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# Effects of biochar and poultry manure on soil characteristics and the yield of radish

A.O. Adekiya[a,*], T.M. Agbede[b], C.M. Aboyeji[a], O. Dunsin[a], V.T. Simeon[a]

[a] College of Agricultural Sciences, Landmark University, P.M.B 1001, Omu-Aran, Kwara State, Nigeria
[b] Department of Crop, Soil and Pest Management Technology, Rufus Giwa Polytechnic, P.M.B. 1019, Owo, Ondo State, Nigeria

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ABSTRACT

Studies on the effect of biochar and poultry manure on soil properties and radish productivity is rare, hence, field experiments were conducted over two years, 2015 and 2016, to evaluate the effects of biochar (B) and poultry manure (PM) on soil properties, leaf nutrient concentrations and root yield of radish (*Raphanus sativus* L.). Each year, the experiment consisted of 3 × 3 factorial combinations of biochar (0, 25 and 50 t $ha^{-1}$) and poultry manure (0, 2.5 and 5.0 t $ha^{-1}$). Application of B and PM alone, and in combination, improved soil physical and chemical properties, leaf nutrient concentrations and yield components of radish. In 2016, the application of B alone increased the soil pH and concentrations of organic matter, N, P, K, Ca and Mg, as well as leaf nutrient concentrations and yield of radish, but in 2015 it only increased soil pH and organic matter and not leaf nutrient concentrations and yield. In both years, the application of B significantly influenced the root length of the radish. In both years, there was a significant interaction effect of biochar and poultry manure (B × PM) and this was attributed to the ability of the B to increase the efficiency of the utilization of the nutrients in the PM. The combination of 50 t $ha^{-1}$ B and 5 t $ha^{-1}$ PM ($B_{50}$ + $PM_5$) resulted in the highest radish yield. Averaged over the two years, ($B_{50}$ + $PM_5$) increased the root weight of radish by 192, 250 and 257% compared with biochar alone at 50 t $ha^{-1}$, biochar alone at 25 t $ha^{-1}$ and no application of B or PM (control). Therefore, for a short season crop like radish the expected benefit of the biochar alone without the addition of poultry manure may not be achieved within the first year.

## 1. Introduction

Decline in soil fertility has been identified as a major biophysical root cause for the declining *per capita* food availability from small holder farms in the tropical Africa (Gichuru et al., 2003). In tropical soils, the use of synthetic fertiliser has not been sustainable due to its induced soil acidity, nutrient imbalance (Agbede et al., 2017) and physical degradation leading to increased soil erosion. Some experts found that the application of chemical fertilisers alone to achieve high yield has not been successful because the crop response to the applied fertiliser depended on soil organic matter (Ojeniyi, 2012). Soil organic matter have significant effect on soil physico-chemical health, sequestration of carbon, controlling land erosion and protecting land from degradation (Galantini and Rosell, 2006).

The rapid decomposition of organic matter in the tropics means that nutrient retention is a limiting factor to soil productivity. One emerging management strategy to maintain higher yields is the addition of biochar (Fagbenro and Onawumi, 2013). Biochar is the product of pyrolysis of organic materials in the absence of oxygen and at high temperature. When added to soil, biochar has been reported to increase available nutrients and prevent their leaching, stimulate activity of agriculturally important soil micro-organisms, act as effective carbon sink for several hundred years, sequester atmospheric $CO_2$ in soil, suppress emissions of other greenhouse gases and mitigate the detrimental effects of agrochemicals (Thies and Rillig, 2009).

While biochar has proven to have a positive conditioning effect on soil, it may be limited as a nutrient supplier alone, because of its relatively low nutrient composition and recalcitrance to biodegradation (Partey et al., 2014). For a short season crop like radish, the expected benefit of the biochar alone may not be achieved within the first year, therefore for improved soil and radish productivity in the first year of cropping, addition of poultry manure may be the answer.

Biochar application to soils in combination with either organic or inorganic fertiliser has been reported to have a pronounced effect on plant growth and yield (Dou et al., 2012; Chan et al., 2007). Biochar can effectively retain $NH_3$, $NH_4^+$, and $NO_3^-$ in animal manure (Steiner

* Corresponding author.
*E-mail address:* adekiya2009@yahoo.com (A.O. Adekiya).

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et al., 2010). Recent studies demonstrated that bulking manure with biochar reduced N loss while simultaneously enhancing humification, and producing mature manure with a high fertiliser value (Ishizaki and Okazaki, 2004), thereby increasing the yield of crops

No field study has been conducted in Nigeria to determine the effects of application of biochar in combination with organic or inorganic fertiliser on crop yield. A pot trial was carried out to investigate the effect of biochar produced from greenwaste by pyrolysis on the yield of radish (*Raphanus sativus* var. Long Scarlet) and the soil quality of an Alfisol (Chan et al., 2007). Three rates of biochar (10, 50 and 100 t $ha^{-1}$), with and without, additional nitrogen application (100 kg N $ha^{-1}$) were investigated. In the absence of N fertiliser, application of biochar to the soil did not increase radish yield even at the highest rate of 100 t $ha^{-1}$. However, a significant biochar × nitrogen fertiliser interaction was observed, in that higher yield increases were observed with increasing rates of biochar application in the presence of N fertiliser, highlighting the role of biochar in improving N fertiliser use efficiency of the plants. Stockpiled dairy manure (42 Mg $ha^{-1}$ dry wt) and hardwood-derived biochar (22.4 Mg $ha^{-1}$) were applied to an irrigated calcareous soil, alone and in combination (Lentz and Ippolito, 2012). Biochar treatment resulted in a 1.5-fold increase in available soil Mn and a 1.4-fold increase in total carbon and total organic carbon, whereas manure produced a 1.2 to 1.7-fold increase in available nutrients (except Fe), compared with the controls. The combined biochar-manure effects were not synergistic except in the case of available soil Mn. In England, Partey et al. (2014) tested the application of green biomass of V*icia* faba and T*ithonia* diversifolia, either applied alone or in combination with biochar or compared with application of inorganic fertilisers and a control (no input). They reported that the combined application of biochar and *V. faba* or *T. diversifolia* increased maize grain yield by 35 and 25%, respectively, compared with application of *V. faba* and *T. diversifolia* alone. Relative to the application of fertiliser application alone, there was a 27% increase in maize grain yield when fertiliser was combined with biochar. Also in Pakistan, Arif et al. (2012), studied the effect of biochar, farm yard manure and mineral nitrogen alone and in combination on yield and yield components of maize. The authors recommended biochar at the rate of 30 t $ha^{-1}$ in combination with mineral nitrogen at the rate of 75 kg $ha^{-1}$ for improving maize productivity.

The working hypothesis in this study was that application of biochar and poultry manure would significantly improve soil physical and chemical properties and radish yield in comparison with applications of biochar and poultry manure alone. Therefore, the objective of the study was to examine the effects of biochar and poultry manure on soil properties, leaf nutrient concentrations and yield of radish.

## 2. Materials and methods

### 2.1. Site description and treatments

Field experiments were conducted at the Teaching and Research Farm, Landmark University, Omu-Aran, Kwara State, Nigeria during the cropping seasons of 2015 and 2016. Landmark University lies between lat 8° 9′N and long 5° 61′E at an altitude of 560 m and is located in the derived savanna ecological zone of Nigeria. The rainfall pattern was bimodal with peaks in June and October. The total annual rainfall in the area is about 1300 mm while mean annual temperature is 32 °C. The soil at the site of the experiment is an Alfisol classified as Oxic Haplustalf or Luvisol. The experimental site had previously been under fallow for one year after arable cropping with a variety of crops such as yam (*Dioscorea rotundata* Poir), maize (*Zea mays* L.), groundnut (*Arachis hypogaea* L.), cassava (*Manihot esculenta* Crantz) and melon (*Colosynthis citrullus* L.) for the previous five years.

In both years, the experiment consisted of 3 × 3 factorial combinations of biochar (B) (0, 25 and 50 t $ha^{-1}$) and poultry manure (PM) (0, 2.5 and 5.0 t $ha^{-1}$). The nine treatments were factorially arranged in a randomized complete block design with three replications. Each block comprised of 9 plots and each plot was 2 × 2 m. Blocks were 1 m apart and plots were 0.5 m apart. The exact same location and layout of the plots and treatments were used for the experiment in 2015 and 2016.

### 2.2. Incorporation of biochar and poultry manure and sowing of radish seeds

Biochar used in the experiment was obtained from a local commercial charcoal producer at Omu-Aran, Kwara State, Nigeria who uses hardwood such as *Parkis biglosa*, *Khaya senegalensis*, *Prosopis africana* and *Terminalia glaucescens* in traditional kilns to produce charcoal for domestic use. The temperature inside the kiln was monitored with a thermocouple and had an average temperature of 580 °C for 24 h of carbonizing. The biochar was ground and sieved to 2 mm before application. The poultry manure (PM) was obtained from the poultry unit of the Teaching and Research Farm of Landmark University. The PM was composted for 3 weeks to allow for mineralisation.

After land preparation (ploughing and harrowing), the experimental site was laid out to the required plot size of 2 × 2 m. The B and PM were weighed and spread evenly on the plots according to the required rates (B: 0, 25 and 50 t $ha^{-1}$; PM; 0, 2.5 and 5.0 t $ha^{-1}$) over the soil. A hand held hoe was used to incorporate the amendments into the soil to the depth of approximately 10 cm. The B and PM were incorporated to the soil 3 weeks before sowing of radish seeds. In both years, 2015 and 2016, the treatments with B and PM were applied at the beginning of the year, i.e. the same amendments were applied consecutively to the same plots in two years.

Radish (*Raphanus sativus* L. cv. French Breakfast), grown for its large succulent bulbous tap root, was sown on 17 June and 16 June in 2015 and 2016, respectively, when rain was steady in the ecological zone. Direct seed sowing was done at two seeds per hole at an inter-row and intra-row spacing of 30 cm × 3 cm and the seedlings were later thinned to one plant per stand. Weeding was done on weekly basis manually. No fertiliser or irrigation water was applied during the course of the experiment. Harvesting was done on 21 and 22 July (35 days after sowing) in 2015 and 2016, respectively. During the period between the two crops of radish, no cash crop was grown on the land and weeds such as *Tridax procumbent* and *Aspilla africana*, were cleared before preparation (ploughing and harrowing) of the land for the crop in 2016

### 2.3. Determination of soil physical and chemical properties

Prior to the commencement of the experiment in 2015, surface soil (0 to 0.15 m depth) samples were randomly collected from ten different points in the experimental site. The soil samples collected were bulked, air-dried and sieved using a 2-mm sieve and analysed for particle size, soil organic matter, N, P, K, Ca, Mg and pH. Soil samples were also collected at harvest of the radish in 2015 and 2016, on an individual plot basis, and were similarly analysed for chemical properties. Samples were analysed as described by Carter and Gregorich (2007). Soil organic carbon (OC) was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). Organic matter (OM) was calculated by multiplying C by 1.724. Total N was determined by the micro-Kjeldahl digestion method *(*Bremner, 1996). Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank et al., 1998). Exchangeable K, Ca and Mg were extracted using 1 M ammonium acetate (Hendershot et al., 2007). Thereafter, concentration of K was determined on a flame photometer, and Ca and Mg were determined by EDTA titration method. Soil pH was determined using a soil-water medium at a ratio of 1:2 with a digital electronic pH meter.

In both years, at one month after sowing the radish, soil samples were also collected from all plots for determination of soil physical properties. Five undisturbed samples (0.04 m diameter, 0 - 0.10 m depth) were collected from each plot using core soil samplers and were used for the for the evaluation of bulk density, total porosity and gravimetric moisture content after oven-drying at 100 °C for 24 h. Total porosity was calculated from the values of bulk density and particle density of 2.65 Mg $m^{-3}$.

### 2.4. Analysis of biochar, poultry manure and radish leaves

The B and PM used were analysed for nutrient composition after being air-dried and crushed to pass through a 2-mm sieve. Analysis was done for organic carbon (OC), total N, P, K, Ca and Mg (AOAC, 2006). At harvest (5 weeks after sowing), ten leaf samples were collected from radish plants from each plot, oven-dried for 24 h at 80 °C and ground in a Willey mill. These samples were analysed for leaf N, P, K, Ca and Mg as described by Tel and Hagarty (1984).

### 2.5. Determination of yield parameters

Radishes grew to maturity in 5 weeks after sowing after which they were harvested. Harvesting was done manually using hand to uproot the roots with its leaves. Harvesting was done on plot basis. The up-rooted tap roots were washed in water to remove any traces of sand and the leaves separated from the tubers before weighing the leaves and the roots on a top loading balance to determine their fresh weights. Tap root girth was calculated by measuring the tap root diameter with the use of a vernier caliper and the length was determined by using meter rule.

### 2.6. Statistical analysis

Data collected from each experiment were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GENSTAT and Genstat, 2005) and treatment means were compared using Duncan's multiple range test at $p = 0.05$ probability level.

## 3. Results

### 3.1. Soil physical and chemical properties at the start of the experiment and chemical analysis of biochar and poultry manure used for the experiment

The physical and chemical properties of the soil before the start of the experiment and the chemical analysis of the B and PM used for the experiment are presented in Tables 1 and 2, respectively. The soil at the experimental site was sandy loamy, high in bulk density, acidic, low in organic matter, total N, available P and exchangeable K, but adequate in exchangeable Ca and Mg according to the critical level of 3.0% OM, 0.20% N, 10.0 mg $kg^{-1}$ available P, 0.16–0.20 cmol $kg^{-1}$ exchangeable K, 2.0 cmol $kg^{-1}$ exchangeable Ca, and 0.40 cmol $kg^{-1}$ exchangeable Mg recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000). The B was alkaline, while PM was slightly acidic in nature. B was high in organic C and had a high C:N ratio compared with PM, but PM had higher concentrations of N, P, K, Ca and Mg and micronutrients compared with biochar.

**Table 1**
Soil physical and chemical properties of the site before experimentation in 2015.

| Property | Value |
|---|---|
| Sand (%) | 76 |
| Silt (%) | 13 |
| Clay (%) | 11 |
| Textural class | Sandy loam |
| Bulk density (Mg $m^{-3}$) | 1.49 |
| pH (water) | 5.61 |
| Organic matter (%) | 1.58 |
| Total N (%) | 0.16 |
| Available P (mg $kg^{-1}$) | 8.2 |
| Exchangeable K (cmol $kg^{-1}$) | 0.14 |
| Exchangeable Ca (cmol $kg^{-1}$) | 2.2 |
| Exchangeable Mg (cmol $kg^{-1}$) | 0.42 |

**Table 2**
Chemical composition of biochar and poultry manure used in the experiment.

| Property | Biochar | Poultry manure |
|---|---|---|
| pH (water) | 7.56 | 6.81 |
| Ash (%) | 0.028 | 12.1 |
| Organic C (%) | 52.3 | 21.6 |
| Nitrogen (%) | 0.65 | 2.88 |
| C:N | 80.5 | 7.50 |
| Phosphorous (%) | 0.73 | 1.30 |
| Potassium (%) | 1.25 | 1.67 |
| Calcium (%) | 0.75 | 0.89 |
| Magnesium (%) | 0.26 | 0.54 |
| Copper (%) | 0.013 | 0.35 |
| Manganese (%) | 0.068 | 0.22 |
| Sulphur (%) | 0.091 | 0.31 |
| Zinc (%) | 0.008 | 0.25 |
| Sodium (%) | 0.21 | 0.28 |

### 3.2. Effect of biochar and poultry manure on soil physical properties

The effect of the applications of B and PM on soil physical properties are shown in Table 3. In both years, when considered as individual factor, application of PM significantly ($p < 0.05$) influenced soil physical properties – reduced bulk density and increased porosity and moisture content compared with the control. Similarly, B as individual factor also significantly improved soil physical properties compared with the control. The interactive effect of biochar and poultry manure (B × PM) was also significant in both years for soil bulk density, porosity and moisture content.

### 3.3. Effect of biochar and poultry manure on soil chemical properties

Table 4 shows the effect of biochar and PM on soil chemical properties in 2015 and 2016. In both years, and when considered as an individual factor, PM significantly ($p < 0.05$) increased concentrations of N, P, K, Ca, Mg, OM and the pH, with PM applied at 5 t $ha^{-1}$ having the highest values. Also, the application of B, as individual factor,

**Table 3**
Effect of biochar and poultry manure on soil physical properties in 2015 and 2016.

| Biochar (t $ha^{-1}$) | Poultry manure (t $ha^{-1}$) | Bulk density (Mg $m^{-3}$) | | Porosity (%) | | Moisture content (%) | |
|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| 0.0 | 0.0 | 1.49 a | 1.56 a | 43.8 i | 41.1 i | 10.3 g | 9.6 g |
| 0.0 | 2.5 | 1.36 b | 1.41 bc | 48.7 h | 46.8 h | 11.9 f | 10.5 f |
| 0.0 | 5.0 | 1.23 cd | 1.39 c | 53.6 g | 47.5 gh | 13.3 e | 11.9 e |
| 25.0 | 0.0 | 1.20 d | 1.29 d | 54.7 fg | 51.3 f | 14.1 de | 12.9 de |
| 25.0 | 2.5 | 1.10 e | 1.18 e | 58.5 e | 55.5 e | 16.1 c | 14.7 c |
| 25.0 | 5.0 | 0.99 fg | 1.07 fg | 62.6 d | 59.6 d | 17.9 bc | 16.4 bc |
| 50.0 | 0.0 | 1.11 e | 1.17 h | 58.1 c | 55.8 c | 16.6 c | 15.6 c |
| 50.0 | 2.5 | 0.97 g | 1.04 g | 63.4 b | 60.8 b | 17.2 bc | 16.9 bc |
| 50.0 | 5.0 | 0.88 h | 0.91 i | 66.8 a | 65.7 a | 19.6 a | 18.1 a |
| Biochar (B) | | * | * | * | * | * | * |
| Poultry manure (PM) | | * | * | * | * | * | * |
| B x PM | | * | * | * | * | * | * |

*Notes*: Values followed by the same letters, within columns, are not significantly different at $p < 0.05$ according to Duncan's multiple range test.
* = significant at 5% level of probability.

**Table 4**
Effect of biochar and poultry manure on soil chemical properties in 2015 and 2016.

| Biochar (t ha$^{-1}$) | Poultry manure (t ha$^{-1}$) | pH (Water) | | Organic matter (%) | | Total N (%) | | Extractable P (mg kg$^{-1}$) | | Exchangeable K (cmol kg$^{-1}$) | | Exchangeable Ca (cmol kg$^{-1}$) | | Exchangeable Mg (cmol kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| 0.0 | 0.0 | 5.45 g | 5.41 g | 1.48 i | 1.34 i | 0.14 g | 0.13 f | 5.3 h | 6.2 g | 0.14 h | 0.12 h | 2.01 h | 1.18 g | 0.30 g | 0.32 h |
| 0.0 | 2.5 | 5.55 fg | 5.58 fg | 1.66 h | 1.71 h | 0.16 ef | 0.17 d | 11.5 f | 10.5 e | 0.21 f | 0.24 f | 2.82 f | 2.91 e | 0.39 d | 0.46 f |
| 0.0 | 5.0 | 5.91 ef | 5.98 ef | 1.84 g | 1.89 g | 0.19 cd | 0.19 c | 13.5 e | 14.8 c | 0.26 de | 0.28 e | 3.50 d | 3.82 c | 0.44 c | 0.54 d |
| 25.0 | 0.0 | 5.94 ef | 5.99 ef | 2.10 f | 2.17 f | 0.15 fg | 0.15 e | 5.2 h | 6.4 g | 0.15 gh | 0.12 h | 2.11 gh | 1.19 g | 0.30 g | 0.33 h |
| 25.0 | 2.5 | 6.20 de | 6.29 de | 2.56 e | 2.64 e | 0.18 d | 0.19 c | 13.8 de | 12.8 d | 0.24 e | 0.29 de | 3.20 e | 3.41 d | 0.35 e | 0.49 ef |
| 25.0 | 5.0 | 6.42 cd | 6.51 cd | 2.91 d | 2.98 d | 0.20 bc | 0.22 ab | 15.2 c | 15.3 bc | 0.29 bc | 0.32 c | 3.93 c | 4.12 bc | 0.39 d | 0.55 cd |
| 50.0 | 0.0 | 6.30 d | 6.38 d | 3.20 c | 3.31 c | 0.15 fg | 0.17 d | 5.4 gh | 7.2 f | 0.15 gh | 0.19 g | 2.12 gh | 2.50 f | 0.31 fg | 0.36 g |
| 50.0 | 2.5 | 6.54 bc | 6.60 bc | 3.52 b | 3.48 b | 0.20 bc | 0.21 bc | 16.3 bc | 14.9 c | 0.28 c | 0.34 bc | 4.40 b | 3.90 c | 0.46 bc | 0.61 b |
| 50.0 | 5.0 | 6.86 ab | 6.93 ab | 3.89 a | 3.93 a | 0.22 a | 0.23 a | 19.1 a | 18.7 a | 0.34 a | 0.42 a | 4.93 a | 4.72 a | 0.51 a | 0.68 a |
| B | | * | * | * | * | ns | * | ns | * | ns | * | ns | * | ns | * |
| PM | | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| B x PM | | * | * | * | * | * | * | * | * | * | * | * | * | * | * |

*Notes*: Values followed by the same letters, within columns, are not significantly different at $p < 0.05$ according to Duncan's multiple range test.
* = significant at 5% level of probability; ns = not significant at 5% level of probability; B = Biochar; PM = Poultry manure.

significantly increased soil N, P, K, Ca, Mg, OM and pH, but only in 2016. In 2015 the effect of the application of B on these soil chemical properties was not significant, apart from for pH and OM In 2016, the biochar alone only increased soil chemical properties when applied at higher rate (50 t ha$^{-1}$), apart from N where there was a significant increase at the lower rate. The interactive effect of B x PM was significant for N, P, K, Ca, Mg, OM and soil pH in both years.

### *3.4. Effect of biochar and poultry manure on leaf nutrient concentrations of radish*

The data on the effect of B and PM on leaf nutrient concentration of radish are shown in Table 5. As an individual factor, PM significantly influenced leaf N, P, K, Ca and Mg of radish in both years. B, as an individual factor, only increased leaf nutrient concentrations (apart from for N) of radish in 2016, but not in 2015. The interactive effect of B x PM was significant for all leaf nutrient concentrations of radish in both years.

### *3.5. Effect of biochar and poultry manure on yield components of radish*

Data on the effect of B and PM on the yield components of radish are shown in Table 6. When studied as individual factor, PM influenced yield components of radish in both years. PM significantly ($p < 0.05$) increased leaf weight, root length, root weight and root girth, with PM applied at 5 t ha$^{-1}$ having the highest values. Application of B significantly influenced radish yield in 2016, but not in 2015, apart from for root length which was significantly increased with application of B in both years. When B x PM are considered, the interaction was significant for all yield components of radish in both years. Application of B at 50 t ha$^{-1}$ and PM at 5 t ha$^{-1}$ ($B_{50}$ + $PM_5$) significantly increased the yield components of radish compared with all other treatments. Therefore, using the mean of the two years, application of biochar at 50 t ha$^{-1}$ and PM at 5 t ha-1 ($B_{50}$ + $PM_5$) increased root weight of radish by 192, 250, 25, 47 and 257%, compared with biochar alone at 50 t ha$^{-1}$ ($B_{50}$ + $PM_0$), biochar alone at 25 t ha$^{-1}$ ($B_{25}$ + $PM_0$), PM alone at 5 t ha$^{-1}$ ($B_0$ + $PM_5$), PM alone at 2.5 t ha$^{-1}$ ($B_0$ + $PM_{2.5}$) and no application of biochar or PM (control) ($B_0$ + $PM_0$), respectively.

## 4. Discussion

The application of biochar and poultry manure alone, or in combination with each other, significantly improved soil physical properties compared with the control. They reduced bulk density and increased moisture content and porosity. In case of PM, this was attributed to the enhancement of soil organic matter by the manure. The organic matter in PM was likely to have stabilised soil structure thereby reducing bulk density and increasing porosity and moisture content. The improvement in soil physical properties with increasing rates of PM was adduced to increase in soil organic matter as the manure rate increases. A similar effect of PM in terms of improving soil physical properties has been reported by Agbede et al. (2017). The

**Table 5**
Effect of biochar and poultry manure on leaf nutrient concentrations of radish in 2015 and 2016.

| Biochar (t ha$^{-1}$) | Poultry manure (t ha$^{-1}$) | N (%) | | P (%) | | K (%) | | Ca (%) | | Mg (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| 0.0 | 0.0 | 2.20 f | 1.18 e | 0.11 f | 0.10 h | 1.16 f | 1.15 f | 0.29 f | 0.27 g | 0.07 g | 0.06 h |
| 0.0 | 2.5 | 3.30 e | 3.15 d | 0.17 e | 0.15 e | 1.95 e | 1.39 d | 0.49 e | 0.36 e | 0.16 e | 0.12 f |
| 0.0 | 5.0 | 4.50 ab | 3.95 b | 0.22 ab | 0.19 c | 2.13 d | 1.54 cd | 0.54 d | 0.41 d | 0.19 de | 0.15 de |
| 25.0 | 0.0 | 2.21 f | 1.19 e | 0.10 f | 0.11 gh | 1.10 f | 1.16 f | 0.30 f | 0.28 g | 0.07 g | 0.06 h |
| 25.0 | 2.5 | 3.70 d | 3.57 c | 0.19 d | 0.17 d | 2.10 d | 1.56 c | 0.55 cd | 0.40 d | 0.18 e | 0.14 e |
| 25.0 | 5.0 | 4.20 bc | 3.97 b | 0.21 bc | 0.22 b | 2.42 bc | 2.11 b | 0.63 ab | 0.46 bc | 0.22 b | 0.17 c |
| 50.0 | 0.0 | 2.20 f | 2.71 e | 0.10 f | 0.14 f | 1.11 f | 1.31 e | 0.29 f | 0.31 f | 0.07 g | 0.10 g |
| 50.0 | 2.5 | 4.10 c | 3.91 b | 0.20 cd | 0.19 c | 2.35 c | 2.17 b | 0.60 b | 0.45 c | 0.20 cd | 0.18 bc |
| 50.0 | 5.0 | 4.70 a | 4.36 a | 0.23 a | 0.25 a | 2.65 a | 2.48 a | 0.66 a | 0.52 a | 0.25a | 0.20 a |
| B | | ns | * | ns | * | ns | * | ns | * | ns | * |
| PM | | * | * | * | * | * | * | * | * | * | * |
| B x PM | | * | * | * | * | * | * | * | * | * | * |

*Notes*: Values followed by the same letters, within column, are not significantly different at $p < 0.05$ according to Duncan's multiple range test.
* =significant at 5% level of probability; ns = not significant at 5% level of probability; B = Biochar; PM = Poultry manure.

**Table 6**
Effect of Biochar and poultry manure on yield components of radish in 2015 and 2016.

| Biochar ($t\ ha^{-1}$) | Poultry manure ($t\ ha^{-1}$) | Leaf weight (g) | | Root length (cm) | | Root weight ($kg\ m^{-2}$) | | Root girth (cm) | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| 0.0 | 0.0 | 7.49 g | 8.91 h | 6.72 f | 7.44 g | 0.24 g | 0.25 g | 2.88 g | 2.39 h |
| 0.0 | 2.5 | 14.90 e | 15.70 f | 8.24 e | 9.28 f | 0.56 e | 0.63 e | 4.41 f | 3.51 f |
| 0.0 | 5.0 | 17.83 d | 18.96 de | 11.36 d | 12.32 e | 0.66 bc | 0.74 d | 5.45 d | 4.77 e |
| 25.0 | 0.0 | 9.51 fg | 9.10 h | 11.20 d | 12.48 e | 0.24 fg | 0.26 g | 2.98 g | 2.42 h |
| 25.0 | 2.5 | 17.70 d | 17.95 e | 13.04 c | 14.32 d | 0.63 d | 0.76 cd | 5.04 e | 5.00 de |
| 25.0 | 5.0 | 21.20 bc | 21.80 c | 15.04 ab | 15.76 c | 0.69 bc | 0.85 bc | 6.12 bc | 5.76 c |
| 50.0 | 0.0 | 9.52 fg | 12.20 g | 12.88 c | 13.92 d | 0.32 g | 0.28 f | 2.93 g | 2.83 g |
| 50.0 | 2.5 | 20.30 c | 22.71 bc | 14.08 bc | 16.08 bc | 0.69 bc | 0.86 bc | 6.13 bc | 6.89 b |
| 50.0 | 5.0 | 26.18 a | 25.30 a | 15.76 a | 18.20 a | 0.77 a | 0.98 a | 7.75 a | 8.41 a |
| B | | ns | * | * | * | ns | * | ns | * |
| PM | | * | * | * | * | * | * | * | * |
| B x PM | | * | * | * | * | * | * | * | * |

*Notes*: Values followed by the same letters, within columns, are not significantly different at $p < 0.05$ according to Duncan's multiple range test.
* = significant at 5% level of probability; ns = not significant at 5% level of probability; B = Biochar; PM = Poultry manure.

increase in porosity of biochar applied to soil could be related to the high porous nature of biochar. Biochar application reduced soil bulk density because porosity of biochar is high and when it is applied to soil, it significantly decreased bulk density by increasing the pore volume. Githinji (2014) reported that bulk density decreased linearly ($R^2 = 0.997$) from 1.325 to 0.363 g $cm^{-3}$ while the particle density decreased ($R^2 = 0.915$) from 2.65 to 1.60 g $cm^{-3}$ with increased biochar amendment, with porosity increasing ($R^2 = 0.994$) from 0.500 to 0.773 g $cm^{-3}$. While an exact mechanism for increase in moisture content as a result of biochar application was unknown, it was speculated that this result may be a combination of having more micropores for physically retaining water, or improved aggregation that created pore spaces resulting from greater earthworm burrowing in the biochar amended soil and hence improved moisture content. The reason for the differences in water content between biochar treated plots and the control could probably also be due to the differences in bulk density between treatments. The bulk density of the control plots was higher (reducing the spaces where water could be retained) compared with the bulk density of the biochar treated plots. In this current study, the moisture content of biochar amended soil at rate of 25 t $ha^{-1}$ was 36% higher than the moisture content of the control soil. Laird et al., (2010) stated that the biochar amended soil retained 15% more moisture contents as compared with a control.

The significant increase in soil pH, N, P, K, Ca and Mg values of the soil in response to application of PM was consistent with the analysis recorded for the PM (Table 2). The mechanism responsible for increase in soil pH was likely due to ion exchange reactions which occur when terminal $OH^-$ of $Al^{3+}$ or $Fe^{2+}$ hydroxyl oxides are replaced by organic anions which are decomposition products of poultry manure such as malate, citrate and tartrate (Duruigbo et al., 2007; Dikinya and Mufwanzala, 2010). The ability of organic manure to increase soil pH could also have been due to the presence of basic cations contained in the poultry manure. Duruigbo et al. (2007) reported that such basic cations are released upon microbial decarboxylation.

As the organic matter components of the PM decomposed, nutrients were released to the soil and hence, the findings that increasing rates of PM to 5 t $ha^{-1}$, increased OM, N, P, K, Ca and Mg. The increase in soil nutrients in the second year (2016) in soil amended with biochar may have been as a result of nutrient retention. This was attributed to the large surface area of black carbon found in biochar. The carboxylate groups found in black carbon provide cation exchange capacity (CEC), increase the O/C ratio, and are the primary source of biochar's high nutrient retention ability (Glaser et al., 2001). Also, biochar can efficiently adsorb ammonia ($NH_3$) (Oya and Iu, 2002; Iyobe et al., 2004) and acts as a buffer for ammonia in soil, therefore having the potential to decrease ammonia volatilization from agricultural soils. Biological immobilisation of inorganic N also aids in retaining N and in decreasing ammonia volatilization, due to the low N concentrations and high C/N ratios of biochar (Lehmann and Rondon, 2006). Furthermore, biochar is very efficient at adsorbing dissolved soluble nutrients such as ammonium, nitrate, phosphate, and other ionic solutes (Radovic et al., 2001; Lehmann et al., 2002; Yao et al., 2012). The interactive effect of biochar and poultry manure in increasing soil chemical properties can be explained by the fact that addition of poultry manure to biochar may facilitate surface oxidation of biochar by elevated temperature, especially at the beginning of the process. It also changes biochar properties biotically by the high microbial activity or the co-metabolic decay during the degradation of available carbon sources (Hamer et al., 2004; Kuzyakov et al., 2009). Biochar absorbs leachate generated during the process, resulting in increased moisture content. With the leachate, biochar also absorbs organic matter and nutrients, resulting in increased concentrations of water-extractable organic carbon, total soluble nitrogen, plant-available phosphorus and plant-available potassium, therefore increasing nutrient retention capability of the soil (Jia et al., 2015).

The response of leaf nutrient concentrations of radish to application of biochar and PM was consistent with the values of soil chemical properties recorded for these treatments. There was increased nutrient availability in the soil as a result of application of biochar and PM leading to increased uptake by radish plants.

The findings that PM improved nutrient availability in soil leading to significant improvement in nutrient status and yield of radish is consistent with the initial low fertility of the soil at the experimental site. The PM contains macro and micro-nutrients such as Fe, Mn, Cu, B and Zn (Oladotun, 2002). Enhancement of radish performance and nutrient status by PM in this study was attributable to the fact that PM had a low C:N ratio (7:2). The high nutrient concentrations and the low C:N ratio of the PM in the current study should have increased decomposition and nutrient release for a short duration crop like radish.

In 2015, application of biochar did not influence the yield of radish significantly, but in 2016, it did. This could be attributed to the nature of biochar applied and the growing period of the crop (radish) used. The wood feedstock and the fairly high temperature (580 °C) used to produce the biochar may have led to loss of N, concentration of C and a high C:N ratio (Table 2) which may have contributed to the relatively low level of surface oxidation of the biochar and hence the lack of a significant impact of biochar additions on soil chemical properties and the non-significant difference in yield in the first year. Synchrotron-based near edge X-ray absorption fine structure (NEXAFS) spectra have revealed that biochars produced at high temperatures are typically poorly crystalline (Keiluweit et al., 2010). This implies that some metals in the C lattice may possibly be volatilized, and that the mineral fraction will be less (Bridgwater and Boocock, 2006). Therefore, these biochars would consequently have lesser reactivity in soils than biochars produced at lower temperature, which tend to have a greater impact on soil fertility (Steinbeiss et al., 2009). High-temperature pyrolysis also produces biochars that are characteristically highly aromatic and recalcitrant to breakdown (Baldock and Smernik, 2002). Also, biochar produced from nutrient rich feed stock such as animal manure will have a higher nutrient content than biochar produced from lignin rich plant biomass feed stock (Filiberto and Gaunt, 2013). Alburquerque et al. (2014) also reported that nutrient–poor feedstock biochar may have limited soil fertility benefits in the short term leading to little improvement in crop growth. Major et al. (2010) reported that the beneficial effects of applying biochar to soil improve with time. Freshly produced biochar is hydrophobic and contains few polar, functional groups at the surface (Cheng et al., 2008; Chintala et al., 2014). However, biochar develops reactive surfaces with time after exposure to water and oxygen in the soil, which allows it to adsorb nutrients, reduce leaching (Singh et al., 2010; Chintala et al., 2013) and contribute to improved fertiliser use efficiency. Chan and Xu (2009) also suggested that the addition of freshly made biochar to soil did not consistently improve soil conditions. In the study reported here, in the second year (2016), biochar may have affected soil nutrients through the reduction in leaching losses (Laird et al., 2010); biochar's porous structure, large surface area and negative surface charge (Bird et al., 2008; Downie et al., 2009) increase the soil's cation exchange capacity and allow for the retention of nutrients.

The significant interactive effect of biochar and PM in both years for radish yield components suggested that the biochar had the ability to improve the efficiency of the utilization of nutrients in the PM. The biochar itself had low nutrient concentrations and mineralisation rate because of the high C:N ratio (Table 2), the application of biochar could not have contributed much to the increased yield of radish on soils that received mixed biochar and poultry manure treatments. However, the inclusion of biochar in such mixed treatment applications could have potentially reduced nutrient leaching and increased the nutrient holding capacity of the soil and thus increase in radish yield. Furthermore, the conditioning effect of the biochar may have augmented the effects of the poultry manure treatments on radish yield through improved nutrient use efficiency.

Biochar influencing the tuber length of radish significantly in both years could be related to its physical soil properties. The correlation coefficient between soil bulk density and radish tuber length in 2015 and 2016 were $-0.988$ ($p < 0.05$) and $-0.976$ ($p < 0.05$), respectively, while that between porosity and radish tuber length were 0.988 ($p < 0.05$) and 0.975 ($p < 0.05$) in 2015 and 2016, respectively. The reduced bulk density and high porosity of biochar soils would have reduced mechanical impedance to radish tuber growth and this will increase the length of the tuber. The findings that application of biochar at 50 t $ha^{-1}$ and PM at 5 t $ha^{-1}$ increased yield of radish is consistent with the soil physical and chemical properties and leaf nutrient concentrations of this treatment.

Application of poultry manure to crop lands as a nutrient source serves as an important means of its safe disposal (Reddy et al., 2008). Nutrients provided by poultry manure have been reported to have positive effects on crop production (Mitchell and Tu, 2005; Reddy et al., 2007; Adekiya et al., 2016). Continuous application of poultry manure will increase levels of soil nutrients. However, there is a growing concern that the indiscriminate disposal of poultry manure can cause nonpoint water contamination; groundwater contamination through $NO_3$—N leaching and eutrophication of lakes and water bodies with runoff P (Zhu et al., 2004). Poultry manure addition is increasingly being recognized as a major source of heavy metals input to soils, with repeated applications having resulted in elevated concentrations of heavy metals in soil (Bolan et al., 2004). Continuous /repeated applications of poultry manure can also lead to accumulation of metals in soils to levels that exceed crop requirements and thus to metal phytotoxicity (Bolan et al., 2004). However, there have been only limited reports on yield suppression as a consequence of metals accumulation from manure application (Berti and Jacobs, 1996; Schmidt, 1997).

In general, the carbon (C) in biochar is very stable in soil environments (Kuzyakov et al., 2009; and Lehmann et al., 2009). Most of the results of deliberate biochar additions to soil showed increasing crop yields with increasing additions up to very high loadings of 140 Mg C $ha^{-1}$ (Lehmann and Rondon, 2006). Concerning possible negative impacts of biochar on soil ecosystem functions, this is an insignificant increase and, on the contrary, such an increase has potential positive effects on soil productivity (Lehmann and Rondon, 2006). However, Painter (2001) and Joseph et al. (2010) reported that condensates on the surface of biochars may contain compounds such as polycyclic aromatic hydrocarbons, cresols, xylenols, formaldehyde, acrolein, and other toxic carbonyl compounds that can have bactericidal or fungicidal activity. Ogawa (1994) has shown that these substances can, and do, serve as C and energy sources for selected microbes. The associated long-term environmental risks of repeatedly application of biochar and poultry manure in tropic areas should be further investigated in the future.

## 5. Conclusions

Findings from the study revealed that application of biochar and PM alone, or in combination, improved soil physical (reduced bulk density, and increased porosity and moisture content) and chemical (pH, OM, N, P, K, Ca and Mg) characteristics, leaf nutrient concentrations and yield components of radish. Biocharalone increased soil chemical properties, leaf nutrient concentrations and yield of radish in 2016 only, but not in 2015. There was a significant interactive effect of biochar and poultry manure (B × PM) in both years of study, highlighting the effect of the biochar in terms of improving nutrient utilization of the PM. The combination of 50 t $ha^{-1}$ biochar and 5 t $ha^{-1}$ PM resulted in the highest radish yield.

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