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Positive and negative effects of biochar from coconut husks, orange bagasse and pine wood chips on maize (*Zea mays* L.) growth and nutrition

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ABSTRACT

Transformation of organic waste into biochar for land application is a relatively new green technology management tool. Land-applied biochars can improve soil quality and plant growth. The aim of our study was to investigate the effects of biochars derived from coconut husk, orange bagasse and pine wood chips at different rates of application (0, 5, 10, 20 and 60 t ha^{-1}), on the biomass, nitrogen (N) and phosphorus (P) status of maize (*Zea mays* L) cultivated in a sandy soil, under greenhouse conditions. The treatments were arranged in a completely randomized block design with four replications. The effects of biochar addition on plant dry biomass and nutrition were dependent upon the biochar type and application rate. Soil treated with coconut husk biochar at an equivalent rate of 30 t ha^{-1} resulted in a 90% increase in maize biomass and plant N and P concentrations of 0.88 and 0.12%, respectively. Orange bagasse biochar applied at a similar rate had no effect on plant biomass, and resulted in plant N and P concentrations of 0.85 and 0.15%, respectively. Application of pine wood chip biochar to soil did not affect plant biomass or nutrition. Even though soil total N increased with an increasing application rate of orange bagasse biochar, N leaching may not have posed a problem since KCl extractable N decreased. However, the associated increase in soil pH may result in potentially greater N losses over time. Thus, the increase in plant biomass and nutrition indicates the superiority of the coconut husk biochar as soil amendment; yet, the application of orange bagasse biochar needs more investigation.

1. Introduction

A wide variety of organic residues and wastes have been converted into biochar, with the purpose of deliberately applying it to soils. Incorporated biochar stores carbon, improves soil quality and increases plant growth and productivity, especially in highly weathered soils with strong acidity, low clay content and poor fertility (Jien and Wang, 2013). Biochar, also known as black carbon, is a recalcitrant, carbon-rich material that when applied to soil, has the potential to store as much as 9 to 11 Gt C each year (Wang et al., 2013). According to Lehmann and Joseph (2015), one ton of dry biomass pyrolyzed at 300 to 700 °C, under a low oxygen atmosphere, can produce 400 kg of biochar containing 80 to 90% pure carbon. The recalcitrance of biochar allows its permanence in soil to be approximately 10–1000 times longer than the residence times of most soil organic matter (Lehmann and Joseph, 2009).

Orange bagasse and coconut husks are two agricultural by-products produced in large quantities in many warm-climate countries. Orange bagasse constitutes roughly 49% of the orange fruit mass and is a waste product of the orange juice industry. Considering that approximately 98.7 million tons of fresh citrus fruit are produced each year, on a global scale (Zirebwa et al., 2012), the amount of citrus waste generated by both, agricultural and industrial activities is remarkable. Citrus waste creates a severe environmental problem, as its carbohydrate content is highly fermentable (Van Heerden et al., 2002). Coconut husk corresponds to around 85% of the fruit weight and disposal is also problematic (Leitão et al., 2010). The conversion of these residues to biochar can provide an alternative strategy for managing agronomic waste disposal.

Feedstock composition translates into biochars with different elemental composition and release rates in soils, which directly impact crop growth. Therefore, there is a need to investigate the characteristics and effects of agricultural biochars developed from different feedstocks.

Many studies have addressed the production, characterization and application of woodchip biochar for agronomic and environmental use (Varela-Milla et al., 2013; Biederman and Harpole, 2013; Albuquerque

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et al., 2013; Agegnehu et al., 2015; Ippolito et al., 2015), and consequentially, woodchip biochar is often used as a reference for comparison purposes. Additionally, a few studies have addressed the use of coconut husk biochar (Sukartono et al., 2010; Dao et al., 2013; Hariz et al., 2015; Ippolito et al., 2015; Suman and Gautam, 2017). Sukartono et al. (2010) produced and characterized biochar from coconut shell but did not test it as a soil amendment. Suman and Gautam (2017) produced coconut shell biochar under different pyrolysis temperatures and observed high variability in biochar characteristics. Dainy et al. (2016) were one of the few who tested coconut husk biochar as a soil amendment. They performed biochar characterization and applied treatments to the field at different application rates. The authors observed a significant impact on soil chemical properties as well as on the yield of yard-long bean.

Some studies have reported the use of orange waste biochar as an adsorption matrix to remove organic and inorganic ionic species from contaminated water (Tran et al., 2016); however, few studies have tested this biochar as soil amendment. Tran et al. (2016) reported the potential of using orange peel biochar as a sorbent to remove Cd from aqueous solutions. The authors reported a maximum sorption capacity of 114.7 mg Cd g^{-1}, suggesting that this might be considered a new green adsorbent and a cost effective alternative to activated carbon. Abdelhafez et al. (2014) evaluated the potential effect of orange peel biochar on improving the physicochemical properties of a contaminated soil and reported increases in soil pH, CEC and water holding capacity. However, it was conducted as a soil incubation study where plants were not included.

We conducted a pot experiment study to test the hypothesis that a single application of biochar from orange bagasse will compare favorably to coconut husk- and woodchip-derived biochars, in terms of soil fertility and plant growth. Our objectives were to investigate: i) the effect of biochar source and application rate on corn growth and N and P nutrition; ii) the effect of biochar source and application rate on soil pH and N and P availability; and iii) develop a common set of recommendations from similar agronomic feedstocks.

2. Material and methods

2.1. Biochar production and characterization

Biochars were produced from coconut husks (CHB), orange bagasse (OBB) and pine woodchips (PWB) using slow pyrolysis in a Top-Lit Updraft retort unit, a micro-kiln that uses a reburner to eliminate volatile byproducts of pyrolyzation, developed by members of the International Biochar Initiative (IBI). Both, the vapors, as well as the non-condensable gases, were burned to provide heat for driving the pyrolysis reaction. All feedstocks were previously oven-dried at 40 °C for 2 days. The coconut husks and orange bagasse were pyrolyzed at a temperature of 500 °C, which was measured using an infrared thermal gun during the one h processing time. The wood chip biochar was pyrolyzed overnight, using the same process. After cool-down, the biochars were weighed, crushed, sieved to a 2 mm screen size and stored in airtight plastic bags. The biochars were stored at ambient temperature until analysis and experimentation.

Biochar yield was determined as the ratio of the biochar mass to feedstock mass:

Biochar yield (%) = (W2/W1) × 100, where W1 is the dry weight of feedstock sample prior to pyrolysis and W2 is the biochar weight.

The proximate analysis (ash content, volatile matter and fixed carbon) was determined according to ASTM standards [ASTM-E 1755, 1995; ASTM-E 872, 1982]. Ultimate analysis (elemental C, N, H and S) was determined using an elemental analyzer via flash combustion at 1020 °C. Percent oxygen was calculated, as follows:

$O = 100 - (C + H + N + S)$.

Biochar pH was determined at a 1:5 biochar:DI water ratio after 1.5 h shaking and 1 h equilibration (Gaskin et al., 2008). Electrical conductivity (EC) was determined in the same extract. Sample calorific value (HHV) was measured by the bomb calorimeter method, according to ASTM 5865. The specific surface-area was obtained according to the Brunauer–Emmett–Teller (BET) method (Zhang et al., 2011). Biochar porosity was determined using Nitrogen (N_2) adsorption isotherms (Zhang et al., 2011). Cation exchange capacity was determined by the ammonium acetate method (Thomas, 1982).

2.2. Greenhouse experiment

The soil used in this experiment was collected from a fallow field that had been out of cultivation for more than ten years, at the North Florida Research and Education Center (NFREC), Quincy, Florida, USA. The soil was air-dried and passed through a 2 mm sieve. The soil was classified as a Loamy, kaolinitic, thermic Grossarenic Kandiudult (Soil Survey Staff, 2007), with 90% sand, 6% silt and 4% clay, pH (ratio of 1:5 w/v) of 5.8, 0.72% organic matter, 3.70 cmolc kg^{-1} CEC, 149 mg P kg^{-1}, 65 mg K kg^{-1}, 345 mg Ca kg^{-1}, and 56 mg Mg kg^{-1}. Cation exchange capacity was determined by the ammonium acetate method (Thomas, 1982); soil organic matter by the Walkley Black method (Nelson and Sommers, 1982); and soil texture by the pipette method (Day, 1965). Concentrations of extractable P, K, Ca and Mg were determined by the Mehlich 3 method (Mehlich, 1984).

The experiment was a 3 × 5 factorial, completely randomized design, with 3 types of biochar (coconut husks, orange bagasse and wood chips), 5 biochar application rates (0, 5, 10, 20 and 60 t ha^{-1}), and 4 replications (n = 60). A known weight (2.0 kg) of air-dried and sieved (2 mm) soil was put into a plastic bag and thoroughly mixed with a given application rate of biochar, then transferred into a 2.5 L plastic pot. The pots were randomly positioned on benches. After two weeks of equilibrium under soil field capacity, three maize seeds were sown into the center of each pot, approximately 40 mm deep. At 9 days after germination, the two weakest seedlings were removed. The soil was kept at 80% field capacity during plant growth.

Each pot was given an identical dose of starter fertilizer via fertigation, as recommended by Rajkovich et al. (2012), consisting of 10 kg N ha^{-1}, as ammonium sulfate, 80 kg P ha^{-1} as triple super phosphate, and 60 kg K ha^{-1} as potassium chloride. All of the pots received an additional application of N fertilizer (100 kg N ha^{-1}), via fertigation, 25 days after planting. The control pots also received the same amount of fertilizer.

The plants were allowed to grow for 60 days, when they were harvested and separated into roots and shoots. Plant tissues were washed thoroughly with tap water, and then rinsed with deionized water. The tissues were oven-dried for 3 days at 65 °C, weighed and ground, using a Wiley mill to pass through a 1 mm mesh screen for N and P analysis. Plant samples were digested in a hot block digestion system following the TKN protocol for N determination (Bremner, 1996). Analysis of total N was performed with a continuous flow diffusion and conductivity cell N analyzer (Timberland, Boulder, CO). Total P was determined using the molybdenum blue method (Murphy and Riley, 1962). Soil plant-available P was determined by extracting soil with sodium bicarbonate and the concentration in the extracts measured by the molybdenum-blue method (Murphy and Riley, 1962). Soil inorganic N (NH_4-N and NO_3-N) was extracted with 2 M KCl (Robertson et al., 1999) and analyzed as described for total N.

2.3. Statistical analyses

All results were expressed as an average of four replicates. Treatment effects were determined by a two-way analysis of variance (ANOVA) according to the General Linear Model procedure of the Statistical Analysis System (SAS, 2013). The two fixed factors were: type of biochar and application rates to soil. The Tukey-Kramer mean separation test was applied to treatment means at $P < 0.05$ probability level. Regression analysis was performed and a coefficient of