmi and Akintola, 2010).

Rice bran compost (RBC) was prepared using windrow aeration composting method based on the standardized procedure adopted for use at the organomineral preparation plant as described (Omueti *et al*. (2000). Briefly, rice bran was measured by volume and mixed with cattle dung (CD) in ratio 1:3 inside the windrow. The rice bran was piled up in layers with CD, turned manually and sprinkled with water once in a week with moisture content maintained at 60% Field capacity (Fadare *et al*., 2000). The monitoring of the composting commenced immediately after heap building. The temperature builds up in each composting bin was measured daily at 11:00 hour with the aid of a thermometer dipped to a depth of about 0.35m in three different parts of the compost pile and the average temperature value was thereafter obtained. The pH of the pile was determined fortnightly using a pH meter in aqueous extract of 5g decomposing samples with distilled water at solid: water ratio of 1:4 (w.v) according to Guerra-Rodriguez *et al*. (2000) and Banout *et al*. (2008). At eight weeks when the temperature of the pile dropped to that of ambient temperature and remained relatively constant over a period of two weeks, compost samples were randomly taken from the pile, homogenized and labeled.

The conventional compost used as a check was also a company's product, obtained from Alesinloye Compost Company, Alesinloye market, Ibadan, Oyo State, Nigeria. Moringa leaves were harvested at the Department of Agronomy, University of Ibadan, Nigeria and then air dried for five days to reduce the moisture content. Chemical analyses of the composts and moringa leaves (Table 1) were carried out using standard procedures (Thomas, 1996).

Table 1: Chemical analysis of the composts and moringa leaf

Parameters	Rice bran compost	Conventional compost	Moringa leaf
pH (H_2O)	7.9	9.7	na
Total C (gkg^{-1})	110	170	na
Total N (gkg^{-1})	17	12	28
Available P (gkg^{-1})	10	8	4
Exchangeable cations (gkg^{-1})			
K	1.19	17	19
Ca	10.5	3.2	19
Mg	8.1	1.0	2
Na	8	4	2
Extractable micronutrients ($mgkg^{-1}$)			
Mn	390	393	4.4
Fe	11600	1670	53
Zn	50	186	11
Cu	80	78	8
C:N ratio	64	140	na

NA - not applicable

The physical and chemical analyses of the pre-treated soil was also carried out using standard procedures (Hendershot and Lalande, 1993; Bremner, 1996; Nelson and Sommers, 1996; Thomas, 1996; Gee and Or, 2002) and are shown in Table 2. The Wesley University Ondo soil was low in N, P and organic carbon, but marginal in K (FFD, 2012). The textural class was sandy loam based on USDA textural triangle (Soil Survey Division Staff, 1993).

Table 2: Some physical and chemical properties of soil used for the experiment

Parameters	Value
pH (H_2O)	6.3
Org C (gkg^{-1})	5.5
Total N (gkg^{-1})	0.4
Available P (mg/kg)	6.9
Exchangeable cations ($cmolkg^{-1}$)	
K^+	0.4
Ca^{2+}	3.5
Mg^{2+}	0.9
Na^+	0.4
Extractable micronutrients ($mgkg^{-1}$)	
Mn	400
Fe	83
Zn	1.0
Cu	0.8
Particle size distribution (gkg^{-1})	
Sand	779
Silt	158
Clay	63
Textural class (USDA)	Sandy loam

The treatments applied were rice bran-based compost (RBC), conventional compost (CC), moringa leaves (ML) and NPK 20-15-15 mineral fertilizer at 100 kg N ha^{-1} each. All the fertilizer materials were milled into powder before application. The amaranth variety planted was obtained from National Institute of Horticultural Research (NIHORT), Ibadan, Nigeria and the design was randomized complete block replicated three times to give 15 experimental plots. Each plot size was $2m^2$. Seeds of green amaranth were drilled in 20 cm rows and thinned to one plant per stand two weeks after sowing, giving a plant population of 55 stands per plot. The inter-row spacing was also 20 cm equivalent to 250, 000 plants/ha. The compost treatments were applied a week before sowing while the inorganic fertilizer was applied at one weeks after sowing (WAS) and weeding was carried out as necessary. Data were collected on growth parameters; plant height (cm), number of leaves/ plant, stem girth (cm) at 4, 6 and 8 WAS and biomass (fresh and dry yields). At 8 WAS, the roots were carefully removed and washed. Thereafter, root, leaves and stem were oven-dried at 70°C until constant weight. After oven drying, the materials were milled and analyzed for N, P and K concentrations.

Nutrient uptake in leaves was calculated using the formula: Nutrient uptake = % nutrient concentration x dry matter yield ($kgha^{-1}$) Akanbi (2002). Data were statistically analyzed and significantly different means were separated by Duncan's Multiple Range Test (DMRT) at 5 % probability level.

Result

Effects of various organic fertilizers on amaranth plant height, number of leaves and stem girth

The result showed significant differences among the treatment means for all the parameters (Table 3). The result of the fertilizer treatment on height, number of leaves and stem girth of amaranth are presented in Table 3. With respect to the plant height, the result showed that there were significantly differences ($p<0.05$) among the treatment means in 4, 6 and 8 weeks after sowing (WAS). At 4 WAS, the RBC gave the highest mean plant height (21.9 cm) which was significantly taller than CC (17.5 cm), ML (14.9 cm) and NPK (13.8 cm). The control gave the shortest plant (10.2 cm). However, at 6 WAT, RBC gave the highest mean plant height (32.6 cm) which differ significantly from other treatments apart from CC (25.3 cm) while the control gave the significantly lowest plant height (12.4 cm). A similar result was obtained at 8 WAT.

In terms of number of leaves, at 4 WAT, RBC gave the highest mean number of leaves (15.3) which differ significantly from other treatments. The control treatment resulted into significantly lowest mean value of number of leaves (8.4). However, at 6 WAT, RBC gave the highest number of leaves (23.1) which differ significantly from other treatments apart from CC (20.2) while the control gave the significantly lowest number of leaves (9.4). A similar result was obtained at 8 WAS.

The result obtained in stem girth showed that at 4 WAS, RBC gave the highest mean value of (7.5 cm) stem diameter which did not differ significantly from CC (6.5 cm) but significantly higher than ML (5.2 cm), NPK (4.0 cm) and control (2.5 cm). At 6 WAT, RBC still gave the highest mean stem diameter of amaranth (10.5 cm) which was not significantly different from ML (9.2 cm) but higher than others. The control treatment resulted into significantly lowest mean value of stem diameter (3.5 cm). At 8 WAT, there were significant differences ($p<0.05$) among the treatment means. The RBC still gave the highest mean stem diameter (11.1 cm) which was not significantly different from CC (10.1 cm) but significantly higher than other treatments.

Table 3: Effects of fertilizer treatment on growth performance of Amaranth at different weeks after planting

Treatment	Plant height (cm)			Number of leaves			Stem girth (cm)		
	WAS								
	4	6	8	4	6	8	4	6	8
Control	10.2d	12.4c	15.2c	8.4d	9.4c	12.3c	2.5b	3.5c	3.9c
Rice-bran based compost	21.9a	32.6a	37.2a	15.3a	23.1a	26.4a	7.5a	10.5a	11.1a
Conventional compost	17.5b	25.3a	29.5a	13.5b	20.2a	23.6a	6.5a	8.7b	10.1ab
Moringa leaf	14.9bc	19.7b	23.6b	11.8c	14.9b	18.5b	5.2b	9.2ab	9.3b
NPK (20:10:10)	13.8c	19.5b	23.6b	10.8c	14.1b	22.5b	4.0b	5.5c	6.1c

Means with the same letter (s) in the column are not significantly ($p<0.05$) using Duncan's Multiple Range Test.
WAS= weeks after sowing

Effects of various organic fertilizers on amaranth fresh and dry biomass yield

The result showed that there were significantly differences ($p<0.05$) among the treatment means across all the parameters (Fig. 1). With respect to fresh biomass yield, RBC produced the highest mean of fresh weight of leaves (0.3 $kgha^{-1}$) which was significantly different from others, while the control gave the lowest significant fresh weight of leaves (0.03 $kgha^{-1}$). It was also noted that in both fresh root and stem, RBC performed significantly than other treatments.

With dry biomass yield (Fig. 2), RBC gave the highest mean value (0.04 $kgha^{-1}$) of dry weight of leaves which was significantly different from other treatments. The control gave the lowest (0.005 $kgha^{-1}$) significant value. A similar result was obtained in dry root and stem.

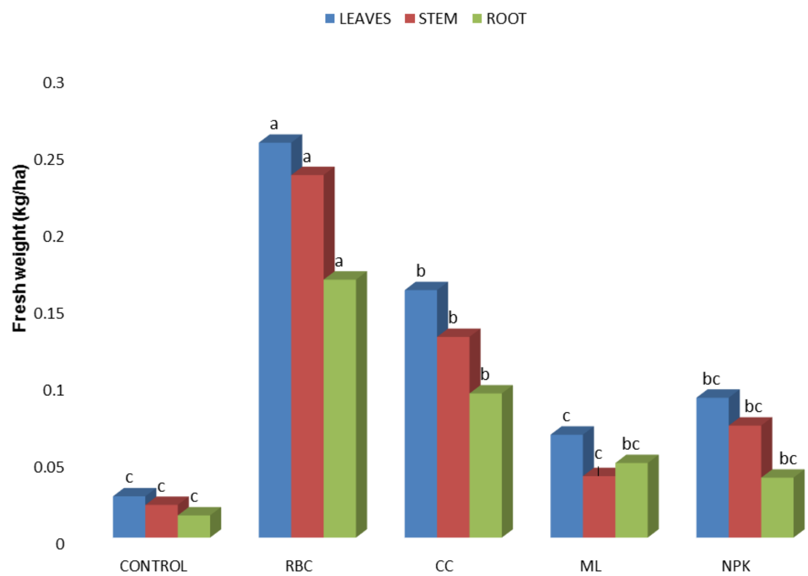

Fig 1: Effects of the treatments on fresh biomass yield

Legend: RBC= Rice bran based compost, CC= Conventional compost, ML= Moringa leaves, NPK= NPK 20 - 10 - 10.
Means with the same alphabet are not significantly different at p<0.05

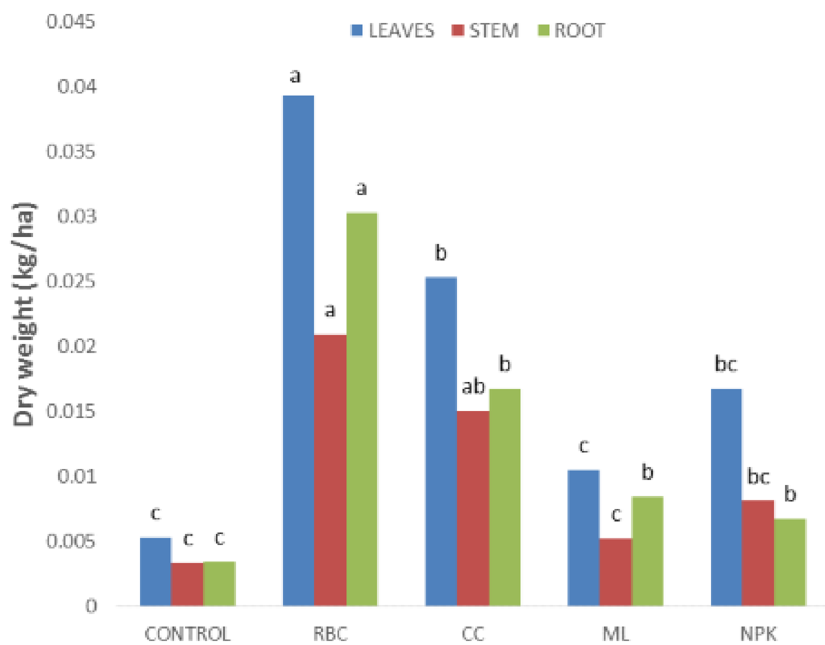

Fig 2: Effects of the treatments on dry biomass yield

Legend: RBC= Rice bran based compost, CC= Conventional compost, ML= Moringa leaves, NPK= NPK 20 - 10 - 10.
Means with the same alphabet are not significantly different at p<0.05

Nitrogen, Phosphorus and Potassium concentration (gkg^{-1}) and uptake ($kgha^{-1}$) in the amaranth leaves at 8 weeks after transplanting as influenced by various organic fertilizers

The result of the N, P and K concentrations and uptake in the tissue of the amaranth plants due to the different fertilizer treatments is shown in Table 4. With the nitrogen content, RBC gave the highest nitrogen content (39.3 gkg^{-1}) which was not significantly different from CC (32.1 gkg^{-1}). However, ML (28.2 gkg^{-1}) was not significantly different from NPK (24.9 gkg^{-1}) which was significantly higher than the control (3.1 gkg^{-1}). However, application of organic fertilizers showed no significant differences in the nutrient contents of phosphorus and potassium.

With the nitrogen uptake, RBC treatment gave the highest nitrogen uptake (1.5 $kgha^{-1}$) which was not significantly different from CC (0.8 $kgha^{-1}$). However, ML (0.3 $kgha^{-1}$) and NPK (0.4 $kgha^{-1}$) were not significantly different from one another and that of control gave the lowest nitrogen uptake (0.01 $kgha^{-1}$). In phosphorus and potassium uptake, RBC gave the highest value (0.4 and 1.3 $kgha^{-1}$). Also, the result showed no significant difference among the CC, ML and NPK in phosphorous and potassium uptake.

Table 4: Nutrient content (gkg^{-1}) and uptake ($kgha^{-1}$) of amaranth as influenced by organic fertilizers

Treatment	Nutrient content (gkg^{-1})			Nutrient uptake ($kgha^{-1}$)		
	N	P	K	N	P	K
Control	3.1c	10.5	32.2	0.1c	0.1c	0.2c
Rice-bran based-compost (RBC)	39.3a	10.9	32.9	1.5a	0.4a	1.3a
Conventional compost (CC)	32.1ab	9.33	35.2	0.8a	0.2b	0.9b
Moringa leaf (ML)	28.3b	10.7	34.0	0.3bc	0.2b	0.4c
NPK (20:10:10)	24.9b	11.8 ns	34.2 ns	0.4b	0.2b	0.5bc

NS: not significant

Means with the same letter(s) in a column are not significantly different at 5 % level of probability by Duncan Multiple Range Test (DMRT).

Discussion

Adding compost to the soil increased the crop yields compared to the mineral fertilizer and control. This increase was a function of the dose of compost applied and shows the importance of the use of organic matter, in particular RBC recognized to be rich in nutrients. The obtained yields with the soil show that with the use of compost, it is possible to sustainably increase the yields of amaranth. The results indicate that the applied compost has the potential to be used as a fertilizer. The results indicate that the most effective compost was obtained from RBC. A number of reports illustrated that composts obtained from solid organic waste are capable to increase nutrient supply and meet subsequent plant demand in soil (Iglesias-Jimenez and Alvarez, 1993; Mylavarapu and Zinati, 2009). Moreover, sufficient amount of cowdung which serve as nitrogen source was present in the compost and it increased the morphological growth and development of vegetables. In this study, RBC exhibited a significant influence on growth characteristics of vegetables at different growth period (Tables 2). The improved growth characteristics of amaranth plants produced as a result of RBC could be attributed to the enhanced decomposition of the RBC and mineralization of nutrients (Abdelhamid *et al.*, 2004; Ojo *et al.,* 2014). In unfertilized soil, amaranth plants did not grow well. The leaves of the plants were very small and chlorotic presenting a yellowish color, probably due to nitrogen deficiency. The addition of organic compost to soil significantly increased the plant growth (Table 2). Weinfurtner (2001) also reported a positive effect of organic compost on yield.

However, plants grown only with NPK and ML had lesser biomass yields (fresh and dry weights) than those grown with composts (Fig. 1 and 2). The high increase in biomass yields due to the addition of RBC could be related to the increase of availability of nitrogen source (cowdung) throughout the growing season. The high biomass (fresh and dry yields) in treatments with RBC and CC applications, shown that amaranth yield is very dependent on the nitrogen source that is embedded in the composts. Therefore, this can be a strategy to reduce greenhouse emissions due to the use of the compost, as pointed out by Gruda (2019). It also indicates that the application of composts allowed obtaining a high amaranth biomass yields. Also Xu *et al.* (2005) in a study on yield and quality of leafy vegetables grown with organic fertilizers reported that vegetables grown with organic fertilizers grew better and resulted in a higher total yield than those grown with chemical fertilizers. Similar result was also found in a study by Magkos *et al.* (2003) who evaluated the dry matter yields of several vegetables and found that organically cultivated crops had higher yields than those grown conventionally.

Application of fertilizer increase the supply of nutrients which ultimately result in greater nutrient uptake (Table 4). Plant growth and development depend on nutrient supply and in general enhances good yield. The findings with regard to nutrient uptake by amaranth revealed that the uptake of N, P and K were higher with the application of composts and NPK but least with control plants indicating short supply of these nutrient elements to amaranth in the control plots. This is in agreement with the findings of Kayode *et al.,* (2018) that the application of compost improved N, P and K uptake of amaranth. The application of nitrogen led to an increase in leaf nutrient concentration of N. Leaf N concentration in plants of the RBC was 73% higher than in the plants fertilized with nitrogen fertilizer. The increase in leaf nitrogen concentration may be related to an increase in the availability of nitrate in root medium, since it is known that when the nitrate is taken by plants roots, nitrogen uptake is enhanced (Jones, 2016). In the case of leaf P, concentrations were above the sufficiency range. This was probably due to the high availability of P in soil and the addition of organic compost to the soil. The addition of organic compost to soil can increase water-extractable soil P by direct addition, dissolution, displacing sorbed, or reducing sorption capacity for P (Adler and Sikora, 2003). Organic matter is a source of phosphorus and it may reduce P sorption (Gorgin *et al.,* 2011). It may increase P uptake by plants since it forms complexes with organic phosphate and increases the volume of soil that plant roots explore (Ouni *et al.,* 2014). In spinach, Maftoun *et al.*, (2005) also reported that the addition of municipal waste compost to soil led to an increase in P uptake. While the highest K uptake was observed in plots that received recommended rates of RBC but not significantly different from the applied CC.

Conclusion

The result revealed that the performance of RBC followed the same pattern across the plant growth and with no significant difference in CC. Amaranth growth increased with inorganic fertilizer application but was not affected by nitrogen source of ML. RBC led to an increased in fresh and dry biomass yields and nutrient uptake of amaranth plants. NPK and ML had no influence in the biomass yields and nutrient uptake. RBC is a veritable source of plant nutrition. It is easily available, affordable and harmless to soil ecosystem.

It would be best to use RBC for crop production to minimize the harmful effects of NO_3^- to humans from the use of NPK. The RBC showed promise, as an alternative to recommended dose of NPK fertilizers, for amaranth production and also for the benefits of human nutrition and health. It is therefore reasonable to recommend the use of rice bran based-compost (RBC) as an alternative to the recommended NPK dose for production of amaranth.

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