How do biochar characteristics influence its capacity to mitigate N_2O emissions in agricultural soils?

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Abstract

There is an increasing interest in the use of biochar as a strategy to mitigate nitrous oxide (N_2O) emissions from soils. Some authors have reported a substantial decrease in the N_2O emitted when biochar was applied as soil amendment. However, the mechanisms involved in this process have not been identified yet, neither the characteristics that make a biochar ideal for N_2O mitigation. In this study, an incubation experiment was performed with nine biochars that were applied at 2% (w/w) to an organic soil under optimal denitrification conditions and N_2O emissions were monitored. All biochars used in this experiment decreased N_2O emissions; however, biochar properties defined the magnitude of mitigation, which ranged between 37 and 77%. Biochar pH and ash content were identified as important characteristics imprinting biochar mitigation capacity, however no correlation was found between N_2O mitigation and C/N ratio.

Introduction

The decrease of N_2O emissions after biochar soil amendment was first reported in a greenhouse experiment by Rondon et al. (2005) [1]. They observed that N_2O emissions were reduced by up to 50% for soybean and by 80% for grass growing in a low-fertility oxisol from the Colombian savanna. Since then, the interest in biochar as a N_2O mitigation strategy in agricultural soils is continuously increasing and the number of studies evaluating N_2O emissions in biochar-treated soils has exponentially risen.

Several laboratory and field experiments reported important reductions in the N_2O emitted after biochar soil application. For instance van Zwietten et al (2010) [2] found reductions up to 85% and Stewart et al (2012) up to 92% [3]. Nonetheless, an increase in N_2O emissions in soil amended with biochar has been reported as well [4, 5] and as the number of studies increases, the responses obtained become extremely variable depending on environmental conditions, soil and biochar characteristics.

Different hyphotheses have been postulated to explain why biochar might decrease N_2O emitted from soils. Biochar could enhance soil aeration, increase soil pH, favour nitrogen immobilization or it could induce a toxic effect in the soil nitrifier/denitrifier microbial communities.

To date the theorized mechanisms and the importance they might have remain controversial. Similarly, the characteristics that make a biochar suitable for N_2O mitigation are unknown. Without the basic knowledge on when, how much and why biochar modifies N_2O emissions from soil, using biochar to mitigate N_2O emissions from fertilized agro-ecosystems remains a difficult challenge.

In general, most studies reported lower mitigation capacity for low-temperature (250-400 °C) biochars [2, 6] and Kammann et al. (2012) [7] warned about the risk of increased emissions with hydrochars (by-procucts of hydrothermal carbonization). But there are not many studies that concentrate on the specific causes of reduction. A recent work [8] demonstrated that an increase in soil aeration makes only a minimal contribution to the suppression of N_2O emissions in a sandy-loam soil, suggesting that microbial or physical immobilization of NO_3^- in soil following biochar addition could be more important factors for N_2O suppression.

The focus of this study was on the denitrification pathway. The aim was to identify the physico-chemical characteristics of biochars related to their capacity to mitigate N_2O emitted from a soil exposed to optimum denitrification conditions. The effect on soil porosity was counteracted by selecting a soil where addition of biochar would not modify its water retention curves at high moisture content. Therefore, the target variables were principally pH and C/N although other characteristics as ashes, volatiles, Fe content and biochar surface were contemplated as well.

Material and Methods

Incubation experiments.

An organic soil (cultivated histosol, USDA (1999) [9]) was selected for the experiments for two main reasons:

(i) histosols are reported to emit high fluxes of N_2O, and if biochar plays a role on N_2O emissions, it will be easier to observe the effect in a system with high emission rates;

(ii) this soil had a very low bulk density (0.65 $g \cdot cm^{-3}$) and biochar application at 2% (w/w) did not modify its porosity as demonstrated by its water retention curves (Table 1). 90% WFPS in this soil would correspond to 10 cm pressure, which was not significantly modified by biochar treatments.

The soil was sampled from a horticultural field in New York State (43°7'48'', -78°6'38''), sieved at <2mm and stored at 4 °C for less than one month until the beginning of the experiments.

Table 1. Water retention curves for the organic soil unamended (control) and with 2% (w/w) of four selected biochars used in the experiment.

Pressure ($cm\ H_2O$)	Volumetric water content (vwater:vsoil)				
	control	Grass	Brush	Manure	Woodchips
1	0.96	0.95	0.95	0.96	0.96
3.5	0.91	0.90	0.89	0.90	0.91
10	0.80	0.80	0.81	0.81	0.83
30	0.76	0.78	0.79	0.79	0.80
100	0.67	0.66	0.64	0.70	0.72
300	0.64	0.62	0.58	0.66	0.70

Nine biochars produced at 500 °C by slow pyrolysis were selected to get a wide range of pH (6.4-10.7) and C/N ratios (11-859). Biochars were throughly mixed with the soil at a rate of 2 % (w/w) and incubated at optimum conditions for denitrification (90% WFPS, 30 °C) during 45 days. The experiment was laid out as a randomized block design with four replicates per treatment.

Gas sampling and measurements.

Gas sampling was conducted by sealing each unit with gas-tight screw caps for 40 min and N_2O concentration was measured with gas chromatography equipped with an electron capture detector (GC-ECD). We investigated the role that certain characteristics of biochars (ash, C/N and pH) play in the control of N_2O produced through the denitrification pathway.

Results

Figure 1 shows the percentage of reduction of N_2O emissions for each of the nine tested biochars in relation to their C/N ration and their pH. All biochars used in this study decreased N_2O emissions compared to the unamended soil. The biochar leading to higher N_2O mitigation was obtained from woodchips (C/N 231, pH 6.4) and decreased by 77% the amount of N_2O emitted from soil. The biochar with lowest impact on N_2O emissions was made from grass (C/N 11; pH 9.5) and decreased emissions by 37%. The observed pattern seems to indicate that high pH biochars led to lower effect on N_2O reduction. However, no correlation was found between N_2O mitigation and biochar C/N or pH, showing that these and other factors might be interacting simultaneously.

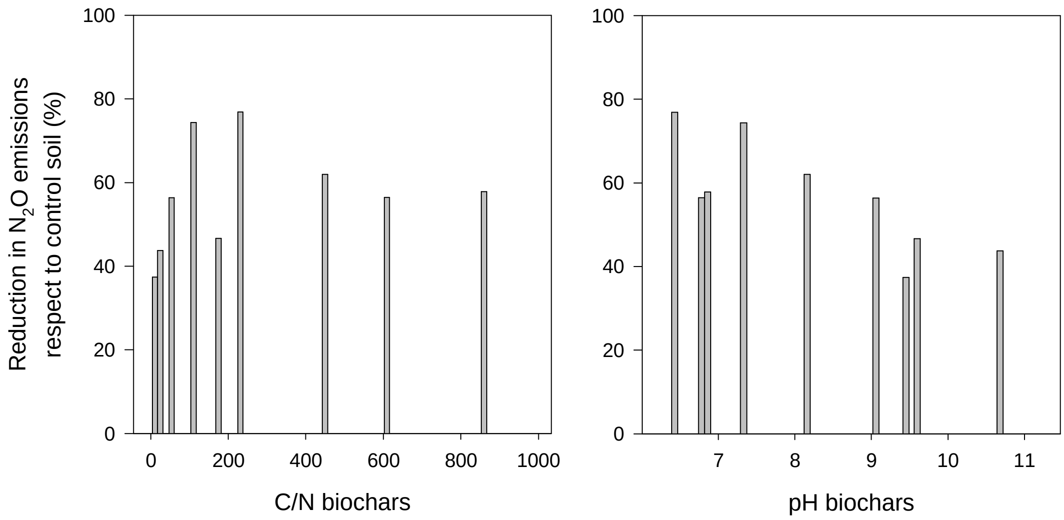

Figure 1. Percentage of reduction in N_2O emitted from soil after biochars application related to the biochars' C/N ratios (Fig 1A) and pH (Fig 1B).

After two weeks of incubation, once the peak of emissions had levelled-off, the concentration of water-extractable NO_3^- was determined in the control soil (12 mg N-NO_3^- kg^{-1} soil) and in a treatment amended with a high C/N (C/N 609) biochar (48 mg N-NO_3^- kg^{-1} soil), which suggests that N immobilization/adsorption was not the cause of N_2O reduction.
To offset the effect of pH we repeated the experiment after adjusting the pH of all biochars with hydrochloric acid to the same of the soil (pH 5.6). Figure 2 shows the results for N_2O reduction with the same biochars but when the pH had been adjusted prior to soil application.

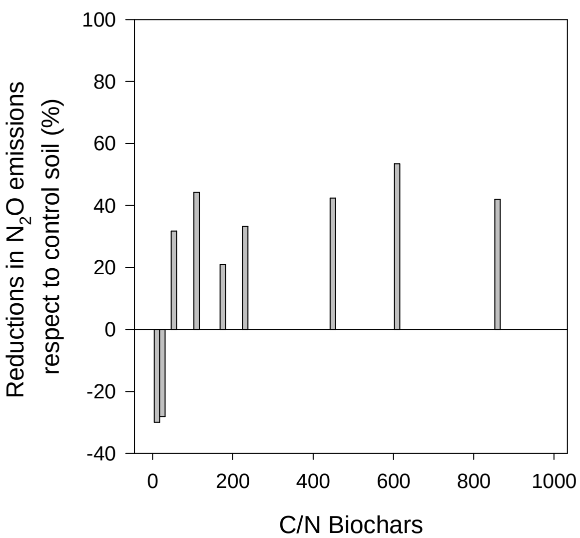

Figure 2. Percentage of reduction in N_2O emitted from soil after application of biochars which pH had been adjusted to the same of the soil (pH 5.6).

We observed lower mitigation with adjusted-pH biochars compared to the original biochars where pH had not been adjusted, which demonstrates the importance of biochar liming capacity for its effectiveness reducing N_2O. When pH was not a factor, N_2O mitigation correlated with ash content (r 0.899; P<0.01), which might indicate that biochars with high salt content might induce a salting-out effect through an increase of the ionic strength in the soil solution, which might reduce the solubility of N_2O [10].

Conclusion and perspectives

The characteristics of biochar imprint its ability to reduce N_2O emissions from soil. In this experiment no direct correlation was found between biochar C/N ratio and its ability to reduce N_2O emissions. After two weeks of incubation the amount of NO_3^- content in soil amended with high C/N biochar was higher than in the unamended soil, which suggests that N immobilization/adsorption is not the prevalent mechanism for the observed N_2O reductions during denitrification in the case of slow-pyrolysis, high-temperature biochars.

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