



Characterization of biochar from fast pyrolysis and its effect on chemical properties of the tea garden soil

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ABSTRACT

The characteristics and application of biochar from conventionally slow pyrolysis have been studied a lot, but biochar, as a byproduct in the bio-oil production process, produced by fast pyrolysis was rarely studied. This work assessed the characterization and utilization of biochars derived from rice husk (RH) and elm sawdust (ES) by fast pyrolysis. Incubation experiment of rice husk biochar (RHB) and acid soil in a controlled cabinet was carried out to test the effect of biochar on soil available elements. The volatile and fixed carbon was 2.2 and 1.7-fold respectively higher in elm sawdust biochar (ESB) than those in RHB, but the ash content was 4.2-fold higher in RHB than that in ESB. Although the C, H, N, and O contents were significantly varied in two biochars, the ratio H/C and O/C were nearly the same. The Fourier Transform Infrared Spectroscopy (FTIR) results revealed that RHB had more functional groups than ESB. More surface area was found in RHB ($78.15 \text{ m}^2 \text{ g}^{-1}$) than ESB ($0.22 \text{ m}^2 \text{ g}^{-1}$) by BET test. Incorporation of the biochar improved the quality of acid soil properties. The levels of soil pH, K, Ca, Mg, Na and total C and N increased while the Al and Pb contents decreased. Total carbon and potassium increased by 72% and by 6.7-fold respectively over the control at 4% of rice husk biochar adding level.

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1. Introduction

The bioenergy production by biomass resources leads the attention in many countries. Agricultural residue is a form of biomass and widely available. Thermochemical conversion is one of the convenient ways for converting biomass into energy. It includes combustion, gasification and pyrolysis progress [1]. Of these processes, pyrolysis has been receiving increasing attention as an efficient way of converting biomass into syngas, liquids, and biochar in recent years. The term 'biochar' is developed in conjunction with soil management and carbon sequestration issues due to the specifically stable structure [2]. Pyrolysis reactor design, biomass type, reaction parameters (temperature, heating rate, residence time, catalyst and pressure) and feedstock characteristics (particle size, shape, and structure) have strong effects on the yield and properties of biochar [3].

Poor agricultural management has increased the CO₂ emissions from soil and conventional inversion tillage practices in sandy soil accelerate organic residue decomposition [4]. Some methods have been used to increase the soil organic carbon such as adding crop residue and animal waste into soil, but the biomass could be degraded in several years [5]. Biochar has its unique advantages due to its special element composition and surface structure. Specially, unlike compost or other bio-waste, biochar appears to permanently sequester carbon that plants have absorbed from the atmosphere [6]. Biochar is carbon-rich organic material often produced by biomass pyrolysis. The application of biochar into soil is a promising strategy for sequestering atmospheric carbon dioxide and improving soil quality [7,8].

Generally, the biochar is beneficial for acidic and unfertilized soils. The application of biochar into soils could increase soil nutrient retention, water holding capacity, soil pH value and crop yield because the biochar contains inorganic components (e.g., Ca, K, Mg, P, etc.) that acts a liming agent and supply plant available nutrients [9–11], and decrease the bioavailability of heavy metals and organic contamination [7,8,12]. In addition, biochar could improve soil for long time by changing the microbial community [8]. Review of previous research showed a huge range of biochar application rates (0.5–135 t/ha of biochar) as well as a huge range of plant responses

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(–29 to 324%)[13]. Some research reported the carbon of biochar in the soil lost seriously due to the low quality of biochar. Moreover the quality of the biochar on soil nutrient improvement is varied based on the pyrolysis condition. Biochar made at low temperature is easy to be degraded but at high temperature is hard to be degraded [14]. In addition, biochars will not last forever in soils, and any organic char in soil is decomposed finally [15]. However, agricultural residues considered as a huge form of biomass is often burned, and pollutes the environment of China. So, a proper technique is required to utilize the agriculture waste. Rice husk is often used to produce bio-oil by Fluidized-bed reactor or other fast pyrolysis system. And biochar was produced at the same time. Although the characteristics of biochar from slow pyrolysis and its soil application have been studied for many years, soil application study of RHB from fast pyrolysis was rarely reported. Bare in this mind, the objectives of present research work were to assess characters of biochar from rice husk and elm sawdust by fast pyrolysis, and to investigate the possible application of RHB in soil for enhancing soil nutrients.

2. Materials and methods

2.1. Production of biochar and soil sample collection

The fully controlled fluidized-bed reactor fast pyrolysis system with a biomass throughput of 1–5 kg/h was constructed at Shanghai Jiao Tong University, and the reactor structure was described previously [16]. RH and ES particles ranged from 0.2 to 1 mm were used as the feedstock for the biochar production by fast pyrolysis. The feedstock was heated at 105 °C for 12 h to remove water before producing biochar. The reaction temperature was 550 ± 25 °C and Nitrogen (99.9%) was used as carrier gas in the system, and its flow was 60 L/min.

Soil samples were collected from the 0 to 20 cm surface layer in a Ling Gu tea plantation which has a long history of planting tea in Yi Xing, China. The soil sample was air dried, grounded to pass through a 2-mm sieve before use.

2.2. Incubation of biochar and acid soil

Three repeated soil samples (1000 g) were mixed thoroughly with biochar to create mixture with ratios of (biochar/soil) 0, 0.5%, 1%, 2% and 4% by weight. All mixtures were placed in foamed plastic boxes. Deionized water was added to bring soil water content to about 75% of field water-holding capacity. Plastic film was used to cover the boxes and a small hole was made to allow gas exchange but minimize moisture loss. All boxes were placed in a climatic box and incubated at 25 ± 1 °C for 60 days. After 60 days, soil samples were taken from the boxes, air-dried, and ground to pass through a 2-mm sieve for determination of pH, extractable Ca, Mg, K, Na, Al and Pb content. Part of soil was passed through a 0.25-mm sieve for determination of total carbon and nitrogen.

Table 1
Proximate and ultimate analysis of biomass and their biochars (fresh basis).

Proximate analysis (wt.%)				Ultimate analysis (wt.%)						
Materials	Water content	Volatile component	Fixed carbon ^a	Ash content	C	H	N	O ^a	H/C	O/C
RH	10.08	72.40	3.40	14.12	35.15	4.16	0.36	46.21	0.12	1.31
RHB	2.60	13.11	33.35	50.94	37.66	1.83	0.30	9.27	0.05	0.25
ES	4.93	87.75	4.29	3.03	47.00	5.39	0.29	44.29	0.11	0.94
ESB	2.38	29.08	56.55	11.99	67.98	3.78	0.39	15.86	0.06	0.23

^a By difference

2.3. Methods

The moisture contents of biomass and biochar (wt/wt) were determined by drying 2 g portion of each feedstock in oven at 80 °C for overnight [12]. The pH of the biochar was measured (1:10 ratio of biochar solutions in de-ionized water) by a pH meter (METTLER TOLEDO, FE-20K). The ash and volatile matter of feedstock and biochar samples were tested according to ASTM-E1755 and ASTM-E872, respectively. The contents of carbon, nitrogen, hydrogen and oxygen of biomass and biochar were analyzed by CHNO elemental analyzer (Perkin Elmer, PE2400II). In this method, the O content was determined by difference. Fourier transform infrared spectra of biomass and biochar were recorded in the 4000–400 cm⁻¹ region with a resolution of 0.4 cm⁻¹ by a FTIR spectrometer (EQUINOX55, Brucks). Scanning electron microscopes (SEM) of biomass and biochar samples were taken by using a FEI Nova Nano Scanning Electron Microscope. Varying magnifications were used to compare the structure and surface characteristics of the two biomass and two biochar samples. Special surface area of biochar was measured in automated volumetric gas adsorption apparatus by ASAP 2010 using nitrogen as an adsorbent at 77 K. The available nutrients of biochar extracted by Mehlich 3 extraction (0.2 mol/L CH₃COOH + 0.25 mol/L NH₄NO₃ + 0.013 mol/L HNO₃ + 0.015 mol/L NH₄F + 0.001 mol/L EDTA) [17] were measured by Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES).

The soil pH was determined in a ratio of 1: 2.5 soil-KCl solutions (1 mol/L) with a pH meter (METTLER TOLEDO, FE-20K). Total content of carbon and nitrogen of soil were determined by an elemental analyzer (Perkin Elmer, PE2400II). According to literature [17], soil extractable elements were extracted with Mehlich 3 extraction and determined by ICP-AES.

2.4. Statistical analysis

Quantitative data are presented as mean values ± standard error (n = 3). One-way analysis of variance (ANOVA) was undertaken to determine significant differences between the treatments. Significant difference was statistically considered at the level of *p* < 0.05.

3. Results and discussion

3.1. Proximate and ultimate analysis of biomass and their biochars

Table 1 shows the proximate and ultimate analysis of biomass and their biochars. Results showed that the fixed carbon and the elementary carbon contents of the biomass (being biochar) increased after biomass pyrolysis at the expense of volatile matter, elemental oxygen, and hydrogen. The ash contents of biochars were also higher than the biomass samples due to the reason that the mineral matter formed ash which remained in biochars after pyrolysis. Compared to ESB, RHB contained more ash, less fixed carbon and volatile component, which was consistent with the raw materials. The contents of fixed carbon, volatile component

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