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Impact of biochar addition to soil on greenhouse gas emissions following pig manure application

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A B S T R A C T

The application of biochar produced from wood and crop residues, such as sawdust, straw, sugar bagasse and rice hulls, to highly weathered soils under tropical conditions has been shown to influence soil greenhouse gas (GHG) emissions. However, there is a lack of data concerning GHG emissions from soils amended with biochar derived from manure, and from soils outside tropical and subtropical regions. The objective of this study was to quantify the effect on emissions of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) following the addition, at a rate of 18 t ha^{-1}, of two different types of biochar to an Irish tillage soil. A soil column experiment was designed to compare three treatments ($n = 8$): (1) non-amended soil (2) soil mixed with biochar derived from the separated solid fraction of anaerobically digested pig manure and (3) soil mixed with biochar derived from Sitka Spruce (*Picea sitchensis*). The soil columns were incubated at 10 °C and 75% relative humidity, and leached with 80 mL distilled water, twice per week. Following 10 weeks of incubation, pig manure, equivalent to 170 kg nitrogen ha^{-1} and 36 kg phosphorus ha^{-1}, was applied to half of the columns in each treatment ($n = 4$). Gaseous emissions were analysed for 28 days following manure application. Biochar addition to the soil increased N_2O emissions in the pig manure-amended column, most likely as a result of increased denitrification caused by higher water filled pore space and organic carbon (C) contents. Biochar addition to soil also increased CO_2 emissions. This was caused by increased rates of C mineralisation in these columns, either due to mineralisation of the labile C added with the biochar, or through increased mineralisation of the soil organic matter.

1. Introduction

Increasing amounts of greenhouse gases (GHG) in the atmosphere are causing changes in world climate (IPCC, 2007). The production of biochar and renewable energy through pyrolysis is seen as one prospective strategy, which could result in reduced global carbon dioxide (CO_2) concentrations. Roberts et al. (2010) found negative values for the net GHG emissions following the pyrolysis of corn stover and yard waste and the application of the biochar to soil (−864 and −885 kg CO_2 equivalent emissions reduction per tonne dry feedstock, respectively), compared with ethanol production from the corn stover and compost production from the yard waste. The majority (62–66%) of these GHG emission reductions were realised through C sequestration within the soil. Gaunt and Lehmann (2008) found that when biochar was applied to agricultural land, the potential reduction in GHG emissions was between 2 and 5 times greater than when it was burned to offset fossil fuel usage. These potential reductions in GHG emissions following biochar application to soil are primarily due to the sequestration of carbon (C) within the soil (Gaunt and Lehmann, 2008; Roberts et al., 2010), with other potential reductions due to savings in fertiliser requirement, reductions in fossil fuel usage, and reductions in soil emissions (Gaunt and Lehmann, 2008).

In Ireland, recent landspreading legislation (Nitrates Directive, 91/676/EEC) has limited the magnitude, timing and placement of organic manure to land. Currently, the amount of livestock manure that can be applied to land has been limited to 170 kg of nitrogen (N) per hectare per yr. The land available for landspreading will further be restricted, starting in 2013, and culminating in 2017, when landspreading of pig manure can no longer exceed the crop's phosphorus (P) requirements for growth (S.I. 610 of 2010). The implication of this will be that an additional ∼50% land area will be required for manure application than is the case in 2012, thereby increasing the cost of manure handling. The resulting increase in

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manure transport costs for farmers, along with the potential of surface and groundwater pollution from the landspreading of manure, has resulted in the need to examine practical solutions for pig manure treatment. The production of biochar from pig manure may be a solution for some farmers living in very pig dense regions.

Biochar application to agricultural soils has the potential for long-term C sequestration, due to the stability of biochar in soil environments. Biochar is composed of a range of different forms of C, from recalcitrant aromatic ring structures, which can persist in soil for millennia, to more easily degradable aliphatic and oxidised C structures, which mineralise to CO_2 more rapidly through degradation by biotic and abiotic oxidation (Schmidt and Noack, 2000; Cheng et al., 2006; Liang et al., 2008). Increased CO_2 emissions, following biochar addition to soil, have been attributed to increased mineralisation rates in the biochar-amended soil due to (1) mineralisation of applied biochar C (Major et al., 2010a; Smith et al., 2010) or (2) enhanced soil organic C mineralisation (Rogovska et al., 2011). In a two-year experiment, Major et al. (2010a) found that only 3% of applied biochar C was lost as CO_2, with 75% of the biochar mineralisation occurring in the first year, which suggested that the stimulatory effects were short-term. The stability and resistance of the biochar against oxidation is known to vary depending on the feedstock and pyrolysis procedures and temperatures (Schmidt and Noack, 2000; Liang et al., 2008). Mukherjee and Zimmerman (2013) showed that the loss of biochar C, N and P to leaching water correlated with biochar volatile matter content and was greater from biochar made at lower temperatures than from high temperature biochar. Rogovska et al. (2011) found accelerated soil organic C mineralisation with biochar addition to soil, and hypothesised that the increases may be due to (1) increased aerobic microbial activity as a result of higher soil aeration due to the lower bulk density of the biochar-amended soil and (2) enhanced microbial colonisation, causing accelerated decomposition of organic compounds.

The long-term effects of biochar can be seen in fertile Anthrosols found around the Amazonian basin. These soils have very high biochar contents due to the charring of forest wood by the indigenous people thousands of years ago (Lehmann et al., 2003). Nutrient leaching has been shown to be minimal from these soils despite their high nutrient content, which has resulted in high soil fertility in contrast to the low fertility adjacent acid soils. Biochar potentially has a superior ability to retain nutrients in comparison to other forms of organic matter (OM) (Lehmann, 2007). Previous experiments have shown that the ability of biochar to retain nutrients in the soil can influence nutrient leaching (Novak et al., 2009; Laird et al., 2010a), nutrient availability (Laird et al., 2010b) and plant growth rates (Asai et al., 2009; Major et al., 2010b).

Biochar addition to soil has been shown to influence the concentrations of inorganic-N, organic C and oxygen (O_2) in the soil and, hence, the emissions of nitrous oxide (N_2O) from the soil (Clough et al., 2010; Singh et al., 2010). Nitrous oxide has a global warming potential estimated as being 296 times that of CO_2 (IPCC, 2007). Emissions of N_2O have been reported to either increase (Clough et al., 2010) or decrease (Singh et al., 2010), following biochar application to soil. Singh et al. (2010) found that wood biochar adsorbed ammonium (NH_4) in a soil, thereby reducing the pool of inorganic-N for the N_2O-producing mechanisms. Clough et al. (2010) attributed higher N_2O emissions from biochar-amended soil to greater nitrite (NO_2) concentrations brought about by nitrification inhibitors on biochar, which slowed nitrate (NO_3) formation. Yanai et al. (2007) found an 89% suppression of N_2O emissions at 73–78% soil water filled pore space (WFPS) due to the adsorption of water by biochar. However, the same study found a 51% increase in N_2O emissions at 83% WFPS. The authors attributed this increase to better soil aeration and the stimulation of N_2O-producing activity due to the neutralisation of soil pH. Studies have shown that biochar addition to soil may also influence methane (CH_4) emissions, which have a global warming potential estimated as being 23 times that of CO_2 (IPCC, 2007). Soil CH_4 emissions have been reported to either increase (Zhang et al., 2010) or decrease (Rondon et al., 2005), following biochar addition. Rondon et al. (2005) credited a near complete suppression of CH_4, following biochar addition to soil, to a reduction in anaerobic conditions and increased soil aeration. However, in a field experiment in a rice paddy, Zhang et al. (2010) found that soil amended with biochar at 40 t ha^{-1} increased CH_4 emissions by 34% when N fertiliser was applied, and by 41% without N fertilisation.

There are few studies concerning GHG emissions from biochar from feedstocks other than wood, and data from soils outside tropical and subtropical regions are also required (Verhejien et al., 2010). Therefore, the objectives of this study were to investigate CO_2, N_2O and CH_4 emissions from Irish tillage soil, amended with biochar derived from either pig manure or wood (Sitka Spruce), with and without fertilisation with pig manure.

2. Materials and methods

2.1. Soil column preparation

The soil used in this study was an Acid Brown Earth (Regan et al., 2010) collected to a depth of 0.2 m from a tillage farm near Fermoy, County Cork. The 0.2 m depth was chosen as this is an average plough depth for tillage soil. The soil was air dried, passed through a 2 mm sieve, and mixed to ensure homogeneity. Two types of biochar were used for this study: pig manure biochar and wood biochar. Pig manure biochar was produced from the solid fraction of pig manure after anaerobic digestion, which had been separated using a decanter centrifuge. The separated manure was then mixed with Sitka Spruce (*Picea sitchensis*) sawdust (at a 4:1 ratio by wet weight), dried, and subjected to slow pyrolysis in a custom-built laboratory pyrolysis reactor operated at 600 °C, with a residence time of 15 min. After pyrolysis, the biochar was moved to a cooling area of the reactor before removal from the reactor. Sawdust was added to the manure as separation, drying and pyrolysis of pig manure alone is not economically viable, and does not produce a positive energy balance (Troy et al., unpublished results). Wood biochar was produced by slow pyrolysis of Sitka Spruce (*P. sitchensis*) wood in a large-scale pyrolysis reactor at 600 °C and a residence time of 15 min. Both biochars were ground to pass through a 2 mm sieve. The characteristics of the biochars are given in Table 1.

Soil columns were constructed using 0.3 m-deep and 0.104 m-internal diameter pipes, which were sealed at the base with perforated PVC end-caps to ensure that the soil remained free-draining. Pea gravel from a commercial supplier, manually sieved to a particle size of between 5 and 10 mm, was placed at the base of each column to a depth of 0.05 m. The three treatments

Table 1
Characteristics of the biochars and soil used in the column experiment (Means ± SD).[b]

	Pig manure biochar	Wood biochar	Soil
Organic matter ($\%_{db}$)[a]	72.5 ± 0.78	97.0 ± 1.24	4.62 ± 0.013
Ash content ($\%_{db}$)	27.5 ± 0.78	3.0 ± 1.24	95.38 ± 0.013
Bulk density (g cm^{-3})	0.19 ± 0.020	0.18 ± 0.016	1.10 ± 0.010
Total N ($\%_{db}$)	2.67 ± 0.042	0.42 ± 0.024	0.21 ± 0.008
Total C ($\%_{db}$)	62.7 ± 1.30	82.0 ± 1.15	1.75 ± 0.049
pH	9.6 ± 0.34	9.3 ± 0.19	6.9 ± 0.20

[a] db, dry basis.
[b] SD, standard deviation.