Applied Soil Ecology 98 (2016) 243–253

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Effects of biochar and compost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil

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ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form 16 October 2015
Accepted 25 October 2015

Keywords:
Biochar amendment
Compost
Enzyme activity
Microbial community
Apple orchard

ABSTRACT

The use of biochar and compost as soil amendments and their comparative effects on microbial activities and related processes were investigated in an apple orchard site at Mountain River in Tasmania, Australia. Biochar derived from Acacia green waste was applied at a rate of 47 ton ha^{-1} just before planting and has been *in situ* for 3.5 years. Compost produced by the Luebke system was also applied separately at 10 ton ha^{-1} as a top dressing one week after planting. Chemical analysis indicated that there was no significant impact on total ions by either biochar or compost additions. However, organic carbon was significantly increased ($p = 0.009$) by 23% for biochar and 55% for compost treatments. Soil pH decreased in both biochar and compost treatments. Microbial abundance was improved after the addition of biochar, but the effect of compost addition was greater. There were no significant differences across a panel of enzyme activities among treatments. There were slight increases in alkaline phosphatase while fluorescein diacetate activity and hydrolysis activity slightly decreased. The entire community of the soil was assessed using 16S rRNA and 18S rRNA genes amplicon pyrosequencing. Significant differences in bacterial and fungal but not archaeal or other eukaryota community components were observed. These results indicated that biochar and compost carbon amendments can subtly affect the community structure of the orchard soils despite active application of inorganic and organic fertilizers. The overall effects on fundamental activity is largely neutral, however, likely due to the enormous structural resilience and functional redundancy present.

1. Introduction

Biochar is an organic material containing a high level of carbon, and is produced by heating biomass in the absence of oxygen. It has an aromatic structure that makes it stable and highly resistant to chemical and biological degradation in soil (Atkinson et al., 2010). Biochar is increasingly being used as a soil amendment with the aim to improve soil physical, chemical and biological properties, reduce greenhouse gas emissions, and sequester carbon. Due to the specific properties of biochar, biochar addition may have significant impacts on soil chemical and physical properties, which also potentially affect the biochemical processes and microbial functions in soil. However, the interactions between biochar additions and chemical and biological properties in soil are not fully understood (Lehmann et al., 2011). There is widespread debate about the use of biochar and its agricultural benefits in soil.

Many reviews indicate that the application of biochar to soils influences chemical and physical properties as well as the function and structure of microbial communities that can be associated with an increase in soil fertility (Lehmann et al., 2011; Liu et al., 2012; Partey et al., 2015). However, some studies have revealed that biochar addition can also have negative impacts on soil properties. Biochar can adsorb agri-chemicals such as pesticides and also organic matter which can then prevent microbial enzyme access that are subsequently released *via* microbial activity (Kookana et al., 2011; Zimmerman et al., 2011). Some biochar products may be toxic depending on the source materials used in its manufacture (Kookana et al., 2011). A comparison study conducted by Paz-Ferreiro et al. (2012) to evaluate the impact of sewage sludge derived biochar and unpyrolyzed sewage sludge on the biochemical activity on soil showed that the organic amendments had different impact on biochemical activity, while the geometric mean of enzyme activities was increased in the higher biochar treatment and decreased in sewage sludge amended soil. This may indicate that pyrolyzed organic materials are suitable for enhancement of soil biochemical activity; however, impact on

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http://dx.doi.org/10.1016/j.apsoil.2015.10.021
0929-1393/

enzyme activity stemming could be variable, dependent on the soil as well as enzyme type specific (Bailey et al., 2011).

Due to its high surface area, biochar may provide a habitat for soil microorganisms (Lehmann and Joseph, 2009; Kookana et al., 2011). Consequently, biochar application may influence all aspects of soil fertility related to the physical characteristics of soil. Depending on the pyrolysis conditions, biochar produced from the same material may have different specific surface areas and porosity. The study by Kookana et al. (2011) showed that specific surface area and porosity were increased with increasing pyrolysis temperature; however, micropores might be destroyed at higher temperatures. The difference between biochar and soil matrix in physical properties leads to an overall change in soil density and aggregation, hydraulic conductivity and gas transportation, which in turn impacts chemical properties and microbial activity in soil (Lehmann et al., 2011). The application of biochar may also improve irrigation management and water infiltration and enhance fertiliser treatment response in soil. Asai et al. (2009) investigated the effect of biochar on soil physical properties and rice green yields. The results showed an improvement in the hydraulic conductivity and increased rice yields in sites with low P content and noticeable responses to the fertiliser treatments. It has been reported that the compost amendment and increase soil organic content can enhance hydraulic conductivity, however, the impact might be variable between different soils and application rates (Aggelides and Londra, 2000; Rawls et al., 2003). Improving hydraulic conductivity and other physical characteristics in soil provides suitable conditions for the chemical interactions and microbial activity. Furthermore, because biochar has high resistance to microbial degradation; the impact of biochar addition in soil is presumably persistent for years.

Biochar is more likely to be beneficial in soils that have poor physical characteristics such as sandy soils. An experiment conducted by Basso et al. (2012) suggested that biochar addition to sandy soil increases water holding capacity which might increase water availability for plant use. Evidence showing the biochar contribution and its effect on soil stability and aggregation, water management, porosity and surface area indicate that understanding the biochar functions and effects in soil would assist in choosing a particular biochar in specific agriculture soils, thus gaining the maximum benefits from biochar as a soil amendment (Sohi et al., 2010).

In the same way that biochar affects physical properties, the addition of biochar also affects soil chemical properties but the impact could be more complicated because of the wide scale of biochar effects on soil chemistry. Additionally the effects will depend on the type of biochar as chemical composition differs with different feedstocks (Unger et al., 2011). Unger et al. (2011) conducted an incubation experiment to determine if biochar produced under different reactions from various feedstocks would differentiate the influence of biochar on soil chemical properties. Their results suggested that the reaction conditions and organic materials used to produce biochar will affect specific chemical properties. Biochar additions to soil can increase cation exchange capacity (CEC) and thus nutrient holding capacity, resulting in increased soil nutrients such as potassium (K), calcium (Ca) and nitrogen (N). Also the high cation exchangeable capacity (CEC) enhances binding cations and anions in soil to increase nutrient retention and availability to microbes and plants (Atkinson et al., 2010). Biochar has also been shown to increase soil pH, thus influencing the concentration of many nutrients in soil and their availability for crop uptake (Fowles, 2007).

The impact of biochar on biotic processes and related microbes has been discussed recently by many researchers; however, there is limited understanding of the interactions between biochar amended soil and biological processes including the direct impact of biochar on soil microbes. The main purposes of using biological fertilisers and soil amendments are to reduce the expense of chemical additions, improve crop production, and reduce greenhouse gas contributions. Biochar seems to be a beneficial way to achieve this purpose because of its long term impact on the soil ecosystem. Theoretically, biochar could alter the biological processes in soil such as N mineralisation and nitrification by affecting the bacteria which are involved in these processes as well as providing a suitable environment to increase microbial activity (Berglund et al., 2004). Several studies indicate that using biochar as a soil amendment enhances populations and activity in soil by inducing metabolism and growth of soil microorganisms (Kookana et al., 2011; Tong et al., 2014). Biochar and its application in soil is involved in many aspects related to soil health and quality, for instance, chemical and physical changes in soil. However, the major aspect, which is still far from being understood and has so far received less attention than any other aspect, is the impact of biochar applications on the entire soil community and how soil biota interact and adjust with carbon-amended soil environments.

The study reported here was conducted in an apple orchard that was amended with either biochar or compost. To date the affects on physical characteristics (Hardie et al., 2014) and tree growth have been reported (Eyles et al., 2015). The aim of this study is to (i) understand the impact of biochar in relation to compost on the functional behaviour of soil microbes related to the biological processes that occur following application; (ii) determine the impact of the additions on the entire soil community (archaea, bacteria and eukaryotes); and (iii) determine how this relates to alterations in soil physico-chemical properties.

2. Materials and methods

2.1. Site characteristics and trial design

Soil samples were collected from an established apple orchard trial site at Mountain River located in the Huon Valley in southern Tasmania (42°57′2.91″S, 147°5′52.13″E). This site was established in November 2009 during replanting of the orchard. The experimental design was a randomised complete block with four treatments and five replicates; trees were blocked on position within the tree-row. Each replicate contained three trees and plot size was 3.18 m long and 1 m wide. The four treatments were biochar (B), compost (C), and biochar + compost (B + C) and untreated control (U), the biochar + compost treatment (B + C) was excluded and not reported in this study. Biochar was sourced from Pacific Pyrolysis, Somersby, NSW (Australia); feedstock consisted of Acacia as a whole tree green waste which had undergone pyrolysis in a continuous flow kiln at temperatures up to 550 °C for 30–40 min. The average pore size of the biochar estimated by using scanning electron microscopy, ranged from 0.8 μm to 235 μm. The biochar had a pH of 6.4, contained 8.93% (w/v) organic carbon, 3 mg kg^{-1} NH_4^+, 1 mg kg^{-1} NO_3^-, extractable P of 234 mg kg^{-1} and 1117 mg kg^{-1} K. Physiochemical characteristics of the biochar are also detailed by Hardie et al. (2014). Biochar was applied on 2nd November 2009 before tree planting, each replicate received 15 kg biochar, equivalent to 5 kg per tree space or 47 ton ha^{-1}. The biochar was spread evenly to a width of 1 m across the tree row and worked into the top 10 cm of the soil profile. The orchard was replanted with 'Naga-Fu No 2 Fuji' trees on M26 rootstock with a 'Royal Gala' interstem. Tree spacing was 1.06 m within the row and 4.5 m between rows. The compost (produced by the Luebke system) sourced from Renew (Plenty, Tasmania, Australia) was composed of 43% (w/v) organic carbon, 4.5% total nitrogen (Kjeldahl), 1.8% water soluble nitrogen and 0.017% nitrate nitrogen (Eyles et al., 2015). The compost was applied at 10 ton ha^{-1} as a top dressing within the tree row 1 week