Soil & Tillage Research 157 (2016) 65–72

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Biochar impact on nitrate leaching as influenced by native soil organic carbon in an Inceptisol of central India

Anil Kumar Kanthle[a,b], Narendra Kumar Lenka[a,*], Sangeeta Lenka[a], K. Tedia[b]

[a] Indian Institute of Soil Science, Nabibagh, Bhopal, India
[b] Indira Gandhi Krishi Viswa Vidyalaya, Raipur, India

ARTICLE INFO

Article history:
Received 29 July 2015
Received in revised form 20 November 2015
Accepted 21 November 2015
Available online 1 December 2015

Keywords:
Biochar
Nitrate leaching
Total dissolved salt
Soil column study
Soil functions

ABSTRACT

Biochar is anticipated to be an effective mitigation option to nitrate leaching. However, the extent to which its effectiveness is influenced by native soil organic carbon (SOC) is not known. Thus, the present study was conducted to investigate the interactive effect of native SOC and biochar amendment on leaching of nitrate and total dissolved salts (TDS) using a laboratory column experiment. The study was conducted in a loamy (Mixed Hyperthermic Udic Ustocrept) soil of central India, with three native SOC levels, four levels of biochar amendment, and three replications, in a factorial design. The three native total SOC levels were 1.18% (C_1), 0.97% (C_2) and 0.79% total SOC (C_3) and four biochar amendment levels were 0 (B_0, control), 5 (B_5), 10 (B_{10}) and 20 (B_{20}) g biochar kg^{-1} of air dry soil. Repacked soil columns (40 cm height and 11 cm internal diameter) were leached with deionized water once a week for 15 consecutive weeks. Nitrate in form of KNO_3 was added at the rate equivalent to 100 mg kg^{-1} soil (220 kg ha^{-1}) at each application in the 1st, 9th and 12th week. Leaching of NO_3^--N and TDS significantly reduced with increase in native SOC content ($p < 0.01$) and increase in amount of biochar ($p < 0.01$) amendment. However, interaction effect was significant only for the TDS flux. At higher SOC content, leaching of NO_3 - N and TDS of the leachate were significantly lower. As compared to C_1 soil, total NO_3^--N leached in C_3 soil was higher by 40, 45, 37 and 11% under B_0, B_5, B_{10} and B_{20} biochar amendment levels indicating biochar application at the rate of 20 g kg^{-1} soil (B_{20}) could mitigate nitrate leaching by 29% in the low carbon (C_3) soil. Differential behaviour of biochar at different SOC level was observed with regard to NO_3^--N and TDS leaching. The effectiveness of higher dose of biochar (B_{20}) in mitigating NO_3^- leaching was higher in soils with low SOC level. The best biochar treatment (B_{20}) could reduce NO_3^--N leaching by 14% under C_1, as compared to 23 and 32% under C_2 and C_3 soils. Increased sorption and water retention under high biochar treatments might be responsible for reduced NO_3 leaching.

1. Introduction

Nitrate leaching is a major concern of intensive agriculture (Beaudoin et al., 2005). The severity of the problem is increasing due to heavy dependence on added soil nutrients in form of chemical fertilizers and low supplementation of organic inputs. As nitrate is an anion and is very mobile, the coarse and medium textured soils are particularly prone to nitrate leaching due to less clay content and dominance of Fe- and Al-oxides and 1:1 phyllosilicates with low surface area. Mitigating nitrate leaching from agricultural fields is important for (1) reducing the economic loss to the farmers, (2) to minimize the effect of enhanced nitrate loading on the ecological balance in water bodies, and (3) to lessen the impact on human and animal health.

Recently, biochar has been used as an amendment to improve soil quality, reduce leaching loss of nutrients (Glaser et al., 2002; Laird et al., 2010a; Mukherjee et al., 2014) and a host of benefits to the soil environment. Biochar is the recalcitrant carbon rich product obtained by thermal decomposition of biomass in an oxygen free environment and is used with the aim of soil improvement (Mukherjee et al., 2014). Biochar application to soil increases the cation exchange capacity and the overall sorption capacity and thus may influence the soil function to retain nutrients and filter harmful chemicals (Glaser et al., 2002). The high surface charge density of biochar helps retain the cations and the high surface area, internal porosity, and the presence of both polar and non-polar surface sites enable biochar to adsorb organic molecules and associated nutrients (Laird et al., 2010b). With regard to retention of NO_3-N in soil, three possible mechanisms

* Corresponding author. Fax: +91 755 2733310.
E-mail address: nklenka@rediffmail.com (N.K. Lenka).

http://dx.doi.org/10.1016/j.still.2015.11.009
0167-1987/

have been reported, viz. (i) increase in anion exchange capacity (Singh et al., 2010; Knowles et al., 2011), (ii) presence of volatile matter in biochar resulting increased microbial activity and thus causing immobilization (Deenik et al., 2010), (iii) increased pyrolysis temperature (>600 °C) of the feedstock resulting in a shift in the ratio of basic to acidic surface functional groups affecting overall surface charge and increasing the anion exchange capacity (Kameyama et al., 2012; Al-Wabel et al., 2013). Further, biochar application results in significant carbon sequestration benefits, apart from improving water and nutrient use efficiency (Mukherjee and Zimmerman, 2013). Improvement in soil physical properties have been reported with reduced soil bulk density, increased soil water retention and porosity (Novak et al., 2012; Ouyang et al., 2013; Yu et al., 2013), altered soil hydrophobicity (Kinney et al., 2012) and beneficially modified hydraulic conductivity and aggregate stability (Herath et al., 2013; Ouyang et al., 2013).

Despite a number of studies examining impact of biochar on soil water and nutrient retention, the exact mechanism and mode of action varies with type of soil, type of biochar and the level of biochar use (Mukherjee and Zimmerman, 2013; Borchard et al., 2014). For instance, in a recent study, Eykelbosh et al. (2015) from a Brazilian sugarcane soil reported biochar to attenuate dissolved organic carbon leaching but not nitrate leaching. Mukherjee et al. (2011) have shown that biochar materials though possess characteristically higher cation exchange capacity, significant amount of anion exchange capacity develops only in aged biochars. Similarly, residence time of nitrate in the crop root zone varies with pyrolysis temperature of the biochar and high temperature bagasse biochar showed highest residence time (Kameyama et al., 2012). Conversely, nitrate leaching was minimized by 75–100% by biochar application (Knowles et al., 2011; Ventura et al., 2012). Action of biochar seems to be favourable in the tropics in degraded soils because these soils have a net anion exchange capacity and the benefits accrue from increase in the cation exchange capacity due to biochar application (Liang et al., 2006). As most of the benefits accrued from biochar use arise from increased ion exchange capacity and surface charge density, it is likely that soil organic matter (SOM) influences the performance of the biochar in soil system to mitigate nitrate leaching. This is because SOM has significant contribution to the surface area and ion exchange capacity of a particular soil and also most of the nitrogen in soil remains in organic pool. Previous studies assessing the impact of biochar on nitrate leaching has mostly concentrated on dose of biochar, type of biochar material and on added manures (Laird et al., 2010b; Singh et al., 2010; Mukherjee and Zimmerman, 2013). The effect of native SOM, though vital, has not been taken into consideration. Further, studies on biochar impact on nitrate leaching in Indian soils are few. Thus, the present study was conducted to test the hypothesis that performance of biochar in mitigating nutrient leaching varies with native soil organic carbon (SOC) content. The specific objectives of the investigation were to study the interactive effect of biochar and native SOC content on leaching of nitrate and total dissolved salt (TDS).

2. Materials and methods

2.1. Study location and treatments

The experiment was conducted through a column study in laboratory set-up at the Indian Institute of Soil Science, Bhopal, (Madhya Pradesh) during the year 2014–15, using a loam textured soil (Mixed Hyperthermic Udic Ustocrept) collected from Raipur region of Chhatisgarh. The bulk soil from the surface 0–20 cm layer from different land uses were collected to obtain a soil organic carbon gradient with three soil organic C levels. The selected land uses included those under permanent vegetation cover, agricultural land use and nearby fallow lands. The bulk soil collected was air dried and ground to pass through a 2 mm sieve, and then stored for use in the column study.

2.2. Treatments

The experiment was conducted with three native SOC levels and four levels of biochar amendment under each SOC level. The three native total soil organic carbon levels were 1.18% (C_1), 0.97% (C_2) and 0.79% (C_3) as measured by dry combustion method using Shimadzu Make TOC Analyser. There were four levels of biochar amendment at 0 (B_0), 5 (B_5), 10 (B_{10}) and 20 (B_{20}) g kg^{-1} of air dry soil (equivalent to 0, 11.2, 22.4, and 44.8 t biochar ha^{-1}). The treatments were replicated thrice in Factorial Completely Randomized Design (FCRD). The soils collected from the three land uses were almost similar in soil physical properties, pH and electrical conductivity (EC) but were different in organic carbon content (Table 1).

In this experiment, biochar made from corn (*Zea mays*) stalks pyrolysed at 350 °C for 3 h were used. The biochar was ground in a wooden hammer and the portion less than 2 mm fraction was separated by dry sieving. In the biochar treatment, required amount of biochar as per the treatment requirement was weighed for upper half of the soil column (i.e. for top 20 cm soil depth). Biochar was mixed thoroughly with the soil before filling in the upper half of the soil columns under the biochar treatments. As measured in 1:10 soil: water suspension, pH of the biochar was 11.2 and EC was 4.88 dS m^{-1}.

2.3. Preparation of soil columns

For the column experiment, PVC made cylindrical pipes were used with assembly for leaching and collection of leachate. The columns were 40 cm long with 11 cm internal diameter (3800 cm^3 volume). The columns were provided with an end cap and funnel arrangement for collection of leachate. All columns were packed to a bulk density of approximately 1.2 Mg m^{-3}. Taking into account the bulk density and the volume of each column, 4.562 kg of soil was filled in each column. The columns were packed gently with small taps in small layers of about 5 cm followed by scratching with laboratory spatula so as to maintain natural continuity among the filling soil layers.

Table 1
General characteristics of the soil as varied with carbon level (C_1, C_2, and C_3) used in the experiment.

Sl. No.		Soil property		Inceptisol
1	Particle size distribution	Sand (%)		44–48
		Silt (%)		34–36
		Clay (%)		18–20
		Textural class		Loam
	SOC level	C_1	C_2	C_3
2	pH (1:2.5 soil:water)	6.51	6.42	6.31
3	EC (dS m^{-1}) (1:2.5 soil:water)	0.99	0.95	0.90
4	Total organic carbon (%)	1.18	0.97	0.79
5	Cation Exchange Capacity (cmol (p$^+$) kg^{-1})	31	28	25
6	Available N (kg ha^{-1})	226	223	218
7	Available P (kg ha^{-1})	28	25	22
8	Available K (kg ha^{-1})	312	295	288
9	NO_3^- N (mg kg^{-1})	35	28	21