The role of biochar in reducing nitrous oxide emissions and nitrogen leaching from soil

Bhupinder Pal Singh[A], Blake J. Hatton[B], Balwant Singh[B] and Annette L. Cowie[A,C]

[A]Forest Science Centre, Industry and Investment NSW, P.O. Box 100, Beecroft, NSW 2119, Australi, Email bp.singh@sf.nsw.gov.au
[B]Faculty of Agriculture, Food and Natural Resources, The University of Sydney, NSW 2006, Australia, Email B.Singh@usyd.edu.au
[C]National Centre for Rural Greenhouse Gas Research University of New England Armidale 2351, Australia, Email Annette.cowie@une.edu.au

Abstract
This study examined the influence of four biochars on nitrous oxide (N_2O) emission and nitrogen (N) leaching from the two contrasting soils (an Alfisol and a Vertisol) using repacked soil columns over three wetting–drying (W–D) cycles and two leaching events spanning five months. A control (acid-washed sand) was also included for each soil. The four different biochars used were:

(i) W400 - woodchip (*Eucalyptus saligna*) biochar prepared at 400 °C, non-activated

(ii) PM400 - poultry manure/rice hull biochar prepared at 400 °C, non-activated

(iii) W550 - woodchip (*Eucalyptus saligna*) biochar prepared at 550 °C, activated

(iv) PM550 – poultry manure/rice hull biochar prepared at 550 °C, activated

During the first two W–D cycles, W400 and W550 had inconsistent effects on soil N_2O emissions; however, the soils amended with poultry manure biochars, especially PM400, generally produced higher soil N_2O emissions, relative to the control. The greater initial N_2O emissions from the PM400-amended soils (*cf.* control) can be ascribed to its higher intrinsic N content, which may be relatively labile, compared with the other biochars. Notably, during the third W–D cycle, all biochars, including PM400, consistently decreased soil N_2O emissions (cumulatively by 14–73% from the Alfisol and by 23–52% from the Vertisol) than the control soil. In the first leaching event, after two months, none of the biochars influenced the leaching of NH_4^+-N and NO_3^--N, except for PM400, which caused higher leaching of NO_3^--N than the other treatments. In the second leaching event, after four months, the leaching of NO_3^--N was not affected by the biochar treatments; whereas, leaching of NH_4^+-N was significantly reduced by 55–93% from the W550- and PM550-amended Alfisol and Vertisol, and by 87–94% from the W400- and PM400-amended Vertisol. We hypothesize that the increased effectiveness of biochars in reducing N_2O emissions and NH_4^+-N leaching over time is due to an increase in sorptive properties as biochar 'ages' in soil through oxidative reactions on the biochar surfaces.

Key Words
Biochar, nitrous oxide emission, nitrate, ammonium, leaching.

Introduction
Soil biochar application is promoted as a climate change mitigation tool due to its potential to increase long-term soil carbon pools and reduce greenhouse emissions. Biochars are reputed to affect soil N transformation processes, but only a few studies have tested in detail the influence of biochars on soil N_2O emissions and inorganic N leaching. Biochar is generally produced from biomass materials at temperatures between 300 to 600°C under partial or complete exclusion of oxygen (pyrolysis) and is considered highly resistant to biological degradation due to its increased chemical recalcitrance (aromaticity) compared with the parent biomass (Baldock and Smernik 2002). Biochars are highly porous, usually alkaline, and exhibit large specific surface area (Glaser *et al.* 2002; Downie *et al.* 2009). Oxidation of biochar in soil leads to the development of negatively-charged organic functional groups on its surfaces (Cheng *et al.* 2008). Due to these inherent chemical and physical properties, biochars can potentially influence a number of soil properties including soil pH, porosity, bulk density, and water holding capacity (Glaser *et al*. 2002; Chan *et al.* 2007). Furthermore, biochars sorb ions from soil solution by a combination of electrostatic, complexation, and capillary forces on their surfaces and in pores (Major *et al*. 2009; Moreno-Castilla 2004). These properties of biochars can potentially decrease leaching of nutrients from soil (Lehmann *et al.* 2003) and accessibility of ions to soil microorganisms. However, the influence of biochars on soil properties could be highly variable (Glaser *et al.* 2002) because biochar properties vary widely, depending on the biomass source and pyrolysis conditions (Baldock and Smernik 2002; Downie *et al.* 2009; Major *et al.* 2009).

Biochar application to soil could affect N_2O emissions by (a) altering soil properties (e.g. pH, aggregation, CEC) and the availability and distribution of key electron acceptors (O_2, NO_3^-), and donors (NH_4^+, dissolved organic matter), (b) inducing catalytic reduction of N_2O to N_2 following oxidation and subsequent reactions of biochars with soil minerals and (c) influencing microbial community structures, and microbial enzymes and processes (N mineralisation-immobilisation turnover, nitrification, denitrification) involved in N cycling in soil (Šimek and Cooper 2002; Yanai *et al.* 2007 Van Zwieten *et al.* 2009). Some of these effects are expected to be a function of chemical composition (ratio of aromatic to aliphatic groups, intrinsic N content and form, ash content, etc.) and physical nature (specific surface area, porosity) of biochars produced from a range of biomass sources and pyrolysis conditions. Furthermore, through the development of charged functional groups on biochar surfaces during their oxidation, biochars may further affect abiotic and biotic N cycling processes governing soil N_2O emissions. The aim of the present study was to assess the influence of four biochars on the emission of N_2O and leaching of NO_3^--N and NH_4^+-N from two contrasting soils subjected to 3 W–D cycles over a 5-mo period.

Methods

Four biochars, Agrichar™, made from woodchips (W) or poultry manure + rice hulls (PM) at 400 °C, non-activated, or at 550 °C, activated, abbreviated as: W400, PM400, W550, PM550, were used; these biochars varied widely in important properties (pH 6.93 to 10.26; CEC 7.3 to 28.3 cmol(+)/kg; total C 415 to 802 g/kg; ash content 3.5 to 44.4%) (see further details in Singh *et al*. 2010). Biochars or acid-washed sand (control) were mixed with a sandy loam (Kurosol) and a clay (Vertosol) soil. According to the USDA Soil Classification, these soils are classified as an Alfisol and a Vertisol, respectively. Soil–biochar mixtures, adjusted to 0.85 water-filled pore space (WFPS), were repacked to 1.3 g/cm^3 bulk density in PVC columns (Figure 1). Glucose-C and nutrient (N, P, K) solution were added. Gas samples were collected from the enclosed headspace and analysed for N_2O. Following drying to ~0.3 WFPS, the soils were rewetted and gas sampling was continued. In total, soils were subjected to three W-D cycles during the five-month study period. Leachate was collected at the start of the second and third W-D cycles, and analysed for NH_4^+-N and NO_3^--N.

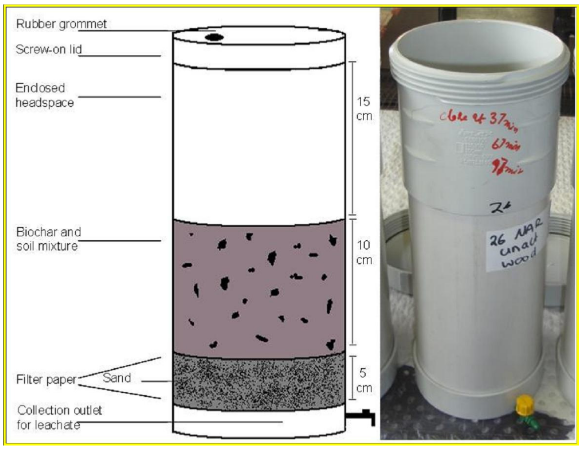

Figure 1. A schematic representation and photo of experimental column.

Results

Nitrous oxide emissions

- During the first two W–D cycles, W400 and W550 had inconsistent effects on soil N_2O emissions and the soils amended with poultry manure biochars, especially PM400, produced higher soil N_2O emissions relative to the control. The initially greater N_2O emissions from the PM400-amended soils (cf. control) initially can be ascribed to its higher intrinsic N content, which may be relatively labile, compared with other biochars.
- During the third W–D cycle, all biochar treatments consistently decreased soil N_2O emissions, cumulatively by 14 to 73% from the Alfisol and by 23 to 52% from the Vertisol, relative to their controls.

Nitrogen leaching

- In the first leaching event, biochars did not decrease the leaching of NH_4^+-N and NO_3^--N from soils (cf. control); PM400 caused higher leaching of NO_3^--N than the other treatments, including control.
- In the second event, NO_3^--N leaching was not affected by the biochar treatments (*cf.* control); whereas, NH_4^+-N leaching was reduced by 55–93% from the W550- and PM550-amended Alfisol and Vertisol and by 87–94% from the W400- and PM400-amended Vertisol.

Conclusion

Results show that biochar application can be effective in reducing N_2O emissions and inorganic-N leaching from soils. The most effective biochars were: (a) both the low- (400°C, non-activated) and high-temperature (550°C, activated) wood biochars and (b) the high-temperature (550°C, activated) poultry manure biochar. Initially, in comparison with the control, the application of high-N poultry manure biochar synthesized at low temperature (400°C, non-activated) increased N_2O emissions and NO_3^--N leaching whereas other biochar treatments either decreased N_2O emissions or did not affect inorganic N from soil. However, after four months, all biochars decreased N_2O emissions by up to 73% and NH_4^+-N leaching by up to 94%, relative to the control. We hypothesise that the increased effectiveness of biochars in reducing soil N losses is due to an increase in sorptive properties as biochar 'ages' through oxidative reactions on biochar surfaces and their subsequent interactions with soil minerals.

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