

Research Article

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Biochar, poultry manure and NPK fertilizer: sole and combine application effects on soil properties and ginger (*Zingiber officinale* Roscoe) performance in a tropical Alfisol

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Abstract: Biochar has a low chemical composition and is recalcitrant to degradation. For good soil fertility and nutrient use efficiency of crops it becomes imperative that addition of a fast releasing nutrient source to biochar be sought. Therefore, studies were conducted in 2017 and 2018 to evaluate the effects of biochar with poultry manure (PM) and NPK fertilizer on soil properties, growth and yield of ginger. Treatments evaluated were: biochar applied alone at 15 t ha⁻¹, PM applied alone at 15 t ha⁻¹, NPK fertilizer applied alone at 200 kg ha⁻¹, biochar applied at 15 t ha⁻¹ with poultry manure applied at 15 t ha⁻¹ (B+PM), biochar applied at 15 t ha⁻¹ with NPK fertilizer applied at 200 kg ha⁻¹ (B+NPK) and a control with no amendment whatsoever. The experimental design was a randomized complete block design with three replications. Biochar, PM, NPK fertilizer alone or B+PM and B+NPK improved soil physical and chemical properties, growth and yield of ginger compared to no amendment (control). NPK fertilizer did not improve soil physical properties nor increased pH, OM, Ca and Mg significantly. B+PM and B+NPK improved soil physical and chemical properties, growth and ginger

yield compared to their sole forms. Although B+PM had better soil physical properties, B+NPK increased yield and growth of ginger compared to B+PM. B+NPK increased the yield of ginger by 12.2% and 10.6% in 2017 and 2018, respectively compared with B+PM. B+NPK also increased the yield of ginger by 49.2% and 50.3% in 2017 and 2018, respectively compared to biochar alone. This was related to high presence of nutrients in B+NPK especially N and K which are important for ginger rhizome formation.

Keywords: Biochar; NPK 15-15-15 fertilizer; poultry manure; rhizome yield; soil chemical properties; soil physical properties; *Zingiber officinale*

1 Introduction

Ginger (*Zingiber officinale* Roscoe) is a rhizome spice crop that belongs to the family Zingiberaceae. In Nigeria, farmers' interest on the cultivation of ginger has risen over the past one decade due to its demand, which is attributed to its medicinal and industrial values. The crop today is seen produced and blended in different forms such as raw ginger, dry ginger, bleached dry ginger, ginger powder, ginger oil, ginger candy, ginger flakes (Akhter et al. 2013). Ginger according to literature (Egbuchua and Enujeke 2013) is effective in the control of life challenging ailments. Ginger has also been found to increase bile secretion, prevent the occurrence of gastric ulcers and enhance pancreatic lipase (Chrubasik et al. 2005).

On tropical soils, for sustained rhizome yield of ginger, fertile soil is required, because ginger has a high demand for nutrients. It was reported that ginger will remove 400, 32 and 394 kg ha⁻¹ of N, P and K, respectively

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(Lujiu et al. 2004). However, in Nigeria most fertile land have been degraded by water and wind erosions and also by decline of the natural resources which include among others, the reduction in soil biodiversity (Lal 2001). Consequently, the yield of ginger is low in Nigeria which is about 12 - 15 t ha⁻¹ (NRCRI 2009) compared to the yield up to 63 t ha⁻¹ reported by Pradeepkumar et al. (2001) in Wynad, Kerala, India. One of the ways of sustaining soil productivity and increase yield on tropical soil is by the addition of soil amendments like biochar.

Biochar is the result of the thermochemical conversion of organic materials with limited oxygen at high, low or intermediate temperatures. When applied to the soil, biochar has the advantages of soil fertility improvements, mitigation against climate change and absorption of toxic elements (Ennis et al. 2012; Malghani et al. 2013; Stewart et al. 2013). Biochar can increase nutrients availability to crops and prevent nutrients leaching. Biochar is an important material that adds a lot of carbon to the soil (Glaser et al. 2001). It is also more stable than any other soil amendment and increase nutrient availability beyond a fertilizer effect (Lehmann et al. 2009). It also has liming effects (Liu et al. 2012). Though biochar has positive effects on soil fertility improvement, it may be inadequate as a sole nutrient provider because of its low nutrient content and its resistance to degradation.

Adekiya et al. (2019) reported that biochar alone due to its recalcitrant nature was not able to increase radish yield positively in the first year of application. However, the interaction of biochar and poultry manure was significant in the first year of their application. Therefore, for good soil fertility and nutrient use efficiency especially in the first year, the addition of biochar with either organic or inorganic soil amendment is important; thus it is important to find a fast releasing nutrient source to biochar.

In Nigeria, studies to evaluate the effects of organic and inorganic fertilizers with biochar on soil productivity and yield of ginger are limited. Wisnubroto et al. (2017) reported an experiment on the effect of biochar on red chili (*Capsicum annum* L.). The treatments were: biochar residue (with and without biochar) and fertilizer application (no fertilizer, N fertilizer, farmyard manure (FYM)). The highest yield was obtained from plots having biochar with N fertilizer and FYM. Studies on the effect of the combination of biochar, chemical fertilizer and organic fertilizer is scarce (Sohi et al. 2010).

Therefore, this experiment was to determine the effect of biochar, PM and NPK fertilizer on soil properties and ginger performance. It was hypothesized that soil physical and chemical properties and ginger performance will react

differently to addition of PM and NPK fertilizer to biochar. Experiments were carried out to confirm this hypothesis.

2 Materials and methods

2.1 Site description and experimental layout

Field experiments were carried out at Owo, Ondo State, Nigeria in 2017 and 2018 to evaluate the effects of biochar with poultry manure (PM) and NPK fertilizer on soil properties, ginger yield and growth. Owo is located on latitude 7°12'N and longitude 5°32'E and is 348 m above sea level. The soil of the area is an Alfisol or Luvisol. Owo has a diurnal rainfall that is ranging between 1240 to 1346 mm with an annual air temperature that is between 24-31°C. The first rainy season starts from March to July with a short dry spell in August called "August break", followed by the second rainy season between September and November. Weeds in the experimental soil before cultivation included Mexican sunflower (*Tithonia diversifolia* Asteraceae) and Guinea grass (*Panicum maximum* Jacq).

For the experiment each year, the treatment consisted of: (i) biochar applied alone at the rate of 15 t ha⁻¹ (B) (ii) poultry manure alone applied at 15 t ha⁻¹ - based on field recommendation for ginger production (Fariyike et al., 2016) (PM) (iii) NPK 15-15-15 fertilizer applied alone at 200 kg ha⁻¹ - based on field recommendation for ginger production (Ebeniro et al., 2017) (NPK) (iv) biochar applied at 15 t ha⁻¹ with poultry manure applied at 15 t ha⁻¹ (B+PM) (v) biochar applied at 15 t ha⁻¹ with NPK 15-15-15 fertilizer applied at 200 kg ha⁻¹ (B+NPK) (vi) control, no amendment whatsoever (C). The experimental design was a randomized complete block design with three replications.

The size of each experimental plot was 3.0 x 3.0 m. plots were separated by a margin of 1 m apart while blocks were 2 m separated from each other. The experiment was performed in the same location in 2017 and 2018.

2.2 Biochar and PM incorporations, crop establishment and application of NPK fertilizer

The biochar used was purchased from a local charcoal producer that uses hardwood to produce charcoal for commercial purposes using a traditional kiln. The temperature in the traditional kiln was approximately 580 °C for 24 h of pyrolysis (Adekiya et al. 2019). The PM was obtained from

a commercial poultry farm at Owo. The PM was allowed three weeks of decomposition before application.

Preparation of land for the experiment starts in April 2017 and 2018 with initial manual clearing of the land with cutlass, the site was later ploughed and harrowed to the depth of 20 cm. After laying out the land each year, the biochar and PM were weighed and incorporated to the depth of about 10 cm three weeks before planting of the ginger rhizome of about 50 g and planting with a hoe to a depth of about 10 cm (Agbede and Adekiya 2018) at a spacing of 25 cm × 25 cm to give a plant population of 160,000 plants ha⁻¹. NPK 15-15-15 was applied 10 cm away round each plant (ring method) at four weeks after planting at the rate of 200 kg ha⁻¹. Hand weeding was done on monthly interval during the period of the experiment.

2.3 Determinations of growth and yield parameters of ginger

When ginger had fully established, about 5 months after planting (Agbede and Adekiya 2018), ten plants were randomly selected per plot for the determination of plant height, number of leaves and number of tillers. Plant height was taken by measuring from the ground level to the tallest leaf apex using a ruler. Number of leaves and tillers were measured by counting. Harvesting was done eight months after planting when all the leaves had started drying by uprooting individual plants on plot basis using hoe. The number of rhizomes were counted and fresh weight of ginger rhizomes was measured on a balance.

2.4 Determination of soil properties

Before the start of the experiment in 2017, disturbed soil samples were randomly collected (0-15 cm depth) from ten points on the study area using steel coring tubes. They were mixed together, air dried and sieved using a 2 mm sieve and analyzed for particle size, organic matter (OM), N, P, K, Ca, Mg and pH. Samples were also put in the oven set at 105 °C for 24 h for determination of bulk density.

Similarly, at the end of the experiment in 2017 and 2018, soil samples were also collected on plot basis and analyzed for soil chemical properties. The procedures for the analysis of OM, N, P, K, Ca, Mg and pH have been provided in details elsewhere (Adekiya *et al.* 2019).

In June each year, determination of certain soil physical properties in all plots started and this was done on monthly basis for four months each year with the mean of the four months computed for each year. 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 evaluation of bulk density, total porosity and gravimetric moisture content (Adekiya *et al.* 2019).

2.5 Analysis of biochar and PM

The PM and biochar used for this experiment were analyzed to determine their nutrient compositions after being air dried and sieved using a 2-mm sieve. The analyses for OC, N, P, K, Ca and Mg were done in accordance with AOAC (2003).

2.6 Statistical analysis

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

3 Results

3.1 Pre-plant soil and chemical analysis of biochar and PM

The pre-plant physical and chemical characteristics of the soil of the site used before experimentation and the chemical analysis of the biochar and PM used for the study are presented in Table 1 and 2, respectively. The texture of the soil was sandy loam. The soil was moderate in bulk density, acidic and low OM, N, P, K, Ca but adequate in Mg (Table 1). Biochar had higher values of pH, OC, C: N ratio, Ca and Na compared to PM but PM had higher micronutrients (Zn, S, Mn and Cu), Mg, N, P, K and ash compared to biochar. Also, NPK fertilizer had higher N, P and K values compared to biochar and PM.

3.2 Response of soil physical properties

Table 3 shows data on the effect of biochar, PM and NPK fertilizer on soil physical properties. Biochar and PM alone increased porosity and moisture content (MC) and reduced soil bulk density significantly ($p < 0.05$) compared to the control. NPK fertilizer alone did not improve soil physical properties significantly. Biochar with PM (B+PM)

improved soil physical properties (increased MC and porosity and reduced bulk density) significantly ($p < 0.05$) compared to biochar with NPK (B+NPK). Also, the addition of biochar to either PM or NPK improved the soil physical properties compared to sole applications of either PM

or NPK fertilizer except in the case of B+NPK fertilizer not being significantly different from biochar alone.

Table 1: Initial soil characteristics at Owo in 2017 before experimentation

Property	Value	*Critical values of nutrients
Sand (%)	68.1	
Silt (%)	16.2	
Clay (%)	15.7	
Textural class	Sandy loam	
Bulk density (g cm^{-3})	1.30	
Porosity (%)	50.9	
Soil organic matter (%)	2.50	3.0
pH (water)	5.69	
Total N (%)	0.19	0.20
Available P (mg kg^{-1})	9.10	10.0
Exchangeable K (cmol kg^{-1})	0.11	0.16-0.20
Exchangeable Ca (cmol kg^{-1})	1.70	2.0
Exchangeable Mg (cmol kg^{-1})	0.42	0.40

*critical values of soil nutrients according to Akinrinde and Obigbesan (2000)

Table 2: Chemical analysis of biochar, poultry manure and NPK fertilizer used

Property	Biochar	Poultry manure	NPK 15-15-15 fertilizer
pH (water)	7.12	6.78	
Ash (%)	0.48	12.8	
Organic C (%)	58.7	20.8	
Total N (%)	0.77	2.89	15
C: N ratio	76.2	7.19	
P (%)	0.68	1.39	15
K (%)	1.36	1.88	15
Ca (%)	1.10	0.78	
Mg (%)	0.38	0.60	
Na (%)	0.41	0.27	
Cu (%)	0.022	0.38	
Mn (%)	0.079	0.23	
S (%)	0.10	0.28	
Zn (%)	0.09	0.23	

3.3 Response of soil chemical properties

Data on the effects of biochar, PM and NPK fertilizer on soil chemical properties are presented in Table 4. Biochar and PM alone increased soil pH significantly ($p < 0.05$) compared to the control. NPK fertilizer alone did not increase soil pH significantly. B+PM or B+NPK fertilizer increased soil pH compared to the control. B+PM increase pH compared to B+NPK. Sole application of B and PM increased OM, N, P, K, Ca and Mg significantly ($p < 0.05$) compared to the control. Biochar did not increase N and P significantly compared to the control. Also, NPK did not increase SOM, Ca and Mg but only increase N, P, and K significantly. Combinations B+PM and B+NPK increased soil chemical properties compared to their sole forms. B+NPK significantly increased N, P and K compared to B+PM whereas B+PM increased pH, OM, Ca and Mg compared to B+NPK.

3.4 Response of ginger growth and yield

The response of ginger growth and yield to biochar, PM and NPK fertilizer are presented in Figure 1 (a – e). Biochar, PM and NPK fertilizer alone or the combination of biochar with PM or with NPK fertilizer increased the growth (plant height, number of leaves and number of tillers)

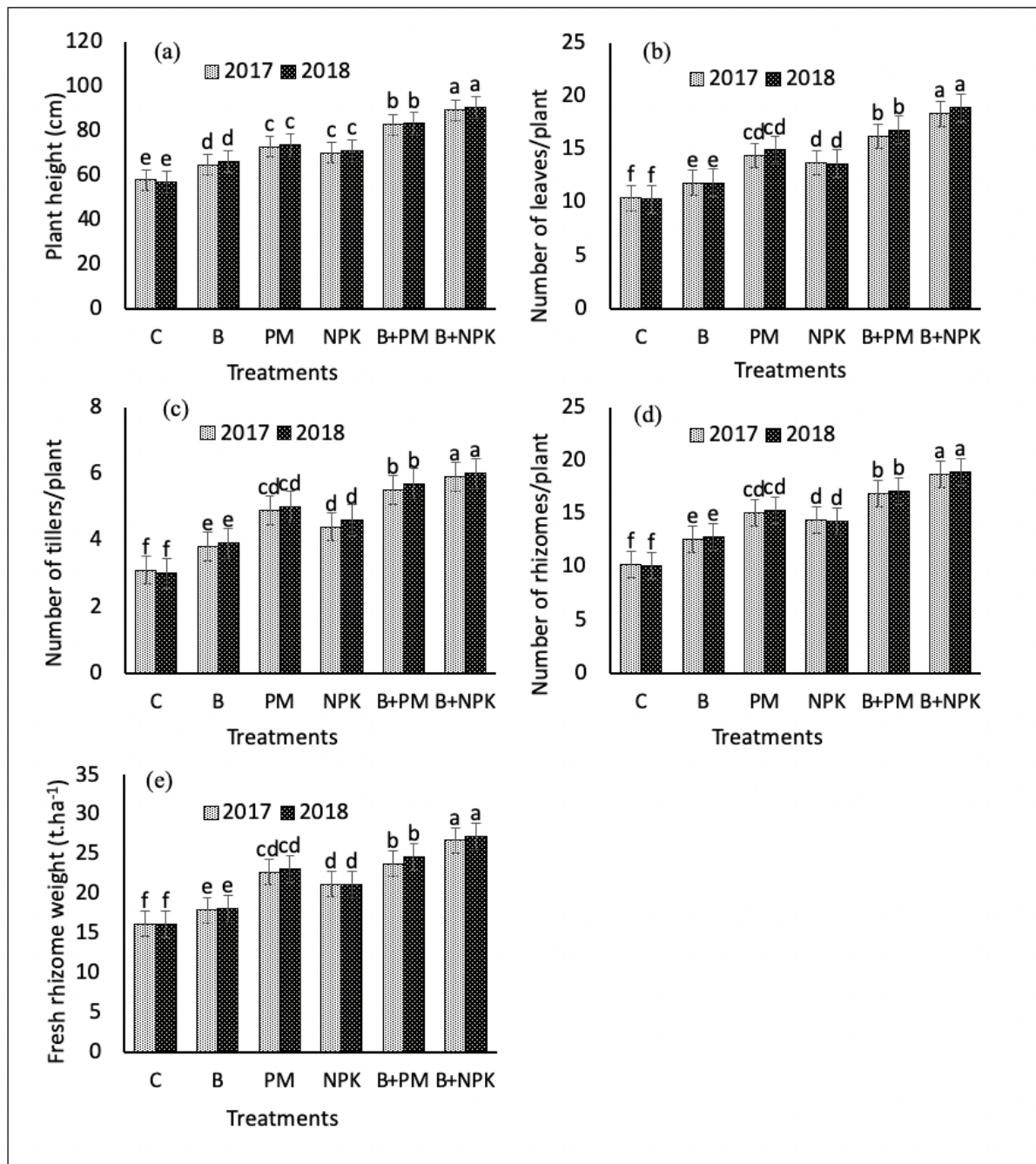


Figure 1: Effect of biochar, poultry manure and NPK 15-15-15 fertilizer on growth and yield of ginger in 2017 and 2018; C = control; B = biochar; PM = poultry manure; B+PM = biochar + poultry manure; B+NPK = biochar + NPK 15-15-15 fertilizer. Vertical bars show standard error of paired comparisons; bars marked with different letters show means significantly different at 5% level using Duncan's multiple range test

and yield (number of rhizomes and fresh rhizome yield) of ginger significantly ($p < 0.05$) compared to the control. For this experiment, there were no significant differences between sole applications of PM and NPK. B+NPK fertilizer increased growth and yield of ginger significantly compared to B+PM. In 2017 and 2018, B+NPK fertilizer increased the rhizome yield of ginger by 12.2% and 10.6%, respectively. B+NPK also increased the yield of ginger by

49.2% and 50.3% in 2017 and 2018, respectively compared to biochar alone. Also, B+NPK increased the yield of ginger by 64.8 and 68.9 in 2017 and 2018, respectively compared with control. Using the mean of the two years, the correlation coefficient between bulk density, porosity, moisture content, pH, OM, N, P, K, Ca and Mg and ginger yield and rhizome number were presented in Table 5. In both ginger yield and rhizome number, the correlations were negative

Table 3: Effect of biochar, poultry manure and NPK 15-15-15 fertilizer on soil physical properties

Treatment	Bulk density(g cm ⁻³)		Porosity (%)		Moisture content (%)	
	2017	2018	2017	2018	2017	2018
C	1.30a	1.31a	50.9d	50.6d	11.1c	10.1c
B	1.18bc	1.16bc	55.5b	56.2b	12.6b	12.9b
PM	1.13c	1.10c	57.3ab	58.5ab	12.9b	13.3b
NPK	1.28a	1.29a	51.7cd	51.3cd	11.6c	11.8c
B+PM	1.08d	1.01d	59.2a	61.9a	15.6a	16.8a
B+NPK	1.17c	1.15bc	55.8b	56.6b	12.7b	13.0b

Values followed by similar letters under the same column are not significantly different at $p = 0.05$ according to Duncan's multiple range test. C = control; B = Biochar; PM = poultry manure; NPK = NPK 15-15-15 fertilizer; B+PM = biochar plus poultry manure; B+NPK = biochar plus NPK 15-15-15 fertilizer

for soil bulk density and positive for other soil parameters. The correlations were strong for N, P and K.

4 Discussion

Biochar and PM alone or combinations of B+PM and B+NPK enhanced soil physical properties relative to the control. The reduction in bulk density with biochar application was attributed to the low bulk densities of biochar (Ulyett et al. 2014). Values of bulk density of 0.3 – 0.43 g cm⁻³ have been reported for biochar by Pastor-villegas et al. (2006). The lower bulk density of soil with biochar could also be related to the porous nature of the biochar which results from retaining the cell wall structure of the biomass feedstock (Yadav et al. 2018). An experiment conducted by Mankasingh et al. (2011) showed that soil bulk density decreased from 1.66 to 1.53 g cm⁻³, and another involving biochar-amended soil columns showed significantly lower bulk density compared to no-biochar controls in a column incubation study (Laird et al. 2010). The improved moisture content of the soil due to biochar was added to the porous nature of biochar which would have allowed it to retain water in its micro and mesopores (Adekiya et al. 2019). In addition, the improvement in soil physical properties due to biochar application could also be related to biochar providing better habitat for soil microorganisms (Pietikainen et al. 2000) as a result of improved soil organic matter and aggregation (Lehmann et al. 2011).

The improved soil physical characteristics due to PM was related to increased soil organic matter from the manure. Other researchers (Adekiya 2018; Are et al. 2012; Jones et al. 2011) also found that organic matter from

manure enhanced soil physical characteristics. Compared with the control, Ojeniyi et al. (2013) found that 5 t ha⁻¹ of poultry manure reduced the soil bulk density by 13.9%. The improved moisture content with PM application can be added to mulching effect of the PM and improved moisture retention and water acceptance as a result of improved soil structure and macro porosity (Aluko and Oyedele 2005). Adekiya (2018) also found that poultry manure application enhanced the moisture content of the soil compared to the control

B+PM had improved soil physical properties compared to B+NPK. This was as result of improved soil organic matter in B+PM relative to B+NPK. Soil amended with organic manure have been reported (Edmeades 2003; Lal 2009) to have lower bulk density, higher porosity and moisture content relative to chemical fertilizer. The improved soil physical properties in treatments where biochar was added with PM may similarly be due to greater stabilization of soil organic matter due to their combination which might have stimulated greater microbial growth and better soil aggregation.

Sole application of biochar and PM increase pH and nutrient contents of the soil. Biochar improves chemical properties of the soil due to its porous nature, high surface area and its ability to absorb soluble organic matter and inorganic nutrients (Thies and Rillig 2009). Biochar also contains some amounts of extractable humic-like and flavic-like substances (Lin et al. 2012). Biochar also contains ash, which is rich in available nutrients especially cations (Rajkovich et al. 2012). The ash content may even serve as reason why the pH of biochar soils is higher than the control. It was reported (Jones et al. 2012; Wang et al. 2014) that biochar increased total C from 2.27 up to 2.78%, total N from 0.24 up to 0.25%, P from 15.7 up to 15.8 mg kg⁻¹, pH 3.33 up to 3.63. Wang et al. (2014) reported an increase of

Table 4: Effect of biochar, poultry manure and NPK 15-15-15 fertilizer on soil chemical properties

Treatment	pH (water)		Organic matter (%)		Total N (%)		Available P (mg kg ⁻¹)		Exchangeable K (cmol kg ⁻¹)		Exchangeable Ca (cmol kg ⁻¹)		Exchangeable Mg (cmol kg ⁻¹)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
C	5.65de	5.62de	1.51e	1.49e	0.16f	0.16f	8.9e	8.7d	0.10f	0.09f	1.68d	1.60e	0.41d	0.39d
B	6.48ab	6.52ab	3.56c	3.60c	0.17ef	0.18ef	9.0e	9.1fd	0.12e	0.13e	2.24b	2.28c	0.49c	0.51c
PM	5.91cd	5.96c	2.50d	2.55d	0.22c	0.23c	17.5d	18.2c	0.22d	0.23d	2.01c	2.21d	0.56b	0.58b
NPK	5.55e	5.51e	1.50e	1.46e	0.20d	0.20ed	20.5ab	21.8ab	0.26c	0.26c	1.69d	1.61e	0.40d	0.39d
B+PM	6.81a	6.88a	3.95a	4.02a	0.26b	0.28b	18.0cd	18.3c	0.34b	0.35b	2.66a	2.71ab	0.89a	0.92a
B+NPK	6.24b	6.25b	3.76bc	3.79bc	0.29a	0.30a	21.0a	22.4a	0.38a	0.39a	2.24b	2.30c	0.53b	0.54b

Values followed by similar letters under the same column are not significantly different at $p = 0.05$ according to Duncan's multiple range test. C = control; B = Biochar; PM = poultry manure; NPK = NPK 15-15-15 fertilizer; B+PM = biochar plus poultry manure; B+NPK = biochar plus NPK 15-15-15 fertilizer

Table 5: Correlation coefficient between yield parameters of ginger and soil physical and chemical properties.

	Bulk density	Porosity	Moisture content	pH	OM	N	P	K	Ca	Mg
Ginger yield	-0.608	0.604	0.458	0.349	0.543	0.974**	0.883*	0.957**	0.516	0.486
Rhizome number	-0.656	0.655	0.465	0.463	0.640	0.973**	0.846*	0.960**	0.612	0.541

* Significant difference at $p = 0.05$; ** Significant difference at $p = 0.01$

60-70% of extractable K, Ca, Na and Mg upon application of biochar. PM increased soil nutrients due to the fact that the organic matter in PM decomposed and nutrients were released to the soil. Adekiya *et al.* (2016) also reported increase in pH, OC and soil nutrients as a result of application of PM. Increase in soil nutrient concentration as a result of PM is because PM is a natural and active source of nutrients (Agbede and Ojeniyi 2010). It increases the cation exchange capacity of soil and also has liming effect on the soil (Odedina *et al.* 2011). NPK fertilizer alone did not increase pH, OM, Ca and Mg significantly, because NPK fertilizer did not contain Ca and Mg nor had decaying matter necessary to increase soil organic matter.

B+NPK improved the concentration of N, P and K in the soil relative to B+PM because NPK 15-15-15 fertilizer contains greater values of N, P and K. B+PM has significant greater values of Ca and Mg in soil compared with B+NPK, because PM contains both micro and macronutrients (Table 2).

B, PM and NPK fertilizer applied alone increased the growth and rhizome yield of ginger in this experiment. Ginger performance with biochar application can be adduced to the optimization of the available plant nutrients (Abiven *et al.* 2015; Lehmann *et al.* 2003). Biochar increased the microbial and nutrient contents of the

soil by changing soil physical properties (bulk density, porosity and moisture content) (Ding *et al.* 2016), thereby increasing growth and yield. Better growth and yield due to biochar could also be adduced to rise in soil pH compared to the control. The increase in soil pH could change the type of nutrient elements and enable some elements adsorption of the root (Ding *et al.* 2016). Again, increase in cations in soil amended with biochar brings an enhancement in soil fertility and retention of nutrients which may be adduced to the high specific area and a number of carboxylic groups of biochar (Cheng *et al.* 2006). It was reported (Viger 2015) that lettuce and *Arabidopsis* plant biomass increased by 111% after application of poplar wood chips biochar. Also, Solaiman (2010) reported that wheat grain yield was increased by 18% with the use of oil mallee biochar.

PM increasing the performance of ginger in this experiment was due to PM increasing nutrients in soil leading to adsorption by plant, hence increase in yield. The enhancement of greater yield by PM could be as a result of its low C:N ratio (7.2), which could have accelerated decomposition and nutrient release. The increase in yield could also be related to improvement of soil physical properties (reduced bulk density and increase porosity and moisture content) by the manure. The reduced bulk

density would have increased greater root growth and nutrient adsorption and hence greater yield relative to the control. Adekiya et al. (2016) also found PM to increase the growth and yield of cocoyam.

The increase in performance of ginger due to application of NPK fertilizer was because the site of the experiment was deficient of vital nutrients needed for the growth and yield of ginger (Ogbonna and Nweze 2012). Ebeniro et al. (2017) had earlier found that NPK 15-15-15 increased the growth and yield of ginger. B+NPK and B+PM have significantly higher yield compared with sole forms of biochar, PM, NPK and the control. NPK fertilizer and PM contains nutrients that are prone to losses. Tropical climate is prone to high leaching and quick mineralization of soil organic matter, which means that soil applied manure and chemical fertilizers are lost through mineralization and leaching. Leaching of nutrients can result to exhaustion of soil nutrients, speed up soil acidification, increase cost of fertilizers to farmers and reduce yield (Lehmann et al. 2003; Major et al. 2012).

However, the addition of B+PM or B+NPK as seen in this experiment retains nutrients and the nutrients remain in an available form in the soil through adsorption mechanism to minerals and organic matter (Jenberu 2017). Therefore, biochar may store nutrients and then start to release them slowly like slow release fertilizer. Biochar can adsorb nutrients because of its greater surface area, negative surface charge and density (Jaafer et al. 2015; Sombroek et al. 2003). Biochar application has been demonstrated to reduce significant leaching of ammonium, nitrate, phosphate and other ionic solutes (Beaton et al. 1960; Lehmann et al. 2002; Mizuta et al. 2004; Radovic et al. 2001). Adekiya et al. (2019) found significant increase in radish yield with B+PM compared with sole biochar.

The increased in yield of ginger in treatment with B+NPK compared to B+PM was related to high presence of nutrients in B+NPK soils especially N and K. The synergistic relationship between biochar and chemical fertilizer may have resulted in increased plant nutrient uptake, less nutrient losses and improved availability of cationic elements (Lehmann et al. 2003). The significant correlation between yield parameters of ginger and N, P and K indicated that the yield of ginger in this experiment was more dependent on N, P and K than other soil chemical and physical properties. Therefore higher nutrients supplied by NPK fertilizer were adsorbed and prevented from leaching by biochar making the difference in this experiment. Although B+PM had better soil physical characteristics, the effect of soil chemical characteristics prevailed. In this experiment, the average bulk density of 1.16 g cm^{-3} , porosity of 56.2% and moisture content of 12.9% might be

sufficient for ginger rhizome formation. Therefore, potassium is particularly important for ginger rhizome formation. Pradeepkumar et al. (2001) shows that N and K are two important nutrients for ginger production.

5 Conclusion

Results of this experiment revealed that biochar, PM, NPK fertilizer alone or combinations of biochar and poultry manure and biochar and NPK fertilizer improved soil physical (reduced bulk density, and increased porosity and moisture content) and chemical (pH, OM, N, P, K, Ca and Mg) properties, growth and yield of ginger compared to the control. NPK fertilizer did not improve soil physical properties nor increased pH, OM, Ca and Mg significantly. B+PM and B+NPK improved soil physical and chemical properties, growth and ginger yield compared with their sole forms. Although B+PM had better soil physical properties, B+NPK increased yield and growth of ginger compared to B+PM. This was related to high presence of nutrients in B+NPK especially N and K, which are important for ginger rhizome formation.

Conflict of interest: Authors declare no conflict of interest.

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