Geoderma 336 (2019) 1–11

Contents lists available at ScienceDirect

Geoderma

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

Influence of rice husk biochar and inorganic fertilizer on soil nutrients availability and rain-fed rice yield in two contrasting soils

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ARTICLE INFO

Handling editor: M. Vepraskas

Keywords:
Rice productivity
Biochar
Nitrogen fertilizer
Soil nutrient
Alfisol
Ultisol

ABSTRACT

The co-application of biochar and inorganic N fertilizer has been shown to be a sustainable and environmental friendly technology for the improvement of soil fertility and crop yield. However, their interactive effects on nutrient availability and rain-fed rice productivity in contrasting soil types in the tropics have been scarcely studied. A field study was set up to investigate the effects of rice husk biochar and N-fertilizer applications at different rates on rain-fed rice yield and soil nutrient distribution in the 0–20 cm soil layer. Biochar was applied at four rates; 0, 3, 6, and 12 t/ha^{-1}, in combination with N fertilizer (urea) applied at four rates; 0, 30, 60 and 90 kg/ha^{-1} to two different soil types (sandy clay loam Oxic-Paleustalf and sandy loam Oxic-Paleustult). In the Oxic-Paleustaif, biochar × N-fertilizer interaction significantly ($p < 0.05$) enhanced rain-fed rice yield and yield components such as number of panicles/m^2 by 71%, filled spikelet (%) by 24%, grain yield (t/ha^{-1}) by 78%, straw yield (t/ha^{-1}) by 74% and 1000 grain weight (g) by 16% when compared to the control. In the Oxic-Paleustult, interaction between biochar and N-fertilizer significantly ($p < 0.05$) increased number of panicles/m^2 by 73%, filled spikelet (%) by 24%, grain yield (t/ha^{-1}) by 83%, straw yield (t/ha^1) by 68% and 1000 grain weight (g) by 13% in the when compared to the control. Leaching of soil nitrate (NO_3-N) was mostly reduced in the Oxic-Paleustalf, while soil pH, soil organic carbon (SOC), total nitrogen (TN), available P and K content at the soil depth of 0–10 cm were significantly ($p < 0.05$) increased in both soil types. The result from this study suggest that biochar amendment and N fertilization have the potential to enhance rain-fed rice productivity and soil nutrient availability, while minimizing nitrate (NO_3-N) leaching.

1. Introduction

Rice is a staple food for over 3 billion people in the world and the sixth most important crop cultivated in Nigeria after sorghum, millet, cowpea, cassava and yam (Dauda and Dzivama, 2004; Olaleye et al., 2004). It is the only crop grown nationwide and in all agro ecological zones from sahel to the coastal swamps (Oladele and Awodun, 2014). Two rice production environments are dominant in this region namely rain-fed upland and lowland. However, sustainable productivity of rain-fed rice in Nigeria is limited by environmental and socio-economic constraints such as fluctuating rainfall patterns, soil acidity, low soil fertility, and limited access to chemical fertilization. Resource poor farmers in the region often resort to the use of limited organic and expensive chemical fertilizer to increase rice yield. However, this approach has not achieved desired results due to low stability, poor efficiency of fertilizer utilization and potential environmental pollution (Zhao et al., 2016; Chaudhary et al., 2017).

Most of the organic fertilizer amendments undergo swift mineralization because of the rapid decomposition of soil organic matter under high temperature and aeration of the tropics (Glaser et al., 2002), while inorganic fertilizers are prone to losses through surface runoff, volatilization, and leaching (Cameron et al., 2013; Agegnehu et al., 2016), which often results in severe soil quality depletion and groundwater pollution. An effective and timely soil management strategy needs to be urgently developed not only to improve crop yield and quality but also to enhance soil fertility status. With this in hindsight, the use of a sound agronomic technology such as biochar, which will help improve soil properties, seems a good option to increase quantity and stability of rice production. Biochar is a carbonaceous and porous material that is highly recalcitrant due to its condensed structure (Spokas et al., 2012). It is derived from the thermal decomposition of biomass in an environment with low or no oxygen at moderately low temperatures.

It contains stable carbon content, large specific surface area, and

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https://doi.org/10.1016/j.geoderma.2018.08.025
Received 26 February 2018; Received in revised form 6 August 2018; Accepted 19 August 2018

negative surface charge (Mukherjee et al., 2011), which bestows on it, its beneficial soil amendment role in improving soil properties (Ali et al., 2015; Vaccari et al., 2011; Paz-Ferreiro et al., 2012), improving soil water and nutrient retention, carbon sequestration, greenhouse gas emission reduction (Downie et al., 2009) and enhancing crop yield (Butnan et al., 2015; Schulz et al., 2013). Studies conducted by Gaskin et al. (2010) found that two years of biochar application increased soil organic carbon (SOC) and total nitrogen content (TN) without affecting soil available phosphorus (P). Major et al. (2012), reported that the amendment of a soil low in fertility with wood biochar at 20 t ha^{-1} increased the concentration of nitrate (NO_3-N) in the soil solution. Liao et al. (2015), also reported that a one-time application of 4.5 t/ha^{-1} biochar significantly increased cotton yields, by 24–37%, in a one-year field study. Zhang et al. (2012), observed that biochar application enhanced rice yields by 10% in the first crop cycle and by 10–29% in the second crop cycle. Most of these studies were conducted with the application of biochar singly without complementary organic or inorganic fertilization. In recent times, some studies have observed significant improvement in soil properties and crop yield when biochar and inorganic or organic fertilizer were co-applied. Gathorne-Hardy et al. (2009), observed a significant interaction effect on barley yield when biochar was co-applied with nitrogen fertilizer. Lusiba et al. (2016), reported a significant interaction between eucalyptus biochar and phosphorus fertilizer on select soil physical and chemical properties and chickpea yield. Liu et al. (2012), also reported a positive interactive effect of combined application of compost and biochar on Dystric Cambisol SOC content, nutrient content and physical properties under field conditions.

Other studies have also indicated that the combined application of biochar with organic fertilizer could lead to enhanced soil fertility, improved plant growth and carbon storage potential (Schulz and Glaser, 2012; Schulz et al., 2013). However, biochar amendment effects on soil properties could be dependent on soil texture and mineralogy (Butnan et al., 2015) as its performance tends to differ in different soil types. In Nigeria, a large proportion of upland soils are highly weathered, characterized by low activity clays with uneven charged surface; i.e., kaolinite and oxides and hydroxides of Fe and Al (Naidu et al., 1997) and belonging to the order Ultisols, Oxisols and Alfisols. In recent times, studies conducted by Hossain et al., 2010; Major et al., 2010 and Chan et al., 2007, have shown that when these types of soils are amended with biochar, there is a significant improvement in soil chemical properties, reduction in aluminum (Al^{3+}) toxicity and soil acidity. Conversely, Kolb et al. (2009) reported that application of 10% w/w biochar produced from a mixture of bull manure, dairy manure and pine wood in ratio (2:1:1) increased total N in a sandy loam Spodosol, but no effect was observed in a clay loam Alfisol. Furthermore, Yeboah et al. (2009) reported that application of wood biochar increased TN and P uptake in corn plants grown in a sandy loam soil, while uptake was decreased in a silt loam soil in the savanna region of Northern Ghana. Agegnehu et al. (2014), suggested that an integrated soil fertility management approach may have more sustainable agronomic and economic benefits than the use of inorganic fertilizer alone. Studies in this direction are still scanty, as there is little information on the interactive effects of biochar and N fertilizer on soil fertility and crop performance in contrasting agricultural soils. Specifically, the objective of this study was to determine the effect of rice husk biochar, N fertilizer and their interactions on (Agegnehu et al., 2014) growth and yield of upland rice; and (Agegnehu et al., 2016) soil nutrient status under rain- fed conditions in south west Nigeria. We hypothesized that application of biochar and N fertilizer will have significant incremental benefits on (i) rain-fed rice yield, (ii) improve soil fertility, and (iii) decrease nitrate leaching in contrasting soil types (Oxic-Paleustalf and Oxic-Paleustult).

2. Materials and methods

2.1. Experimental site characteristics

The study was conducted between July–October 2016 concurrently at two different locations namely; the Teaching and Research Farm of the Federal University of Technology Akure (7°20 N, 5°30E) and Faculty of Agriculture research field, Adekunle Ajasin University Akungba-Akoko (7°28 N, 5°44E) Ondo State, Nigeria. Local conventional cropping system history of the experimental sites is predominantly cultivation of upland rice or maize during the rainy season and cassava during the dry season. The long-term average annual rainfall at Akure is 1450 mm and 1318 mm at Akungba-Akoko of which about 85% falls from June to September with the remainder from January to May at both locations. Average air temperatures are 25.3 °C and 24.7 °C respectively and the soil type is isohyperthermic clayey skeletal Oxic-Paleustalf sandy clay loam alfisol for Akure and isohyperthermic kaolinitic Oxic-Paleustult sandy loam ultisol for Akungba-Akoko.

Alfisols are formed in semiarid to humid areas, typically under a hardwood forest cover, moderately leached soils with a clay-enriched subsoil, relatively high native fertility and a base saturation > 50%, while Ultisols are soils formed in humid areas and are intensely weathered. They typically contain a subsoil horizon that has an appreciable amount of translocated clay, relatively acidic and a base saturation lesser than 35% (IUSS Working Group WRB, 2014). Two weeks prior to planting, soil samples were collected from 0 to 15 cm depth at each experimental site. Eight sampling locations were selected by dividing the trial area into 8 cells (10 m × 10 m). Three sampling points were randomly selected within each of the 8 cells. At each sampling point, surface debris and litters were cleared away and four samples from a 3-m radius were collected using a manual auger with 20 cm core barrel of 6 cm internal diameter. The 12 samples were combined, making a composite sample for each cell, resulting in 8 composite samples per site for analysis. Soil samples collected were homogenized and ground to pass through a 2-mm sieve. Soil samples were analyzed for pH using a ratio of 2.5 ml water to 1 g soil (McLean, 1982); available P using the Bray-I method (Bray and Kurtz, 1945); SOC using the Walkley and Black (1934) method; total N content by the Kjeldahl digestion (Nelson and Sommers, 1982); exchangeable cations and CEC using ammonium acetate method (Black, 1965) at the soil and plant analysis laboratory of the Department of Agronomy, University of Ibadan, Nigeria. Table 1 shows the pre-planting chemical

Table 1

Initial soil chemical properties (0–15 cm) at the two sites and rice husk biochar properties used for this study. Means are given with standard deviations of replicate measurements for soil (n = 3) and biochar (n = 2).

Parameters	Soil		Biochar
	Akure	Akungba	
pH (H_2O) 1:10	4.90 ± 0.42	4.65 ± 0.38	8.50 ± 0.24
Total organic carbon (%)	0.37 ± 0.01	0.16 ± 0.03	51.13 ± 1.63
Total Nitrogen (g/kg)	0.41 ± 0.02	0.15 ± 0.01	0.30 ± 0.02
P (mg/kg)	38.06 ± 1.44	13.88 ± 1.12	0.73 ± 1.04
K (cmol/kg)	0.17 ± 0.07	0.24 ± 0.09	0.92 ± 0.04
Ca (cmol/kg)	0.62 ± 0.09	0.35 ± 0.08	1.25 ± 0.01
Mg (cmol/kg)	0.30 ± 0.01	0.20 ± 0.01	4.50 ± 0.03
Na (cmol/kg)	0.68 ± 0.04	0.60 ± 0.02	0.95 ± 0.19
CEC (cmol/kg)	1.77 ± 0.02	2.66 ± 0.09	–
Exchangeable acidity (cmol/kg)	0.33 ± 0.04	0.40 ± 0.06	–
ECEC (cmol/kg)	2.10 ± 0.25	3.06 ± 0.11	–
Base saturation (%)	61.58 ± 1.35	56.83 ± 1.40	–
Cu (mg/kg)	0.09 ± 0.00	0.08 ± 0.00	226.5 ± 1.41
Fe (%)	0.46 ± 0.08	0.18 ± 0.04	4.80 ± 1.21
Zn (mg/kg)	0.38 ± 0.10	0.32 ± 0.03	561.5 ± 2.45
Mn (mg/kg)	0.13 ± 0.05	0.20 ± 0.05	332 ± 2.10