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Biochar-mediated reductions in greenhouse gas emissions from soil amended with anaerobic digestates

Sarah L. Martin [a], *Michèle L. Clarke* [b], *Mukhrizah Othman* [a], *Stephen J. Ramsden* [a], *Helen M. West* [a,*]

[a] *School of Biosciences, University of Nottingham, Sutton Bonington Campus, Loughborough, Leicestershire LE12 5RD, UK*

[b] *School of Geography, University of Nottingham, University Park Campus, Nottingham NG7 2RD, UK*

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ABSTRACT

This investigation examines nitrous oxide (N_2O) fluxes from soil with simultaneous amendments of anaerobic digestates and biochar. The main source of anthropogenic emissions of N_2O is agriculture and in particular, manure and slurry application to fields. Anaerobic digestates are increasingly used as a fertiliser and interest is growing in their potential as sources of N_2O *via* nitrification and denitrification. Biochar is a stable product of pyrolysis and may affect soil properties such as cation exchange capacity and water holding capacity. Whilst work has been conducted on the effects of biochar amendment on N_2O emissions in soils fertilised with mineral fertilisers and raw animal manures, little work to date has focused on the effects of biochar on nitrogen transformations within soil amended with anaerobic digestates. The aim of the current investigation was to quantify the effects of biochar application on ammonification, nitrification and N_2O fluxes within soil amended with three anaerobic digestates derived from different feedstocks. A factorial experiment was undertaken in which a sandy loam soil (Dunnington Heath series) was either left untreated, or amended with three different anaerobic digestates and one of three biochar treatments; 0%, 1% or 3%. Nitrous oxide emissions were greatest from soil amended with anaerobic digestate originating from a maize feedstock. Biochar amendment reduced N_2O emissions from all treatments, with the greatest effect observed in treatments with maximum emissions. The degree of N_2O production and efficacy of biochar amelioration of gas emissions is discussed in context of soil microbial biomass and soil available carbon.

* *Corresponding author*. Gateway Building, School of Biosciences, University of Nottingham, Sutton Bonington Campus, Loughborough, Leicestershire LE12 5RD, UK. Tel.: +44 (0) 115 9516268.

E-mail address: helen.west@nottingham.ac.uk (H.M. West).

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1. Introduction

Nitrous oxide (N_2O) is an important greenhouse gas estimated to have 298 times the global warming potential of CO_2 over a 100-year period [1]. Agricultural activities contribute up to 60% of the global annual anthropogenic emissions; this value is predicted to increase by 35–60% in the next 15 years because of increasing use of nitrogen fertilisers and enhanced production of animal manure [1]. In terms of N_2O emissions from soil, nitrifier-nitrification, nitrifier-denitrification and denitrification are the principal sources and may occur simultaneously at different microsites within the soil ecosystem [2]. Denitrification is affected by soil temperature, nitrate concentrations, organic matter availability, redox potential and pH [3].

Residues derived from anaerobic digestion can be used as fertilisers and soil conditioners with nutrients in digestates more readily available than those within slurry or fresh manure [4,5], although variability is associated with the feedstock used, the retention time and conditions within the AD unit [6].

Biochar is a black carbon generated by pyrolysis of biological materials such as wood, crop residues, poultry litter, cattle manure and municipal wastes [7]. Biochar is not a uniform product since it can be formed from a variety of feedstocks at different temperatures (e.g. 350–1000 °C). It has been proposed that biochar application to soil can sequestrate carbon, adsorb inorganic and organic contaminants, improve soil fertility and quality through increases in pH, macronutrients and improved soil water holding capacity [8–12]. It has been estimated that the C-residence time of biochar in soils is hundreds to thousands of years, compared to decades for that of crop residues [8].

Recently, attention has focused on the effect of biochar amendment on soil gas fluxes and in particular on N_2O. Several studies showed that biochar amendment decreased N_2O emissions [13–15] whilst others showed no effect [16] or increased emissions [17]. The impact of biochar on soil N_2O fluxes is variable and depends on factors such as soil type, soil water content, additional fertiliser application, biochar feedstock and pyrolysis temperature [15,18–20]. N_2O emissions have been measured from soil amended with anaerobic digestates [21] and from soil amended with biochar [22,23], but few have quantified the effects of N_2O fluxes associated with AD and pyrolysis residues simultaneously [24].

The effects of biochar on CO_2 fluxes are also varied, with numerous observations of increased emissions [25,26], some of decreased emissions [27] and others showing little consistent effect, with some types of biochar promoting CO_2 production whilst others inhibit it [28]. A consistent observation is that gas emissions are dependent on pyrolysis temperature and amendment rates [23].

Recent studies have investigated the effects on GHG emissions from soils amended with biochar and other fertilisers such as wastewater sludge, urea, ammonium chloride and potassium nitrate [15,22], however to date only one study has compared GHG emissions from soil simultaneously amended with anaerobic digestate and biochar [24]. Use of anaerobic digestate as an organic amendment will become more prevalent since there is an increasing drive to produce energy from waste in the UK [29] and elsewhere and to farm sustainably, meaning potentially greater use of organic fertilisers. Therefore, the aim of the current investigation was to quantify N_2O emissions from soil after simultaneous amendment with one type of biochar and three anaerobic digestates derived from different feedstock material. Carbon dioxide fluxes were also measured. Most of the emphasis in the literature has been on effectiveness of biochar produced under different pyrolysis conditions; the current study quantified the effects of modifying the digests, whilst maintaining a consistent biochar and soil type.

2. Materials and methods

2.1. Characteristics of the anaerobic digestates, biochar and soil

Anaerobic digestates (ADFs) were obtained from three different anaerobic digestion (AD) facilities in the UK and consisted of the separated fibre component. The AD plants were fed with different feedstocks; (i) cattle dung and potato waste (designated ADF 1), (ii) cattle slurry and maize silage (ADF 2) and (iii) maize silage (ADF 3). All digesters were mesophilic and sizes were (i) 265 m^3, (ii) 1.48 dam^3 and (iii) 6.60 dam^3 respectively. The feeding rates ranged from 55 Mg to 100 Mg day^{-1} on a fresh weight basis and varied according to the dry matter content of the feedstock. AD samples were all stored at 4 °C prior to analysis and soil amendment. The pH of all three ADFs was 8.2; the moisture content was 83.2%, 92.0% and 82.1% and the organic matter content based on loss on ignition was 84.0, 91.7 and 88.5% for ADF 1, ADF 2 and ADF 3 respectively. The atomic C:N ratios were 20:1, 29:1 and 21:1 respectively; the majority of extractable N was in the form of NH_4^+–N (2260 ± 120, 4309 ± 231, 3250 ± 126 mg kg^{-1} for ADFs 1–3).

Biochar was commercially sourced from BioRegional HomeGrown® (BioRegional Charcoal Company Ltd, Wallington, Surrey, UK). Mechanically chipped trunks and large branches of *Fraxinus excelsior* L., *Fagus sylvatica* L. and *Quercus robur* L. were pyrolysed at 450 °C for 48 h [11]. The C:N ratio of the biochar was 116:1; pH 9.

A sandy loam soil (Dunnington Heath series; sand 66%, silt 18%, clay 16%, organic matter 3.7%, pH 7.35, NH_4^+–N 0.97 mg kg^{-1} and NO_3^-–N 3.5 mg kg^{-1}) was collected from the University of Nottingham farm site at Sutton Bonington, Leicestershire, UK (SK 512 267) at a depth of 10–30 cm and sieved (<2 mm) prior to use. The field was bare at the time of sampling, but is under a conventional tillage regime and the crop prior to collection was wheat.

2.2. Experimental set-up

Field-fresh soil was combined with the ADFs and biochar as outlined below:

(i) Soil only (control), (ii) ADF 1 + soil, (iii) ADF 2 + soil, (iv) ADF 3 + soil. Each ADF treatment (none, ADF 1, ADF 2 and ADF 3) also received 0%, 1% or 3% biochar (<4 mm) to give a total of 12 treatments. For the soil only treatment, 125 g dry weight