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Research article

Greenhouse gas emissions and soil properties following amendment with manure-derived biochars: Influence of pyrolysis temperature and feedstock type

Raghunath Subedi [a, b, *], Natalie Taupe [b], Simone Pelissetti [a], Laura Petruzzelli [a], Chiara Bertora [a], James J. Leahy [b], Carlo Grignani [a]

[a] *Department of Agricultural, Forest and Food Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, Italy*
[b] *Department of Chemical and Environmental Sciences, University of Limerick, Plassey Park Rd., Castletroy, Co., Limerick, Ireland*

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ABSTRACT

Manure-derived biochars can offer a potential option for the stabilization of manure, while mitigating climate change through carbon sequestration and the attenuation of nitrous oxide emission. A laboratory incubation study was conducted to assess the effects of four different manure-derived biochars produced from different feedstocks (poultry litter and swine manure) at different temperatures (400 or 600 °C). A commonly available standard wood chip biochar, produced at a greater temperature (1000 °C), and non-amended treatments were used as references. Two different soils (sandy and silt-loam) were amended with 2% (w/w) biochar on a dry soil weight basis (corresponding to 20 Mg ha^{-1}), with the soil moisture being adjusted to 75% saturation level. After a pre-incubation period (21 days), 170 kg N ha^{-1} of NH_4NO_3 fertilizer was added. Measurements of CO_2, N_2O, CH_4 emissions and soil N mineralisation were carried out on different days during the 85 days of incubation. The net C mineralization and N_2O emissions from both soils amended with poultry litter biochar at 400 °C were significantly greater than the other biochar treatments. Nitrate availability was greater in both soils in which the manure-derived biochar was used instead of the standard biochar. All of the biochars increased the pH of the silt-loam, sub-acid soil, but failed to improve the cation exchange capacities (CEC) in either soil. Total C and N, P, K and Mg (except Ca) were significantly increased in the manure-derived biochar amended soils, compared to the Control, and were positively correlated to the biochar nutrient contents. This study indicates that the soil application of biochar engenders effects that can vary considerably according to the biochar properties, as determined on the basis of the feedstock types and process conditions. Low-temperature biochar production from manure represents a possible way of producing a soil amendment that can stabilize C while supplying a significant quantity of nutrients.

1. Introduction

Biochar obtained from the thermo-chemical conversion of biomass is being promoted as a potential solution to reduce greenhouse gases (GHGs) (Gaunt and Lehmann, 2008), and as a beneficial soil amendment (Forbes et al., 2006). It has been claimed that biochar has the potential to reduce the impact of agricultural systems on global warming through carbon (C) sequestration and nitrous oxide (N_2O) suppression (Sohi et al., 2010; Taghizadeh-Toosi et al., 2011; Case et al., 2014; Van Zwieten et al., 2014; Gwenzi et al., 2015). The enhanced physico-chemical properties of biochar amended soils are believed to be the result of increased nutrient retention and availability, a greater water holding capacity, CEC and surface area, and a rise in pH in acidic soils (Liard et al., 2010; Lehmann et al., 2011; Anderson et al., 2011; Jeong et al., 2015). The improved biological properties are linked with the increased microbial diversity along with the provision of a suitable aerated habitat for soil flora and fauna due to the porous nature of biochar (O'Neill et al., 2009; Lehmann et al., 2011). However, all of the aforementioned effects vary considerably according to the specific

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* Corresponding author. Department of Agricultural, Forest and Food Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, Italy.
E-mail addresses: raghunath.subedi@unito.it, subedirn@gmail.com (R. Subedi).

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properties of the biochar. Jeffery et al. (2015) and Gwenzi et al. (2015) have reviewed the possible trade-offs between the expected biochar benefits, potential risks and associated uncertainties, as this debate continues to grow among biochar researchers.

The stability of biochar in soils and its interaction with the soil micro-organisms that are responsible for its decomposition depend on several factors, such as the nature of the biochar feedstock, the type of process used for the biochar production (dry/wet pyrolysis, slow/fast pyrolysis, gasification), and the operating conditions (temperature as well as residence time) (Lehmann et al., 2011; Ameloot et al., 2013; Jeong et al., 2015). The microbial degradation of biochar C in soil is often associated with labile organic compounds, such as alkanoic and benzoic acids, and phenols, whose concentration falls with increasing pyrolysis temperature (Liang et al., 2010; Novak et al., 2009; Graber et al., 2010; Troy et al., 2013). Biochars produced from plant residues contain stable aromatic structures and are more resistant to microbial attack (Foereid et al., 2011; Ippolito et al., 2012; Case et al., 2014; Jeong et al., 2015).

The results of N_2O emissions from biochar amended soils are not consistent. Some authors reported decreased N_2O emissions (Rondon et al., 2005; Van Zwieten et al., 2010; Taghizadeh-Toosi et al., 2011; Jia et al., 2012; Nelissen et al., 2014; Martin et al., 2015), some reported no-effects (Clough et al., 2010; Nelissen et al., 2014), and yet others reported increased N_2O emissions (Yanai et al., 2007; Scheer et al., 2011; Troy et al., 2013). Increased soil porosity, associated with soil biochar amendment, results in improved soil aeration, which ultimately suppresses N_2O emissions (Richardson et al., 2009; Clough et al., 2013), whereas the anaerobic conditions, a more biochar labile C content, and conditions that favour a greater abundance of denitrifiers in the soil, due to biochar additions, can lead to increased soil N_2O emissions (Cayuela et al., 2014; Kammann et al., 2012; Dalal et al., 2003). Therefore, the extent of N_2O emissions from biochar-amended soils is greatly affected by the fertilizer types (Nelissen et al., 2014), biochar C:N ratio and the nature of C present (Troy et al., 2013; Zhu et al., 2014), biochar porosity, surface area and particle size (Jeong et al., 2015; Martin et al., 2015) and the response of denitrifiers (Van Zwieten et al., 2014). Despite many studies being conducted (both incubation and in field), there still remain substantial scientific doubts on the mechanisms by which biochar affects soil N_2O emissions, thus seeking further investigation studies (Troy et al., 2013).

The modification of N dynamics on biochar amended soil has been suggested to have shift (either increase or decrease) on GHG emissions and the availability of other nutrients after fertiliser application (Clough and Condron, 2010; Clough et al., 2013). Enhanced crop growth, associated with increased efficiency in N use and reduced leaching in biochar-amended soils, has also been reported by some authors (Major et al., 2012; Schomberg et al., 2012). The immobilization of N can occur when a biochar with a large C:N ratio is amended in a soil with a smaller C:N ratio (Kuzyakov et al., 2009).

Pyrolysis may play a role in the manure processing chain, especially in EU regions where intensive livestock production exist, via energy production, nutrients recovery, and reducing both the manure volume and transportation costs (Cantrell et al., 2007; Hossain et al., 2011). Additionally, the deployment of biochars derived from the pyrolysis of locally available resources as a soil conditioner can be a strategically important option for soil fertility improvement and mitigation of GHG emissions (Steiner et al., 2007; Kimetu et al., 2008). While biochars derived from woody biomass and their effects on soil have been reported extensively, there have been few reports on the use of biochar derived from animal manures in which amendment effects in different soil types are compared.

A laboratory incubation study was undertaken, with two different soil types, to test the following hypothesis: (i) manure-derived biochars play a different role in amending the soil than wood-derived biochars, and could combine the agronomic advantages of manure and the environmental benefits of biochar (ii) the feedstock type and pyrolysis temperature can be used as a means to modulate the expected effects of manure-derived biochars on GHG emissions and soil properties; (iii) the effects of such biochars also vary according to the soil type. Therefore, the N_2O and CH_4 emissions, the potential for C sequestration, nutrient availability and the final soil quality (chemical) were measured, after amending two soils (sandy and silt-loam) with biochars from different feedstocks (poultry and swine manures) at two temperatures (400 or 600 °C), and were compared with a readily available standard wood-derived biochar.

2. Materials and methods

2.1. Soil collection and characterization

Two types of soil with contrasting characteristics were used in this experiment (Table 1): i) a less C content sandy soil with sub-alkaline pH, designated “Soil A”, and ii) a more C content silt-loam soil with sub-acidic pH, called “Soil B” (USDA, 2013). They were both collected from the top 20 cm of arable fields (NW Italy) in order to mimic the ploughed layer. They were subsequently air-dried and mechanically sieved to below 2 mm, using an electric auto-rotating sieving device (Neotron s.r.l., Autopack NTR 83, Modena, Italy). Both soils were less in N, P and K contents, but rich in Ca content (Table 1).

2.2. Biochar production and characterization

Four different manure-derived biochars, produced from two different feedstocks (poultry litter and swine manure) at two different temperatures (400 or 600 °C), were used for this experimental study. The poultry litter biochars (“PL400” and “PL600”) were produced at the University of Limerick in Ireland, using a laboratory pyrolysis plant. The swine manure biochars (“SM400” and “SM600”) were supplied by ECN, (the Netherlands) (www.ecn.nl). These manure-derived biochars were compared with the most widely available biochar i.e. wood chip biochar (“WC”) produced at a greater temperature (1000 °C), and with another control treatment i.e. unamended soil (“Control”). The wood chip biochar was produced from kiwi fruit pruning residue via industrial gasification at Agrindustria, Italy (www.agrind.it).

The biochars were analysed for their total C and N contents by means of elemental analysis (Vario El Cube CNS analyser, Elementar, Hanau, Germany). The pH was measured in deionized water at a 1:10 biochar-water ratio using a pH electrode (Cyberscan 510 pH meter, Staffordshire, UK) after shaking the mixture for 18 h. The moisture, ash and volatile matter (VM) contents were analysed according to the NSAI standard testing method (NSAI, 2009). Available P was extracted in a 2% formic acid solution and measured spectrophotometrically (Wang et al., 2012). Calcium, Mg and K were analysed by Atomic Absorption (Varian Techtron AA6, Melbourne, Australia), following acid digestion (Cantrell et al., 2012). The CEC of the samples was determined by means of sodium chloride adsorption and potassium nitrate displacement method (Silber et al., 2010). The surface acidity of the chars was determined by means of the base adsorption method reported by Cheng and Lehmann (2009). The surface area and porosity were determined according to the Brunauer, Emmet and Teller (BET) method, on the basis of the measurements obtained by N_2 adsorption at 77 K using ASAP-2400 Micrometrics apparatus. Each sample was analysed in