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Properties of a clay soil from 1.5 to 3.5 years after biochar application and the impact on rice yield

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ABSTRACT

We assessed the impact of a single application of wood biochar on soil chemical and physical properties and aerobic rice grain yield on an irrigated kaolinitic clay Ferralsol in a tropical Savannah. We used linear mixed models to analyse the response of soil and plant variables to application rates of biochar (0, 8, 16 and 32 t ha^{-1}) and mineral N fertilization (0, 30, 60 and 90 kg N ha^{-1}), and their interaction. The response was analysed within three aerobic rice-growing seasons (S), equivalent to 1.5, 2.5 and 3.5 years after biochar application (S1.5, S2.5 and S3.5). The fraction of oxidisable C in soil increased with biochar application rate, irrespective of N fertilization, at S2.5 and S3.5, whereas the rice stress-free available water (soil water retention between −6 and −100 kPa) decreased with biochar application rate at S1.5 and S2.5. Rice grain yield and yield components varied with the seasons according to the changes in soil properties and weather conditions. A single application rate up to 32 t ha^{-1} of the wood biochar type used in this study had no impact on aerobic rice yield increase on a kaolinitic clay Ferralsol under the climatic conditions of the Brazilian Savannah prone to dry spells. Most likely, the beneficial effects of wood biochar on soil chemical properties on rice production were offset by a decrease in soil water retention capacity and N uptake by the crop.

1. Introduction

1.1. Aerobic rice systems in the Brazilian Savannah

Approximately 3 billion people depend on rice as a staple food worldwide (Nguyen, 2005). In Brazil, total rice consumption is 11 million t annually (IBGE, 2009). In March 2012, the total rice area grown in Brazil was of 2.5 million ha, of which around 44% was covered by aerobic systems (IBGE, 2012). Aerobic rice is typically grown on well-drained soils, without water ponding on soil surface (Fageria, 2001). A consistent decline in the total area of aerobic rice has been observed since the mid 80s (Pinheiro et al., 2006), and in the 2011/12 growing season alone a decline in area as large as 13% was reported (Conab, 2012). The key reason for a decline in aerobic rice area is the greatly variable yield, ranging from 1 to 5 t ha^{-1}, caused by high rainfall variability with frequent, extended dry spells (Conab, 2012). Programs for aerobic rice breeding have attained a genetic gain for grain yield of 0.67% per year in 25 years (Breseghello et al., 2011); yet low productivity is a concern in aerobic rice systems due to the environmental constraints cited above. Particularly among farmers who have limited or no access to mineral fertilization and supplementary irrigation.

In the Brazilian Central West region, where about 38% of the rice production area is located (IBGE, 2012), the predominant biome is a tropical Savannah, characterized by acid-dystrophic soil types. In this region, low aerobic rice yield is not only a result of water stress, which can cause severe damage during the reproductive phase (Heinemann et al., 2011), but is also a consequence of the low N recovery of this crop (Fageria, 2001). Although low competitiveness of rice with weeds and high incidence of rice blast (*Magnaporthe grisea*) also has a profound effect (Breseghello et al., 2011), it is evident that improving soil quality is key for overcoming low productivity (Fageria, 2001). The soil quality has three components (physical, chemical and biological), which are dependent on the inherent characteristics of the soil and on the management practices implemented (Abbott and Murphy, 2003).

1.2. The use of biochar as a soil amendment in cropping systems

Biochar is the charred by-product of biomass pyrolysis (Sohi et al., 2010). The usefulness of biochar in agriculture depends on its

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composition and availability. We tested a by-product of charcoal production from plantation timber, which is potentially available in the Brazilian Central West region. The use of biochar as a soil amendment might increase aerobic rice yields by increasing soil pH and soil water retention capacity (Jeffery et al., 2011).

The wood biochar used in this study is rich in internal porosity (Fig. 1), which may lead to changes in soil water retention capacity (Sohi et al., 2010; Kookana et al., 2011). The effect of biochar on soil water retention capacity of a clay soil can vary according to the biochar type and rate. For example, Major et al. (2012) found no effect on water retention capacity of a Ferralsol (40–44% clay) with application of 3% w/w wood biochar. Likewise, Asai et al. (2009) found no effect on water retention capacity of a 48% clay soil with application of 1.2% w/w wood biochar. Significant effects of biochar on water retention capacity of clay soils were observed with much greater rates (Tryon, 1948; Chen et al., 2010; Fellet et al., 2011; Kameyama et al., 2012; Pudasaini et al., 2012). Tryon (1948) observed significant effects on decreasing the water retention capacity of a clay loam soil with rate of 15, 30 and 45% (by volume) of wood biochar amendment. To the contrary, Fellet et al. (2011) found significant increase in water retention capacity of an 83% clay soil with 5 and 10% w/w prune residue biochar. Kameyama et al. (2012) found an increase in water retention capacity with increasing sugarcane bagasse biochar application rate (from 1 to 10% w/w) but only for soil water retention at saturation point (0 kPa) and −10 kPa. Similarly, Chen et al. (2010) observed a 39% increment in available soil moisture with 3% bagasse biochar application in a heavy clay soil. Pudasaini et al. (2012) only found significant increase in water retention capacity in a clay Ferralsol treated with massive rates of 40% and 60% w/w green waste biochar. These divergent results on the effect of biochar on water retention capacity of a clay soil call for clarification.

Additionally, the influences of biochar application on chemical and physical soil properties and, consequently on crop yields, may change over time due to the biogeochemical interactions that occur in the soil (Kookana et al., 2011). To understand better these interactions, long-term field trials are necessary. Some studies conducted in cropping systems have shown lasting positive effects of biochar on crop yields and soil chemical properties. For example, even 4 years after incorporation of biochar into a sandy clay loam Ferralsol, soybean yields were still significantly increased (Madari et al., 2010 cited by Maia et al., 2011). On a Colombian Ferralsol, there was no immediate effect, but in the second to fourth season after application of 20 t ha^{-1} wood biochar maize yields were consistently higher (Major et al., 2010). One weakness revealed in the meta-analysis done by Jeffery et al. (2011) is that most of the available field data was on effects at 1 or 2 years after application. So far, there are no studies showing how a single application of biochar might affect aerobic rice yields over a longer period in a tropical Savannah. Likewise, in a meta-analysis by Liu et al. (2013) they highlighted the importance of field studies, especially because crop response to biochar application could be overestimated under laboratory conditions.

Therefore, aiming to assess the effect of biochar application under field conditions, we studied the impact of wood biochar along three growing seasons of aerobic rice. This study is a follow up of the study by Carvalho et al. (2013). They observed a decrease in plant growth and no yield response in the first rice season following biochar application, although soil nutrient availability increased significantly with biochar amendment.

Here we tested the following hypotheses: i) there is a lasting beneficial effect of biochar on soil chemical properties; ii) since the wood biochar is rich in C, and about 6% of this C is labile, application of high amounts (>16 t ha^{-1}) results in a temporary decrease in N availability to the crop; iii) positive effects of biochar application rate on rice grain yield depends on adequate N fertilization; and iv) application of biochar in the cropping system can reduce the bulk density and the water retention capacity of the clay soil. The aim of this study was to investigate the effects of a single application of wood biochar combined with mineral N fertilization on soil chemical and physical properties and on aerobic rice grain yield at time intervals of 1.5, 2.5 and 3.5 years after biochar application in an irrigated clay Ferralsol.

2. Materials and methods

2.1. Experimental setup and agronomic management

An experiment under centre pivot irrigation was installed in June 2009 on a kaolinitic clay Rhodic Ferralsol at Embrapa Rice and Beans, Capivara Farm, in Santo Antônio de Goiás, Goiás State, Central West region of Brazil (16°29′17″S and 49°17′57″W). Since 2001, the area had been cultivated under no-tillage with an intercrop of corn (*Zea mays*) with grass (*Urochloa ruziziensis*) in summer (November to February), followed by irrigated common bean (*Phaseolus vulgaris*) in winter (June to August). Immediately after establishment of the field trial, irrigated common bean was cultivated as the first crop in winter, followed by rice (*Oryza sativa*) in summer, under a no-tillage system. This was repeated for subsequent cropping seasons, except that a third crop, rice from March to June in 2010 and millet (*Pennisetum glaucum*) from March to June in 2011 and 2012, was grown in between rice and common bean in succession. At establishment of the field trial, the soil was ploughed twice to a depth of 0–20 cm in order to incorporate crop residues and ensure the flatness of the soil surface. The biochar used was a by-product of charcoal made of *Eucalyptus* spp. timber via slow pyrolysis in a cylindrical metal kiln under a temperature around 450–500 °C. Biochar was milled to pass through a 2000-μm sieve, spread manually over the soil surface, and incorporated into the soil to a depth

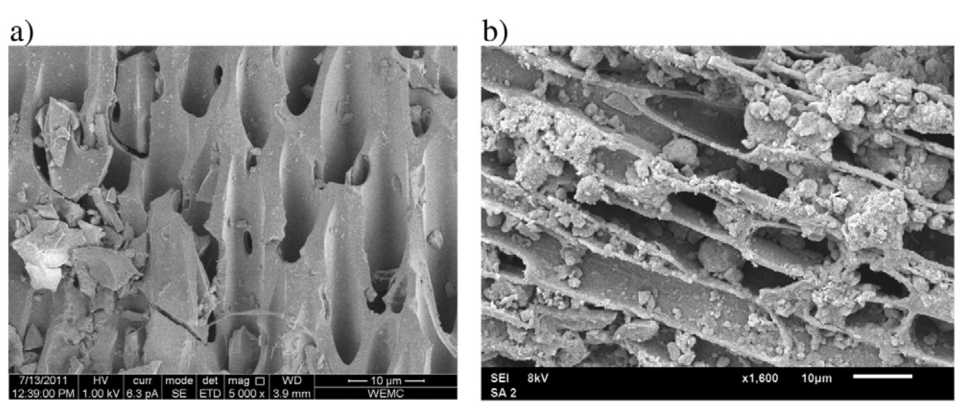

Fig. 1. Scanning electron microscopy images of wood biochar milled to pass through a 2000 μm sieve before (a) and 1.5 years after incorporation to a clay Ferralsol (b).