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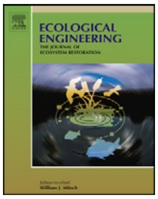

Short communication

Biochar preparation from *Parthenium hysterophorus* and its potential use in soil application

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ABSTRACT

Besides soil carbon sequestration, thermal conversion of weeds like *Parthenium hysterophorus* to biochar would be a sustainable weed management strategy. *Parthenium* was charred at different temperature (200–500 °C) and residence time (30–120 min). With increase in temperature, biochar yield decreased, whereas the stability increased. Stable organic matter yield index (SOMYI) was higher at 300–350 °C temperate with 30–45 min residential time. Elemental analysis, TGA, and FTIR, indicated the aromaticity and stability of biochar carbon. GC–MS spectra showed that ambrosin, an allelochemical present in *Parthenium* was lost during pyrolysis. Laboratory experiments on effect of *Parthenium* biochar (PBC) on soil microbial activity and *Zea mays* showed an increase in seedling vigour index with PBC addition. Soil dehydrogenase activity (DHA) increased ($P < 0.05$) from 5 g/kg PBC onwards; catalase activity increased at lower doses (1 and 3 g/kg PBC). Hydrolytic enzyme activities decreased with PBC application. Active microbial biomass carbon was 1.4, 1.7, and 2.1 times higher than control at 1, 3, and 5 g/kg PBC treatments, respectively. Basal soil respiration progressively increased up to 20 g/kg PBC. The stress indicator or the metabolic quotient decreased with PBC application and no adverse effect was observed even at the highest rate of PBC addition.

1. Introduction

Parthenium hysterophorus L. is one of the world's seven most devastating and hazardous weeds (Patel, 2011). Direct incorporation of *Parthenium* residues to soil may exhibit allelopathic effects affecting the growth and establishment of crops (Singh et al., 2005). Though there are many traditional weed control measures, researchers have tried alternative gainful weed management strategies, notorious weeds like water hyacinth (*Eichhornia crassipes*), and cabomba (*Cabomba Caroliniana*) were used as feedstock for bio energy production through anaerobic digestion (Sullivan et al., 2010). The present study is hypothesized that pyrolytic conversion of *Parthenium* to biochar (BC) could be an alternative option for weed control and removal of allelochemicals. Thermochemical process like combustion, pyrolysis, and gasification have wide application to convert bulky and heterogeneous biomass into useful forms tailored to user needs (Kim et al., 2012). BC is the carbonaceous residue left in the pyrolysis process, which is even used by pre-Columbian farmers and recently being recognized as an interesting material to store carbon in soils and to improve soil quality (Renard et al., 2012). Soil amendment of paddy straw biochar enhanced soil fertility, rice productivity, and found to be a unique ecological engineering measure to reduce N_2O emission from rice ecosystems (Liu et al., 2012). In the process of pyrolysis, biomass tends to undergo structural transformations leading to the formation of stable aromatic rings. The pyrolysis process parameters like temperature and residential time will greatly affect the qualities of biochar and its potential value to agriculture. For farm level preparation of BC from the local agricultural wastes, the pyrolysis process must be aimed at maximizing the BC yield without compromising the BC stability. There are many studies on the stability of BC carbon. Harvey et al. (2012) developed recalcitrance index to evaluate the quality of BC, based on the relative thermal stability of BC. However, many of these studies did not address the absolute yield of BC from pyrolysis. Thus, this study is aimed at the preparation of maximum quantity of stable BC from *Parthenium* biomass, and to evaluate the effect of *Parthenium* biochar (PBC) on soil microbial activity and test plant, *Zea mays.*

2. Materials and methods

2.1. Preparation of biochar

Fresh *Parthenium* weed collected from Bhowrah, Dhanbad, India was air dried and cut to small pieces (30–50 mm). Known quantity

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of air dried material was taken in closed perforated stain less steel boxes and heated in muffle furnace at different temperature (200, 250, 300, 400, 500 °C), and time (30, 60, 90, 120 min). The experiment was carried out in three replications. After carbonization, the biochar yield was recorded. The resultant biochar was characterized for oxidizable organic carbon (OC) content by potassium dichromate oxidation method (Tandon, 1995). Loss on ignition (LOI) was determined by ASTM method, D-1762-84. Carbon lability index was calculated as the OC/LOI ratio. A comparative measure of stable organic matter (SOM) was calculated as below:

$$\mathrm{SOM} = \mathrm{LOI} - (\mathrm{OC} \times 1.724) \tag{1}$$

where 1.724 is the factor to convert organic carbon to organic matter. Stable organic matter yield index (SOMYI) was determined by the following equation:

$$\mathrm{SOMYI} = \frac{\text{char yield}}{100} \times \mathrm{SOM} \tag{2}$$

The process parameter for biochar preparation was optimized to get a maximum SOMYI using a response surface method.

The elemental composition and the morphological properties of the PBC were determined by elemental analyzer (Elementar, Vario EL III) and scanning electron microscopy (JEOL, JSM – 6390LV), respectively, at the Sophisticated Test and Instrumentation Centre, Cochin University of Science and Technology, India. The spectral properties were determined by infrared spectrophotometer (Bruker). Differential scanning calorimetry (DSC) and thermo gravimetric analysis (TGA) was carried out in a simultaneous thermal analyzer (Netsch, 409C). Allelochemicals in *Parthenium* biomass and PBC were qualitatively analyzed with GC–MS (Varian, 450GC-240MS).

2.2. Laboratory experiment

To evaluate the impact of PBC on seedling establishment of *Z. mays* and on the soil biological quality, red soil collected from Digwadih, Dhanbad was treated with PBC at different doses. The soil has sandy loam texture with the following properties: sand 75.5%, silt 6.5%, clay 18%, pH (1:2.5) 7.29, electrical conductivity (1:2.5), 0.165 dS/m, cation exchange capacity (CEC) 10.8 cmol (p+)/kg, soil organic carbon 0.86%, total nitrogen: 0.11%. Initially the soil sample was air dried and passed through 2 mm sieve. The processed soil sample was treated with PBC at different doses: 0, 1, 3, 5, 10, and 20 g/kg. The PBC prepared at pyrolysis temperature 300 °C with 30 min residential time was used for the study. Some of the basic properties of the PBC are pH 9.85; EC 10.5 dS/m; C 55.13%, H 4.94%, N 4.19%, S 0.67%, and O 35.0%. The experiment was carried out in plastic containers of 0.5 kg capacity; there were 6 treatments and 3 replications. Three healthy maize seeds were sown on each pot. The pots were irrigated as and when needed, and the maize plant was harvested after 20 days. Data on percent seed germination, shoot length, root length, shoot and root weight were recorded. Seedling vigour index (SVI) was calculated as below:

$$\mathrm{SVI} = \frac{G_\mathrm{T} \times (\mathrm{SL_T} + \mathrm{RL_T})}{G_C \times (\mathrm{SL_C} + \mathrm{RL_C})} \tag{3}$$

where G_T and G_C are germination percentage under treated and control soil, respectively; SL and RL are respective shoot and root length.

After the harvest of maize, pot soil samples were analyzed for the following parameters. Soil pH and electrical conductivity (EC) were determined at 1:2.5 soil–water suspensions using a glass electrode and conductivity bridge, respectively (Tandon, 1995). All the soil microbial parameters were analyzed in triplicate, and the mean values are presented on dry weight basis. Dehydrogenase (Klein et al., 1971), catalase (Xu and Zheng, 1986), phosphatase (Tabatabai and Bremner, 1969), fluorescein diacetate hydrolase (Dick et al., 1996) activities were measured by corresponding standard procedures. AMBC and BSR were determined as per the method prescribed by Islam and Weil (2000).

2.3. Statistical analysis

Response surface method was employed for optimization of pyrolysis conditions. Statistical software SYSTAT-12 was employed for one-way analysis of variance to compare the means. Least significant differences at $P < 0.05$ were obtained using Duncan's multiple range test (DMRT).

3. Results and discussion

3.1. Biochar preparation

PBC yield decreased with increasing temperature and time (Fig. 1a). PBC yield obtained at 30 min for 200, 250, 300, 400, and 500 °C were 54, 45, 41, 18, and 11%, respectively. Higher temperature leads to more release of volatile components due to the severe pyrolysis conditions that increased the decomposition of biomass (Mašek et al., 2011). After 400 °C, the biochar yield decreased drastically, for instance at 30 min it decreased from 41 to 18%. The oxidizable carbon (OC) measured by wet oxidation with potassium dichromate could be used to estimate the labile fraction of C in biochar (Calvelo Pereira et al., 2011). At 30 min time the OC was 48, 44, 38, 33, and 27% for 200, 250, 300, 400, and 500 °C, respectively. OC was further decreased by increasing the residential time. LOI decreased with increase in pyrolysis temperature. The carbon lability calculated as the OC/LOI ratio decreased with increase in pyrolysis temperature and time. At 30 min, the OC/LOI was 0.50, 0.46, 0.40, 0.37, and 0.33, respectively, for 200, 250, 300, 400, and 500 °C. SOM content increased with increase in temperature and time (Fig. 1a). Based on the above discussion it is clear that biochar prepared at higher temperatures contains a higher proportion of the stable carbon than that at low temperatures. However, as with SOM in biochar, which increased with temperature while the biochar yield decreased (Fig. 1a). For soil carbon sequestration, after all, the yield of the stable fraction that is important rather than merely its concentration in biochar (Mašek et al., 2011). Thus we proposed the stable organic matter yield index (SOMYI), Eq. (2). The calculated SOMYI decreased at temperature >300 °C (Fig. 1a). A comparison between the SOMYI at different temperatures and time showed that moderate pyrolysis conditions would be beneficial. The response of SOMYI to pyrolysis temperature and time are presented in Fig. 1b. The SOMYI increased up to 300–350 °C, thereafter it decreased. This low temperature pyrolysis is much applicable for using biochar for soil carbon sequestration.

3.2. Biochar characterization

The scanning electron microscope (SEM) images (Fig. 2a) for biochar showed the micro-porous structure of the biochar. The SEM-EDX (Fig. 2a), illustrates the composition of biochar particle consisting of a combination of C > O > K > Cl > S > Mg > P. The van Krevelen diagram (a plot of H/C and O/C ratios), depicts the stability and aromaticity of PBC (Fig. 2b). The H/C and O/C ratios decreased on conversion of biomass to PBC, and it is assumed that the lower the ratio the greater the degree of aromaticity and stability. A decrease in the H/C and O/C ratios, down to 1.07 and 0.48 for biochar from 1.78 and 0.74 for initial biomass may be a result of the increasing degree of aromaticity within the biochar. TGA is a useful tool to quickly approximate biochar stability (Enders et al., 2012).