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Biochar ameliorates crop productivity, soil fertility, essential oil yield and aroma profiling in basil (*Ocimum basilicum* L.)

Vineeta Pandey, Anju Patel, D.D. Patra*

Agronomy and Soil Science Division, CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow 226015, India

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ABSTRACT

The combined application of biochar (BC) and chemical fertilizer (CF) increased crop and essential oil yield in two successive years (2013 and 2014) in basil (*Ocimum basilicum*). Organic carbon (OC) content increased under both: BC and BC mixed with CF treatments. The increase in OC ranged from 5.55% to 29.26% in the first year and 2.73–30.58% in the second year, respectively. Addition of biochar also led to increase in the soil microbial biomass carbon and soil microbial biomass nitrogen, suggesting that the higher concentration of biochar promotes the overall microorganism population. Soil dehydrogenase enzyme activity was 27% higher over the control in BC treatment. In the second harvest (2014), the urease activity increased from 7.4% to 39% in BC + CF treatment. Essential oil constituents (aroma compounds) did not change in biochar amended pots. The results show that the amendment of biochar with chemical fertilizer offers an appropriate alternative strategy to achieve higher crop productivity and essential oil yield in basil without compromising the aroma quality of the oil. Strategic addition of biochar in fertilizer regime has the concomitant advantage of enriching soil fertility for long-term sustainable agriculture with potential to reduce chemical fertilizer inputs.

1. Introduction

Biochar is a carbonaceous pyrogenic material (PCM) that is distinguished from charcoal by its use as a soil amendment for agronomic and environmental management (Glaser et al., 2002; Lehmann et al., 2003; Lehmann and Joseph, 2009). Application of biochar to soil is potentially significant for two global issues- climate change and sustainable soil management (Chan et al., 2007). Organic carbon content of biochar has been reported to be as high as 90%, depending upon the source of the material (Chan and Xu, 2009). High carbon content of biochar encourages experimental application of biochar to the soil to enhance crop productivity and improve soil health (Lehmann, 2007). Biochar in soil endures biological and chemical degradation for much longer periods as compared to uncharred organic matter. The carbon component of biochar is highly recalcitrant with 10–1000 times higher residence period of most other soil organic matter (SOM). Therefore, use of biochar as amendment in croplands can provide a potential sink for carbon. Amendment of biochar to the soil has been proposed worldwide as one effective countermeasure to increase soil organic carbon (SOC) stock. Addition of biochar further improves soil fertility and ecosystem with climate change mitigation in agriculture (Lehmann et al., 2006; Lehmann, 2007; Laird, 2008; Sohi et al., 2010). Application of biochar amendment is an ecological engineering tool for sustainable agriculture (Singh et al., 2015). Biochar when applied to soil, boosts soil fertility, improves soil quality, raises soil pH, increases water holding capacity, improves cation exchange capacity (CEC), and facilitates nutrient retention resulting in higher crop yield (Lehmann et al., 2006).

Application of organic amendment provides more C and energy sources for proliferating soil microorganisms that are responsible for enzyme production in the soil. Enzymes influence the release of nutrients for plant and microbial growth (Tate, 2000). Biochar affects the soil biotic communities in several ways. Biochar effect ranges from potentially providing a habitat for microorganism to controlling presence of toxic compounds. The biological impact of biochar in the soil ecosystem is less understood (Lehmann et al., 2011). However, such knowledge could be crucial due to the potentially high quantity and long persistence of biochar in the soil.

Therefore, there is a need to develop agricultural practice for efficient conversion of farm waste to biochar that replenish soil profiling and improve crop productivity. Previous studies have a

* Corresponding author.
E-mail addresses: pandeyvineeta48@gmail.com (V. Pandey), ddpatra@rediffmail.com (D.D. Patra).

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generated sizeable amount of data on biochar application in soils in terms of crop productivity and soil quality in food crops. However, there is no research report elucidating the effect of biochar on aromatic plants, essential oil yield, and aroma compound along with soil physical, chemical, and biological properties. Cultivation of aromatic plants plays a paramount role in the economic development of a country by providing alternative high-value crops for cultivation and opportunities of higher income generation. Worldwide there is resurgence in the business of natural aroma compounds. Aromatic plants and their natural aroma compounds are finding novel uses in therapeutics as well. Globally demand for plant-based medicines, health products, flavoring agents, pharmaceuticals, neutracueticals, food supplements and cosmetics are growing. Precise agricultural management practices are critical to the success of aromatic plant cultivation. *Ocimum basilicum* L. (family Lamiaceae), popularly called basil, is an aromatic herb that has been traditionally used as a medicinal herb for the treatment of headache, cough, diarrhea, constipation, warts, worms and kidney malfunctions. Basil is also a source of the wide range of aroma compounds, and the essential oil contains several biologically active constituents. Basil oil possesses insecticidal, nematicidal, fungicidal and antimicrobial properties (Wannissorn et al., 2005). In general, basil exhibits virtually all pharmacological activities essential for human health.

In the present study, basil was grown under different treatments of biochar (BC) and chemical fertilizers (CF) in a controlled condition. Biochar was produced from the wood pruning of eucalyptus (*Eucalyptus citriodora*) trees. The objectives of this study are to (1) evaluate the effect of biochar addition to the growth and oil yield of basil (2) investigate the impact of biochar and chemical fertilizer on the aroma compounds of the basil, and (3) study the effect of biochar and chemical fertilization on soil chemical and biological properties.

2. Material and methods

2.1. Experimental site

The pot experiment was conducted in the years 2013 and 2014 from July to October at the experimental farm of the CSIR-Central Institute of Medicinal and Aromatic Plants (26.890°N and 80.9816°E) situated at Lucknow, India. A long summer climate prevails in the area with mean maximum and minimum temperature ranging from 24.5 to 44.5 °C and 3.9 to 27.5 °C, respectively. The climate is humid sub-tropical with an annual rainfall of 900 mm. Table 1 shows the chemical properties of topsoil (0–15 cm) before the experiment.

2.2. Biochar amendment

Biochar was prepared from *Eucalyptus citriodora* Hook. pruning collected from the trees planted in the CSIR-CIMAP campus, Lucknow India. Eucalyptus prunings were collected, air-dried and chopped into small pieces. Air-dried material was powered by a grinding machine, and the powdered material was sieved through a 2 mm sieve, and mixed thoroughly to obtain fine uniform sized particles. The mixture was pyrolyzed at a temperature of 450 °C in a muffle furnace.

The temperature selection was on the basis of recommendation of Day et al. (2004) for the manufacturing of biochar for soil amendment purposes.

2.3. Experimental detail

Experimental pots were filled with 8 kg of air-dried soil. Biochar was added to the pots in three ratios i.e. 0, 1.25 g kg^{-1} and 2.5 g kg^{-1}, respectively with or without chemical fertilizers (CF). The powdered biochar was added and mixed well with the soil immediately before filling the pots. CF was applied at the rate of 75 g kg^{-1} N (urea), 30 g kg^{-1} P (single super phosphate), and 30 g kg^{-1} K (muriate of potash). Urea (N) was applied in two split dosages for each basil cycle, the first dosage as base fertilizer before transplanting and the second dosage at the vegetative stage.

Change in soil nutrient status and chemical profile of the experimental soil (Table 1) was recorded on the basis of the four treatments. The treatments were (1) control-without any amendment (2) BC-biochar at the 2.5 g kg^{-1} (3) BC + CF – 1.25 g kg^{-1} biochar plus chemical fertilizer (N:P:K) 37.5:15:15 g kg^{-1} and (4) CF-chemical fertilizer (N:P:K) 75:30:30 g kg^{-1}.

The soil was preconditioned to stabilize the soil microbial activity and replenished twice a week to stabilize the pots before planting. For preconditioning of the soil, all pots were watered with deionized water. Soil moisture was maintained at 60% of the maximum water holding capacity.

The pots were arranged in a completely randomized design. The seeds of basil variety *CIM-Saumya* were grown in a nursery for four weeks in June 2013 and 2014. The seedlings were transplanted at the rate of two plants per pots during mid-July 2013 and 2014 and harvested in the month of October 2013 and 2014.

2.4. Soil sampling and analysis

Soil samples were collected twice-first before planting and second after harvesting of the basil. Soil samples were taken from each pot (0–15 cm depth) and homogenized. Roots and visible plant residues were removed and passed through a 2-mm sieve and stored at 4 °C in a refrigerator for the determination of soil enzyme activity, microbial biomass carbon and nitrogen. Part of the soil was air-dried for soil for analysis of the chemical properties.

Organic C was determined by Walkley and Black (1934) method. CHNS analyzer analyzed total C. For the determination of total N and total P, the organic material was digested in 1.2:1 H_2SO_4/H_2O_2 mixture at 360 °C and measured by Flow Inject Analyzer. Available P was extracted with sodium bicarbonate and determined by the molybdo-phosphate blue color method (Olsen et al., 1954). Available K was extracted with ammonium acetate and analyzed by flame photometry. Dehydrogenase activity in soil was determined by the method described by Casida et al. (1964). Acid and alkaline phosphatase activity were measured by Tabatabai and Bremner (1969), Eivazi and Tabatabai (1977) respectively. β-Glucosidase was determined by Eivazi and Tabatabai (1988) protocol. Urease activity was analyzed by Tabatabai and Bremner (1972) method. Soil microbial biomass C and N were estimated using the fumigation extraction method (Vance et al., 1987).

2.5. Extraction of the essential oil

The essential oil was extracted by hydro-distillation in a Clevenger (1928) type apparatus. Extracted oil was dried with anhydrous sodium sulphate. The oil yield was calculated in mL of oil per 100 g of dried material. The collected oil was stored in at −20 °C for analysis.

2.5.1. Gas chromatography (GC) of essential oil for aroma compounds

GC analysis of the essential oils was carried out on a Perkin–Elmer Auto System XL gas chromatograph, equipped with DB-5 capillary column (50 m × 0.32 mm i.d., film thickness 0.25 μm) fixed in a Varian CP-3800 Gas Chromatograph. The column was programmed from 60 °C, at the rate of 5 °C/min, using H_2 as carrier gas at constant flow rate of 1 mL/min, a split ratio of 1:40 and S/SL injector and detector (FID) temperatures were 270 °C