European Journal of Soil Biology 88 (2018) 36–40

Contents lists available at ScienceDirect

European Journal of Soil Biology

journal homepage: www.elsevier.com/locate/ejsobi

A soil management strategy for ameliorating soil acidification and reducing nitrification in tea plantations

Jing Wang[a,b], Beibei Zhang[c], Ye Tian[a,b], Huanchao Zhang[a,b], Yi Cheng[d,*], Jinbo Zhang[d]

[a] College of Forestry, Nanjing Forestry University, Nanjing, 210037, China
[b] Co-Innovation Center for Sustainable Forestry in Southern China, Nanjing Forestry University, Nanjing, 210037, China
[c] Key laboratory of Disaster Survey and Mechanism Simulation of Shanxi Province, College of Geography and Environment, Baoji University of Art and Sciences, Baoji, 721013, China
[d] School of Geography Sciences, Nanjing Normal University, Nanjing, 210023, China

ARTICLE INFO

Handling editor: Christoph Tebbe

Keywords:
Acidification amelioration
Biochar
Nitrification rate
Quicklime
Tea soil

ABSTRACT

The cultivation of tea requires acidic soils which further acidify in plantations due to increased levels of nitrogen fixation. Ameliorating soil acidification by increasing pH is commonly implemented but as consequence, soil microbial nitrification causes losses of nitrate and limits the availability of NH_4^+ for tea, the latter being the preferred nitrogen source. Thus, the aim of this study was to analyze a strategy which can ameliorate soil acidification and simultaneously minimize the stimulation of nitrification in a typical tea soil. Net N transformation rates in different amounts of quicklime (CaO) and rice straw biochar addition treatments were determined through an incubation experiment, to test the effects of quicklime and biochar on acidification and nitrification in a typical tea soil. Our results showed that the addition of quicklime resulted in a significant increase in soil nitrification rate when soil pH increased from 3.77 to 4.10, but it decreased when soil pH increased to > 5.10. Soil nitrification rate with biochar application continued to rise with increasing soil pH (3.77-3.85-4.01-4.38). When nitrification rates from all treatments were plotted against soil pH, we found that nitrification rate increased linearly with increasing soil pH from 3.63 to 4.38, then sharply declined to the values lower than that in the original soil pH when soil pH was increased from 4.38 to 5.10, and finally remained stable. Our results suggest that nitrification may be optimized in tea soil at ca. pH 4.40. Therefore, when we employed pH-raising practices to alleviate soil acidification, the soil pH should be enhanced to more than the optimum pH range for nitrification (approximately 5.10 in this study) to avoid stimulating soil nitrification.

1. Introduction

Tea, *Camellia sinensis* L., is an intensively managed broadleaf, evergreen crop in tropical and subtropical regions. While tea plants require acidic soils for successful growth, where the optimum pH range is 5.0–5.6, they can also acidify soil [1,2]. Recently, excessive application of ammonium-based fertilizers and large leave harvests have increased acidification in tea soils [3,4]. Soil acidification invariably increases the toxicity of aluminum to microorganisms and at the same time adversely affects the growth and quality of the tea plants [5], so ameliorating tea soil acidification through addition of an alkaline substance seems logical. At present, the application of lime, quicklime and biochar has been confirmed to be effective in ameliorating soil acidity [6–8]. However, the effect of alkaline substances on the rates of soil nitrification in tea plantations remains poorly understood.

Soil nitrification is highly pH sensitive, and increasing soil pH has been found to stimulate nitrification and decrease the suppression of nitrification [9,10], therefore, amelioration of acidification in tea soils may stimulate nitrification. Since tea plants preferably use NH_4^+-N [11,12], it is likely that NO_3^--N produced from ammonium-based fertilizers through nitrification would not be taken up by tea plants. In addition, in tropical and subtropical regions characterized by abundant precipitation and heavy rainfall events where tea plants grow, NO_3^--N produced from nitrification would be susceptible to losses through runoff, leaching and denitrification. Therefore, we devoted to find a strategy which can ameliorate soil acidification and simultaneously minimize the stimulation of nitrification. Theoretically, soil nitrifying microorganisms in tea soil may be adapted tothe highly acidic tea soil environment [13–15]. Here, we speculated that there is an optimum pH range for nitrification in tea soil, above which it would be suppressed, which has not been previously reported. To verify our speculation, we studied the effects of quicklime and biochar application to tea soil as

* Corresponding author.
E-mail address: ycheng@njnu.edu.cn (Y. Cheng).

https://doi.org/10.1016/j.ejsobi.2018.06.001
Received 26 March 2018; Received in revised form 4 June 2018; Accepted 4 June 2018
1164-5563/

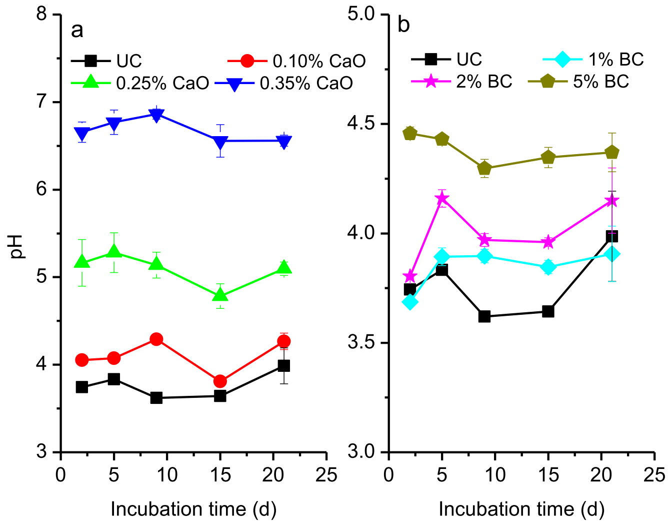

Fig. 1. Changes in soil pH over a 21-day incubation period with and without the application of CaO (a) and BC (b). UC, 0.10% CaO, 0.25% CaO and 0.35% CaO represent application rates of 0 g, 0.10 g, 0.25 g and 0.35 g CaO per 100 g soil, respectively, and UC, 1% BC, 2% BC and 5% BC represent application rates of 0 g, 1 g, 2 g and 5 g rice straw biochar per 100 g soil, respectively. Bars represent standard deviation (n = 3). CaO: quicklime; BC: biochar.

acidification and nitrification mitigation strategies.

2. Materials and methods

2.1. Study samples

Tea soil was sampled from Yixing (31°07′-31°37′N, 119°31′-120°03′E), in southern Jiangsu Province, China, a region characterized by a subtropical monsoon climate with an annual rainfall of 1177 mm. The brown-red soil (Oxisols, US Soil Taxonomy) was a loam, which comprised 7.3% sand, 41.7% silt, and 51.0% clay, and received N in the form of urea at approximately 600 kg ha^{-1} $year^{-1}$. Soil total C, total N, and pH were 9.69 g kg^{-1}, 1.18 g kg^{-1}, and 3.74, respectively.

2.2. Incubation experiment

A preliminary experiment was carried out to determine the exact amounts of quicklime (CaO) and rice straw-derived biochar (BC; pH: 9.16, 62% C, and 1.3% N) addition required for obtaining the desired final pH range (Fig. 1). The treatments of the actual incubation experiment comprised untreated control (UC); 0.10% (20 mg) CaO; 0.25% (50 mg) CaO; 0.35% (70 mg) CaO; 1% (0.2 g) BC; 2% (0.4 g) BC; and 5% (1.0 g) BC. Fresh soil (equivalent to 20 g dry weight) were mixed with quicklime or biochar in 250 mL flasks, and the moisture content of each mixed sample was adjusted to 40% water holding capacity (WHC). The flasks were sealed with rubber stoppers and pre-incubated at 25 °C in the dark for 7 days. Following pre-incubation, net N transformation rates were determined by incubating the soil samples, which had been treated with urea (100 mg N kg^{-1}), for 21 days at 25 °C and 60% WHC. During incubation, the flasks were opened for 30 min each day to renew the atmosphere inside each flask. The moisture content of the incubated soil samples was maintained by adding water every 3 days to compensate for water lost through evaporation. After 2, 5, 9, 15 and 21 days of incubation, gas samples were taken during 6-h sealed incubation from the headspace of the flasks to analyze NO concentration using a NOx analyzer (ThermoFisher 42i, chemiluminescence detector, USA) and N_2O and CO_2 concentrations using gas chromatography (Agilent 7890 A, USA). Soil concentration of NH_4^+ and NO_3^- in 100 mL 2 M KCl solution was determined using a San++ Continuous Flow Analyzer (Skalar, Netherlands) and net N mineralization rates were calculated as the difference between final and initial mineral N concentrations divided by 21 days. Net nitrification rates were calculated in the same manner as the daily mean accumulation of NO_3^-.

2.3. Statistical analyses

One-way ANOVA was used to compare the differences in net N mineralization and nitrification rates and cumulative N_2O, NO, and CO_2 emissions.

3. Results

After 7 days of pre-incubation, soil pH of the UC, 0.10% CaO, 0.25% CaO and 0.35% CaO treatments was 3.63, 4.04, 4.91, and 6.40, respectively (Fig. 1a); and 3.84, 3.95, and 4.27 in the 1% BC, 2% BC and 5% BC treatments, respectively (Fig. 1b). Although soil pH in all treatments following urea application was more or less maintained (Fig. 1), the ameliorating effect of quicklime was superior to biochar.

For all treatments, NH_4^+-N concentrations increased during the first 5 days of incubation, due to hydrolysis of the urea; subsequently it tended to decrease or remain stable (Figs. S1a and b); NO_3^--N concentrations gradually increased over the incubation period (Figs. S1c and d). Rates of net mineralization over the 21 day incubation period in the control were not significantly different from those in the 0.10% CaO and 0.25% CaO treatments, but were significant lower than that in the 0.35% CaO treatment ($p < 0.05$) (Fig. 2a). In contrast, the addition of biochar had no effect on net mineralization rates, regardless of application rate (Fig. 2b). Rates of net nitrification in the control were significantly lower than in the 0.10% CaO treatment, but significantly higher than in the 0.25% and 0.35% CaO treatments ($p < 0.05$) (Fig. 2c). In contrast, the net nitrification rates gradually increased with increasing application rate of biochar ($p < 0.05$) (Fig. 2d).

Cumulative N_2O emission over the 21 day incubation period was largely enhanced by quicklime and the application of 2% and 5% BC, compared with the untreated control (Fig. 4a and b). In contrast, cumulative NO emission declined due to the quicklime application, but increased in the 1% BC and 2% BC treatments (Fig. 4c and d). Cumulative CO_2 emission, as an indicator of soil microbial activity, was enhanced by the quicklime application, but unaffected by biochar application (Fig. 4e and f).

4. Discussion

Generally, soil pH is the main factor affecting nitrification, where increasing and decreasing pH stimulates and depresses net nitrification, respectively [9,10]. In our study, the nitrification rate may have been constrained by low soil pH (3.77) and thus the increase in soil pH as a result of biochar application increased the rate of nitrification (Fig. 3a). Biochar has been shown to optimize conditions for nitrifier and increased the rates of nitrification [7,16]. We suggest that nitrification in our study was driven by pH-sensitive nitrifying microorganisms [17,18]. In contrast, biochar can also decrease nitrification by limiting the NH_3 or NH_4^+ availability for oxidation due to either the surface adsorption [19,20], or increased emissions of NH_3 because of enhanced soil pH.

In comparison with biochar application, we found that quicklime increased soil pH but decreased net nitrification rate (Fig. 3b), which was inconsistent with previous studies that report that quicklime and liming promote nitrification in acidic soils [6,8,21]. Previous studies found that when soil pH increased from 3.60 to 4.50 to 6.30–6.88 by lime application, net nitrification rate was significantly increased in soils dominated by a single species (pine, rhododendron or tea), but was significantly inhibited in the mixed species forest soil [22]. There is a possibility, therefore, that acid-tolerant or even acidophilic nitrifying microorganisms were responsible for nitrification in this study, since nitrification was not stimulated or was even suppressed by an increase