doi: 10.17221/117/2015-PSE

Effects of rice husk biochar application on the properties of alkaline soil and lentil growth

S. Abrishamkesh[1], M. Gorji[1], H. Asadi[2], G.H. Bagheri-Marandi[1], A.A. Pourbabaee[1]

[1]*Department of Soil Science, University of Tehran, Karaj, Iran*
[2]*Department of Soil Science, University of Guilan, Rasht, Iran*

ABSTRACT

This study evaluated the effects of biochar application on some properties of an alkaline soil and on lentil (Lens culinaris Medik) growth. Lentils were grown in the soil amended with the rates of 0.4, 0.8, 1.6, 2.4, and 3.3 weight percent of two biochars (B_1 and B_2), produced from rice husk under different pyrolysis conditions. Lentils were harvested after 70 days. Soil samples were also analysed for changes in physico-chemical properties. The results indicated that biochar application significantly increased soil organic carbon, cation exchange capacity, available potassium and below ground biomass of lentil, while it decreased soil bulk density. The results suggested that biochar application to alkaline soils has benefits to both soil quality and plant growth.

Keywords: arid and semi-arid soils; charcoal; carbon sequestration; liming effect; sustainable waste recycling

Soil organic carbon depletion, increased emission of greenhouse gases, and global warming are major concerns nowadays. Annual total CO_2-equivalent emissions from world agriculture in 2005 were estimated to be 5.1–6.1 Pg and comprised about 10–12% of global anthropogenic emissions (Smith et al. 2007). One of the most recent measures used to enhance the carbon sequestration in soils is addition of biochar. Biochar is produced through a pyrolysis process, when tissues of biological origin are burned or charred in the absence of, or at low levels, of oxygen (Mohan et al. 2006). Biochar has been shown to improve chemical, physical, and biological properties of soils (Yamato et al. 2006) and enhance plant growth (Rajkovich et al. 2012).

Biomass such as crop residues, woody material, green wastes, animal manures and agricultural wastes, such a rice husks, can be used for biochar production. Conversion of wastes such as rice husk into biochar through pyrolysis can result in advantages such as energy production, sustainable waste recycling, carbon sequestration, improvement of soil quality, and better plant growth.

Research about the beneficial effects of biochar has mostly concentrated on tropical soils. There are few studies on arid and semiarid soils which often have different characteristics and are not primarily limited by low pH. Therefore this study was conducted to evaluate the effects of different application rates of two rice husk biochars on physico-chemical properties of an alkaline soil and on lentil growth as it is a common crop in the dry lands of Iran.

MATERIAL AND METHODS

Soil characteristics. The soil used in this study was collected from top layer (0–20 cm) in the University of Tehran experimental farm, located at the city of Karaj, Iran. The soil is a Calcaric Cambisol. Various physico-chemical properties of the soil (Table 1) were measured as follows: The pH and electrical conductivity (EC) of the soil were measured in 1:1 (soil:water) suspension. Particle size distribution and soil organic carbon (C_{org}) were determined by the hydrometer method (Gee and Or 2002) and the dichromate digestion method (Nelson and Sommers 1982), respectively. Total nitrogen (N_{tot}) was measured by the Kjeldahl method (Bremner and Mulvaney 1982). Available phosphorus (P_{Olsen}) and available potassium (K_{avail})

doi: 10.17221/117/2015-PSE

Table 1. Physico-chemical properties of the experimental soil

Sand	Silt	Clay	Soil texture	CEC	EC	pH_{H2O}	C_{org}	N_{tot}	P_{Olsen}	K_{avail}
(%)				($mmol_+$/kg)	(mS/m)		(g/kg)		(mg/kg)	
33	35	32	Clay loam	139	50.5	7.9	7.6	0.91	11.12	121

CEC – cation exchange capacity; EC – electrical conductivity; C_{org} – soil organic carbon; N_{tot} – total N; P_{Olsen} – available P; K_{avail} – available K

were measured after extracting soil with sodium bicarbonate (Olsen and Sommers 1982) and ammonium acetate (Knudsen et al. 1982), respectively. Cation exchange capacity (CEC) was determined at soil pH = 8.2 by the ammonium acetate method (Chapman 1965).

Biochar production and characterization. The rice husk was air-dried at room temperature and then placed in ceramic crucibles, each covered with a fitting lid, and the pyrolysis process was done under limited oxygen conditions in a muffle furnace. The general conditions of pyrolysis are given in Table 2. Biochars were subsequently analysed for their basic properties (Table 2). Particle size distribution of biochars was assessed by passing a total 20 g biochar through 4.75, 2, 1, 0.5 and 0.25 mm sieves and weighing the various size fractions. The pH and EC of biochar were measured in deionized water at 1:20 (biochar:water) weight ratios (Rajkovich et al. 2012). A subsample of biochar was finely ground before total carbon (C_{tot}), total hydrogen (H_{tot}) and total nitrogen (N_{tot}) content determination by dry combustion analysis using an Elemental analyser (Perkin Elmer 2400 II, Massachusetts, USA). Ash content of biochars was measured by the standard ASTMD-2866 method on a weight basis. Briefly 5.0 g of oven-dried biochar was heated at 500°C overnight, cooled and weighed again. The yield of biochars was calculated as the mass of biochar generated from dry mass of rice husk. Scanning electron microscopy (SEM) and infrared (IR) spectroscopy were also performed on two biochars.

Pot experiment. The 11 treatments were unamended soil (control) and amended soils with 0.4, 0.8, 1.6, 2.4, and 3.3% by weight of B_1 and B_2 biochars: B_0; B_1(0.4); B_1(0.8); B_1(1.6); B_1(2.4); B_1(3.3); B_2(0.4); B_2(0.8); B_2(1.6); B_2(2.4); and B_2(3.3),

Table 2. Production conditions (pyrolysis) and properties of biochars

		Unit	Biochar B_1	Biochar B_2
Production condition	heating rate	(°C/min)	0.25–0.3	0.25–0.3
	initial temperature	(°C)	150	350
	peak temperature		250–300	450–500
	residence time in peak temperature	(min)	225	30
Property	(> 4.75 mm)	(%)	0.22	0.1
	(4.75–2 mm)		6.28	3.15
	(2–1 mm)		26.89	13.91
	(1–0.5 mm)		49.51	57.86
	(0.5–0.25 mm)		12.06	16.91
	(< 0.25 mm)		5.04	8.07
	electrical conductivity	(mS/m)	36	48
	pH_{H_2O}		7.4	8.4
	total C	(g/kg)	451.1	442.4
	total N		5.4	5.6
	total H		29.8	19
	ash	(%)	38	47
	yield		39	32

doi: 10.17221/117/2015-PSE

respectively. 3200 g air dried soil without and with biochar B_1 and B_2 were mixed thoroughly then placed in plastic pots (15 cm diameter and 20 cm depth). A basal dose of 14.45 mg N and 8.00 mg P/kg soil (using stock solutions of $(NH_4)_3\ PO_4$), and 5.18 mg K/kg soil (using stock solutions of K_2SO_4) were applied to the pots. Ten lentils (Lens cullinaris Medik) seeds per pot were sown at a depth of 10 mm, and thinned to the best 4 after germination. Pots were maintained at 25°C and all pots received the same amount of water at the first signs of leaf curl, to minimize drought stress. Plants were harvested on day 70 when plants had not yet reached full maturity but had already begun to produce seeds. Above and below ground biomass was dried to constant weight at 60°C, and dry weights were measured. Core samples were taken from the surface (0–5 cm) of the pots and used for bulk density and field capacity measurements. Surplus soil in pots was taken for chemical analysis and permanent wilting point measurement. The water content of undisturbed soil samples at field capacity and disturbed ones at permanent wilting point were determined using pressure plate apparatus at 0.033 MPa and 1.5 MPa, respectively (Dane and Hopmans 2002). Available water content of the soils was calculated as:

$$AWC\ (cm^3/cm^3) = FC\ (cm^3/cm^3) - PWP\ (cm^3/cm^3)$$

Where: AWC – available water content; FC – field capacity; PWP – permanent wilting point.

Statistical analysis. The triplicate data were subjected to mean separation analysis using the 2-way ANOVA test at a significance of $P = 0.05$ and $P = 0.01$ by use of the Statistical Analysis System software (SAS Institute 2001). The differences between mean values were identified using the *LSD* test at a significance of $P = 0.05$.

RESULTS AND DISCUSSION

Biochar characteristics. General properties of the biochars are presented in Table 2. Biochar B_2 had more ash, less yield and more fine particles than biochar B_1. This is probably due to the higher temperature and more severe pyrolysis condition that enhanced the biomass decomposition for B_2. EC and pH were higher for biochar B_2. The calculated molar H/C ratios (0.79 and 0.52) for B_1 and B_2, suggest aliphatic as well as aromatic carbon compounds, but B_2 with its lower H/C ratio, is likely to have more aromatic carbon compounds. This finding is supported by the IR spectra of the biochars (Figures 1 and 2). Strong peaks around 775.71 (Figure 1 for B_1) and 799.44/cm (Figure 2 for B_2) relate to aromatic CH out-of-plane bending vibration but the peak is stronger in B_2. It can be concluded that with increasing pyrolysis peak temperature, the more aromatization was done. Scanning electron microscopy imaging clearly shows the porous structure of both biochars (Figure 3). **Effect of biochar on soil chemical properties**.

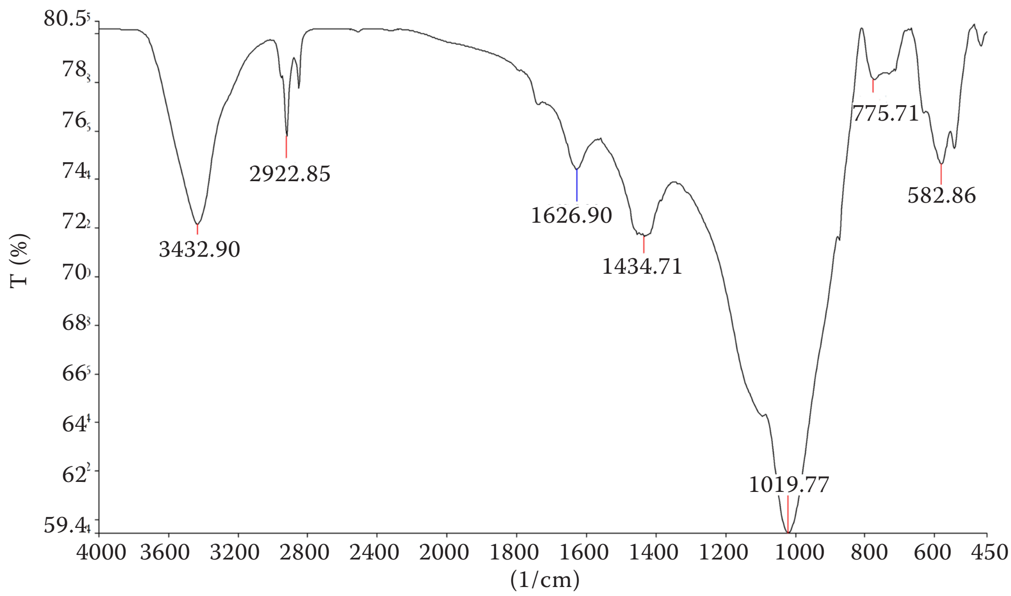


Figure 1. Infrared spectroscopy of biochar B_1. T – transmission

doi: 10.17221/117/2015-PSE

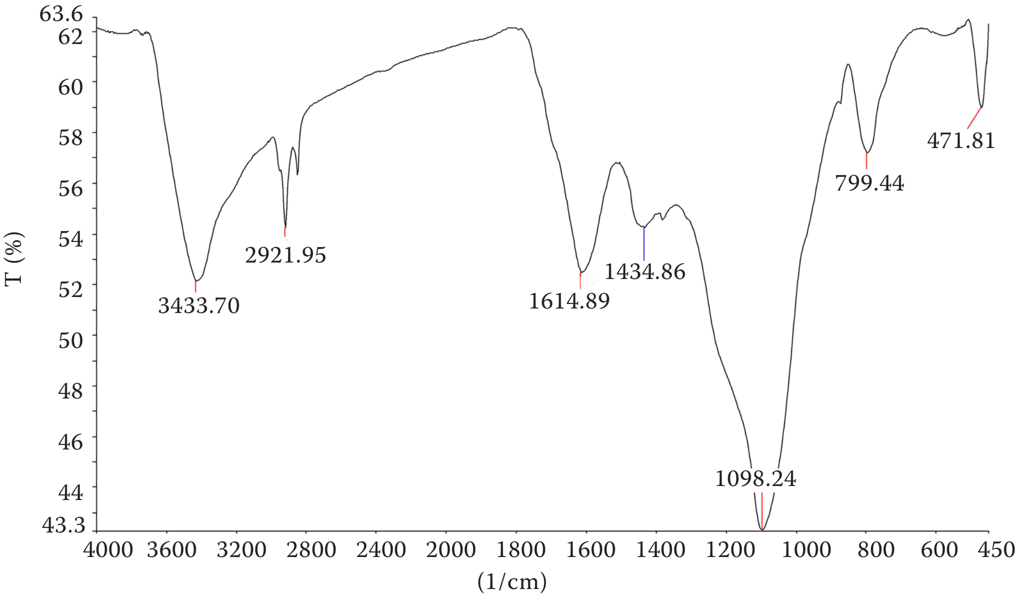
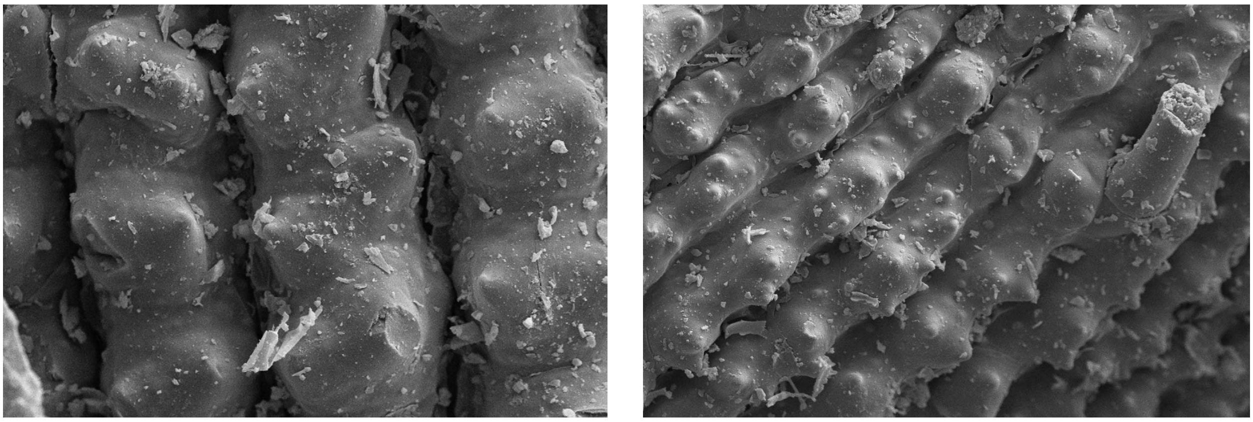


Figure 2. Infrared spectroscopy of biochar B_2. T – transmission

Biochar type showed a significant effect on C_{org} and P_{Olsen} (P < 0.01), and pH (P < 0.05). Biochar application rate had a significant effect on EC, cation exchange capacity (CEC), K_{avail} and P_{Olsen}

(a)



(b)

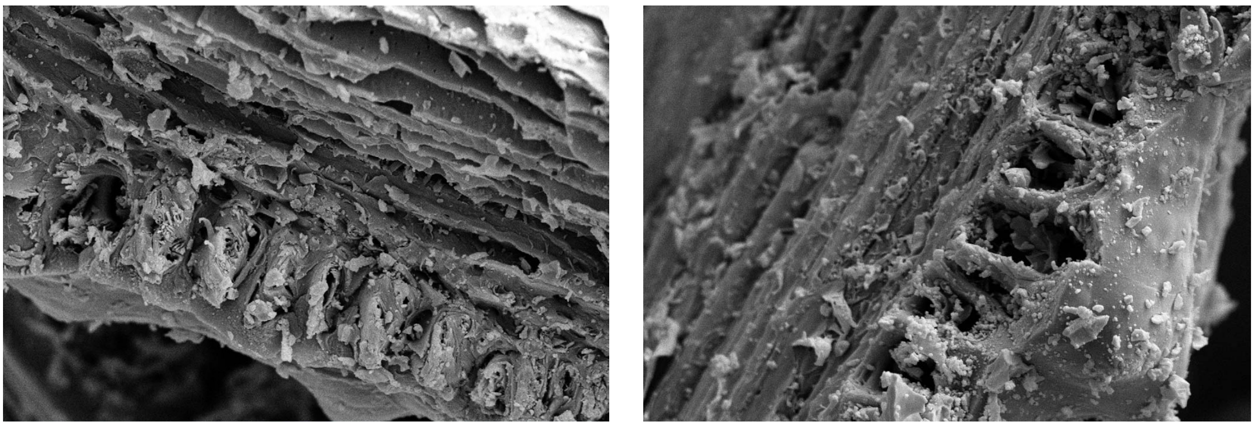


Figure 3. Scanning electron micrographs of biochars: biochar B_1 (left) and biochar B_2 (right) (a) scale bar of 500X, and (b) scale bar of 1000X

doi: 10.17221/117/2015-PSE

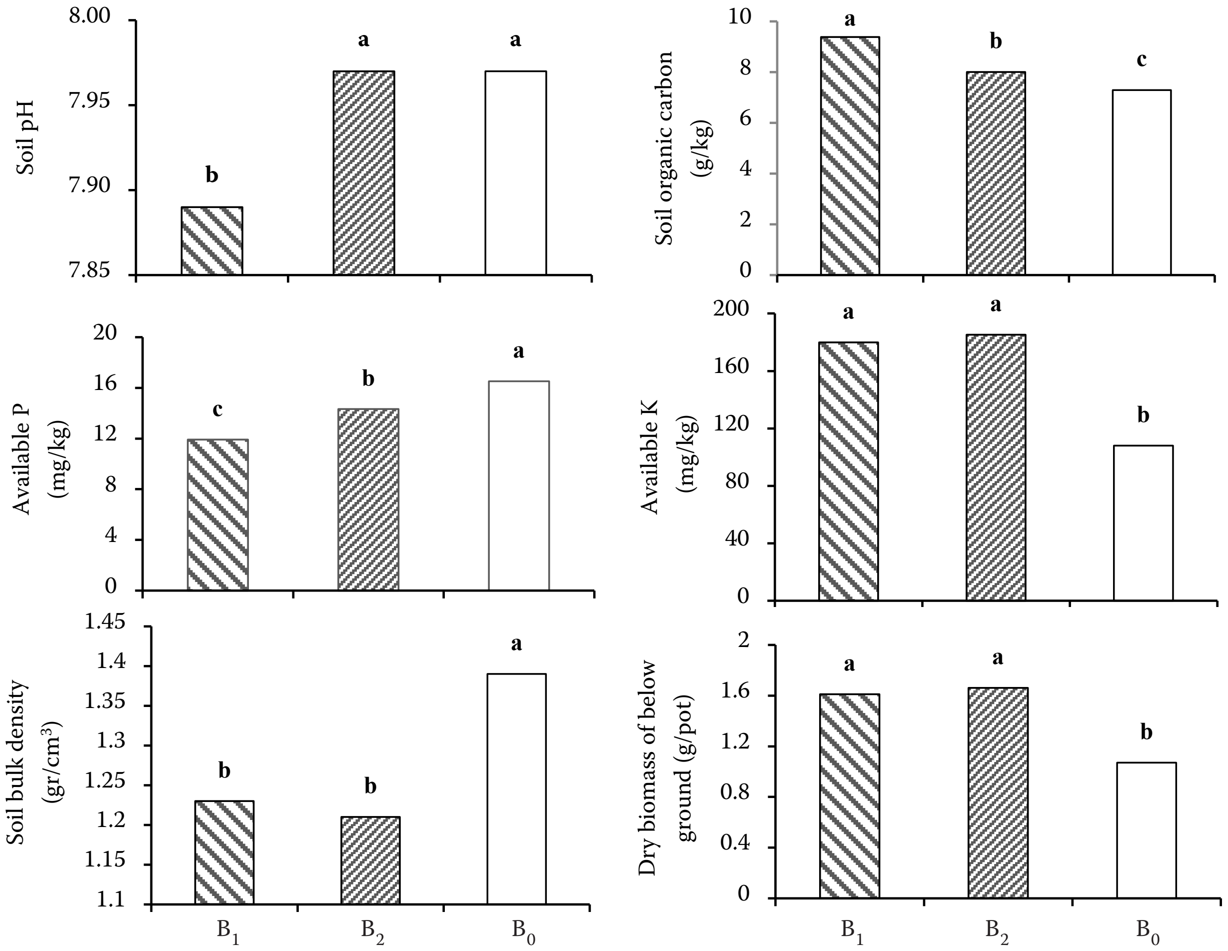


Figure 4. Effects of B_1 (biochar B_1), B_2 (biochar B_2) and B_0 (control) on soil properties and lentil biomass. The means that share the same letters are not significantly different at $P < 0.05$

($P < 0.05$), and C_{org} ($P < 0.01$). Neither biochar type nor the application rate has any significant effect on N_{tot}. No significance in the interaction of the variables (biochar type and application rate) was found in all soil chemical properties but CEC ($P < 0.05$). The significant interaction of the variables in the case of CEC suggests that biochar type influenced the effect of the application rate on CEC and vice versa.

Soil pH was significantly lower in the B_1 amended soils than in the B_2 amended and control soils (Figure 4). Many reports have showed soil pH increases due to biochar application (Yuan et al. 2011). However, most of these studies have been performed on acidic soils with low pH in comparison to the biochar pH. Liu and Zhang (2012) reported that alkaline biochar did not increase the pH of five types of alkaline soils, but instead produced a decreasing pH trend. The alkaline soil used for the study had pH of 7.9, which could have prevented any biochar liming effect. Lower pH of biochar B_1 compared to biochar B_2 and the soil could result in lowering pH in the B_1 amended soils. Biochar is not at all inert and can be oxidized in soil, especially at its surface (Cheng et al. 2006). Biochar B_1 is probably more oxidized than biochar B_2, because of its less aromaticity. Therefore, production of acidic material as a result of biochar B_1 oxidation could also cause lower soil pH in the biochar B_1 amended soils. Soil EC increased in proportion to the biochar application rates. But only the highest rate of the biochar application (3.3%) had significantly higher EC compared to the control soil (Table 3). The increase in EC can be attributed to high amount of ash in the biochars.

The biochar amended soils had significantly more C_{org} than unamended soils and biochar B_1 was more effective in increasing C_{org} (Figure 4). The increase in C_{org} was in proportion to the rates of biochar application (Table 3). The increase of C_{org} in the

doi: 10.17221/117/2015-PSE

Table 3. Effect of biochar application rate on soil properties and lentil biomass

Biochar (%)	EC (mS/m)	C_{org} (g/kg)	P_{Olsen} (mg/kg)	K_{avail} (mg/kg)	SBD (g/cm^3)	DM_b (g/pot)
0 (control)	59.3^{bc}	7.30^{c}	16.51^{a}	108.00^{f}	1.39^{a}	1.07^{c}
0.4	53.5^{bc}	7.65^{bc}	11.91^{c}	121.33^{e}	1.37^{a}	1.34^{b}
0.8	49.8^{c}	7.97^{bc}	10.89^{c}	140.00^{d}	1.29^{b}	1.45^{b}
1.6	54.3^{bc}	8.50^{b}	14.80^{abc}	176.67^{c}	1.17^{c}	1.49^{b}
2.4	62.0^{ab}	9.47^{a}	15.42^{ab}	218.67^{b}	1.14^{c}	1.90^{a}
3.3	69.5^{a}	9.93^{a}	12.78^{bc}	256.00^{a}	1.14^{c}	2.00^{a}

Means within a column that have the same letter are not significantly different at $P < 0.05$. EC – electrical conductivity; C_{org} – soil organic carbon; P_{Olsen} – available P; K_{avail} – available K; SBD – soil bulk density; DM_b – dry biomass of below ground

biochar amended soils could be a result of the high amount of organic carbon in the biochars. High C_{org} in the biochar amended soils suggests that the organic carbon of the biochars is recalcitrant. The biochar amended soils had significantly higher CEC in comparison with the control soil (Figure 5). There was no difference between CEC of the biochar B_1 and B_2 amended soils in rates of 0.4, 0.8, 1.6 and 2.4% but 3.3% (Figure 5). CEC increased more or less in proportion to the biochar application rates. However, the highest CEC of the biochar B_1 and B_2 amended soils was observed in rate of 3.3% and 2.4%, respectively (Figure 5). The increase of soil CEC as a result of biochar application can be caused by the inherent characteristics of biochar, such as high porosity and surface area. High C_{org} and CEC in soils amended by biochar were similarly reported by a number of authors (Nigussie et al. 2012).

The control soil had less N_{tot} than biochar amended soils, but the difference was not significant. Since the nitrogen of biochar is mostly present in unavailable form for plants, this may not be necessarily beneficial to crops (Chan and Xu 2009). P_{Olsen} of the soils amended with 0.4, 0.8 and 3.3 of biochar was significantly lower relative to the control soil. However, there was no significant difference between application rates of 1.6% and 2.4% biochar, and the control soil (Table 3). Among the treatments, significantly higher P_{Olsen} ranked as control > biochar B_2 amended > biochar B_1 amended soils (Figure 4). There is an inconsistence about the reports about effects of biochar on P availability. Significant improvement of available P as a result of biochar application is reported in sandy or loamy soils (Tryon 1948). However, in an incubation study, biochar amendment significantly decreased P levels in leachate solutions and increased its retention in soil (Novak et al. 2009). K_{avail} content in the biochar amended soils was significantly higher than control soil (Figure 4) and it was increased in proportion to the biochar application rates (Table 3). The observed high

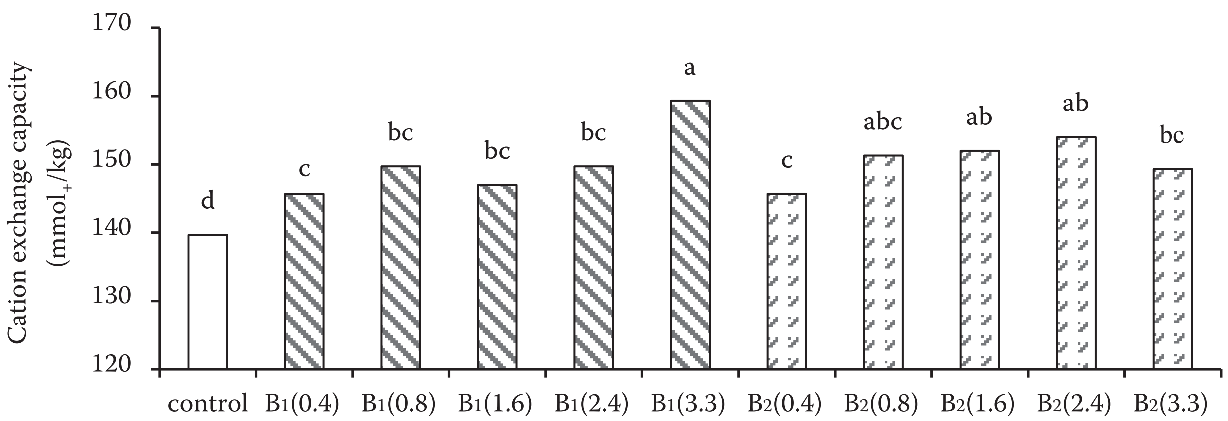


Figure 5. Effects of interactions between biochar type and application rate on soil cation exchange capacity. The means that share the same letters are not significantly different at $P < 0.05$

doi: 10.17221/117/2015-PSE

K_{avail} content in the biochar amended soils could be attributed to high ash content of biochars. The immediate release of K from the ash could result in higher K availability in the biochar amended soils.

Effect of biochar on soil physical properties. Biochar type had no significant effect on soil bulk density (SBD) and available water content (AWC). Biochar application rate showed a significant effect ($P < 0.01$) on SBD but has no significant effect on AWC. The two-way ANOVA found no significance in the interaction of variables (biochar type and application rate) in SBD and AWC. SBD was decreased by increase of the biochar application rates. Biochars have bulk density much lower than that of mineral soils and therefore if the biochar does not have a low mechanical strength, its application can reduce the overall density of the soil (Verheijen et al. 2009). In agronomy, relatively small reductions in soil bulk density can be associated with agronomic benefits (Verheijen et al. 2009). Although biochar induced a slight improvement in available water content of the soils, this effect was not significant. Although improvement of AWC is reported in several studies (Uzoma et al. 2011), Tryon (1948) reported no significant effect of charcoal (biochar) application on AWC of a loamy soil but there was a significant increase in a sandy soil. It can be concluded that the effects of biochar on AWC are soil- and biochar type- specific.

Effect of biochar on above and below ground lentil biomass. Biochar type and interaction between biochar type and application rate had no significant effect on the above and below ground biomass of lentil. Biochar application rate showed no significant effect on above ground dry biomass, whereas it had a significant effect ($P < 0.01$) on below ground dry biomass (roots). The highest below ground dry biomass was obtained in the 3.3% biochar amended soil, and the lowest in the control soil (Table 3). An increase of root biomass as a result of biochar application to soil has been previously reported by other authors such as Yamato et al. (2006). Biochar is known to modify soil physico-chemical parameters (Lehmann et al. 2011), which can likely affect root biomass. Decreases in soil bulk density shown in Figure 4 and Table 3 and porous structure of biochars shown in Figure 3 may have allowed the lentil roots to grow more via facilitation of root penetration in the soil.

Acknowledgment

We thank the Center of Excellence for Soil Quality Improvement for Balanced Plant Nutrition, Department of Soil Science, Faculty of Agricultural Engineering and Technology, University of Tehran, for funding a part of this research.

REFERENCES

Bremner J.M., Mulvaney C.S. (1982): Nitrogen total. In: Page A.L., Miller R.H., Keeny D.R. (eds.): Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. 2nd Ed. Madison, Soil Science Society of America.

Chan K.Y., Xu Z. (2009): Biochar: Nutrient properties and their enhancement. In: Lehman J., Joseph S. (eds.): Biochar for Environmental Management, Science and Technology. London, Earthsacan.

Chapman H.D. (1965): Cation exchange capacity. In: Black C.A. (ed.): Methods of Soil Analysis. Part 2. Madison, American Society of Agronomy.

Cheng C.H., Lehmann J., Thies J.E., Burton S.D., Engelhard M.H. (2006): Oxidation of black carbon by biotic and abiotic processes. Organic Geochemistry, 37: 1477–1488.

Dane J.H., Hopmans J.W. (2002): Water retention and storage. In: Dane J.H., Topp G.C. (eds.): Methods of Soil Analysis. Part 4: Physical Methods. Madison, Soil Science Society of America.

Gee G.W., Or D. (2002): Particle size analysis. In: Dane J.H., Topp G.C. (eds.): Methods of Soil Analysis. Part 4: Physical Methods. Madison, Soil Science Society of America.

Knudsen D., Peterson G.A., Pratt P.F. (1982): Lithium, sodium, potassium. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Ed. Madison, Soil Science Society of America.

Lehmann J., Rillig M.C., Thies J., Masiello C.A., Hockaday W.C., Crowley D. (2011): Biochar effects on soil biota: A review. Soil Biology and Biochemistry, 43: 1812–1836.

Liu X.H., Zhang X.C. (2012): Effect of biochar on pH of alkaline soils in the Loess Plateau: Results from incubation experiments. International Journal of Agriculture and Biology, 4: 745–750.

Mohan D., Pittman C.U., Steele P.H. (2006): Pyrolysis of wood/biomass for bio-oil: A critical review. Energy and Fuels, 20: 848–889.

Nelson D.W., Sommers L.E. (1982): Total carbon, organic carbon and organic matter. In: Page A.L., Miller R.H., Keeny D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Ed. Madison, Soil Science Society of America.

Nigussie A., Kissi E., Misganaw M., Ambaw G. (2012): Effect of biochar application on soil properties and nutrient uptake of lettuces (*Lactuca sativa*) grown in chromium polluted soils.

doi: 10.17221/117/2015-PSE

American-Eurasian Journal of Agricultural and Environmental Science, 12: 369–376.

Novak J.M., Busscher W.J., Laird D.L., Ahmedna M., Watts D.W., Niandou M.A. (2009): Impact of biochar amendment on fertility of a southeastern coastal plain soil. Soil Science, 174: 105–112.

Olsen S.R., Sommers L.E. (1982): Phosphorus. In: Page A.L., Miller L.H., Keeny D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Ed. Madison, Soil Science Society of America.

Rajkovich S., Enders A., Hanley K., Hyland C., Zimmerman A.R., Lehmann J. (2012): Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. Biology and Fertility of Soils, 48: 271–284.

SAS Institue Inc. (2001): SAS/STAT User's Guide. Cary, SAS Institue.

Smith P., Martino D., Cai Z., Gwary D., Janzen H., Kumar P., McCarl B., Ogle S., Mara F.O., Rice C., Scholes B., Sirotenko O. (2007): Agriculture. In: Metz B., Davidson O.R., Bosch P.R., Dave R., Mayer L.A. (eds.): Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, New York, Cambridge University Press.

Tryon E.H. (1948): Effect of charcoal on certain physical, chemical and biological properties of forest soils. Ecological Monographs, 18: 81–115.

Uzoma K.C., Inoue M., Andry H., Zahoor A., Nishihara E. (2011): Influence of biochar application on sandy soil hydraulic properties and nutrient retention. Journal of Food, Agriculture and Environment, 9: 1137–1143.

Verheijen F.G.A., Jeffery S., Bastos A.C., Van der Velde M., Diafas I. (2009): Biochar Application to Soils: A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. Luxembourg, EUR 24099 EN, Office for the Official Publications of the European Communities.

Yamato M., Okimori Y., Wibowo I.F., Anshori S., Ogawa M. (2006): Effects of the application of charred bark in *Acacia mangium* on the yield of maize, cowpea, peanut and soil chemical properties in south Sumatra, Indonesia. Soil Science and Plant Nutrition, 52: 489–495.

Yuan J., Xu R., Wang N., Li J. (2011): Amendment of acid soils with crop residues and biochars. Pedosphere, 21: 302–308.

Received on February 17, 2015
Accepted on October 19, 2015

Corresponding author:

Assoc. Prof. Manouchehr Gorji, University of Tehran, Department of Soil Science, Karaj, Iran
e-mail: mgorji@ut.ac.ir