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Biochar applied with appropriate rates can reduce N leaching, keep N retention and not increase NH_3 volatilization in a coastal saline soil

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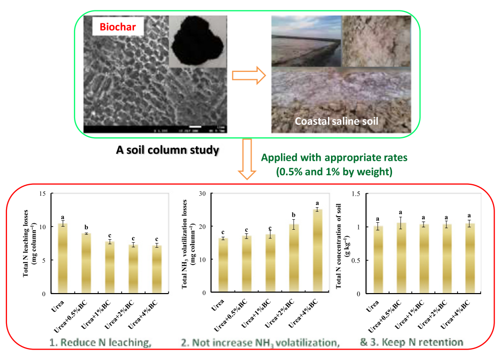
HIGHLIGHTS

- 0.5% and 1% biochar amendments reduce NH_4^+–N, NO_3^-–N and total N leaching losses.
- NH_3 volatilizations were significantly increased at 2% and 4% biochar amendments.
- Total N concentrations of coastal saline soil were kept under biochar treatments.
- Biochar should be applied to the coastal saline soils with appropriate rates for its sustainable use.

GRAPHICAL ABSTRACT



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ABSTRACT

The impacts of biochar addition on nitrogen (N) leaching, (ammonia) NH_3 volatilization from coastal saline soils are not well understood. In this soil column study, the effects of wheat straw biochar application at rates of 0.5%, 1%, 2% and 4% by weight to a coastal saline soil on N leaching, NH_3 volatilization, soil pH and N retention were investigated. Results showed that 0.5% and 1% biochar amendments reduce the NH_4^+–N, NO_3^-–N and total N concentrations of leachate and thereby significantly decrease their cumulative lost loads by 11.6–24.0%, 13.2–29.7%, and 14.6–26.0%, respectively, in compared with the control. The biochar-induced soil N leaching mitigation efficiency was weakened when the biochar application rates increased to 2% and 4%. However, the impact of biochar addition on cumulative NH_3 volatilizations were negative and significantly 25.6–53.6% higher NH_3 volatilizations in soils with 2% and 4% biochar amended than control were detected, which was mainly attributed to the averaged 0.53–0.88 units higher soil pH as results of biochar addition. On average, the total N concentrations of soil were kept same with 1.01–1.06 g kg^{-1} under control and biochar treatments. Therefore, biochar application to the coastal saline soils with appropriate rates (i.e., 0.5% and 1% in current study) can reduce N leaching, keep soil N retention, and not increase NH_3 volatilization, which was beneficial for sustainable use of saline soils.

1. Introduction

Excessive and/or unbalanced application of nitrogen (N) fertilizers to agricultural soils lead to a large amount of N losses via leaching and

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ammonia (NH_3) volatilization, which is not only a major source of pollution for adjacent water and atmosphere systems, but also is a economic concern for the farmer (Galloway et al., 2008; Sun et al., 2013; Zhao et al., 2014a). In addition, N leaching and NH_3 volatilization have become two important limitations to improve the utilization of N fertilizer in agricultural production systems. This condition was much more serious in the coastal saline soils (Dendooven et al., 2010; Elgharably et al., 2010; Steele and Aitkenhead-Peterson, 2013; Sastre-Conde et al., 2015), where volumes of water were used for irrigation to avoid salt accumulation in the root zone, especially in the flooded rice production (Singh et al., 2001; Yin et al., 2007). Saline soils are widely distributed on earth, accounting for approximate 25% of the total land area and distributing in more than 100 countries, and the whole area of saline soils in China is above 3.67×10^7 ha and 30% of them has been cultivated as important land resource (Liu et al., 2015; Zhang et al., 2016). Therefore, it is imperative to abate the N losses via leaching and NH_3 volatilization, improve the N retention in saline soils and therefore increase the N utilization efficiency both from the sustainable production and environmental viewpoints.

In recent years, biochar incorporation application to agricultural soils was reported to manageably provide carbon farming solutions to global climate and satisfying food demand (Prommer et al., 2014). Meanwhile, biochar application indeed improve soil physicochemical properties, enhance crop yield and reduce greenhouse gases emissions (Chan et al., 2007; Barrow, 2012; Lin et al., 2015; Thomazini et al., 2015). As to the relationship of biochar and N cycling, it has been proved that biochar addition affected the dynamics of NH_3 oxidizers and nitrification process in microcosms of coastal alkaline soil (Song et al., 2014), thereby may influence the N_2O emissions (Lin et al., 2015; Zhang et al., 2016). In addition to the above effects, biochar effectively reduced the nitrate (NO_3^-–N), ammonium (NH_4^+–N) in the leachate by 34.0% and 34.7% relative to sandy soil alone (Yao et al., 2012). Also, several other studies reported that the N leaching losses in agricultural soils were mitigated after biochar added (Singh et al., 2010; Zheng et al., 2013; Yoo et al., 2014; Xu et al., 2016). Biochar adsorbed the NH_4^+–N or NO_3^-–N, increased water holding capacity, enhanced microbial biomass and changed bacterial community structure of the soil, which may contribute to the reduction of N leaching (Zheng et al., 2013; Wang et al., 2015; Xu et al., 2016). Given the fact that the benefits of biochar application also varied with the soil type and land use (Schomberg et al., 2013), we need a better understanding of how biochar influence the N leaching losses in the widely distributed coastal saline soils with lower organic matter, nutrient contents, degraded soil organisms and physical and chemical properties (Dendooven et al., 2010; Wu et al., 2013; Wu et al., 2014), which was significantly different from the prior studied soils. However, the relative information is not well understood.

Saline soils always have high pH value and salinity and thereby the applied N is easy to extensively lose through NH_3 volatilization (Vega-Jarquin et al., 2003). According to Dendooven et al. (2010), the high soil pH favored NH_3 volatilization of approximately 50 mg N kg^{-1} soil within a day. Moreover, soil pH was commonly increased under biochar treatments (Liang et al., 2014; Xu et al., 2016). Weather this effect lead the NH_3 volatilization from coastal saline soil in a much higher degree? It is not well understand. Furthermore, prior studies have proved that biochar applied with different rates influence the rate and dynamic of nitrification process N cycling at diverse degree (Song et al., 2014; Zhao et al., 2014b; Xu et al., 2016). These previous results indicated that there may be optimum application rates of biochar that can gain win-win advantages of resource-saving, reducing N leaching, keeping N retention and not increasing the NH_3 volatilization in coastal saline soils.

In this study, we hypothesized that biochar application with appropriate rates to coastal saline soil could reduce N leaching, not affect the NH_3 vitalization, and retain N nutrient in soil. Therefore, the main objectives of this soil column study were to completely evaluate the potential of wheat straw derived biochar applied with varied rates by weight on retarding N losses via leaching and NH_3 volatilization, and also to investigate the soil N content and soil pH responses to biochar amendment. At last, one or two optimum application rates were recommended based on the findings of this study. We believe that this work can improve the knowledge about the impact of biochar applied in coastal saline soils and provide information to guide sustainable development of the reclamation of coastal saline soil resource.

2. Materials and methods

2.1. Soil and biochar

The tested soil for the current work was sampled from two depths, 0–20 cm and 20–40 cm, of a profile at ten different sites of a 15 ha coastal saline filed in SheYang City (33°46′ N, 120°15′ E), Jiangsu Province, China. Soil samples were transported to the laboratory, air-dried for two week and then passed through a 2-mm sieve. The soil is a typical saline alluvial soil (Fluvisols, FAO). The soil texture was determined using the hydrometer method; the bulk density was determined used cutting-ring method; organic matter was extracted with potassium dichromate-external heating method and was measured by UV spectrophotometer; total N content was determined using a 2400-II CHNS/O analyzer (Perkin Elmer Corp., USA) at 1050 °C; the pH and EC was measured in deionized water at a ratio of 1: 5 w/v using combined reference electrodes and a Φ255 pH/temp/mV meter (Coulter Bechman Co., USA), and portable multi parameter analyzer (DZB-718, Shanghai Leici instrument Inc. China), respectively. These physicochemical properties of tested soil see in Table 1.

The biochar was derived from wheat straw in a continuous slow pyrolysis system. The reactor was heated by a stepwise procedure under oxygen-limited conditions. When pyrolyzed, the temperature was raised to 500 °C at a rate of 5 °C min^{-1} and held constant for 8 h (Zhao et al., 2014b). The pH was measured in deionized water at a ratio of 1: 20 using combined reference electrodes and a Φ255 pH/temp/mV meter (Coulter Bechman Co., USA); total C and N contents were determined using a 2400-II CHNS/O analyzer (Perkin Elmer Corp., USA) at 1050 °C; CEC was determined by a modified NH_4 acetate compulsory-Flame Atomic Absorption Spectrophotometer method; the specific surfaces area of the biochar was determined using ASAP2020 HD88 (Micromeritics, USA). These properties of biochar were also listed in Table 1.

2.2. Leaching experiment

The leaching experiment was conducted by a modified method described by Zhao et al. (2014b). The leaching column was designed from polyvinyl chloride (PVC) columns with 4.7 cm in diameter, 55 cm in height. Each column was fixed with a porous baffle at the bottom and had a 5-cm layer of quartz sand above the baffle, then the soil samples were repacked according to the field profile order and fixed the bulk density near to the field condition. Biochar was mixed with the repacked soil samples meanwhile. Lastly, a 2-cm layer of glass wool was packed beneath and 8-cm top room was left for keep about 7 cm depth water layer through the leaching experiment to mimic the rice planted condition. Urea was applied at rate of 200 mg N kg^{-1} soil. The columns received a 2-mm sieved, 40 cm depth and a total of 900 g (oven-dry basis) soil sample and that corresponding 180 mg N supplied by urea. The urea N fertilizer was mixed with the surface soil (0–20 cm). There were five treatments including: (1) Urea: 180 mg N alone, (2) Urea + 0.5%BC: 180 mg N mixed with 4.5 g biochar; (3) Urea + 1%BC: 180 mg N mixed with 9.0 g biochar; (4) Urea + 2%BC: 180 mg N mixed with 18 g biochar; (5) Urea + 4%BC: 180 mg N mixed with 36 g biochar. Each treatment was replicated three times.

Deionized water was added to the soil columns firstly made the soil water content in a saturation status. When the leaching experiments