Scientia Horticulturae 243 (2019) 457–463

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

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

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ARTICLE INFO

Keywords:
Biochar
Poultry manure
Soil physical and chemical properties
Leaf nutrient concentrations
Radish

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

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https://doi.org/10.1016/j.scienta.2018.08.048
Received 5 April 2018; Received in revised form 3 July 2018; Accepted 26 August 2018

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