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Original Research Article

Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil

Mohammad Ghorbani [a,*], Hossein Asadi [b], Sepideh Abrishamkesh [a]

[a] Department of Soil Science, University of Guilan, Rasht, 4818168984, Iran
[b] Department of Soil Science, University of Tehran, Karaj, 77871-31587, Iran

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ABSTRACT

Biochar is a product of pyrolysis of biomass in the absence of oxygen and has a high potential to sequester carbon into more stable soil organic carbon (OC). Despite the large number of studies on biochar and soil properties, few studies have investigated the effects of biochar in contrasting soils. The current research was conducted to evaluate the effects of different biochar levels (0 (as control), 1% and 3%) on several soil physiochemical properties and nitrate leaching in two soil types (loamy sand and clay) under greenhouse conditions and wet-dry cycles. The experiment was performed using a randomized design with three levels of biochar produced from rice husks at 500 °C in three replications. Cation exchange capacity increased significantly, by 20% and 30% in 1% and 3% biochar-amended loamy sand soil, respectively, and increases were 9% and 19% in 1% and 3% biochar-amended clay soil, respectively. Loamy sand soil did not show improvement in aggregate indices, including mean weight diameter, geometric mean diameter, water stable aggregates and fractal dimension, which was contrary to the results for the clay soil. Rice husk biochar application at the both rates decreased nitrate leaching in the clay soil more than in the loamy sand. Our study highlights the importance of soil type in determining the value of biochar as a soil amendment to improve soil properties, particularly soil aggregation and reduced nitrate leaching. The benefits of the biochar in the clay soil were greater than in the loamy sand soil.

1. Introduction

Currently, environmental concerns about human induced CO_2 emission and global warming, high nutrient levels in surface and groundwater, and eutrophication have necessitated identification of efficient strategies to mitigate them. An option to carbon sequestration, reduce methane and nitrous oxide emissions (Juriga et al., 2018; Pratiwi & Shinogi, 2016), and reduce nutrient leaching (Liu et al., 2017) could be the addition of biochar to soils. Biochar is produced by pyrolysis of different carbon rich residues of agriculture and forestry (Van Trinh et al., 2017), some grasses, and municipal and industrial wastes. Biochar can act as a long-term soil carbon sequestration when buried in soil, i.e. remaining for hundreds of years (Ghorbani & Amirahmadi, 2018). Furthermore, improvement of soil properties (Pandian, Subramaniayan, Gnasekaran, & Chitraputhirapillai, 2016) and plant growth enhancement (Rajkovich et al., 2012) can be achieved as a result of biochar addition to soil.

Despite the many researches on influence of biochar on soil fertility and plant growth (Manolikaki & Diamadopoulos, 2017; Mehmood, Baquy, & Xu, 2018), and its carbon sequestration potential (Van Trinh et al., 2017), there are a limited knowledge on the effects of biochar on soil physical properties such as soil structure characteristics in contrasting soils. Aggregate stability is one of the most important factor affecting soil environmental functions e.g. capacity to store and stabilize organic carbon (Wang et al., 2018), and resistance against erosive agents (Chaplot & Cooper, 2015). Aggregate stability can be improved through the formation of biochar-soil minerals complexes (Juriga et al., 2018).

However, present reports about the effects of biochar on soil aggregate stability are not always in agreement with each other and are biochar type, application rate and soil type-specific. Decrease in aggregation in a loamy sand soil amended by biochar after 96 days

* Corresponding author.
E-mail addresses: mghorbani0007@gmail.com (M. Ghorbani), ho.asadi@ut.ac.ir (H. Asadi), sabrishamkesh@guilan.ac.ir (S. Abrishamkesh).

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of incubation were observed (Busscher, Novak, & Ahmedna, 2011). In a study, biochar application increased mean weight and geometric mean diameter in a silty loam soil, but it has no significant influence on soil aggregation and stability in a sandy loam soil (Xiang-Hong, Feng-Peng, & Xing-Chang, 2012). Also in the other study, researchers found that the biochar addition to an Ultisol had no significant effect on mean weight diameter of aggregates (Peng, Ye, Wang, Zhou, & Sun, 2011). Furthermore, it is reported that the use of biochar can delay nitrate leaching which should be beneficial both to the environment and to plants because of nitrogen holding in the soil for longer periods (Knowles, Robinson, Contangelo, & Clucas, 2011). There are few studies reported on the ability of biochar to hold nitrate.

For example, significant reduction of leaching of fertilizer N from soil has been reported as a result of amendment with biochar produced from forest residues (Manolikaki & Diamadopoulos, 2017). Cation exchange by bamboo biochar led to sorption of ammonium ions and retardation of vertical translocation of ammonium into sub surface soil layers during a 70-day incubation (Ding et al., 2010). Reduction of nitrate leaching from soil amended by biochar produced from pecan shells has been demonstrated over 25 and 67 days (Chaplot & Cooper, 2015).

Rice is the staple food in Iran and the single most important crop. Rice husk is the main byproduct of the rice-processing industry and is produced in large quantities in north of Iran. The advantages and drawbacks of burning vs incorporation of rice straw in rice growing have been discussed (Varela Milla, Rivera, Huang, Chien, & Wang, 2013). Rice husk ash for the improvement of rice growth and yield in the peat soil of Sumatra were used (Masulili, Utomo, & Syechfani, 2010). Also has been shown the ability of rice husk and rice husk ash to remove heavy metals from the system (Ahmaruzzaman & Gupta, 2011). Application of biochar in tsunami-affected paddy fields in Sri Lanka were investigated, and the experimental results showed that the application of 2 t rice-husk-charcoal ha^{-1} increased the grain yield from less than 4 t ha^{-1} for the control treatment to more than 5 t ha^{-1} for the biochar treatment (Reichenauer, Panamulla, Subasinghe, & Wimmer, 2009). Now, the rice husks have been used as a bio-fuel for electricity generation (Chaplot & Cooper, 2015). Rice husk biochar, a byproduct of the thermochemical conversion from the rice husk to biofuel, has been proposed to be a new soil amendment. Rice husk biochar can be recycled easily in the rice–wheat system without adverse effect on the soil's health (Shackley et al., 2012). The potential of rice husk biochar as a soil amendment to improve soil physicochemical properties has been reported in several studies (Li et al., 2016; Masulili et al., 2010). Rice husk conversion into biochar may result in secondary carbon advantages via avoiding burning it in field and bio-resource recycling, which have been considered as a matter of concern with air pollution of Iranian agriculture and climate change mitigation. On the other hand, nitrate leaching losses and its health hazard is a serious problem in most northern paddy fields of Iran (Darzi-Naftchali, Shahnazari, & Karandish, 2017). In this context, we hypothesized that rice-husk biochar application in two soil types could improve physicochemical properties in general and also we expect contrasting improvements due to the effect of application rate and soil type. Under these contexts the objectives of this study were to evaluate the effects of rice husk biochar on several soil physiochemical properties and nitrate leaching in a loamy sand soil and a clay soil.

2. Materials and methods

2.1. Soil and biochar

Soil samples (0–25 cm depth) including a loamy sand and a clay soil were collected from two different sites: Lahijan (loamy sand, 37°13′02.0″N 50°00′43.9″E) and Rasht (clay, 37°11′51.0″N 49°39′06.2″E) in Guilan province, North of Iran. The two soils are classified as Typic Hapludepts and Typic Hapludalfs, respectively (Wilson et al., 2008). Rice is the main agricultural crop in Guilan province. The rice husk was used to produce biochar. The biochar was produced by an electrical muffle furnace at peak temperature of 500 °C and 30–45 min pyrolysis process.

2.2. Soil and biochar analysis

Soil samples were air dried and ground to pass through a 2-mm sieve. Physical and chemical properties of the soil samples (Table 1) were determined measured as follows: Soil pH and electrical conductivity (EC) were measured in 1:1 soil to water solution and in saturated extract, respectively. The soil texture was determined by the hydrometer method (Gee & Or, 2002). Organic carbon (OC) was measured by wet oxidation method (Nelson & Sommers, 1996). Nitrogen (N) was determined by the Kjeldahl method (Page, Miller, & Keeney, 1982). Bulk density (BD) was determined by the clod method (Radcliffe & Simunek, 2010). Cation exchange capacity (CEC) was determined by using ammonium acetate extraction at pH 7 (Sumner & Miller, 1996).

Rice husk biochar was analysed for its basic properties (Table 1). The pH and EC of the biochar were measured in deionized water at 1:20 (biochar: water) weight ratios (Rajkovich et al., 2012). BD was determined by the clod method (Radcliffe & Simunek, 2010). CEC was determined by using 0.05 M hydrochloric acid at pH 7 (Munera-Echeverri et al., 2018). Carbon and hydrogen content of biochar was determined by dry combustion analysis using an Elemental analyser (Perkin Elmer 2400 II, Massachusetts, USA). Scanning electron microscopy (Fig. 1) was also performed on biochar by mean of digital scanning electron microscope (KYKY-EM3200).

2.3. Incubation experiment

Incubation experiments were carried out in two parts to study the effects of biochar on (i) selected soil properties and (ii) nitrate leaching.

2.3.1. Incubation experiment of selected soil properties

In incubation experiments of selected soil properties, one kg samples of the soils (loamy sand and clay) were placed in plastic pots (11 cm width and 15 cm depth) and mixed with treatments. The three treatments were unamended soil (control) and amended soils with 1 and 3% by weight of biochar, called here after B1 and B3, respectively. Soils and biochar were mixed thoroughly, and then the pots were subjected to wetting (field capacity plus 20 percent) and drying (permanent wilting point) cycles. The unamended control was also mixed uniformly. The incubated pots were placed in a room at 25 °C and weighed every 7 days to control moisture content. All treatments were prepared in triplicate. The incubation time was 10 months and soils were analysed at 10th month to determine the selected soil properties including BD, porosity, OC, pH, EC, CEC and soil aggregation indices. Soil BD was determined by the clod method (Radcliffe & Simunek, 2010). Porosity was calculated from bulk density and particle density (assuming 2.65 g cm^{-3}). The OC content was determined by the modified Walkley–Black method (Chan et al., 1995). The air-dried, disturbed soil samples were passed through a 2-mm sieve and analysed for pH and EC using 1:2.5 and 1:5 (soil: water) suspensions, respectively. CEC was determined by using ammonium acetate extraction at pH 7 (Sumner & Miller, 1996). In this study soil aggregation was determined by two methods of wet aggregate size distribution and

Table 1
Physiochemical characteristics of the soil samples, rice husk biochar and compost.

Property	Loamy sand soil	Clay soil	Rice husk biochar	Compost
pH	4.28	6.87	9.18	6.11
EC (dS m^{-1})	0.33	0.28	0.347	2.31
CEC ($cmol^{-1}$)	12.26	5.67	17.57	10.3
BD (g cm^{-1})	1.61	1.31	0.84	0.73
Total carbon (g kg^{-1})	5.3	11.0	478	28.9
H (g kg^{-1})	–	–	24.3	–
N (g kg^{-1})	0.4	0.5	0	1.1
C/N	–	–	–	9.63
Sand (%)	66.4	17.6	–	–
Silt (%)	15.3	36.6	–	–
Clay (%)	17.3	45.8	–	–

EC: electrical conductivity, CEC: cation exchangeable capacity, BD: bulk density, H: hydrogen, N: nitrogen, C/N: carbon/nitrogen.

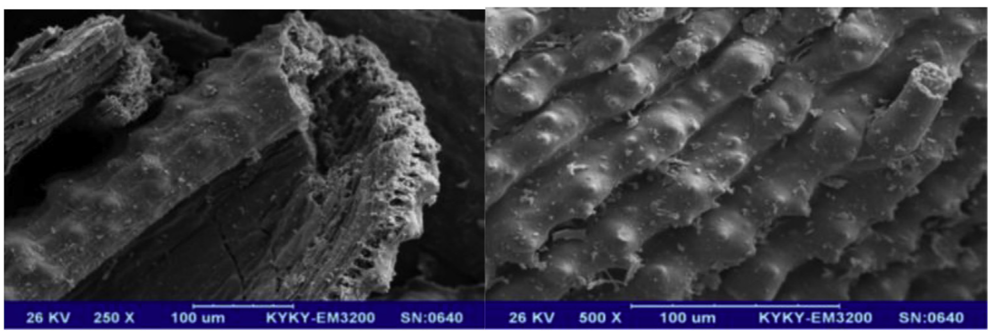

Fig. 1. Scanning electron micrographs of biochar scale bar of 250× (left) and 500× (right).

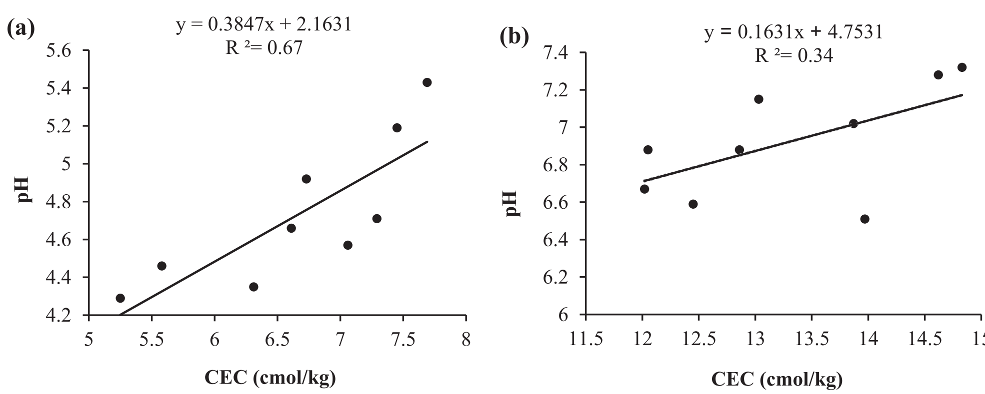

Fig. 2. Regression relationships between pH *v.* cation exchange capacity for Loamy sand (a) and Clay (b) soils.

wet aggregate stability.

2.3.2. Wet aggregate size distribution

Wet-sieving method was used to assess the wet aggregate size distribution. After the air-dried soils prewetted for about 24 h with tap water, the soil immersed in a container of tap water on a set of sieves which had openings of 4, 2, 1, 0.5, 0.25, 0.125, 0.074 and 0.053 mm in diameters, and the sieving took place at 35 oscillations per minute (along 38.1 mm amplitude) for 10 min. The remained material after wet-shaking in each sieve was carefully removed and dried at 105 °C. The mean weight diameter (MWD) and geometric mean diameter (GMD) of soil aggregates were determined using wet sieving data.

Aggregate mass is a scale dependent soil property which can be quantified by fractal geometry (Salako, 2006). Assuming scale-invariant density and shape of aggregates, the following equation is used for the estimation of fractal dimension (D) from mass-size distribution:

$$WSA = \frac{W_A - W_C}{W_O - W_C} \tag{1}$$

Where *D* is the fractal dimension, *M* (x_i) is the mass of aggregates left on the sieve of a nest of sieves, x_i is the size of aggregates in mm, *K* is a constant, relative to the number of fragments in one volume unit.

2.3.3. Wet aggregate stability

In a single-sieve wet-sieving method, 4 g of 1–2 mm air-dried aggregates was weighted into 0.26 mm (60 Mesh) sieve, pre-wetted by water for 24 h, and then shacked vertically about 1.5 cm, 35 times min^{-1}, for 3 min. After drying, the weight of unstable and stable aggregates was determined. Dividing the weight of the stable aggregates by the total aggregate weight (without sand particles > 0.05 mm) gives the index of water stable aggregates (WSA):

$$WSA = \frac{W_A - W_C}{W_O - W_C} \times 100 \quad (2)$$

where *WSA* is the water stable aggregate, W_A is the weight of material on the sieve after wet sieving, W_C is the weight of sand material, W_O is the weight of aggregates placed on the sieve prior to wet sieving size *i*.

2.3.4. Incubation experiment of nitrate leaching

In another part of the study, the impact of biochar on nitrate leaching was studied. Compost was used as a source of nitrogen for studying nitrate leaching. The compost used in this study was azocompost, which was used to create a nitrogen source for nitration and also to compare with the biochar effect on aggregate stability. Azocompost is a mixture of organic matter including azolla and rice straw, which is related to microorganisms in a warm environment, and is treated with a suitable ventilation (Yousefzadeh et al., 2013). The azocompost was prepared from the Rice Research Institute of Iran, which according to the tests carried out by the institute (Table 1), the percentage of nitrogen contained in the compost was 11%. One kg samples of the two types of soil (loamy sand and clay) were placed in plastic pots (11 cm width and 15 cm depth) and mixed with treatments. The 6 treatments were; unamended soil (control), and amended soils with 1 and 3% by weight of biochars (called here after B1, B3), and amended soil with 1% by weight of compost (called here after C), and combinations of 1 and 3% by weight of biochars with 1% compost (called here after B1+C and B3+C). During the experiment, the pots were placed under wetting and drying cycles. In each cycle, outflow drained water from the pots was collected after irrigation, and nitrate concentration was measured by spectrophotometry according to (Clesceri, Greenberg, Eaton, Rice, & Franson, 2005) for a 9-months period.

2.4. Data analysis

The statistical analysis of the effect of biochar on soil properties in two type of soils was performed in factorial arrangement in a completely randomized design with three replications. The triplicate data of selected soil properties and amount of leachate nitrate were subjected to mean separation analysis using the 2-way ANOVA and 1-way ANOVA test, respectively, using SAS 9.4 software (Delwiche & Slaughter, 2012). Treatment means were separated using the least significant difference (l.s.d.) test. Least-square means were used to test for significant differences among the treatments at $P = 0.05$. Linear regression analysis was performed to investigate the relationships among pH and CEC using the PROC REG program in SAS.

3. Results

3.1. Physicochemical soil properties

Both 1% and 3% application rates showed significant increases in soil pH for both loamy sand (pH 4.76 and 5.06, respectively) and clay (pH 6.84 and 7.20, respectively) soils (Table 2).

No significant differences in soil EC were observed among the biochar application rates in both soils compared with the control (Table 2).

OC content significantly increased in 1% and 3% biochar-amended soils. CEC increased significantly ($P < 0.05$) by 20% and 30% in 1% and 3% biochar-amended loamy sand soils, respectively. Increases were 9% and 19% in 1% and 3% biochar-amended clay soils, respectively (Table 2).

BD is an indirect measure of the soil compaction. In this study, BD significantly ($P < 0.05$) decreased with increasing biochar application rate in both soils (Table 2). For example, BD of 3% biochar-treated soil was decreased from 1.31 to 1.21 g cm−3 and 1.61 to 1.26 g cm−3 in loamy sand and clay, respectively (Table 2).

3.2. Soil aggregation

The mean comparison of interaction of biochar and soil type on the indices of soil aggregation are given in Fig. 3. No significant differences in all aggregation indices were observed among the biochar application rates in loamy sand soil, whereas application of 3% biochar led to a significant increase in MWD, GMD, WSA and decrease in D in the clay soil ($P < 0.05$). Results showed that MWD increased significantly from 1.19 mm (control) to 1.50 mm (B3), GWD increased significantly from 0.93 mm (control) to 1.02 mm (B3), WSA increased significantly from 68% (control) to 85% (B3) and D increased significantly from 4.42 (control) to 3.9 (B3) in Clay soil (Fig. 3a, b, c and d).

3.3. Nitrate leaching

The effect of treatments and soil type on the amount of nitrate in leachates was significant at $P < 0.05$. The highest amount of nitrate leaching was recorded for C (soil only treated with compost) and it was significantly higher in all treatments containing compost compared with ones without compost (Fig. 4). Treating the soil with biochar at both 1% and 3% application rates decreased significantly nitrate leaching in both soils, i.e. in the presence or absence of compost. For example, nitrate leachate in the absence of compost was decreased from 5.98 (control) to 4.83 (B1) and 3.56 (B3), and 5.98 (control) to 4.83 (B1) and 3.56 (B3), in loamy sand and clay, respectively. Also nitrate leachate in the presence of compost was decreased from 9.37 (C) to 6.01 (B1+C) and 5.21 (B3+C), and 9.12 (C) to 5.57 (B1+C) and 4.76 (B3+C), in loamy sand and clay, respectively. Significant differences in nitrate leachate were observed in loamy sand and clay soils among treatments without compost (Fig. 4).

Mean comparison of time effect on the nitrate leaching content is presented in Fig. 5. During the experiment, nitrate leaching reduced significantly and almost continuously, reached to a steady rate on the last three months.

4. Discussion

4.1. Physicochemical soil properties

The pH of soil receiving 3% biochar increased by 0.69 and 0.49 units in loamy sand and clay soils, respectively, over the control. A higher absolute increase in pH in loamy sand than clay soil may be due to its initial low pH allowing a greater increase. An increase in pH in biochar-amended soils has been reported in other long-term incubation studies (Ghorbani & Amirahmadi, 2018; Manolikaki & Diamadopoulos, 2017). The pH increase in the soil may be due to the high pH of rice-husk biochar (9.18), which is mainly attributed to the ash being dominated by alkaline carbonates, alkali earth metals and organic anions (Li et al., 2016). Another reason for an increase in soil pH could be the high CEC of biochar-amended soils. Exchangeable Al and soluble Fe tend to decrease as a result of increasing exchangeable sites leading to low potential acidity (Masulili et al., 2010). Significantly high coefficients of determination (R2 = 0.67 and 0.34 for loamy sand and clay soils, respectively; $P < 0.05$; Fig. 2 a, b) confirmed the effect of CEC on pH. This showed

Table 2
Physiochemical properties (mean ± s.d.) of biochar amended soils.

Treatments	pH	EC (dS m^{-1})	OC (%)	CEC ($cmol_c$ kg^{-1})	BD (g cm^{-3})	Porosity (%)
Clay						
Control	6.71 ± 0.02b	0.28 ± 0.003a	1.10 ± 0.03b	12.17 ± 1.07b	1.31 ± 0.05b	50.56 ± 1.17b
B1	6.84 ± 0.03 ab	0.25 ± 0.002a	1.35 ± 0.03a	13.28 ± 1.25 ab	1.28 ± 0.03b	51.69 ± 1.12 ab
B3	7.20 ± 0.01a	0.22 ± 0.006a	1.87 ± 0.04a	14.44 ± 0.57a	1.21 ± 0.04c	54.33 ± 1.11a
Loamy Sand						
Control	4.36 ± 0.02d	0.33 ± 0.001a	0.53 ± 0.02b	5.71 ± 1.13d	1.61 ± 0.02a	39.24 ± 1.12c
B1	4.76 ± 0.03c	0.28 ± 0.002a	1.18 ± 0.01 ab	6.87 ± 1.19cd	1.42 ± 0.04a	46.41 ± 1.15b
B3	5.06 ± 0.05c	0.24 ± 0.002a	1.42 ± 0.03a	7.40 ± 0.94c	1.26 ± 0.06b	52.45 ± 1.03a

Biochar treatments: B1, 1%; B3, 3%. EC, electrical conductivity; OC, organic carbon; CEC: cation exchangeable capacity; BD, bulk density. The means with the same letters are not significantly different at $P > 0.05$.

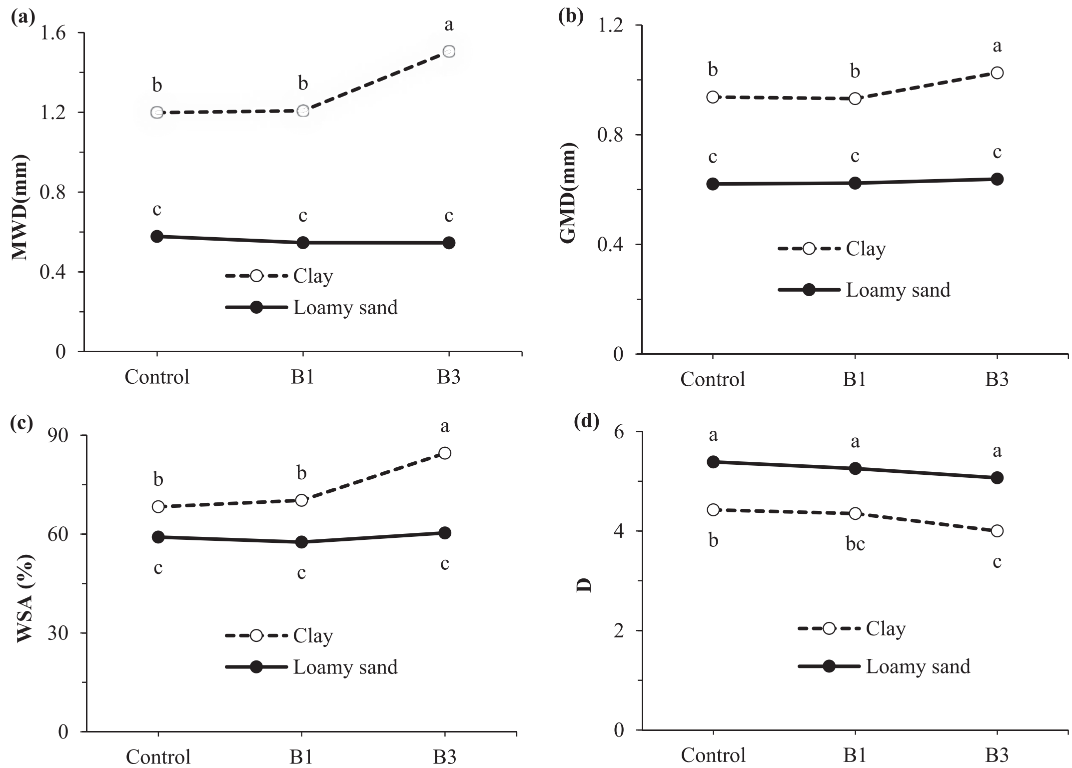

Fig. 3. The Interaction effects of biochar and soil type on (a) MWD: Mean weight diameter; (b) GMD: Geometric mean diameter, (c) WSA: Water stable aggregates, and (d) D: Fractal dimension. The means with the same letters are not significantly different at $P > 0.05$.

the potential of rice-husk biochar as a soil amendment to correct medium acidity, especially in loamy sand soils. Although the pH of clay soil also increased, it stayed within the neutral pH range, with no potential detrimental impact on nutrient availability for crops.

Contradictory results have been found in literature; some studies reported a significant increase (Ghorbani & Amirahmadi, 2018; Masulili et al., 2010) and others reported no significant increase in soil EC with biochar application (Jien & Wang, 2013; Singh Mavi et al., 2018).

The highest OC content was observed for loamy sand (1.42%) and clay (1.87%) soils amended with 3% biochar (Table 2). Increases in OC content were reported with the application of biochar in general (Jien & Wang, 2013; Li et al., 2016) as well as rice-husk biochar even after 30 days of incubation (Masulili et al., 2010). The carbon sequestration potential of biochar is related to the properties of biochar and soil (e.g., pH, OC, and clay content) (Wang et al., 2018). More biochar C was mineralized in the high-pH soil (clay) than in the low-pH soil (loamy sand). Higher microbial biomass was attributed to higher biochar mineralization in the high-pH soil, which was related to the content of OC by offering more available substrates for microbial growth. Nevertheless, when expressed as the mineralization of biochar per unit native OC in different soils, the revised degradation of biochar had a negative relationship with the soil pH (Chaplot & Cooper, 2015).

The increase in CEC may be due to the high CEC of biochar (19.21 cmolc kg−1) from high specific surface area and high porosity (Jien & Wang, 2013). In addition, oxidation of biochar and the development of surface negative charge over time may increase CEC (Mehmood et al., 2018). The percentage increase in CEC was higher in loamy sand than clay even at similar application rates. The CEC of the two soils responded differently to biochar application. Biochar oxidation could decrease because of interaction of biochar with soil minerals (Chaplot & Cooper, 2015). The loamy sand (which include 66.4% sand) with low active mineral content due to a smaller fraction of finer particles (clay and silt). Therefore, surface-charge development of biochar could be higher in loamy sand soil than clay soil. However, improvement of CEC in both soils could provide agronomic and environmental benefits.

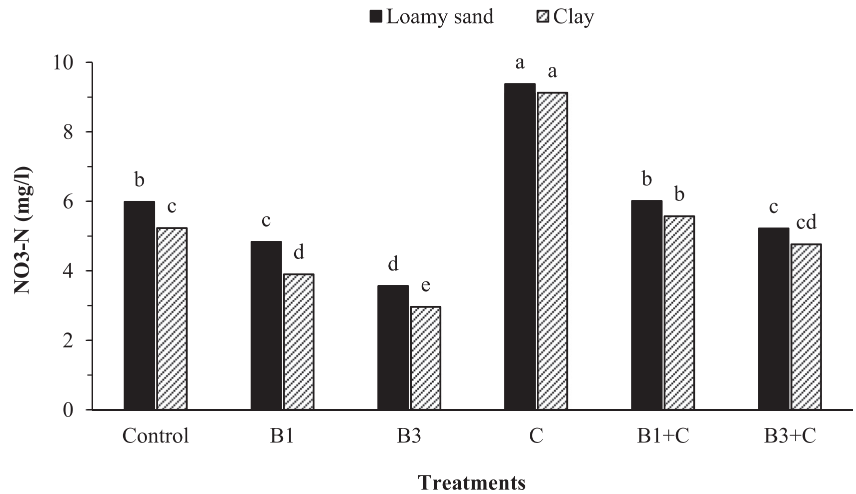

Fig. 4. Effects of treatments on nitrate leaching. B1: 1% biochar; B3: 3% biochar; C: compost; B1+C: 1% biochar + compost; B3+C: 3% biochar + compost. The means with the same letters are not significantly different at P > 0.05.

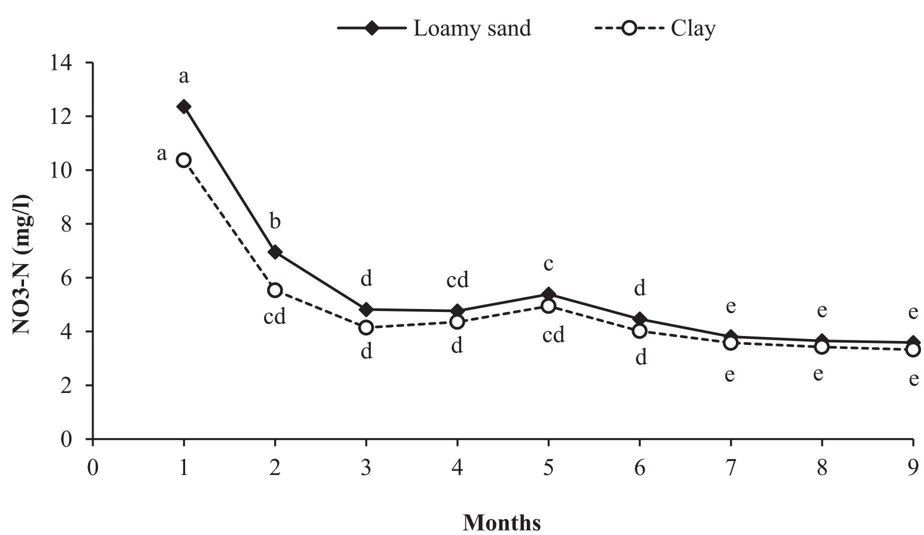

Fig. 5. Effects of time on nitrate leaching. The means with the same letters are not significantly different at P > 0.05.

Any reduction in BD could be due to the increase in the volume of soil biochar mixtures over time. Further, total porosity in both soils significantly increased (Table 2). This indicated an increase in the volume of biochar amended soils, which may be due to the rearrangement of soil and biochar particles. These results are consistent with other soil–biochar incubation studies (Herath, Camps-Arbestain, & Hedley, 2013; Jien & Wang, 2013). Particle rearrangement from release of applied pressure by soil–organic particles could reduce the BD in soils with organic amendments added (Pandian et al., 2016).

4.2. Soil aggregation

Soil aggregate stability is a key soil quality parameter controlling sensitivity to crusting and erosion (Abrishamkesh, Gorji, Asadi, Bagheri-Marandi, & Pourbabaee, 2015). High aggregate stability indicates the high resistance to soil erosion and predominance of macroaggregates (Pandian et al., 2016). The passage of time will certainly increase the stability of aggregates in clay soils, but it does not have a significant effect on the loamy sand soil. The reason for this can be found in the soil components. Probably reasons for this are the low organic matter content and the low particles of less than 0.05 mm in the loamy sand soil (Herath et al., 2013). The role of organic matter in aggregate stability can be attributed to the hydrophobicity of these materials. So that, in a single study results showed that increasing organic matter in the soil from 2.3 to 3.5 percent increased the aggregate stability (in particular, MWD) and reduced soil loss (Lado, Ben-Hur, & Shainberg, 2004). This role of organic matter is complete when the percentage of clay in the soil is high. The particles of the clay have a high level of surface and, as a result, are a lot of free energy that, in order to stabilize, this energy must reach its lowest level. The flocculation of clay particles and the formation of aggregates, which have a lower surface in volume unit, helps to reduce this energy. The greater the organic matter, the greater the aggregation (Van Trinh et al., 2017).

Biochar significantly enhanced the aggregate stability indices of the clay soil mainly consisting of silt and clay particles but had no effect on the loamy sand with more sand content (Herath et al., 2013). The difference may be explained by the clay role as an aggregator in binding organic molecules by bivalent and polyvalent cations (such as Ca^{2+}, Al^{3+}, and Fe^{3+}) which result in formation of macro aggregates and making up a protecting layer to protect soil organic carbon from microbial decomposition and promote aggregation (Jien & Wang, 2013). This can also be due to the high percentage of particles smaller than 0.05 mm (clay and silt) in clay texture compared to the loamy sand (Xiang-Hong et al., 2012). It is not clear how the effect of this mechanism is. But some researchers have argued that this is due to the high concentrations of activated carbon on particle surfaces smaller than 0.05 mm in soils that combine with biochar (Liu et al., 2017). This means that particles smaller than 0.05 mm will prefer black carbon particles to other organic compounds (Li et al., 2016). Some studies have shown that the addition of humic acid to soil by increasing acidic ligands, such as −COOH, improves soil properties, including the absorption of different elements (Singh Mavi et al., 2018). The existence of such ligands has been confirmed in a variety of different biochars. Therefore, it can be assumed that the active agent groups in the particles of biochar are the same reason for the flocculation of soil particles and the formation of aggregates. This may also be the reason why D was reduction in the 3% biochar-amended soil. The D provides a combined measure of irregularities and aggregates rutting (Gregory, Bird, Watts, & Whitmore, 2012). Studies have shown that D of aggregates is an important factor in the distribution of aggregate size. The soil aggregates are more stable, resulting in less D. In contrast, unstable aggregates have greater fragmentation and higher D, which reflects the disadvantages of the soil structure (Caruso, Barto, Siddiky, Smigelski, & Rillig, 2011). In the case of water stable aggregates (WSA) (Liu et al., 2017), also reported an increase in WSA in biochar amended soils having clay content >19%. In this study, loamy sand soil with low clay content (17.3%) showed little improvement in MWD, GMD, WSA and D even with the highest rate (3%) of biochar application. Therefore, high clay content in clay soils may have facilitated the formation of soil macro aggregates.

Although biochar is a recalcitrant organic carbon compound, it is not inert. Biochar could gradually change into stable humus after incorporation into soil (Wang et al., 2018) which its interaction with clay may led to improvement of aggregate stability. Similarly, an 11-month incubation study showed that sawdust biochar application had not any significant effect on the aggregate stability of the loamy sand, but silty loam (Xiang-Hong et al., 2012). In the other study results showed that 2.5 and 5% of biochar application increased mean weight diameter of clay soils after 63-day incubation (Jien & Wang, 2013). Biochar oxidation can produce acidic function groups and humic materials (Li et al., 2016). In spite of slow oxidation of biochar, the promotion of the biochar oxidation has been reported in presence of organic matter addition (Munera-Echeverri et al., 2018). The more organic carbon in the clay compared to the loamy sand could led to formation of more humic material and increase of aggregate stability.

4.3. Nitrate leaching

This suggests the role of the compost as a source of nitrate (Hepperly, Lotter, Ulsh, Seidel, & Reider, 2009). Results showed that an increase in biochar consumption significantly reduces the amount of leachate. The anionic adsorption potential and high superficial levels of biochar are among the possible reasons for the adsorption of nitrate ions and their maintenance in the soil (Li et al., 2016). Results of a study by (Xiang-Hong et al., 2012) showed that biochar can be effectively used to improve the fertilizer nitrogen use efficiency in sandy soil and reduce nitrate loss from loamy soil. As reviewed by (Liu et al., 2017), high cation exchange capacity, enhancement of soil water holding capacity and microbial immobilization of nitrogen as results of biochar application are probable drivers of nitrogen uptake and retention in soil. Perhaps this justifies why nitrate leaching in clay soil treatments (with 47% clay particles) is less than loamy sand (with 17% clay particles). However, treatment C (compost), despite a significant increase in nitrification, is not capable of preserving nitrate, in contrast to treatments containing biochar 3%, and much of it is leached. The low level of leaching in treatments B3, as well as B3+C compared to treatment C can be attributed to the high level of specific surface in biochar particles (Ghorbani & Amirahmadi, 2018).

Higher nitrate leaching on the first month can be attributed to the presence of more nitrate at the beginning of the experiment. Increasing nitrate leaching in the fourth and fifth months shows an increase in nitrification in these two months. This could be due to the fourth and fifth readings in the wet months of the year. Increased moisture content is one of the conditions that increases nitrate production (Metwally & Pollard, 1959). The moisture absorbing of biochar and the high porosity in its structure make it possible for microorganisms and other nitrate synthesis processes (Darzi-Naftchali et al., 2017).

5. Conclusions

We examined the effect of rice husk biochar on selected soil properties and nitrate leaching in two types of soil (loamy sand and clay) in Iran. Enhancing soil structure and nutrient status are an urgent need for sustainable soil management. Results from this study showed that rice husk biochar application had a positive effect on soil properties, aggregation and nitrate retention of soil. In particular, 3% biochar application improved soil aggregate stability indices and nitrate retention in the clay soil. Rice husk biochar has a potential for ameliorating the moderate level of acidity in Loamy sand soil. However, the application of biochar even at the highest rate (3%) in this study did not show any threat of developing alkalinity or salinity in any soil. Although in treatments of biochar without compost, addition of 1% biochar was enough to significantly decrease the amount of nitrate leaching. The different effects of rice husk biochar on CEC, nitrate leaching and soil aggregation in two soils can be related to contrasting characteristics of soils, particularly soil texture. However, the Loamy sand soil is likely to require higher biochar application rates and incubation time than tested in this study to improve soil aggregation. Our study highlights the importance of soil type in determining the value of rice husk biochar as a soil amendment. Any improvement in aggregation can enhance carbon sequestration in soil and consequently mitigate CO_2 emission to atmosphere. The positive changes in nitrate retention of soil may increase and regulate the nitrogen availability to the crops in addition to alleviating the concerns about not point pollution of water bodies by nitrate.

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