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Review on Role of Biochar Amendment in Nitrate Leaching

A.K. Kanthle[1, 2]*, K. Tedia[2] and N.K. Lenka[3]

[1]Department of Agriculture Development, Farmer Welfare and Bio Technology, Government of Chhattisgarh, Mungeli, India
[2]Indira Gandhi Krishi Viswa Vidyalaya, Raipur, India
[3]Indian Institute of Soil Science, Nabibagh, Bhopal, India

**Corresponding author*

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A B S T R A C T

The application of biochar to soil is a recent approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems. Biochar is a soil and sediment component prepared by pyrolysis. Their compositions vary by pyrogenic organic materials ranging from slightly charred biomass to charcoal. It is a good soil amendment that increases water holding capacity of soil; increase soil fertility, increased crop production, reducing emissions and increasing the sequestration of atmospheric CO_2 into soils, strong sorption's affinity for organic contaminant and mostly control pollutant migration such as reduce nitrate leaching from soil. Nitrate leaching from agricultural soils is a major concern to the groundwater, surface water bodies, and environment and also affects the farmers 'economy. Biochar is anticipated to be an effective mitigation option to nitrate leaching.

Introduction

Nitrate leaching is one of the common concerns reported from intensive agriculture areas. The problem is severe in areas depending heavily on added soil nutrients in form of chemical fertilizers with low supplementation of organic inputs. Because of the less clay content and dominance of less activity clays with low surface areas, coarse-and medium-textured soils are prone to nitrate leaching. However, with regular addition of chemical fertilizers and declining soil organic carbon (SOC) content, even clay soils may contribute to nitrate leaching beyond the root zone.

Apart from the role of soil texture, the SOC content has a vital role in regulating nitrate leaching. The SOC content is a function of soil properties and soil management. In intensive agriculture systems, poor SOC management in form of low supplementation of organics is the primary reason for reducing soil quality. Of late, biochar has been used as an amendment to improve soil quality and reduce leaching loss of nutrients (Laird *et al.,* 2010; Mukherjee *et al.,* 2014). Biochar application to soil increases the overall sorption capacity, and thus, may influence the soil function to retain nutrients and filter harmful chemicals.

Use of biochar as a potential soil amendment has recently generated interest among researchers (Laird *et al.,* 2010; Kanthle *et al.,* 2016). Among a host of benefits, biochar is known to mitigate leaching loss of NO_3^- ions (Kanthle *et al.,* 2016) and improve N uptake. Biochar is a solid and recalcitrant carbon rich product derived from the pyrolysis of biomass residues in oxygen limited environment at a relatively low temperature (< 700 °C) (Mukherjee *et al.,* 2014). 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).

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).

Effect of biochar and other soil amendments on nitrate leaching

Biochar is a carbonaceous product (black carbon) formed by thermal decomposition of an organic material under limited supplies of oxygen and at relatively low temperature (< 700 ^oC). It is a potential mitigation tool to reduce NO_3^- leaching (Lehmann and Joseph, 2009). Addition of biochar to soil helps in improving soil quality by improving water and nutrient retention (Glaser *et al.,* 2002). Biochar has the ability to retain nitrogen (N) within a soil due to it being able to enhance ammonia (NH_3), ammonium (NH_4^+) and NO_3^- adsorption (Steiner *et al.,* 2008; Singh *et al.,* 2010), thus making these N sources unavailable for nitrification or NO_3^- leaching. Biochar has been proposed as a key tool to improve soil health and retain plant available soil nutrients from different losses and climate change mitigation because of its potential for an immediate increase in soil carbon (C) storage beyond normal limits due to its stability. Benefits of biochar may also result from its physical structure and chemical composition: soil moisture and solute retention; sorption or stabilization of nutrient ions. Thus biochar properties are likely to impact on the complex interactions between soil, plants and microbes. Several amendments including solid manures, simple sugars such as glucose, glycerol and other carbonaceous materials have been tested to reduce nitrate leaching in agricultural soils. Ritz and Griffiths (1987) observed that amendments with glucose significantly reduced the amount of nitrate leaching from a sandy soil amended with nitrate. Tolner *et al.,* (2012) studied an alternative way to prevent nitrate leaching in sandy soil by using glycerol as a biodiesel by-product. They reported that nitrate leaching can be significantly decreased by using glycerol treatment. Glycerol represents an easily accessible source of energy for microbes in soil.

There are a number of studies available on biochar amendment particularly from the western countries. Burgos *et al.,* (2006) conducted a one year column (19 cm diameter and 60 cm height) experiment to estimate the nitrate losses from the soil amended with three organic materials, a municipal solid waste compost (MWC), a non-composted paper mill sludge (PS), and an agro forest compost (AC). Amendments were mixed with the top soil (0-15 cm) at a rate equivalent to 50000 kg ha^{-1}. The columns were periodically irrigated simulating rainfall in the area of study, receiving in total 415 mm of water, and the water draining was collected during the experimental period and analyzed for NO_3^--N. At the end of the experimental period NO_3^--N content in soil columns at three depths (0-20, 20-35 and 35-50 cm) was determined. Result showed that nitrate leaching was higher in soil treated with municipal solid waste compost (MWC), due to its higher N-mineralization rate compared to non-composted paper mill sludge (PS), and agro forest compost (AC).

Laird *et al.,* (2010) in a laboratory column study used biochar as an amendment with treatments containing 0, 5, 10, and 20 g biochar kg^{-1} soil, with and without 5 g kg^{-1} of dried swine manure. Leaching events were sampled weekly for 45 weeks. Measurements showed a significant decrease in the total amount of N, P, Mg, and Si that leached from the manure-amended columns as biochar rates increased, even though the biochar itself added substantial amounts of these nutrients to the columns. Among columns receiving manure, the 20 g kg^{-1} biochar treatments reduced total N and total dissolved P leaching by 11% and 69%, respectively. These laboratory results indicate that addition of biochar to a typical mid-western agricultural soil substantially reduced nutrient leaching, and suggested that biochar additions to soil could be an effective management option for reducing nutrient leaching in production agriculture.

Singh *et al.,* (2010) studied to assessed the influence of four biochars (wood and poultry manure biochars synthesized at 400 °C, non-activated, and at 550 °C, activated, abbreviated as: W400, PM400, W550, PM550, respectively) on nitrous oxide (N_2O) emission and N leaching from an Alfisol and a Vertisol. They concluded that in the first leaching event, higher nitrate leaching occurred from the PM400-amended soils compared with the other treatments. In the second event, the leaching of ammonium was reduced by 55 to 93% from the W550- and PM550-Alfisol and Vertisol, and by 87 to 94% from the W400- and PM400-Vertisol only. Increased effectiveness of biochar in reducing ammonium leaching over time was due to increased sorption capacity of biochars through oxidative reactions on the biochar surfaces with ageing.

Knowles *et al.,* (2011) in a lysimeter experiment in two silt loam soils used biochar (102 t/ha equivalent) and biosolids (600 and 1200 kg N/ha equivalent) to study whether biochar, a form of charcoal that is added to soil, could reduce nitrate leaching from biosolids amended soil. The data from 5 months of leachate sampling showed nitrate leaching from biochar plus biosolid amended soils is less (4.1%) compared to the control treatments (7.1 %).

Kameyama *et al.,* (2012) evaluated the effects of sugarcane bagasse charcoal on nitrate leaching in a Shimajiri Maji soil with low water- and fertilizer-retaining capacity. The results showed that sugarcane bagasse biochar produced at 800 ^{o}C was able to reduce the leaching of nitrate from a calcaric dark red soil by 5% when applied at a rate of 10% (w/w). They attributed this reduction in leaching to mainly physical adsorption of the nitrate and water by the micro porous biochar.

Soil biochar addition can significantly decrease short-term nitrate leaching as reported by Ventura *et al.,* (2012) in a lysimetric study in Italy. They conducted an experiment to evaluate the effect of biochar addition on short-term N leaching in a mature apple orchard growing on sub-alkaline soils. Cumulative nitrate (NO_3^-) and ammonium (NH_4^+) leaching was measured in treated and control plots 4 months after the addition of biochar and the following year by using ion-exchange resin lysimeters installed below the plowed soil layer. The study showed that cumulative NO_3^- leaching was not affected by biochar after 4 months, whereas in the following year it was significantly (p<0.05) reduced by 75% over the control (from 5.5 to 1.4 kg ha^{-1}). Conversely, NH_4^+ leaching was very low and unaffected by soil biochar treatment.

Zhang *et al.,* (2013) monitored changes in dynamics of soil nitrate accumulation due to biochar application at rates (kg ha^{-1}) of 0 (C_K), 2250 (C_1), and 4500 (C_2) for each of the two crop seasons in 2007. A treatment with 750 kg biochar-based fertilizer ha^{-1} (C_N) for each of two crop seasons was also included. Biochar tended to increase the soil cation exchange capacity (CEC) in the 0–20 cm soil layer and nitrate retention in the 1.0 m soil profile, but there was no significant difference between biochar treatments and C_K. Grain yield of C_1, C_2, and C_N was improved by 10.3%, 16.9%, and 15.5% compared with C_K, respectively, but only C_2 was significantly different from CK. Irshad *et al.,* (2014) in a study in a sandy soil compared the efficacy of different amendments such as charcoal, manure, sawdust and wood ash with application of urea at the rate of 300 kg N ha^{-1}. Nitrate was determined during six leaching events. Results indicated that urea application increased nitrate (NO_3^-) concentration in leachate. Soil amendments substantially reduced NO_3^- in leachates irrespective of the type of material used. The efficacy of amendments to reduce NO_3^- leaching was in the order of charcoal < wood ash < saw dust < manure. Mukherjee *et al.,* (2014) compared the reclamation efficacy of three soil amendments, viz. humic acid, water residual treatment and biochar on leaching of nutrients in a silty loam soil in USA. Biochar-amended soil reduced mean cumulative leaching of TOC by 30%, nitrate by 33%, and nitrite by 34%, compared to the control (control: 93, 75, and 2 mg kg^{-1} of TOC, nitrate, and nitrite, respectively), likely due to sorption by the biochar.

Sika and Hardie (2014) conducted an experiment to determine the potential of pine wood biochar to reduce leaching of ammonium nitrate fertilizer (100 kg N ha^{-1}) from a sandy soil in South Africa and to quantify the exchangeable inorganic N (2 M KCl) remaining after intensive leaching. Laboratory columns containing sandy soil and biochar (0, 0.5, 2.5 and 10.0% w/w) were leached weekly over a period of six weeks simulating heavy winter rainfall. They concluded that biochar (0.5, 2.5 and 10.0% w/w) significantly reduced the cumulative amount of ammonium (12, 50 and 86%, respectively) and nitrate (26, 42 and 96%, respectively) leached relative to the control soil.

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