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Decreased Soil Nitrification Rate with Addition of Biochar to the Acid Soils

Shiyu Li[1], Xiangshu Dong[2], Dandan Liu[a3], Li Liu[4] & Feifei He[5]

Abstract

This study aimed to investigate the effects of mixed biochar on the nitrification rate in acidic soils. A ^{15}N tracer experiment with $(^{15}NH_4)_2SO_4$ was conducted to determine the nitrification rates of four acidic agricultural soils with pH 4.03–6.02 in Yunnan Province, Southern China. The accumulation of $^{15}N\text{-}NO_3^-$ and nitrification rates decreased with the addition of biochar at the end of incubation, suggesting that biochar could be a nitrification inhibitor in acidic fertilized soil. Nitrification rates in soil with pH 4.03 were evidently lower than those in soil with pH 4.81–6.02 with or without biochar. Decreased nitrification rates were detected in the acidic soils with biochar. Soil pH controlled nitrification more than biochar in certain strongly acidic soils.

Keywords: Nitrification rate; Biochar; ^{15}N tracer; Acidic soil

1. Introduction

Biochar is a solid, carbon-rich material that is obtained from the pyrolysis processes of waste biomass. Biochar is used for soil amelioration (van Zwieten et al. 2010), increased yield (Major et al. 2010; Taghizadeh-Toosi et al. 2012), and mitigation of greenhouse emissions (Wang et al. 2011; Zhang et al. 2010; Zhang et al. 2012). Nitrification is an important N transformation process, by which microorganisms oxidize ammonium (NH_4^+) to create nitrate (NO_3^-), releasing N_2O as byproduct. Although nitrification is highly sensitive to soil pH, the nitrification rate accelerates in acidic fertilized soils (Zhao et al. 2007; Zhong et al. 2007; Cai et al. 2014; Zhou et al. 2014). A number of studies have reported that adding biochar to soils may affect soil N transformation, such as stimulate N immobilization (Clough and Condron 2010; Nieder et al. 2011; Zavallonia et al. 2011). However, biochar addition does not show long-term effects on NH_4^+ sorption or the net nitrification rate in field conditions (Castaldi et al. 2011). The present study aimed to investigate the effects of biochar amendment on the nitrification rate in acidic agricultural soils treated with different amounts of biochar. We hypothesized that substrate concentration and pH were important factors in soils, and biochar addition could decrease nitrification.

Materials and methods

Soils classified as mountain red earth were collected from agricultural fields with different land uses in Yunnan Province, Southern China. The soil samples were air dried and sieved through a 4 mm mesh. Soil A contained 27.2 g C kg^{-1} total organic C and 2.60 g N kg^{-1} total N.

[1] School of Agricultural, Yunnan University, Kunming 650091, China;
[2] School of Agricultural, Yunnan University, Kunming 650091, China;
[3] School of Agricultural, Yunnan University, Kunming 650091, China;
[4] College of Resources and Environmental Sciences, Yunnan Agricultural University, Kunming 650302, China
[5] School of Agricultural, Yunnan University, Kunming 650091, China;

Soil A, which had a pH (H_2O) of 4.03, was sampled in late spring from a tea garden cultivated ~20 years in Wenshan (N 24°16'609", E 104°51'788"). Soil B, which was obtained from a corn rotation field in Yuxi (N 24°17'511", E 102°22'505"), contained 23.7 g C kg^{-1} and 2.00 g N kg^{-1} total organic C and N, respectively. The pH (H_2O) was 4.81. Soils C and D were from a vegetable planting field in Kunming (N 24°49'778", E 102°50'279") and Wenshan (N 24°03'271", E 105°04'910"), respectively. Soils C and D contained 12.9 and 7.46 g C kg^{-1} total C, respectively, and 1.22 and 0.85 g N kg^{-1} total N, respectively. The soil pH values (H_2O) of soils C and D were 5.41 and 6.02, respectively. Biochar was produced from wheat straw in the Sanli New Energy Company, Henan Province, China. The production and properties of biochar were described by Zhang et al. (2010). For the incubation experiment, the biochar mass was grounded to pass through a 0.25 mm sieve.

Biochar was incorporated homogenously into the air-dried soils A, B, C, and D at ratios of 0 wt%, 5 wt%, 10 wt%, and 20 wt% (w/w), respectively. Soil samples (80g) were adjusted to 45% water holding capacity and pre-incubated aerobically at 25°C in the dark for 7d before use. About 1ml of $(^{15}NH_4)_2SO_4$ (10.13atom% excess) solution was added at a rate of 50mg of NH_4-N kg^{-1} soil. The soils were adjusted to 60% water holding capacity and incubated for 7d at 25°C. The soils (three replications) were extracted at 2h and 7d after $(^{15}NH_4)_2SO_4$ application to determine the concentrations of NH_4^+ and NO_3^- (AA3, SEAL, Germany) and isotopic composition of NH_4^+ and NO_3^- (Flash EA 1112 HT-Delta V Advantage, Thermo Scientific). The nitrification rate was estimated analogously from the NO_3^- pool at the end of the experiment originating from labeled NH_4^+ (Mørkved et al. 2006).

Results and discussion

$^{15}NH_4^+$-N was significantly enriched in soil A compared with that in soils B, C, and D at 2h and 7d following $(^{15}NH_4)_2SO_4$ application and biochar-mixed treatments (Table 1). In all soils, the $^{15}NH_4^+$ concentrations were significantly lower in 5wt% treatments compared with those in 0wt% treatments at the two sampling times, except for C_5 treatment at 2h. By contrast, the $^{15}NH_4^+$ concentrations increased significantly after applying larger amounts of biochar (i.e., 10wt% and 20wt%), especially in soils C and D. At 2h, soil C had significantly higher $^{15}NO_3^-$ concentration than the other soils corresponding with the biochar treatments. At 7d, $^{15}NO_3^-$-N significantly decreased with the increased application of biochar, except for soil A.

Table 1 Concentrations of $^{15}NH_4^+$ and $^{15}NO_3^-$ in the soils and biochar-mixed soils after adding $(^{15}NH_4)_2SO_4$ (10.13atom% excess) during a 7d incubation period

Nitrification rates were significantly affected as the biochar increased from 0wt% to 20wt% (w/w) in the four soils (Fig. 1). In all the soils that were studied, nitrification rates at 0wt%–5wt% were relatively higher compared with those at 10wt%–20wt%. This result was consistent with the findings of other studies (Dempster et al. 2012; Wang et al. 2015), suggesting that biochar may restrict microbial activity. The abundances of organisms involved in the nitrification of NH_4^+ to NO_2^- were low in the short-stage experiments (Andersona et al. 2011; Song et al. 2014). The presence of organic compound in biochar (e.g., phenolic) weakened nitrification and inhibited AOB abundance and diversity (Wang et al. 2015). Spokas et al. (2010) reported that ethylene derived from biochar or biochar-mixed soil causes a decrease in the available nitrate.

Fig. 1 Nitrification rates in the soils and biochar-mixed soils after adding $(^{15}NH_4)_2SO_4$ (10.13 atom% excess) during a 7day incubation period

Nitrification rates were extremely low in soil A (initial pH 4.03), which was similar to the findings of other studies (Yao et al. 2011; Chen et al. 2014; Jiang et al. 2015). We suspected that strongly acidic soil suppressed nitrification, although the effects of pH and ammonia concentration were not distinguished in this study. The important implication of this finding was the potential utilization of biochar as a nitrification inhibitor, particularly in acidic fertilized agricultural soils. However, the use of biochar as a nitrification inhibitor requires further investigation considering biochar quality (e.g., production conditions, biomass feedstock, and biochar dosage).

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Table 1 Concentrations of $^{15}NH_4^+$ and $^{15}NO_3^-$ in the soils and biochar-mixed soils after adding $(^{15}NH_4)_2SO_4$ (10.13 atom% excess) during a 7 d incubation period

Treatments	$^{15}NH_4^+$-N(mg kg^{-1})			$^{15}NO_3^-$-N(mg kg^{-1})		
	2h	7d		2h	7d	
A_0	34.2±0.42 a	51.1±0.68 a	**	0.22±0.07 e	0.38±0.04 h	n.s.
A_5	30.5±0.01 b	48.0±0.24 b	**	0.46±0.06 e	0.53±0.06 h	n.s.
A_{10}	27.1±0.04 c	47.2 ±0.10 b	**	0.33±0.02 e	0.52±0.05 h	*
A_{20}	29.6±0.19 b	49.7±0.27 a	**	0.32±0.03 e	0.52±0.03 h	*
B_0	12.8±0.15 d	21.7±0.62 f	**	0.42±0.02 e	31.2±0.43 c	**
B_5	8.67±0.11 hi	19.1±0.39 g	**	0.60±0.33 e	24.7±0.21 d	**
B_{10}	10.1±0.04 fg	22.0±0.64 f	**	0.55±0.28 e	13.2±0.43 f	**
B_{20}	11.5±0.29 e	25.0±0.45 e	**	0.69±0.12 e	4.79±0.03 g	**
C_0	3.01±0.04 m	4.68±0.19 i	*	1.92±0.06 d	42.2±0.40 a	**
C_5	6.18±0.03 l	2.69±0.20 j	**	5.26±0.56 a	35.5±2.17 b	**
C_{10}	10.7±0.17 ef	14.9±0.37 h	**	4.54±0.15 b	29.9±0.38 c	**
C_{20}	11.3±1.36 e	34.0±0.33 c	**	3.03±0.51 c	5.72±0.08 g	**
D_0	8.87±0.16 hi	22.3±1.12 f	**	0.19±0.04 e	21.9±0.30 e	**
D_5	6.78±0.04 jk	15.8±0.70 h	**	0.58±0.10 e	22.7±0.42 e	**
D_{10}	9.38±0.01 gh	30.7±0.78 d	**	0.06±0.01 e	5.69±0.11 g	**
D_{20}	7.85±0.09 ij	34.3±0.67c	**	0.03±0.01 e	1.55±0.10 h	**

Letters denoted significant differences ($p < 0.05$) among the treatments in all soils at 2h and 7 day, respectively.
* and ** denoted significant differences at level of $p < 0.05$ and $p < 0.01$ in the same treatment between 2h and 7day, respectively.
n.s. denoted no significant differences in the same treatment between 2h and 7day.

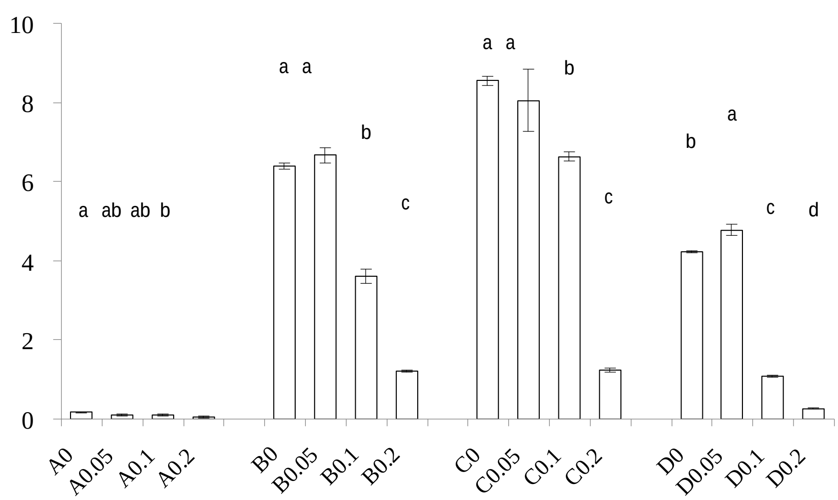

Table 1: Concentrations of $^{15}NH_4^+$ and $^{15}NO_3^-$ in the soils and biochar-mixed soils after adding $(^{15}NH_4)_2SO_4$ (10.13atom% excess) during a 7d incubation period