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RESEARCH ARTICLE

Effects on soil quality of biochar and straw amendment in conjunction with chemical fertilizers

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Abstract

The objective of this study was to evaluate the effects on chemical and microbiological properties of paddy soil of short-term biochar, straw, and chemical fertilizers compared with chemical fertilization alone. Five soil fertilization treatments were evaluated: regular chemical fertilizers (RF), straw+regular chemical fertilizers (SRF), straw biochar+regular chemical fertilizers (SCRF), bamboo biochar (BC)+regular chemical fertilizers (BCRF), and straw biochar+70% regular chemical fertilizers (SC+70%RF). Their effects were investigated after approximately 1.5 years. The soil pH and cation exchange capacity (CEC) were significantly higher in biochar-treated soils. The soil phosphorous (P) and potassium (K) contents increased with biochar application. The soil Colwell P content was significantly increased with the addition of straw biochar in the treatments of SCRF and SC+70%RF. The oxygen (O):carbon (C) ratio doubled in BC picked from the soil. This indicated that BC underwent a significant oxidation process in the soil. The denaturing gradient gel electrophoresis (DGGE) fingerprints of microbial communities differed among the treatments. Soils with added biochar had higher Shannon diversity and species richness indices than soils without biochars. The results suggest that biochar can improve soil fertility.

Keywords: biochar, straw amendment, fertilizer, nutrient, soil bacteria, denaturing gradient gel electrophoresis

1. Introduction

Large-scale application of chemical fertilizers over the last 30 years played an important role in the rapid growth of agricultural production, and fertilizer use is predicted to continue increase in the coming decades. However, long-term intensive cropping using chemical fertilizers alone to boost soil nutrients resulted in the depletion of soil organic carbon (C) and other negative effects on agricultural soils such as soil acidification, breakdown of soil structure, and decline in soil productivity (Ge *et al.* 2008). Therefore, long-term experiments should be performed with the aim of developing new approaches for increasing soil fertility.

The effective use and management of crop residues, crop straw, and green manure have become an important focus of sustainable agriculture in recent years. However, continual application of this organic matter without sufficient chemical N fertilizers often results in N immobilization and accumulation of heavy metals and may adversely affect plant growth and soil quality (Chen *et al.* 2006). Additionally,

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long-term addition of straw to agricultural soils may also significantly increase CH_4 emissions and worsen climate condition (Xia *et al.* 2014).

Biochar is a stable form of organic carbon that improves soil condition and sequestrates carbon. It is a promising solution with many advantageous properties (Joseph *et al.* 2010; Uras *et al.* 2012). Biochar can be produced from a variety of biomass sources including waste straw, woody leftovers, animal manure, and other waste products. Its use can provide an efficient path for waste utilization. Due to its unique structure and composition, application of biochar can potentially increase C sequestration, improve soil quality, and lead to sustainable management of organic waste (Lehmann and Joseph 2009), which is a "win-win" scenario. Biochar can improve many soil properties such as soil cation exchange capacity (CEC) (Zwieten *et al.* 2010), nutrient absorption (which prevents subsequent nutrient run-off), soil water retention capacity (Laird *et al.* 2010; Schulz and Glaser 2012; Zhang *et al.* 2013), and excessive soil acidification (Karami *et al.* 2011). The improved nutrient retention capacity of soils will reduce the use of mineral fertilizers in long term. In addition, the highly porous structure and large surface area of biochar provide refuge for beneficial soil micro-organisms such as mycorrhiza and bacteria (Pietikainen *et al.* 2000). This may have positive effects on microbial processes involved in nutrient cycling, organic matter decomposition, and greenhouse gas emission (Pietikainen *et al.* 2000; Grossman *et al.* 2010; Deal *et al.* 2012). Despite these beneficial properties, in most intensively managed agro-ecosystems, biochar is usually applied in conjunction with chemical fertilizers due to its low N, P, and K contents (Lima and Marshall 2005; Chan *et al.* 2007). In the last two decades, several biochar studies were conducted with and without chemical fertilizers to evaluate the influence on soil bio-physico-chemical properties, plant growth and productivity. However, most of these studies were short-term.

Soil microbes play an important role in soil nutrient cycles, and their activity is an indicator of soil quality and fertility. Therefore, in this study, we used soil chemical properties and microbial community diversity as measurements of soil quality. The objective of this study was to compare the effects of different combinations of straw, two biochars (bamboo and straw), and chemical fertilizers on soil quality in paddy soils amended with biochar for 1.5 years.

2. Materials and methods

2.1. Experimental site and setup

A field experiment was conducted in a rice paddy in Yuhang, Zhejiang Province, China (120°17´E, 30°25´N). The area has a typical subtropical climate with an annual rainfall of 1 550 mm, of which approximately 40% falls from March to early July, and approximately 15% falls from late July to November. Annual evaporation is on average 1 000–1 100 mm, and the average annual temperature is 16–17°C. The studied paddy soil was used for the production of rice (*Oryza sativa* L.) and rapeseed (*Brassica campestris* L.) for at least 50 years. The crop system consists of rice (June to September) and rapeseed (October to May of the next year). The paddy soil contains approximately 30% of clay and is classified as Typic Stagnic Anthrosols (Institute of Soil Science, CAS 2001). Five fertilization treatments were applied: (1) regular chemical fertilizer as a control (RF), (2) straw+regular chemical fertilizer (SRF), (3) straw biochar+regular chemical fertilizer (SCRF), (4) bamboo biochar+regular chemical fertilizer (BCRF), and (5) straw biochar+70% of the regular chemical fertilizer (SC+70%RF). Each treatment was performed in triplicate with an area of 94 m^2 in a randomized block design. The regular fertilization application rates of N, P, and K for a growing season were 80, 60, and 70 kg ha^{-1}, respectively. The N fertilizer (urea) was applied as basal fertilization and during the tillering and ear differentiation stages at the ratio of 3:4:3. P and K were applied as basal fertilization in the forms of superphosphate and potassium chloride, respectively. The biochar used in the trials was obtained from slow pyrolysis at approximately 600°C for 8 h. Biochar was produced in a muffle furnace that was equipped with a digital temperature regulator (detection accuracy <5°C). The production yield of biochar was approximately 25%. The application rates of both the straw biochar (SB, size less than 2 mm) and bamboo biochar (BC, size less than 3 mm) were 7.5 t ha^{-1}. The rice straw chip (2–5 cm) was applied a rate of 30 t ha^{-1}. Biochar properties are shown in Table 1.

The field trials were conducted for three cropping seasons, i.e., rice (June to September, 2011), rapeseed (October to May, 2012), and rice (June to September, 2012). Biochar and straw were ploughed and harrowed homogeneously in 0–20 cm of the top soil at the beginning of the first cropping season (June, 2011). For the second and third cropping seasons, all treatments were applied with the same chemical fertilizer as in the first cropping season

Table 1 Properties of the straw biochar and bamboo biochar used in the experiment

Type	Straw biochar	Bamboo biochar
pH (1:20 H_2O)	9.00	8.60
Density (g cm^{-3})	0.13	0.56
Ash contents (%)	23.00	11.90
Fixed carbon (%)1)	51.80	69.00

1) Fixed carbon, the remaining carbon after biochar being burning at high temperature.