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Effect of Biochar Addition on Maize Growth and Nitrogen Use Efficiency in Acidic Red Soils*1

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ABSTRACT

Biochar added to soil can improve crop growth through both direct and indirect effects, particularly in acidic, highly weathered soils in subtropical and tropical regions. However, the mechanisms of biochar improving crop growth are not well understood. The objectives of this study were i) to determine the crop responses to biochar addition and ii) to understand the effect of biochar addition on N use efficiency. Seven acidic red soils varying in texture, pH, and soil nutrient were taken from southern China and subjected to four treatments: zero biochar and fertilizer as a control (CK), 10 g kg^{-1} biochar (BC), NPK fertilizers (NPK), and 10 g kg^{-1} biochar plus NPK fertilizers (BC+NPK). ^{15}N-labeled fertilizer was used as a tracer to assess N use efficiency. After a 46-d pot experiment, biochar addition increased soil pH and available P, and decreased soil exchangable Al^{3+}, but did not impact soil availabe N and cation exchange capacity ($P > 0.05$). The N use efficiency and N retained in the soil were not significantly affected by biochar application except for the soil with the lowest available P (3.81 mg kg^{-1}) and highest exchanageable Al^{3+} (4.54 cmol kg^{-1}). Greater maize biomass was observed in all soils amended with biochar compared to soils without biochar (BC *vs.* CK, BC+NPK *vs.* NPK). This agronomic effect was negatively related to the concentration of soil exchangeable Al^{3+} ($P < 0.1$). The results of this study implied that the liming effect of biochar improved plant growth through alleviating Al toxicity and P deficiency, especially in poor acidic red soils.

Key Words: agronomic effect, Al toxicity, liming effect, ^{15}N labeling, P deficiency

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INTRODUCTION

Biochar is the product of incomplete combustion of biomass in the absence of oxygen. Recently, biochar has received increasing attention because it is believed to increase soil carbon sequestration (Lehmann, 2007) and to improve soil fertility (Glaser *et al.*, 2002; Steiner *et al.*, 2007; Sohi *et al.*, 2010). Thus, biochar application in soil may offer us a win-win technology to mitigate global warming and sustain food security.

The effects of biochar on agronomic performance are variable, hosting a positive or negative impact on yield of different crops and plants in a wide range of soil types. For example, positive responses were reported for upland rice in northern Laos (Asai *et al.*, 2009), for maize in Ghana (Oguntunde *et al.*, 2004), Colombian (Major *et al.*, 2010), and southern China (Peng *et al.*, 2011), for rice, cowpea and sorghum in central Amazon, USA (Lehmann *et al.*, 2003; Steiner *et al.*, 2007), and for soybean and radish in eastern Australia (Van Zwieten *et al.*, 2010). Yet, negative responses have also been found for wheat and radish in Calcarosol (Van Zwieten *et al.*, 2010), for soybean in volcano ash soil (Kishimoto and Sugiura, 1985), and for maize in Cambisol (unpublished data), but no effect for rice in a paddy soil (Xie *et al.*, 2013). A review of biochar effects on crop growth was presented by Chan and Xu (2009). Overall, relatively well weathered soils with low pH, such as Plinthosols and Ferrosols with a dominance of sesquioxides and kaolinite in subtropical and tropical regions, respond positively (Glaser *et al.*, 2002; Clough and Condron, 2010; Major *et al.*, 2010; Sohi *et al.*, 2010), whereas a negative or zero effect is more likely in fertile alkaline soils. However, the under-

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lying mechanisms of these contrasting effects are still unclear.

The positive effect of biochar on crop yield is mainly attributed to direct nutrient supply and indirect conditioning (Glaser *et al.*, 2002; Peng *et al.*, 2011; Xu *et al.*, 2013). As a soil fertilizer, biochar can provide some nutrients, particularly K, P, Ca, and Mg, because of the properties of itself and its greater cation content relative to soil (Xu *et al.*, 2013). Furthermore, the biochar alkalinity may improve soil pH (Oguntunde *et al.*, 2004; Peng *et al.*, 2011), together with its high surface area enhancing cation exchange capacity (CEC) (Oguntunde *et al.*, 2004; Liang *et al.*, 2006), and its porous structure increasing water-holding capacity and reducing soil strength and nutrient leaching (Chan *et al.*, 2007; Oguntunde *et al.*, 2008; Asai *et al.*, 2009; Laird *et al.*, 2010a, b; Uzoma *et al.*, 2011). The improved soil physical and chemical properties following biochar addition are thus critical to crop growth. Among those, the liming effect of biochar has been attracting a lot of attention. The increase of pH by addition of organic residues and/or lime has been widely proofed to ameliorate Al toxicity and P deficiency, particularly in acidic soils (Haynes and Mokolobate, 2001). Although the relationship between pH and Al activity is clear (Qian *et al.*, 2013), the effect of the alleviation of Al concentration on crop growth after alkaline biochar addition needs to be confirmed.

The positive effect of biochar on plant growth has been partially attributed to the improved N use efficiency (Clough and Condron, 2010). Many researchers reported the enhanced retention of N in soil and the reduced nitrous oxide emission and nitrate leaching following biochar addition. For example, Laird *et al.* (2010b) reported that the addition of 2% hardwood biochar in a Midwestern agricultural soil reduced total N by 11%. Yao *et al.* (2012) reported that the biochar made from pepperwood and peanut hull at 600 °C reduced nitrate by approximately 34% and ammonium by over 14% as compared with the soil alone in a column study. These benefits are expected to improve N use efficiency. However, only a few data are available to provide solid evidence that biochar addition improves N use efficiency through direct and/or indirect effects. Using ^{15}N-labeled fertilizer, Steiner *et al.* (2008) found that the N use efficiency was significantly higher in the plots with NPK fertilizers and charcoal (18.1%) in comparison to the NPK fertilized plots without charcoal (10.9%). In contrast, Lehmann *et al.* (2003) found that the N availability was not improved after charcoal addition in an Anthrosol and a Ferralsol although the N leaching was significantly reduced. Recently, using ^{15}N-labeled biochar, Xie *et al.* (2013) have reported that only $< 2\%$ biochar N was available to plant after one rice season and 12 t ha^{-1} biochar did not improve N use efficiency. They explained that no effect was ascribed to the inertness and extremely low decomposition rate of biochar. The contrasted effects of biochar on N use efficiency may depend on soil characteristics.

Positive effects of biochar application on agronomic perfermance have been reported mainly for tropical soils. We hypothesize that this effect will be signficant in acidic, highly weathered red soils, which are widely distributed in subtropical and tropical China, covering about 113 million km^2. To examine this further, seven acidic red soils different in texture, pH, and parent material were selected from southern China. The soils also presented a wide range of soil fertility. The aims of this study were i) to determine the response of crop growth to biochar application; ii) to evaluate the direct and indrect effects of biochar application on crop growth; and iii) to analyse relationships between soil property and maize growth. This work may provide some useful information for biochar application in red soils of southern China.

MATERIALS AND METHODS

Soils and biochar used

Seven different red soils were collected from southern China (Table I). They are derived from the most common soil parent materials in subtropical and tropical China, *e.g.*, Quaternary red clay, sandstone, granite, and basalt. For the soils derived from Quaternary red clay and sandstone, differences in soil fertility were taken into consideration.

The soil samples were collected from the surface 0–20 mm layer. They were broken down along natural failure surfaces by hands and air-dried at room temperature. Then, they were ground to pass through a 2-mm sieve, used for a pot experiment and for soil property measurements. Soil properties were determined by routine methods (Lu, 1999). Soil pH was measured at a soil:KCl solution ratio of 1:2.5. Soil organic carbon (SOC) was determined by oxidation with potassium dichromate, CEC by the ammonium acetate method, total N by the Kjeldahl method, available N by the Tjurin and Kononova method, available P by Olsen's method, exchangeable Al^{3+} by the 1.0 mol L^{-1} KCl extraction method, and particle size distribution by the pipette method.

The biochar used was produced from rice straw (*Oryza sativa*) using a muffle furnace. The rice straw was dried at 60 °C for 24 h and was milled to < 2 mm.