Production and evaluation of compost tea for cultivation of *Amaranthus hybridus*

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Abstract: The application of organic fertilizer to the soil is considered as good agricultural practice because it improves the fertility of the soil and plant quality. The aim of the study was to produce compost tea using poultry droppings, cow dungs and water leaf (*Talinum triangulare*) in a ratio 5:5:1 and evaluate its effects on soil properties, growth and yield of *Amaranthus hybridus*. The study was carried out in Jalingo, Taraba State, North-Eastern Nigeria in July, 2019. The experimental variables include control (no treatment), 1 kg of compost per 10 L of water compost tea, 1 kg of compost per 20 L of water compost tea, 1 kg of compost per 30 L of water compost tea, 500 kg ha^{-1}solid compost and 500kg ha^{-1} NPK fertilizer. The treatment combinations were done in a randomized complete block design, replicated four times, giving a total of twenty four plots. Each plot was 2.0 m × 2.0 m with 0.5 m alley between the plots and replicates. Soil properties were determined at harvest while growth and yield parameters of Amaranthus hybridus were determined at maturity. The results showed that compost tea, solid compost and NPK compound fertilizer application increased soil porosity, water holding capacity, soil pH, organic matter, nitrogen, phosphorus, calcium, magnesium, potassium, sodium and total exchangeable bases and decreased soil bulk density and particle density to favorable levels. Compost tea, solid compost and NPK compound fertilizer also increased plant height, stem girth, number of leaves per plant, leave area, leave area index, root yield, stem yield and leaves yield. The result showed that 1 kg of compost per 10 L of water compost tea produced tallest plants (118.18 cm) with largest stem girth (2.586 cm), highest number of leaves per plant (42.44), largest leave area (98.66 cm^2), highest leave area index (4.606), highest fresh root yield (5.25 tons ha^{-1}), highest fresh stem yield (30.12 tons ha^{-1}) and highest leaves yield (18.22 tons ha^{-1}). Compost tea elicited higher growth and yield characteristics of *Amaranthus hybridus* plants than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. The result suggests that the 1 kg of compost per 10 L of water compost tea application rate be utilized, as a more appropriate and profitable soil fertility enhancement method in order to achieve better performance of *Amaranthus hybridus* plants. This implies that compost tea extracts from poultry droppings, cow dungs and water leaf (*Talinum triangulare*) can be used in a sustainable agriculture to increase yield and quality of *Amaranthus hybridus*.

Keywords: growth, yield, plants, organic, fertilizer

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1 Introduction

Amaranthus is a genus of an annual vegetable belonging to the family Amaranthaceae (Stephens, 2009). It is a fast growing and highly nutritional vegetable that is widely distributed in the humid zone of the tropics including Nigeria. *Amaranthus* is a very good sources of vitamins, protein and dietary minerals including calcium, iron, magnesium, phosphorus, potassium, zinc, copper and manganese (Ros et al., 2020). Since about 1980s, Amaranth has been rediscovered as a promising food crop mainly due to its resistance to heat, drought, diseases and pests, and the high nutritional value of both seeds and leaves (Wu et al., 2000). According to Onyango (2010), improvement of *Amaranthus* through research and development could produce an easy and cost-effective way of eliminating malnutrition and promoting health of the people as well as achieving food security.

Amaranthus hybridus is an important leafy vegetable from the *Amaranthaceae* family and is a source of nutrients such as vitamins, minerals, sugar, water, protein and fiber needed for healthy body growth and sustenance. The major limitations to the cultivation of *Amaranthus hybridus* are poor soil fertility, availability and affordability of inorganic fertilizers. *Amaranthus hybridus* requires high amount of nitrogen, which is one of the limiting nutrients in the tropical soil (Inyang et al., 2018).

Vegetables are cheaper sources of many nutrients, bio-chemicals and phytochemicals which are responsible for normal physiological functions and also help in reducing the risk of chronic diseases. To enhance the optimal production of this nutrients and phytochemicals, appropriate use of fertilizers has to be employed (Chemutai, 2018). Intensive cultivation, misuse and excessive use of chemical fertilizers may lead to loss of soil organic matter, have adverse effects on the environment and can threaten human and animal health as well as in food safety and quality (Kariithi, 2018; Dayo-Olagbende et al., 2020). The cost of chemical fertilizers, limited resource reserves and the potential environmental risk like polluted air, water, and soil, the degraded lands, depleted soils and increased emissions of greenhouse gases, posed by overuse have renewed the interest in using soil organic matter amendments such as plant residues, manures and composts (Dayo-Olagbende et al., 2020) which are considered economic and environmentally-friendly alternatives (Chemutai et al., 2019). The beneficial effects of composts include increasing water holding capacity and plant water availability, decreasing leaching of nutrients, reducing erosion and evaporation and prevention of plant diseases (El-Farghal et al., 2019). Compared to plant residues and manure, composts release nutrients more slowly and have longer-lasting effects (Kariithi, 2018). The slow decomposition is more effective increasing organic matter content of the soil which plays a key role in soil fertility by retaining nutrients, maintaining soil structure, and holding water (Dania et al., 2018).

Many organic materials are produced around the home, or can be obtained at little or no cost from livestock operations, municipal green waste collection centers, and local landfills. Virtually any organic material can be used as a fertilizer; however, materials vary considerably in the concentration of plant nutrients they contain and the rate at which these nutrients are released for plant use (Jerry, 2017). Therefore, some organic fertilizers are better for certain situations than others, and different materials need to be applied at different rates to supply the correct amount of plant nutrients. A common misconception is that organic fertilizers are safer for plants and the environment than inorganic (chemical) products. Improper organic fertilizer application can also contribute to surface and ground water pollution, may induce a plant nutrient deficiency or toxicity (Jerry, 2017). If properly used, both organic and inorganic fertilizers are safe for plants and the environment. Hence, it is necessary to evaluate the effect organic fertilizers will have on soil properties, growth performance and yield of *Amaranthus hybridus*.

Composting is an aerobic process through which organic matter is decomposed to humus-like substances (Barral et al., 2009). Compost properties vary widely depending on feed stocks and composting procedure (Bernal et al., 2009). Compost can be derived from a number of feedstock materials including woody and herbaceous green waste, crop residues, bio-solids (sewage sludge), wood by-products, animal manures, biodegradable packaging, biodegradable building materials and food scraps. These feed stocks differ substantially in chemical composition, particle size and thus decomposition rates (Cayuela et al, 2009). Loss of nitrogen during composting may be by volatilization of ammonia, leaching and denitrification. Denitrification is an anaerobic process which can be reduced by ensuring that the compost remains well aerated (Tiquia and Tam, 2000). Mature composts are stable and have pleasant smell but if the composting process is ended prematurely, the resulting immature compost may have negative effects on soils and plants and have a bad odour (Farrell and Jones, 2009).

Compost tea is a water extract of various kinds of organic matter, rich in nutrient, organic compounds and microbes. Compost tea is better than solid compost because it contains soluble nutrients and can be used for soaking seeds or seedlings before planting. It also can be applied to soil through irrigation systems or to plant foliage (El-Farghal et al., 2019). Compost tea has emerged as an important component of the integrated nutrients supply system and holds a great promise to improve crop yield through nutrients supplies. It is worthy to note that the compost tea not only acts as a soil amendment but also acts as a bio-organic fertilizer and plant growth promoting Rizobacteria (El-Farghal et al., 2019). Compost tea contains many trace elements and plant grown in it might be more disease resistant than in soil with artificial fertilizer only. Compost tea has been found to increase organic matter content, nutrient availability and microbial activity and helps to improve the soil structure and water holding capacity. Nutrient in compost teas has been detected in plant root as early as an hour immediately after application (Dania et al., 2018). Compost tea is a crop production tool for organic agriculture for a number of reasons as identified by El-Farghal et al. (2019); firstly, it contains microorganisms which can reduce incidences of foliar and or soil ionic diseases, and nutrients contained in compost tea support the survival and the proliferation of these microorganisms. Secondly, it contains nutrients in readily available forms which rapidly benefit plant growth through direct contribution to plant nutrition. Thirdly, compost tea is easily integrated in the existing plant fertility and disease control programs due to its ease of application via existing irrigation or spray equipment or soil drench. Finally, unlike composts, compost tea does not require transportation of large quantities of bulk composts for long distances because compost tea is generally produced at the farm or alternatively compost concentration is bought. Therefore, this study was aimed at producing and evaluating compost tea for cultivation of *Amaranthus hybridus*.

2 Materials and methods

2.1 Experimental site

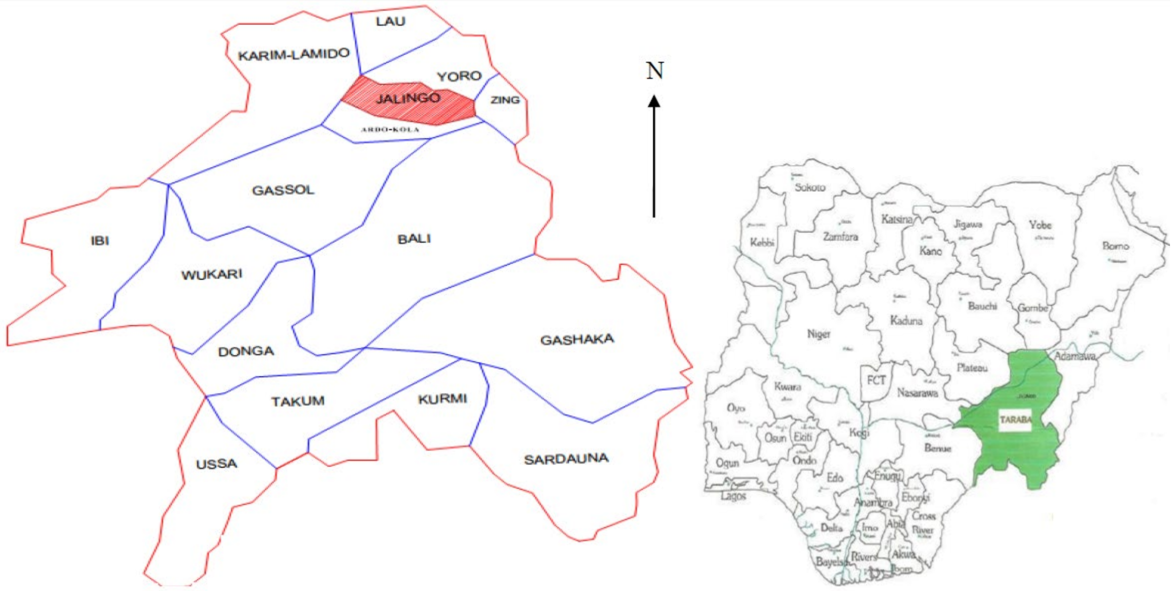
The study was conducted during 2019 farming seasons in Jalingo, Taraba State, North-Eastern Nigeria. Jalingo is located between latitude 8° 47′ N to 9° 01′ N and longitude 11° 09′ E to 11° 30′ E. Jalingo local government area has tropical continental type of climate characterized by well-marked wet and dry season. The wet season usually begins around April and ends in October. Jalingo has a mean annual rainfall of about 1,200 mm. In the rainy season, the relative humidity is much higher and ranges between 60% -70%. The dry season begins in November and ends in March. The dry season is characterized by the prevalence of the northeast trade winds, which is usually dry and dusty. During the dry season, relative humidity is low and falls between 35% - 45%. This low relative humidity coupled with high afternoon temperatures account for the desiccating effects of the dry season. The average minimum recorded temperature is 15.2 °C while the average maximum temperature is 39.7 °C (Umeh et al., 2019). The field trial location was selected on the basis of common practices of vegetable farming among farmers at the selected location. Figure 1 indicates the map of Taraba state showing Jalingo and map of Nigeria showing Taraba.

2.2 Research design and treatments

The experiment was conducted in randomized complete block design (RCBD) in four replications with each experimental unit measuring 2 m × 2 m (4 m^2). The experiment consisted of six treatments: (1) control (no treatment); (2) 1 kg of compost per 10 L of water compost tea; (3) 1 kg of compost per 20 L of water compost tea; (4) 1 kg of compost per 30 L of water compost tea; (5) 500 kg ha^{-1}solid compost; and (6) 500kg ha^{-1} NPK fertilizer. This gave a total of twenty-four experimental plots. A 0.5 m alley was left between plots within a replication and a 0.5 m alley between replications. Figure 2 shows the experimental design field layouts.

2.3 Compost and compost tea preparation

Poultry droppings used were obtained from local poultry farm in Jalingo, cow dungs were sourced from the Taraba state dairy farm in Jalingo and water leaf (*Talinum triangulare*) was obtained from the Taraba Agricultural Development Programme (TADP) office, Jalingo. The passively aerated composting technique (PACT) was used for the preparation of compost. The materials used include poultry droppings, cow dungs and water leaf (*Talinum triangulare*) in a ratio 5:5:1. Turning of the compost was done weekly and water was added when the moisture content level fell below 40 %. This was done to create conducive environment for microbes to hasten decomposition of materials. The process took a month for complete digestion of the material. The prepared compost was brewed, employing the beverage concept for making compost extract. 1 kg of compost corresponding to 2500 kg ha^{-1} of manure was weighed into three (3) different drums. The amount of water added to the drum varied and was 10, 20 and 30 L of water. The compost tea was soaked in different volumes of water for three days and later sieved.



(A) Map of Taraba showing Jalingo (B) Map of Nigeria showing Taraba

Figure 1 Map of Taraba state showing Jalingo and map of Nigeria showing Taraba (Umeh et al., 2019)

2.4 Agronomic practices

2.4.1 Land preparation and fertilizer application

The experimental field was demarcated prior to experimental setup and was cleared using a cutlass and a hoe while ploughing was done using a tractor. The total land area used was 14.5 m×9.5 m (137.75 m^2). After laying-out, the various organic and inorganic materials were then applied on their respective plots. Levelling and application of organic and inorganic materials were done manually using human labour.

2.4.2 Planting

The *Amaranthus hybridus* seeds used were obtained from the Taraba Agricultural Development Programme (TADP) office, Jalingo. Prior to planting, the experiment field was sprayed with glyphosate, a non-selective herbicide, to kill all weeds to avoid competition. The *Amaranthus hybridus* seeds were sown at a planting distance of 30 cm × 30 cm and later thinned two weeks after planting to one plant per stand with a plant population 111,111 plants per hectare. Weeding was done manually using hoe and cutlass thrice at the 2nd, 4th and 6th weeks after planting. Dimethoate 400 gL^{-1} emulsifiable concentrate (Dimethoate 400 EC) was applied at the concentration of 1.5 L ha^{-1} at the 2nd and 4th weeks after planting to control pests.

2.4.3 Compost tea and fertilizers application

The compost extract (compost tea) was applied directly to the field land using watering can. The compost tea was applied at the rate of 1litre per plant twice a week from 2nd to 5th weeks and reduced to once a week at the 6th to 7th weeks after planting. The solid compost fertilizer was applied at the rate of 500 kg ha^{-1} and the soil was allowed to equilibrate two weeks before planting. The NPK fertilizer was applied to the soil at the rate of 500 kg ha^{-1}and mixed thoroughly two weeks before planting.

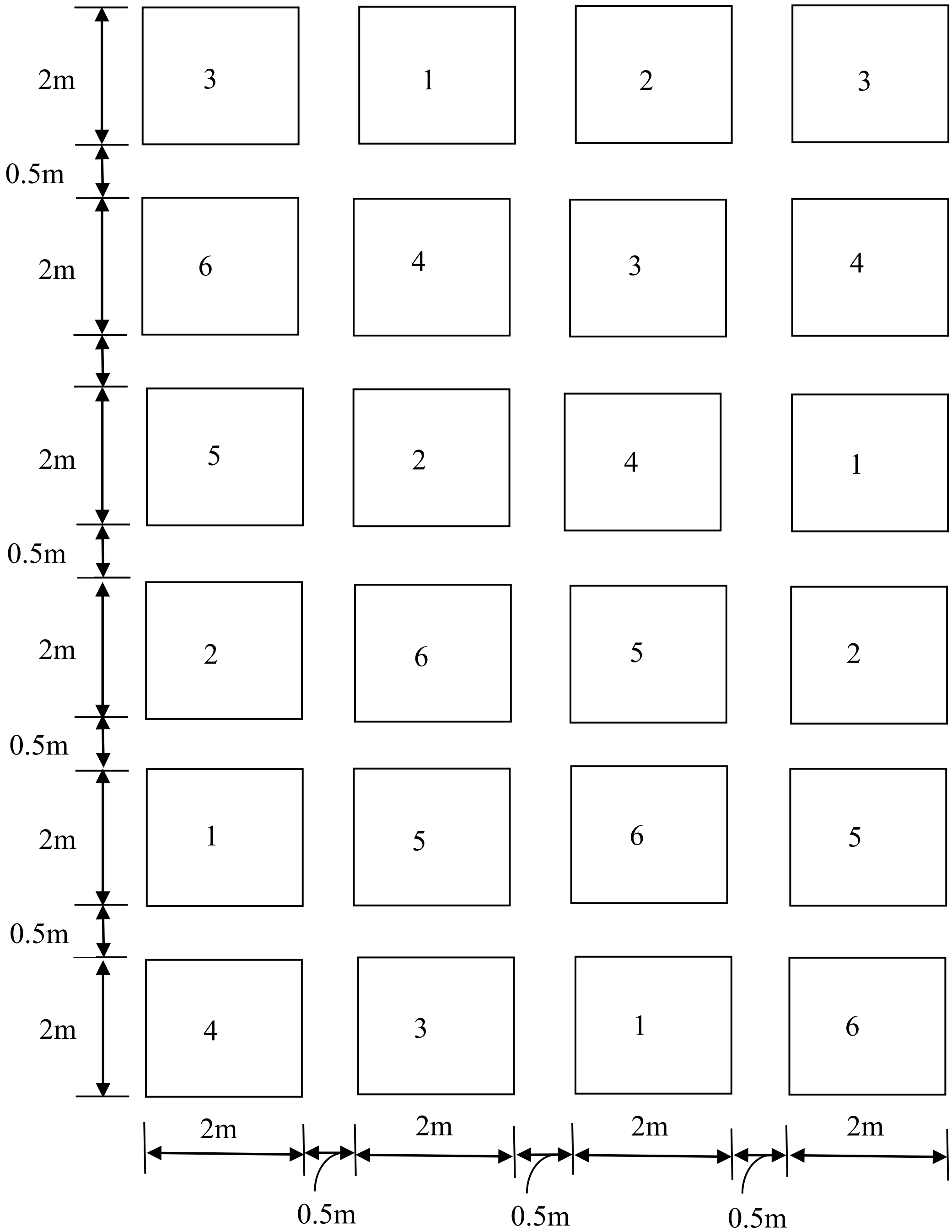


Figure 2 Experimental design field layouts

2.5 Soil sampling and analysis

Surface soil samples (0 to 15 cm in depth) were taken randomly using the zigzag method (Brady and Weil, 2008) on plot basis before planting and at crop maturity. The soil samples were air-dried for a period of one week in a clean well ventilated laboratory, homogenized by grinding, passed through a 2 mm (10 mesh) stainless sieve and were analyzed for physical and chemical properties using standard procedures.

2.5.1 Analysis of soil physical properties

The particle-size distribution (soil texture) was determined using Bouyoucos hydrometer method for mechanical analysis (Cheick, 2014). Bulk density was determined by the Core Method of known soil volume. Dry bulk density was determined as the ratio of mass of dry soil per unit volume of soil cores (Aikins and Afuakwa, 2012). Soil particle density was determined using pycnometer method. The total porosity of the soil was calculated from the values of the dry bulk density and particle density (Aikins and Afuakwa, 2012). Water holding capacity was determined as gravimetric water content of a quantity of soil fully saturated with water. It was determined using the porous cup method.

2.5.2 Analysis of soil chemical properties

Soil pH was measured in a 1:1 soil-water ratio by electrometric method using a digital glass electrode pH meter model HI 9017 (Hanna Instruments). Total organic carbon was analyzed by wet digestion and the organic carbon content was multiplied by a factor (1.724) to get the percentage organic matter (Burt, 2014). Total nitrogen was determined by micro-Kjeldahl digestion method (Burt, 2014). Available phosphorous was extracted using Bray-1 solution and determined by molybdenum blue colorimetry (Burt, 2014). Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined by the neutral ammonium acetate procedure buffered at pH 7.0 (Thomas, 1982).

2.6 Plant data collection

2.6.1 Determination of *Amaranthus hybridus* plant growth parameters

The plant growth data were collected at vegetative phase (market maturity) of plant development. The plant growth data collected were plant height, plant girth, number of leaves and leaf area. Six *Amaranthus hybridus* plants were selected at random from each plot and tagged for growth measurements.

Plant height was measured using a measuring tape from the base of the stem (surface of the soil) to the apex of the leaves (Masarirambi et al., 2012). Data on stem diameter of representative *Amaranthus hybridus* plants on each plot was measured using venire calipers. The number of leaves per plant was determined by physical counting and data from the tagged plants was used to compute the score for each plot (Masarirambi et al., 2012). The leaf length and breadth were measured using a metre rule to obtain the leaf area. The leaf length was measured from the leaf base to the tip whereas the leaf width was measured at the broadest part of the leaf blade. The leaf area was estimated as its length multiplied by its maximum width multiplied by *Amaranthus* leaf calibration or correction factor, 0.578 (Masarirambi et al., 2012). The leaf area index (LAI) was computed using Equation 1 (Msibi et al., 2014).

$$LAI = \frac{Y \times N \times LA}{AP} \quad (1)$$

Where; Y = Population of plants per plot, N = Average number of leaves, LA = Leaf area (cm^2), AP = Area of plot (cm^2).

2.6.2 Determination of *Amaranthus hybridus* plant yield parameters

The entire plants on the plots were harvested by uprooting the whole plant at vegetative phase (market maturity) of plant development. The plants were then separated into roots, stems and leaves. The roots, stems and leaves were weighed and their weights recorded as fresh weights. The various plant parts were put in brown paper envelopes and then oven dried at 80 ^{o}C for 48 h to obtain their dry weights. The roots, stems and leaves obtained after harvest from the net plot area of each plot were weighed on an electronic balance.

2.7 Statistical analysis

All the data that were collected from the field experiments on soil properties, growth and yield characteristics of *Amaranthus hybridus* were subjected to Analysis of Variance (ANOVA) test at $p \leq 0.05$. Treatment means were compared using the Least Significant Difference (LSD) at $p \leq 0.05$. Two statistical packages, SPSS 16 and mini-tab 20 for windows, were used for the statistical analysis.

3 Results and discussion

3.1 Soil properties of the experimental site before the experiment

The properties of the soil at the experimental site before the experiment is presented in Table 1.The result shows that the soils are typically sandy clay loam which indicates that the water holding capacity of the soil is good with a relatively high particle and bulk densities and moderate porosity. The essential nutrients such as organic matter, total nitrogen, available phosphorus, potassium and sodium in soil used are very low and shows the low fertility status of the soil, which is in agreement with Ogedegbe et al. (2013). This observation confirmed Akanbi and Togon (2002) who reported that most agricultural soils were impoverish due to weathering, leaching, erosion and intensive cultivation. A good soil has an organic matter value above 3% (Alam et al., 2007). The soil was acidic and less suitable for Amaranthus. The soil was also low in calcium and magnesium hence its acidic nature which may require addition of soil amendments for optimum crop production.

Table 1 Physical and chemical properties of soil before the experiment

Properties	Value
Sand (%)	58.0
Clay (%)	25.2
Silt (%)	16.8
Soil texture	Sandy clay loam
Bulk density (g cm^{-3})	1.45
Particle density (g cm^{-3})	2.58
Soil porosity (%)	43.80
Water holding capacity (%)	80.5
pH (H_2O)	5.6
Organic matter (%)	1.88
Total N (%)	0.18
Available P (%)	12.22
Exchangeable Ca (cmol (+) kg^{-1})	2.43
Exchangeable Mg (cmol (+) kg^{-1})	1.80
Exchangeable K (cmol (+) kg^{-1})	0.26
Exchangeable Na (cmol (+) kg^{-1})	0.21
Total Exchangeable Bases, TEB (cmol (+) kg^{-1})	4.70

3.2 Effects of compost tea application on soil physical properties

The results of the effect of application of compost tea on soil physical properties are presented in Table 2. The results show that the mean sand fraction of the soil ranged from 56.5 % to 62.5 %, mean clay fraction ranged from 23.6 % to 28.2 % and the mean silt fraction of the soil varied from 13.9 % to 16.1 %. Generally, the mean values indicate that the sand fraction dominated the fine earth separate. This was followed by the clay fraction, while the silt fraction was the lowest. The soil textures in these areas are mainly sandy clay loam, which is medium texture.

The ANOVA shows that the soil particle density, bulk density, soil porosity and water holding capacity were significantly ($p < 0.05$) affected by the imposed treatments. Compost tea, solid compost and NPK fertilizer were found to reduce the soil particle density and bulk density but increase soil porosity and water holding capacity. The multiple comparison of means indicated that the mean soil bulk densities are statistically ($p < 0.05$) different among the treatments. However, there were no significant statistical differences in bulk densities between 500 kg ha^{-1} solid compost and 1 kg (10 L)$^{-1}$ compost tea, and 1 kg (20 L)$^{-1}$ compost tea treated plots. The mean soil particle densities were also found to be statistically ($p < 0.05$) different among the treatments. But there were no significant statistical differences in particle densities between 1kg (30 L)$^{-1}$ compost tea and 1 kg (20 L)$^{-1}$ compost tea, and 500 kg ha^{-1} NPK fertilizer treated plots. There were no also significant differences particle densities between 500 kg ha^{-1} solid compost and 1 kg (10 L)$^{-1}$ compost tea, and 1 kg (20 L)$^{-1}$ compost tea treated plots. Both the mean soil porosities and water holding capacities were statistically ($p < 0.05$) different among all the treatments. Physical characteristics of soil were improved by the application of compost tea, solid compost and NPK fertilizer. This is in line with Gani et al. (2020) who observed that organic fertilizer improved soil biological and physical properties.

Table 2 Effects of compost tea application on soil physical properties

Treatment	Soil Physical Properties						
	Sand (%)	Clay (%)	Silt (%)	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Porosity (%)	Water holding capacity (%)
Control (no-treatment)	60.1^{a}	25.3^{a}	14.6^{a}	1.47^{a}	2.61^{a}	43.68^{a}	80.2^{a}
1 kg(10 L)$^{-1}$ compost tea	56.5^{b}	28.2^{b}	15.3^{b}	1.30^{b}	2.50^{b}	48.00^{b}	87.8^{b}
1 kg(20 L)$^{-1}$ compost tea	59.2^{c}	26.8^{c}	14.0^{c}	1.35^{c}	2.53^{c}	46.64^{c}	86.5^{c}
1kg(30 L)$^{-1}$ compost tea	60.0^{a}	24.7^{d}	15.3^{b}	1.39^{d}	2.55^{cd}	45.49^{d}	86.0^{d}
500 kg ha^{-1} solid compost	58.4^{d}	25.5^{e}	16.1^{d}	1.33^{bc}	2.52^{bc}	47.22^{e}	87.6^{e}
500 kg ha^{-1} NPK fertilizer	62.5^{e}	23.6^{f}	13.9^{c}	1.41^{e}	2.56^{d}	44.92^{f}	84.3^{f}
p-value	0.000	0.000	0.000	0.000	0.004	0.000	0.000
F-LSD $_{0.05}$	0.25	0.15	0.30	0.047	0.025	0.495	0.094

Note: Means having the same letter in the same columns are not significantly different at $p < 0.05$

3.3 Effects of compost tea application on soil chemical properties

The results of the effect of application of compost tea on soil chemical properties are presented in Table 3. The results show that the application of compost tea, solid compost and NPK fertilizer had a significant ($p < 0.05$) positive effect on soil pH, organic matter, nitrogen, phosphorus, calcium, magnesium, potassium, sodium and total exchangeable bases. The soil chemical properties investigated were found to increase with the application of compost tea, solid compost and NPK fertilizer. The highest value of soil pH (6.7), organic matter (3.54 %), nitrogen (0.36 %), phosphorus (19.40 %), calcium (2.81 cmol (+) kg^{-1}), magnesium (1.95 cmol (+) kg^{-1}), potassium (0.48 cmol (+) kg^{-1}), sodium (0.35 cmol (+) kg^{-1}) and total exchangeable bases (5.59 cmol (+) kg^{-1}) were observed in plots treated with 1 kg $(10\ L)^{-1}$ compost tea and were statistically significant ($p < 0.05$). However, there were no significant differences in soil pH between 1 kg $(20\ L)^{-1}$ compost tea and 1 kg $(10\ L)^{-1}$ compost tea, 1 kg $(30\ L)^{-1}$ compost tea and 500 kg ha^{-1} solid compost tea treated plots. Soil pH was significantly higher ($p < 0.05$) in 500 kg ha^{-1} NPK fertilizer and control (no-treatment) treated plots. Regarding soil N, there were no significant differences between 500 kg ha^{-1} NPK fertilizer and 1kg $(30\ L)^{-1}$ compost tea, and 500 kg ha^{-1} solid compost treated plots. There were also no significant differences between 500 kg ha^{-1} solid compost, and 1 kg $(20\ L)^{-1}$ compost tea, 1 kg $(30\ L)^{-1}$ compost tea and 500 kg ha^{-1} NPK fertilizer treated plots in soil K. Concerning total exchangeable bases, there were no significant differences between 1 kg $(20\ L)^{-1}$ compost tea and 500 kg ha^{-1} NPK fertilizer treated plots. Chemical characteristics of soil were improved by the application of compost tea, solid compost and NPK fertilizer. This agrees with Gani et al. (2020) who observed that organic fertilizer improved mineral nutrient status as well as soil biological and physical properties. This work also agrees with Dania et al. (2018) who found that the application of compost significantly ($p \leq 0.05$) improved the soil nutrient content, organic carbon and increased the pH to near neutral.

Table 3 Effects of compost tea application on soil chemical properties

Treatment	Soil Chemical Properties								
	pH	OM	Total N	Avail. P	Ca	Mg	K	Na	TEB
	(H_2O)	(%)	(%)	(%)	←		(cmol (+) kg^{-1})		→
Control (no-treatment)	5.6^a	1.86^a	0.19^a	12.18^a	2.44^a	1.76^a	0.28^a	0.24^a	4.72^a
1 kg$(10\ L)^{-1}$ compost tea	6.7^b	3.54^b	0.36^b	19.40^b	2.81^b	1.95^b	0.48^b	0.35^b	5.59^b
1 kg$(20\ L)^{-1}$ compost tea	6.6^{bc}	2.98^c	0.31^c	18.32^c	2.60^c	1.88^c	0.45^c	0.30^c	5.23^c
1kg$(30\ L)^{-1}$ compost tea	6.4^c	2.73^d	0.26^d	14.08^d	2.55^d	1.80^d	0.42^d	0.26^d	5.03^d
500 kg ha^{-1} solid compost	6.5^{bc}	3.12^e	0.29^e	17.74^e	2.78^e	1.91^e	0.44^{cde}	0.32^e	5.45^e
500 kg ha^{-1} NPK fertilizer	5.8^a	2.86^f	0.27^{de}	15.86^f	2.73^f	1.84^f	0.43^{cde}	0.28^f	5.28^c
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-LSD $_{0.05}$	0.297	0.066	0.029	0.094	0.019	0.029	0.019	0.019	0.105

Note: OM - Organic matter, TEB - Total exchangeable bases. Means having the same letter in the same columns are not significantly different at $p < 0.05$

3.4 Effects of compost tea on growth parameters of *Amaranthus hybridus*

The results of the effect of application of compost tea on growth parameters of *Amaranthus hybridus* are presented in Table 4. The results of the field experiments show that the effects of application of compost tea, solid compost and NPK fertilizer were pronounced on the growth characteristics of *Amaranthus hybridus*.

3.4.1 Plant height

Plant height indicates the influence of various nutrients on plant metabolism. The results showed that compost tea application had a significant ($p < 0.05$) positive effect on the plant height. Increasing the rates of compost tea application resulted to an increase in plant height. Solid compost and NPK compound fertilizer were also found to significantly ($p < 0.05$) increase plant height. The multiple comparison of means showed that the mean plant heights are statistically ($p < 0.05$) different among all the treatments. Compost tea elicited higher plant height than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. Highest plants were obtained with1 kg of compost per 10 L of water compost tea treatment and the lowest plant height was produced by the control (no-treatment). Compost tea, solid compost and NPK compound fertilizer promoted fast *Amaranthus hybridus* growth and development of the plants. These increases of plant heights are attributed to the fact that nitrogen encourages the elongation and cell division leading to an overall increase in the plant height. The findings of this study were in line with findings by Dlamini et al. (2020) who reported that Amaranthus plants fertilized with stillage were found to have a higher mean plant height followed by plants fertilized with kraal manure, compost and control, respectively. Khan et al. (2008) observed that increment in heights of plants with compost tea, solid compost and NPK compound fertilizer application is attributed to nutrients availability especially N which promoted fast growth and development of the plants. According to Alam et al. (2007) and Ogedegbe et al. (2013), the application of organic manure significantly ($p \leq 0.05$) increased the growth of amaranthus. The height of the plant is an important growth character directly linked with productive potential of plants. An optimum plant height is claimed to be positively corrected with productivity of plants (Saeed et al., 2001).

3.4.2 Stem girth

The compost tea application had significant ($p < 0.05$) positive effect on the stem diameter of *Amaranthus hybridus* plants. Increasing the application rate of compost tea increases stem diameter of *Amaranthus hybridus* plants. Solid compost and NPK compound fertilizer were also found to increase stem diameter of *Amaranthus hybridus* plants significantly ($p < 0.05$). The multiple comparison of means revealed that the mean stem girths are statistically ($p < 0.05$) different among all the treatments. Considering the fertilizer types generally, the result reveals that compost tea gave the highest stem diameter; this was followed by solid compost, then NPK compound fertilizer while control (no fertilizer) gave the least stem diameter. Plant girth increased with increasing rates of compost tea application. The highest stem girth (2.586 cm) was recorded in the 1 kg of compost per 10 L of water compost tea treatment and the lowest stem girth (1.565 cm) was in the control (no-treatment). The findings of this study were consistent with findings by Dlamini et al. (2020) who observed that *Amaranthus* plants fertilized with stillage had the thickest stem girth (cm), followed by plants fertilized with kraal manure, then compost and lastly the plants in the control (no fertilizer). This work is also in agreement with Edje and Ossom (2009) who reported that growth including stem girth increased with increased application of organic fertilizers. The positive performance of the composted manure on the stem girth response of *Amaranthus hybridus* may be due to the balance nutrients the compost contained.

3.4.3 Number of leaves

The number of leaves was influenced ($p < 0.05$) by compost tea applications. The number of leaves increased with increasing rates of compost tea applications. Solid compost and NPK compound fertilizer were also observed to significantly ($p < 0.05$) increase the number of leaves. The multiple comparison of means indicated that the mean number of leaves are statistically ($p < 0.05$) different among the treatments. However, there was no significant statistical difference in the mean number of leaves between 500 kg ha^{-1} solid compost and 500 kg ha^{-1} NPK fertilizer treated plots. Compost tea gave higher number of leaves than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. Compost tea applications of 1 kg of compost per 10 L of water compost tea treatment produced the maximum number of leaves and the control (no-treatment) recorded the least number of leaves. This work corroborates Dlamini et al. (2020) who reported that *Amaranths* plants fertilized with stillage were found to have the highest number of leaves, followed by plants fertilized with kraal manure, then compost and lastly the plants in the control (no fertilizer). This study is also in line with Efthimiadou et al. (2010) who observed that organic soil amendments recorded the highest number of leaves. The significant variation in *Amaranthus hybridus* plant leaf count is attributed to the organic material sources and source levels. This high leaves development in the compost is due to the higher amount of nitrogen and continuous release of the nutrients. However, the reason behind the higher number of leaves for plants treated with organic fertilizers than the NPK compound fertilizer may be due to availability of nutrients as affected by the water holding capacity of the soil (Jacobs et al., 2003). Most probably because as the manure quantities increased the water holding capacity of the soil and subsequent nutrient release increases, while the NPK compound fertilizer nutrients have been exhausted as the early stages due to the solubility of the nutrients. The increased number of leaves observed with fertilizer is attributed to nutrients availability especially nitrogen (Khan et al., 2008) provided by the organic materials which promoted fast growth and development of the *Amaranthus hybridus* plants. An increase in the number of leaves could positively affect the photosynthetic activity of the plant since leaf number is a growth index that could enhance crop yields.

3.4.4 Leaf area

The results showed that compost tea treatment had a significant ($p < 0.05$) positive effect on the leaf area. Leaf area increased with increasing rates of compost tea application. Application of solid compost and NPK compound fertilizer also affected the leaf area significantly ($p < 0.05$) with higher values of leave area than the control (no-fertilizer) treatment. The multiple comparison of means revealed that the mean leaf areas are statistically ($p < 0.05$) different among all the treatments. Compost tea recorded higher leaf area than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. Plot treated with 1 kg of compost per 10 L of water compost tea produced the highest value of leaf area while the least leaf area was observed with the control (no-treatment) plots. These findings confirm that of Chawla and Mehta (2015) who also found that growing media affects the survival and growth of transplanted Litchi layers with better root development and therefore better leaf growth. These findings are also in line with the study carried out by Dlamini et al. (2020) where the researchers found that *Amaranthus* plants fertilized with stillage were found to have the highest leaf area (cm^2), followed by plants fertilized with kraal manure, then compost and lastly the plants in the control (no fertilizer). Ratna (2002), states that the provision of neither liquid nor solid organic fertilizer can stimulate the increase of leaf area. The increase in leaf area had been claimed to be directly influence by nitrogen supply in fertilizer applied (Jerry, 2017). Increased leaf means the ability to receive and absorb sunlight, therefore photosynthetic and the energy produced is also higher. The addition of the leaf area is an efficiency of each unit leaf area to do photosynthesis to increase plant dry weight.

3.4.5 Leaf area index

Leaf area index which indicates the photosynthetic ability of the plants was significantly ($p < 0.05$) influenced by different doses of applied compost tea. Leaf area index was found to increase with increasing rates of compost tea application. Solid compost and NPK compound fertilizer application were also found to increase the leaf area index significantly ($p < 0.05$). The multiple comparison of means indicated that the mean leaf area indexes are statistically ($p < 0.05$) different among the treatments. However, there were no significant statistical differences in the mean leaf area indexes between 1 kg (20 L) $^{-1}$ compost tea, 500 kg ha^{-1} solid compost and 500 kg ha^{-1} NPK fertilizer treated plots. Considering the fertilizer types generally, the result reveals that compost tea gave the highest leaf area index; this was followed by solid compost, then NPK compound fertilizer while control (no fertilizer) gave the least leaf area index. The highest leaf area index was recorded in the 1 kg of compost per 10 L of water compost tea treatment and the lowest was in the control (no-treatment) plots. Enhanced seedling growth and leaf proliferation and expansion in leaf vegetables, attributed to organic soil amendments, has similarly been demonstrated in pervious field experiments (Chawla and Mehta, 2015; Jerry, 2017; Dlamini et al., 2020). The findings of this study are similar with those of Masarirambi et al. (2012) who reported that although amaranths were a low management crop and grew in poor soils, the yield is increased with fertilizer application and that organic fertilizers do not only improve yield but it also maintains soil fertility. The significant increase in leaf area index with the application of compost tea indicated the effectiveness of applied compost tea in improving the growth of *Amaranthus hybridus* plants. The higher leaf area index in organic fertilizer (poultry manure) was caused by the relatively higher nutrient availability which increased the leaf length, number of leaves and leaf width per unit area of the plot (Jerry, 2017). Dosage of the fertilizers (concentration levels) had an increment effect on the leaf area index. This implies the higher the dosage the higher the growth performance which can be attributed to the increased amount of nutrients in higher dosage of fertilizers. Hence, the higher nutrients in higher dosage were used for the development of important parts of the plants such as higher foliage and longer shoot.

Table 4 Effects of compost tea on growth parameters of *Amaranthus hybridus* at maturity

Treatment	*Amaranthus hybridus* Plant Growth Parameters

	Plant height (cm)	Stem girth (cm)	Number of leaves	Leaf area (cm^2)	Leaf area index
Control (no-treatment)	97.86^a	1.565^a	24.32^a	67.56^a	1.807^a
1 kg(10 L)$^{-1}$ compost tea	118.18^b	2.586^b	42.44^b	98.66^b	4.606^b
1 kg(20 L)$^{-1}$ compost tea	111.60^c	2.403^c	40.65^c	94.48^c	4.225^c
1kg(30 L)$^{-1}$ compost tea	105.44^d	2.143^d	39.24^d	92.15^d	3.978^d
500 kg ha^{-1} solid compost	109.68^e	2.474^e	39.84^e	96.35^e	4.222^c
500 kg ha^{-1} NPK fertilizer	107.52^f	2.316^f	39.75^e	95.82^f	4.190^c
p-value	0.000	0.000	0.000	0.000	0.000
F-LSD $_{0.05}$	0.029	0.047	0.156	0.029	0.115

Note: Means having the same letter in the same columns are not significantly different at $p < 0.05$

3.5 Effects of compost tea on yield parameters of *Amaranthus hybridus*

The results of the effect of application of compost tea on yield parameters of *Amaranthus hybridus* are presented in Table 5. The results of the field experiments show that the effects of application of compost tea, solid compost and NPK fertilizer were pronounced on the yield characteristics of *Amaranthus hybridus* plants.

3.5.1 Root yield

The fresh root and dry root of *Amaranthus hybridus* plants were significantly ($p < 0.05$) affected by compost tea application. The fresh root and dry root both increased with increase in compost tea application rate. Application of solid compost and NPK compound fertilizer were also found to increase fresh root and dry root of *Amaranthus hybridus* plants significantly ($p < 0.05$). Compost tea elicited higher root yield than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. The 1 kg of compost per 10 L of water compost tea treatment had the highest fresh root weight (5.25 tons ha^{-1}) and dry root weight (1.75 tons ha^{-1}) which were statistically different from the other treatments. The control (no-treatment) had the lowest fresh root weight (0.63 tons ha^{-1}) and dry root weight (0.22 tons ha^{-1}) which were statistically different from the other treatments. The highest fresh root and dry root weights obtained with the application of 1 kg of compost per 10 L of water compost tea could be due to continues slow release and adequate availability of crop nutrients from the organic materials applied to the soil, which were less subjected to leaching loses. This is in agreement with Morales-Corts et al. (2018) who analyzed the growth effect of aerated compost tea (ACT) and aerated vermicompost tea (AVT) on tomato plants and found that both the aerated compost tea (ACT) and aerated vermicompost tea (AVT) produced a positive effect on stem diameter, shoot and root dry weight and chlorophyll content compared to that on control plants. The aerated compost tea (ACT) and aerated vermicompost tea (AVT) enhanced the growth of plants and triple their total dry weight. It was reported that organic amendments positively increased crop growth and net assimilation rates with consequential high crop productivity (Uzoma et al., 2011).

3.5.2 Stem yield

The results showed that compost tea treatment had a significant ($p < 0.05$) positive effect on the fresh stem and dry stem of *Amaranthus hybridus* plants. Both the fresh stem and dry stem of *Amaranthus hybridus* plants increased with the rate of compost tea application. The fresh stem and dry stem of *Amaranthus hybridus* plants also increased significantly ($p < 0.05$) with the solid compost and NPK compound fertilizer treatments. Compost tea recorded higher stem yield than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. The 1 kg of compost per 10 L of water compost tea treatment had the highest fresh stem weight (30.12 tons ha^{-1}) and dry stem weight (10.04 tons ha^{-1}) which were statistically different from the other treatments. The control (no-treatment) had the lowest fresh stem weight (4.57 tons ha^{-1}) and dry stem weight (1.53 tons ha^{-1}) which were statistically different from the other treatments. The highest fresh stem and dry stem weights obtained with the application of 1 kg of compost per 10 L of water compost tea could be due to continues slow release and adequate availability of crop nutrients from the organic materials applied to the soil, which were less subjected to leaching loses. This agreed with findings of Sadeghi and Bahrani (2009) who observed optimum crop growth with the highest crop residues and nitrogen. Margarita et al. (2020) pointed out that nutrients from compost tea could be also responsible for yield increase, demonstrating that as soon as one hour after application, some nutrients were in the plant rhizosphere available to be taken in. From our results, it therefore seems more plausible that a kind of biostimulation could be responsible for the yield increase. Furthermore, Morales-Corts et al. (2018) indicated that compost tea from green waste materials usually shows the presence of indole 3-acetic-acid (IAA) and salicylic acid-like compounds (Margarita et al., 2020) that could positively affect spinach growth.

3.5.3 Leaves yield

The fresh leaves and dry leaves of *Amaranthus hybridus* plants were significantly ($p < 0.05$) influenced by different doses of applied compost tea. The fresh leaves and dry leaves of *Amaranthus hybridus* plants were found to increase with increasing rates of compost tea application. The solid compost and NPK compound fertilizer treatments also increased both the fresh leaves and dry leaves of *Amaranthus hybridus* plants significantly ($p < 0.05$). Compost tea gave higher stem yield than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. The 1 kg of compost per 10 L of water compost tea treatment had the highest fresh leaves weight (18.22 tons ha^{-1}) and dry leaves weight (6.07 tons ha^{-1}) which were statistically different from the other treatments. The control (no-treatment) had the lowest fresh leaves weight (3.98 tons ha^{-1}) and dry leaves weight (1.33 tons ha^{-1}) which were statistically different from the other treatments. This agrees with Dlamini et al. (2020) who noted that *Amaranths* plants fertilized with stillage were found to have the highest fresh and dry leaf masses, followed by plants fertilized with kraal manure, then compost and lastly the plants in the control (no fertilizer). This is also in agreement with Margarita et al. (2020) that evaluated the potential beneficial effect of the foliar application of a compost tea (CT) made from onion and vineyard composts either by itself (CT) or implemented with the beneficial microorganism Trichoderma harzianum T78 (CT + Th) on the "healthy quality" and yield of baby spinach and found that both the CT and CT + Th treatments produced a higher spinach yield than the control. This fact could be attributed to a combination of factors, including beneficial plant microorganisms like biostimulants, biofertilisers, biopesticide microorganisms and growth promoter compounds like phytohormones that can be found in compost teas (Edwards et al., 2006).

Table 5 Effects of compost tea on yield parameters of *Amaranthus hybridus*

Treatment	*Amaranthus hybridus* Plant Yield Parameters					
	Fresh weight (tons ha^{-1})			Dry weight (tons ha^{-1})		
	Root	Stem	Leaves	Root	Stem	Leaves
Control (no-treatment)	0.63^{a}	4.57^{a}	3.98^{a}	0.22^{a}	1.53^{a}	1.33^{a}
1 kg(10 L)$^{-1}$ compost tea	5.25^{b}	30.12^{b}	18.22^{b}	1.75^{b}	10.04^{b}	6.07^{b}
1 kg(20 L)$^{-1}$ compost tea	4.87^{c}	28.34^{c}	17.60^{c}	1.62^{c}	9.45^{c}	5.87^{c}
1kg(30 L)$^{-1}$ compost tea	4.33^{d}	24.73^{d}	15.62^{d}	1.44^{d}	8.24^{d}	5.20^{d}
500 kg ha^{-1} solid compost	4.90^{e}	27.88^{e}	16.41^{e}	1.63^{c}	9.29^{e}	5.47^{e}
500 kg ha^{-1} NPK fertilizer	4.84^{f}	26.66^{f}	15.96^{f}	1.61^{ce}	8.89^{f}	5.32^{f}
p-value	0.000	0.000	0.000	0.000	0.000	0.000
F-LSD $_{0.05}$	0.016	0.047	0.105	0.019	0.016	0.016

Note: Means having the same letter in the same columns are not significantly different at $p < 0.05$

4 Conclusions

From the results it may be concluded that growth and yield of *Amaranthus hybridus* were significantly influenced by different levels of compost tea application, solid compost and NPK compound fertilizer application. The plant growth and yields were increased by application of compost tea, solid compost and NPK compound fertilizer. Compost tea recorded higher growth and yield characteristics of *Amaranthus hybridus* plants than solid compost, NPK compound fertilizer and control (no fertilizer) in decreasing order in the variety of amaranth used. Consecutively, the *Amaranthus hybridus* produced the highest yield with 1 kg of compost per 10 L of water compost tea treatment, with the highest nutrient use efficiency. The highest values of plant height (118.18 cm), stem girth (2.586 cm), number of leaves per plant

(42.44), leave area (98.66 cm^2), leave area index (4.606), fresh root yield (5.25 tons ha^{-1}), fresh stem yield (30.12 tons ha^{-1}), fresh leaves yield (18.22 tons ha^{-1}), dry root yield (1.75 tons ha^{-1}), dry stem yield (10.04 tons ha^{-1}) and dry leaves yield (6.07 tons ha^{-1}) were observed in plots treated with 1 kg (10 L)$^{-1}$ compost tea while the lowest values of plant height (97.86 cm), stem girth (1.565 cm), number of leaves per plant (24.32), leave area (67.56 cm^2), leave area index (1.807), fresh root yield (0.63 tons ha^{-1}), fresh stem yield (4.57 tons ha^{-1}), fresh leaves yield (3.98 tons ha^{-1}), dry root yield (0.22 tons ha^{-1}), dry stem yield (1.53 tons ha^{-1}) and dry leaves yield (1.33 tons ha^{-1}) were observed in the control (no-treatment) plots. Dosage of the fertilizers at different concentration levels had an increment effect on the plant height, average number of leaves, leaf length, leaf width, leaf area and leaf area index, this implies the higher the dosage the higher the growth performance which can be attributed to the increased amount of nutrients in higher dosage of fertilizers. Hence, the higher nutrients in higher dosage were used for the development of important parts of the plants such as higher foliage and longer shoot. The reason behind this increment is because in higher dosage of fertilizers, there are more nutrients for the synthesis of various other nutrients, chemicals and antinutrients in the *Amaranth*.

Compost tea, solid compost and NPK compound fertilizer application increased soil porosity, water holding capacity, soil pH, organic matter, nitrogen, phosphorus, calcium, magnesium, potassium, sodium and total exchangeable bases and decreased soil bulk density and particle density to favorable levels. The highest value of soil porosity (48.00 %), water holding capacity (87.8 %), soil pH (6.7), organic matter (3.54 %), nitrogen (0.36 %), phosphorus (19.40 %), calcium (2.81 cmol (+) kg^{-1}), magnesium (1.95 cmol (+) kg^{-1}), potassium (0.48 cmol (+) kg^{-1}), sodium (0.35 cmol (+) kg^{-1}) and total exchangeable bases (5.59 cmol (+) kg^{-1}) were observed in plots treated with 1 kg (10 L)$^{-1}$ compost tea while the lowest value of soil porosity (43.68 %), water holding capacity (80.2 %), soil pH (5.6), organic matter (1.86 %), nitrogen (0.19 %), phosphorus (12.18 %), calcium (2.44 cmol (+) kg^{-1}), magnesium (1.76 cmol (+) kg^{-1}), potassium (0.28 cmol (+) kg^{-1}), sodium (0.24 cmol (+) kg^{-1}) and total exchangeable bases (4.72 cmol (+) kg^{-1}) were observed in the control (no-treatment) plots.

Further research on different compost tea application rates may be done. This is because the *Amaranthus* responded exceptionally well to compost tea in terms of growth and yield. The quality of *Amaranthus* in terms of taste should be added as a parameter in future researches. This is because most Nigerian people usually go for tasty food over healthy food and having both qualities in the *Amaranthus* will be a leap forward towards promoting healthy eating habits in the country.

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