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Land use and biochar effect on nitrate leaching in a *Typic Haplustert* of central India

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ABSTRACT

Studies on the effect of biochar on nitrate leaching are few. Hence, a laboratory column experiment was conducted using surface (0–20 cm) soil from three different land uses of a Vertisol, to investigate the effect of biochar amendment on leaching behaviour of nitrate and salts. The three selected land uses were: thick forest, agriculture land use with good soil fertility and good crop production history and agriculture land use with low soil fertility and poor crop production history. Biochar was added at 0, 0.5, 1.0 and 2.0% (w/w) to the soil in the upper half of the columns. The treatments were taken with three replications in a factorial completely randomized design. The PVC made columns (40 cm height and 11 cm internal diameter) filled with soil to a bulk density of 1.2 Mg m^{-3} 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 N kg^{-1} soil (220 kg ha^{-1}) at each application in the 1st, 8th and 11th week. The forest soil showed significantly higher salt and NO_3^--N leaching. Biochar amendment @ 0.5% or at higher level showed a significant reduction in NO_3^--N leaching in the forest and good agriculture soil, whereas, in the poor agriculture soil, no significant effect was observed even at 2.0% biochar amendment level. With the highest level of biochar amendment (2%, w/w), reduction in NO_3^--N leaching to the extent of 27% and 23% was observed in the forest and good agriculture soil, respectively. Biochar application significantly reduced salt leaching in the forest soil at 0.5% amendment level, and in the good agriculture soil at 1.0% level. At 2.0% biochar amendment, reduction in salt leaching to the extent of 18% and 16% was observed in the forest and good agriculture soil, respectively.

1. Introduction

The environmental and economic implications of soil degradation and soil fertility decline have been a global issue since last few decades (Lal, 2015; N.K. Lenka et al., 2017). Among the soil fertility parameters, nitrate (NO_3^-) leaching from crop fields are increasingly becoming a matter of concern. Apart from a direct economic loss to the farmers, NO_3^- leaching results in negative nitrogen (N) balance of agricultural systems and significantly affects the ground water quality. Being an anion, NO_3^- is very mobile in the soil system. Regular application of chemical N fertilizers without much addition of organic manures results in significant amount of NO_3^- leaching under intensive agricultural production systems (Christian and Riche, 1998; Beaudoin et al., 2005).

Use of biochar as a potential soil amendment has recently generated interest among researchers (Laird et al., 2010; Kanthle et al., 2016; Blanco-Canqui, 2017). Among a host of benefits, biochar is known to mitigate leaching loss of NO_3^- ions (Mukherjee et al., 2014; Kanthle et al., 2016) and improve N uptake (Wang et al., 2017). Biochar is a solid and recalcitrant carbon rich product derived from the pyrolysis of biomass residues in an oxygen limited environment at a relatively low temperature (< 700 °C) (Mukherjee et al., 2014; Wang et al., 2017). Biochar application is believed to modify the soil environment through increase in the cation exchange capacity, higher surface area, enhanced water retention, modification in the soil pH, influencing the microbial activity and by enhancing the fine root biomass (Glaser et al., 2002; Laird et al., 2010; Ulyett et al., 2014; Eykelbosh et al., 2015; Wang et al., 2017; Amendola et al., 2017).

Some previous studies indicate biochar application reducing NO_3^- leaching by 75–100% (Knowles et al., 2011; Ventura et al., 2012). Biochar amendment possibly reduces NO_3^- leaching through the following actions: (1) Increase in anion exchange and sorption capacity (Singh et al., 2010; Knowles et al., 2011; Kameyama et al., 2012), (2) presence of volatile matter in biochar resulting increased microbial activity and thus causing immobilization (Deenik et al., 2010), (3) Higher N uptake by the plants leaving low soil NO_3 concentration (Wang et al., 2017) and (4) higher soil water retention (Novak et al.,

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2012; Eykelbosh et al., 2015). However, despite several studies in the particular area of research, the mechanisms of action of biochar in reducing NO_3^- leaching are not conclusive. Further, some studies report relative gain from biochar amendment to be higher in degraded and highly weathered soils (Liang et al., 2006; Jien and Wang, 2013).

As the benefits of biochar application mostly accrue from altered ion exchange capacity and surface charge density, it is likely that land use and consequently soil organic matter (SOM) content to be a major factor in regulating the efficiency of biochar in mitigating nitrate leaching. Previous studies assessing the impact of biochar on nitrate leaching has mostly concentrated on the level of biochar, type of biochar material and on added manures (Laird et al., 2010; Singh et al., 2010; Mukherjee and Zimmerman, 2013; Haider et al., 2017; Wang et al., 2017). However, the efficacy and mechanism of action of biochar in mitigating NO_3^- leaching under soils of different land use, are not known. Thus, the present study was conducted to study the interaction effect of biochar and land use on leaching of NO_3^- and salts.

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. Soils of the study area are classified as Vertisols (Isohyperthermic Typic Haplustert) and predominantly clay in texture (S. Lenka et al., 2017). Bulk soil samples were collected from three different land uses of the Bhopal region (23° 18′ North latitude and 77° 24′ East longitude). The three different land uses selected for the study were thick forest, agricultural land use with good soil fertility and crop production history and agricultural land use with low soil fertility and poor crop production history. The bulk soil from each land use was collected from the surface 0–20 cm layer, followed by air drying and grinding to pass through a 2.0 mm sieve. The samples after initial processing were stored for use in the column study.

2.2. Treatments

The experimental treatments consisted of soils from three land uses and four levels of biochar amendment (under each land use), with three replications for each treatment. The soil organic carbon (SOC) content as estimated by Walkley and Black's wet oxidation method, was from 0.45% in the low producing agriculture soil to 0.62% in the better producing agriculture soil and 1.17% in the soil of forest land use. The four levels of biochar addition to the soil were 0, 0.5, 1.0 and 2.0%, w/w (equivalent to 0, 11.2, 22.4, and 44.8 Mg biochar ha^{-1}). The study was conducted in a Factorial Completely Randomized Design (FCRD). The soils of the three land uses were similar in mechanical composition, pH and electrical conductivity (EC) but varied in organic carbon content and NO_3-N level (Table 1). Soil of the forest land use showed a distinctly higher NO_3-N content (39 mg kg^{-1} under forest land use as compared to 16–18 mg kg^{-1} under the two agricultural land uses).

For this study, biochar, prepared by pyrolysis of corn (*Zea mays* L.) stalks at 350 °C for 3 h, was used. The biochar material was ground in a wooden hammer and the fraction lower than 2.0 mm size was separated by dry sieving. Biochar of < 2 mm size fraction was used for the experiment. Depending upon the treatment, quantity of biochar was weighed for upper half of the soil column (i.e. for top 20 cm soil depth). The 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

In this study, PVC made cylindrical columns were used with assembly arrangement for collection of leachate. The columns were 40 cm long with 11 cm internal diameter (3800 cm^3 volume). The soil columns were packed to a bulk density of approximately 1.2 Mg m^{-3}. Considering the soil bulk density and the volume of each column, 4.562 kg of soil was filled in each column. Soil was packed gently in small increments of about 5 cm with small taps, followed by scratching with a laboratory spatula to maintain natural continuity among the filling soil layers.

Table 1
General characteristics of soils collected from different land uses (L_1, L_2, and L_3).

Sl. no.	Soil parameter	Land use/parameter value (Mean of replicates ± standard deviation)		
		L_1	L_2	L_3
1	Sand (%)	22 ± 2	24 ± 3	24 ± 5
2	Silt (%)	28 ± 3	31 ± 5	30 ± 2
3	Clay (%)	47 ± 2	47 ± 6	45 ± 4
4	Textural class	Clay	Clay	Clay
5	pH (1:2.5 soil:water)	7.94 ± 0.06	8.00 ± 0.04	8.07 ± 0.04
6	EC (dS m^{-1}) (1:2.5 soil:water)	0.44 ± 0.02	0.23 ± 0.02	0.19 ± 0.03
7	Soil organic carbon (%)	1.17 ± 0.16	0.62 ± 0.0.5	0.45 ± 0.03
8	Cation exchange capacity (cmol (p^+) kg^{-1})	39 ± 3	22 ± 2	16 ± 2
9	Available P (kg ha^{-1})	18 ± 2	15 ± 2	13 ± 1
10	Available K (kg ha^{-1})	585 ± 12	428 ± 15	416 ± 26
11	NO_3^-N (mg kg^{-1})	39 ± 4	18 ± 4	16 ± 3

L_1: forest soil; L_2: soil from agriculture land with good production history; L_3: soil from agriculture land with poor production history.

2.4. Soil column leaching

The leaching experiment was conducted for 15 consecutive weeks (with one leaching per week) during August to November 2014 (representing standard meteorological week 31–48) in the laboratory condition at room temperature. Potassium nitrate (KNO_3) was added in the upper 3 cm soil in the 1st, 8th and 11th leaching events at the rate of 100 mg NO_3^--N kg^{-1} soil (corresponding to 220 kg N ha^{-1}) in each column. Before initiation of the 1st leaching, soil columns were prewetted with 1450 cm^3 of water, equivalent to 60% water filled porosity. At all the leaching events at a week's interval, the columns were leached with 200 cm^3 of water. Leachate from each column was collected in 250 ml glass conical flask. The experiment was carried out by minimizing evaporation by loosely covering the soil columns from the top. The leachate collected per column in each event was measured and then filtered through Whatman No.1 filter paper to remove any by-passed sediments. To avoid the effect of disturbance due to column installation, the data of initial five events were excluded from the study. The pH and EC of the soil and the leachate were measured using a pH meter and EC meter. The NO_3^- concentration in the leachate was determined by reduction with Devarda's alloy in an alkali medium followed by distillation in a Kjeldahl distillation unit (Tandon, 2009). The salt concentration of the leachate was computed from the EC values by using factor of 640 for EC < 5.0 dS m^{-1} and 800 for EC > 5.0 dS m^{-1} (Hanson et al., 2006). The salt and NO_3^--N concentration were multiplied with the leachate volume to obtain total salt and total NO_3^--N loss from the soil column at individual leaching events. The salt and NO_3^--N leached from the individual leaching events were summed to get the cumulative value after all the leaching events.