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Carbon mineralization and nutrient availability in calcareous sandy soils amended with woody waste biochar

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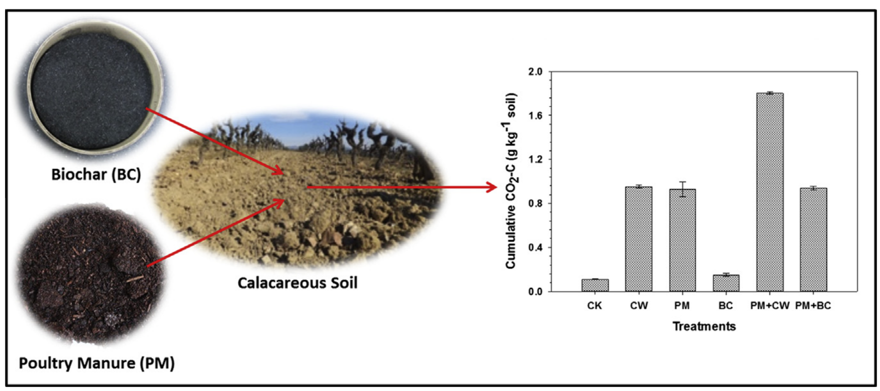
HIGHLIGHTS

- Biochar alone or in combination with manure was applied to sandy calcareous soil.
- Biochar application halted the CO_2–C emission rate compared to manure.
- The combined addition of biochar and manure increased *N*, *P* and *K* contents in soil.
- Biochar has potential to sequester C and improve fertility of the calcareous soil.

GRAPHICAL ABSTRACT



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ABSTRACT

Many studies have reported the positive effect of biochar on soil carbon sequestration and soil fertility improvement in acidic soils. However, biochar may have different impacts on calcareous sandy soils. A 90-day incubation experiment was conducted to quantify the effects of woody waste biochar (10 g kg^{-1}) on CO_2–C emissions, K_2SO_4-extractable C and macro-(*N*, *P* and *K*) and micro-(Fe, Mn, Zn and Cu) nutrient availability in the presence or absence of poultry manure (5 g kg^{-1} soil). The following six treatments were applied: (1) conocarpus (*Conocarpus erectus* L.) waste (CW), (2) conocarpus biochar (BC), (3) poultry manure (PM), (4) PM + CW, (5) PM + BC and (6) untreated soil (CK). Poultry manure increased CO_2–C emissions and K_2SO_4-extractable C, and the highest increases in CO_2–C emission rate and cumulative CO_2–C and K_2SO_4-extractable C were observed for the PM + CW treatment. On the contrary, treatments with BC halted the CO_2–C emission rate, indicating that the contribution of BC to CO_2–C emissions is negligible compared with the soils amended with CW and PM. Furthermore, the combined addition of PM + BC increased available *N*, *P* and *K* compared with the PM or BC treatments. Overall, the incorporation of biochar into calcareous soils might have benefits in carbon sequestration and soil fertility improvement.

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1. Introduction

Biochar is produced by thermochemical conversion of biomass in an oxygen-limited environment (IBI, 2012). It has shown its potential in improving soil fertility and sequestering carbon (C) in soils (Ahmad et al., 2014). Biochar has been estimated to cause a reduction of 1.8–9.5 Pg in annual carbon dioxide (CO_2–C) emissions (Woolf et al., 2010). However, the long-term C sequestration potential of biochar largely depends on its stability in soil (Kuzyakov et al., 2014). Biochar can act as both a sink and a source of carbon depending on its interactions with soil organic matter (OM) and microbes (Zimmerman et al., 2011). The influence of biochar on native soil organic carbon (SOC) mineralization is controversial. Several studies have reported that the application of biochar stimulated SOC mineralization (Luo et al., 2011; Wardle et al., 2008; Cely et al., 2014). Conversely, suppression of SOC mineralization by biochar has also been reported (Zimmerman et al., 2011; Kuzyakov et al., 2009; Singh and Cowei, 2014). The anomalous behavior of biochar towards SOC mineralization primarily depends on characteristics of the biochar and soil properties (Cely et al., 2014; Singh and Cowei, 2014). In general, enhanced microbial and enzymatic activities due to the breakdown of labile organic C of biochar and the supply of nutrients from biochar result in increased SOC mineralization (Fang et al., 2015), a phenomenon commonly known as the positive priming effect. On the other hand, SOC mineralization can be suppressed by the sorption of labile organic C onto the surface or into the pore network of biochar (Lehmann et al., 2011), a phenomenon commonly known as the negative priming effect. It is therefore important to study changes in C mineralization, nitrification and denitrification processes induced by biochar application in soils (Hu et al., 2014).

The calcareous sandy soils of arid and semi-arid regions are generally nutrient and SOM deficient. At present, inorganic fertilizers are being intensively used to meet the increasing demand of agricultural products in these areas, thereby threatening to contaminate groundwater as a consequence of nitrate percolation. Thus, there is a need to find an appropriate soil management strategy that could reduce inorganic fertilization and enhance soil fertility. Nutrient-enriched manure is commonly applied as a cost-effective alternative to inorganic fertilizers (Moore et al., 2014; Leytem et al., 2011). Manure treatment in calcareous soils could be a promising strategy for maintaining soil OM and improve soil physical and biochemical properties (Zhao et al., 2009). However, negative environmental impacts including greenhouse gas emissions are generally associated with manure applications (De Vries et al., 2012). The microbial degradation of organic matter in manure contributes to CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions (Sun et al., 2014). For instance, according to FAO (2013), the emission of N_2O from the application of manure to agricultural soils in 2012 was estimated to 186,500 Gigagrams of emissions (CO_2 equivalent). It is therefore desirable to develop strategies to reduce the greenhouse gas emissions from manure-applied soils. We hypothesized that the incorporation of biochar to sandy calcareous soil may be another plausible alternative of inorganic fertilizers and it could also maintain a stable decomposition rate of organic matter compared with uncharred wastes. This hypothesis is based on the studies of *terra preta* soils indicating low C respiration rates from soils containing high black carbon and natural OM contents compared with native tropical soils, which are typically deficient in OM (Glaser, 2007). Generally, the high cation exchange capacity, anion sorption ability and pore structure of biochar favor the sorption of dissolved OM (Barnes et al., 2014; Kasozi et al., 2010); however, these properties vary depending on the feedstock and biochar production conditions (Al-Wabel et al., 2013; Mohan et al., 2014). In this way, biochar may retard SOC mineralization, thus mitigating greenhouse gas emissions. Additionally, biochar can improve soil fertility by directly or indirectly supplying nutrients to plants. Particularly, biochar can modify soil functions and act as a fertilizer (by saving nutrients), enhancing the efficiency of fertilizer use by improving the physical properties of soil and reducing the amount of nutrients leaching due to charge and the surface area characteristics of biochar (Chan and Xu, 2009). Impacts of biochar on high pH soils have been studied by some researchers (Zhang et al., 2013; Lentz and Ippolito, 2012; Artiola et al., 2012). The main problematic with applying biochar to arid soils having alkaline reaction may be due to its high pH. The study of Gunes et al. (2014) showed that application of biochar to alkaline soil have benefits to increase its nutrition status of *N*, *P* and *K*, but it has negative impact on micro-nutrients of plants. However, Lentz and Ippolito (2012) found that biochar addition to calcareous soils did not make changes in soil pH and soil available *P* as well as the soil cations, but the changes were observed for acidic soils. In this context, the effect of biochar on nutrient status and C sequestration in arid and low productive soils need to be studied further.

Considering the aforementioned potential of biochar, this study is intended to determine the C mineralization and nutrients availability in calcareous sandy soil amended with woody waste biochar and poultry manure. The combined effect of biochar and manure application was assessed by comparing individual applications of biochar and manure by measuring CO_2–C emission, K_2SO_4-extractable C and macro-(NPK) and micro-nutrient (Fe, Mn, Zn and Cu) availability in a calcareous soil of Saudi Arabia.

2. Materials and methods

2.1. Characterization of soil, conocarpus wood wastes, biochar and manure

The soil used in this study was collected from the agricultural farm of the College of Food & Agricultural Sciences, King Saud University, Saudi Arabia. The soil samples were air dried and ground to pass through a 2-mm sieve. The physico-chemical soil properties were measured according to standard methods (Sparks, 1996). The particle size distribution was determined using the pipet method (Gee and Bauder, 1994). Soil pH and electrical conductivity (EC) were measured electrometrically in a 1:5 ratio of soil to water. Calcium carbonate content was determined using a calcimeter. The soil organic matter was measured according to Nelson and Sommers (1996). The soil has a sandy loam texture with an EC value of 0.37 dS m^{-1}, pH value of 8.50, calcium carbonate content of 10.2% and SOC content of 0.01%.

Conocarpus wood wastes were chopped into small pieces (7–10 cm) and then pyrolyzed in a stainless steel cylindrical container (30 cm radius and 60 cm length) in an outdoor pyrolysis reactor for 150 min at a temperature of 400 ± 10 °C. The pH of the conocarpus waste and biochar was measured using a ratio of 1:10. The results showed that the samples of conocarpus waste feedstock have an acidic pH of 5.26, but the produced biochar has an alkaline pH of 9.67. Meanwhile, the pH value of the poultry manure samples was found to be 7.74. The total content of elements (C, H, O, S and N) in conocarpus waste, biochar and poultry manure samples was measured by elemental analyzer (series II, Perkin Elmer, USA). The percentage of C, O, H and N contents in feedstock and biochar were 44.96% and 76.18%, 45.82% and 14.16%, 5.41% and 2.83% and 0.62% and 0.87%, respectively. Meanwhile, these (C, O, H and N) percentages in the poultry manure samples amounted to 47.85%, 25.45%, 11.89% and 1.14%, respectively (Table 1).