International Research Journal of Pure & Applied Chemistry

21(9): 1-8, 2020; Article no.IRJPAC.57823
ISSN: 2231-3443, NLM ID: 101647669

Effect of Straw Biochar on Soil Acidity and Phosphorus Nutrition in Wheat

M. N. Rangaswami[1], G. C. Banik[1*], S. Rakesh[1] and K. T. Uma[2]

[1]Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India.
[2]Department of Seed Science and Technology, CCS Haryana Agricultural University, Hisar, Haryana, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author MNR performed the chemical analysis. Author GCB designed the study and wrote the first draft of the manuscript. Authors SR and KTU assisted in chemical analysis and data interpretation. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IRJPAC/2020/v21i930193
Editor(s):
(1) Hao-Yang Wang, Shanghai Institute of Organic Chemistry, China.
Reviewers:
(1) Johana E. Delgado, India.
(2) Alessandra Da Róz, Ciência e Tecnologia de São Paulo, Brazil.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57823

Original Research Article

Received 25 March 2020
Accepted 02 June 2020
Published 19 June 2020

ABSTRACT

Two biochars were produced from the rice and wheat residues by slow pyrolysis (at 400°C) in muffle furnace with an aim to study the effect of their application on some chemical properties of acidic soil such as pH, exchangeable acidity and cation exchange capacity (CEC) as well as their effect on phosphorus uptake by wheat in a greenhouse experiment. The incubation study was conducted incubating acidic soil (Typic Fluvaquent, pH 5.07) with assorted doses of biochars (0, 10, 20 and 60 g kg^{-1}) for 120 days. A dose of lime at half or the lime requirement was also added separately for comparison. Results indicated that incubation period (F, 84.81; Pr>F, <.0001) and application rate (F, 281.05; Pr>F, <.0001) had significant effects ($p < 0.05$) on the pH of soil. Both the biochars had significant effects on exchangeable acidity and CEC. Application of biochar derived from wheat residues showed relatively greater increase of soil pH. Graded doses (0, 5, 10 and 20 g kg^{-1}) of both biochar addition significantly increased the phosphorus uptake by different plant parts as well as yield of wheat in greenhouse experiment.

**Corresponding author: E-mail: gcbanik79@yahoo.co.in;*

Keywords: Rice biochar; wheat biochar; soil pH; exchangeable acidity; phosphorus uptake; wheat.

1. INTRODUCTION

Biochar is the carbon-rich product obtained when biomass, such as wood, manure, leaves and residues thermally decomposed at relatively low temperatures (<700°C) under limited supply of oxygen called pyrolysis [1]. This process often analogous to the production of charcoal which is one of the most ancient industrial technologies developed by mankind- if not the oldest [2]. However, biochar distinguishes itself from charcoal by the fact that it is produced with the intention to be applied to soil not only as a carbon sink but also as a mean of optimizing favorable soil physico-chemical condition and improving crop productivity. The effect of biochar as a soil amendment depends on its properties which is significantly influenced by feedstock source and pyrolysis conditions. These suggest detailed characterization of biochar before application to improve soil fertility [3]. Low-temperature biochars were noticed to have a less condensed carbon structure and were expected to give a greater reactivity in soil than high temperature biochar and also expected to give a better contribution to soil fertility [4]. Further, the carbonate content of biochar added is likely to increase acidic or neutral soil pH to more alkaline pH. This increased pH can effectively stimulate microbial activity, thereby may promote mineralization of existing soil organic matters and increases nutrient availability [5]. Biochar is also reported to reduce exchangeable acidity and increase the cation exchange capacity (CEC) of soil [6]. Such increase of soil pH with biochar application is reported to reduce sorption and precipitation of phosphorus (P) on reactive Al surfaces in acidic soil and thus increased the bioavailability of phosphorus [7]. Inherent P content of biochar may also influence the P availability in amended soil [8]. However, the extent, rates and implications of biochar application in acidic soil for favorable improvement are still far from being understood, and this knowledge is needed for an effective evaluation of the use of biochar as a soil amendment and tool for improvement of P bioavailability. Moreover, little information is available on the comparison between the amelioration effects of biochars derived from different straws on soil acidity and P availability. Therefore, the objective of the present study is to compare between amelioration effects of biochars prepared from easily available rice and wheat residues on an acidic soil of the *terai* agro-climatic zone situated at Himalayan flood-plain.

2. MATERIALS AND METHODS

2.1 Collection of Soil Sample

The soil for the present experiments was collected from surface layer (0-15 cm) from the instructional farm of Uttar Banga Krishi Viswavidyalaya (UBKV) at Pundibari (Cooch Behar II administrative Block), district: Cooch Behar, West Bengal, India (26°19′86″N, 89°23′53″E, altitude of 43 m a. s. l.). The soil was Typic Fluvaquent with sandy loam in texture having clay content 20.37%, pH 5.07 (1:2.5), EC 0.07 dSm^{-1}, Exchangeable acidity 0.23 $cmol(p^+)\ kg^{-1}$, oxidizable organic carbon 0.42%, CEC 4.08 $cmol(p^+)\ kg^{-1}$, bulk density 1.43 $g\ cc^{-1}$, available N 116.87 $kg\ ha^{-1}$, available P_2O_5 18.24 $kg\ ha^{-1}$, available K 108.43 $kg\ ha^{-1}$ and DTPA extractable Fe 192.86 $mg\ kg^{-1}$. The collected soil samples were dried under shade and powdered with wooden mortar and pestle and then passed through 2 mm brass sieve. The sample was then stored with proper label in paper bag for further analysis.

2.2 Biochar Preparation

Biochar was prepared from rice and wheat straws collected from the experimental fields of instructional farm of Uttar Banga Krishi Vishwavidyalaya. Air dried straws were separately placed in lidded stainless-steel containers for pyrolysis in a muffle furnace at 400°C for 4 hours. All possible care was taken to restrict the entry of air from outside into the muffle furnace. In this temperature biochar had predominantly amorphous carbon structure with lower aromaticity and relatively higher nutrient content [9]. After pyrolysis, biochar samples were cooled to room temperature and stored in air tight paper bags for use in the experiments. Wheat biochar had little more pH (7.69) than rice biochar (7.52). Total P content was also higher in wheat (0.27%, *w/w*) than rice (0.23%, *w/w*) biochar.

2.3 Determination of Effect of Biochar on pH and Other Properties of Soil

A laboratory incubation experiment was set to evaluate the effect of biochar on soil chemical properties by placing 200 g air dry soil samples in a number of plastic pots of 6 cm diameter and 10 cm deep and mixing these with rice and wheat biochar separately at application rate of 0, 10, 20 and 60 $g\ kg^{-1}$ of soil. Lime in the form of finely ground $CaCO_3$ was also added in another cup as separate treatment at a rate of 4 g kg^{-1} of soil. All the treatments were replicated thrice and the combinations were laid out in completely randomized design (CRD). The soil, lime and biochar were mixed thoroughly and then wetted with single distilled water to 70% of maximum water holding capacity of the soil. All cups were properly covered with plastic film and a small hole was made to allow gaseous exchange and was incubated at constant temperature of 25ºC. Sub-samples from each pot were taken at 15, 30, 45, 60, 75, 90, 105, 120 days for analysis. The incubation study was carried out (for 120 days) until the approximate steady state was achieved in chemical properties. These sub-samples were dried in air and ground to pass a 2- mm sieve, later, these soil samples were used to determine soil pH (soil:water :: 1:2.5). Exchangeable acidity was determined by extracting soil with 1.0 M KCl followed by titration with 0.25 M NaOH [10] and cation exchange capacity was measured by ammonium (pH 7.0) extraction method at the end of 120 days [11].

2.4 Determination of Effect of Biochar on P Nutrition of Wheat in a Greenhouse Experiment

In order to assess the phosphorus nutrition in wheat (*Triticum aestivum L.*) a greenhouse experiment was conducted during the winter season of 2017-2018 (November 2017 to March, 2018). Certified seeds of wheat (Variety HD-2967) were obtained from the Department of Genetics and Plant Breeding, UBKV. The clay pots (25 cm in diameter and 20 cm in height) were filled with 4 kg of soil collected from the instructional farm of UBKV. Prior to pot filling the soil was mixed with rice and wheat biochar separately at application rates of 0, 5, 10 and 20 g $kg^{-1}$of soil (*w/w*) as treatments. All these treatments were replicated thrice and were arranged in completely randomized design. Wheat seeds (initially 6-7 seeds pot^{-1}) were sown in each pot. Seven days after germination only 4 plants pot^{-1} were maintained to grow till maturity. Doses of fertilizers (150:60:40 kg of NPK ha^{-1}) were added as per recommendation following proper agronomic practices. In control pot no biochar was added. The fertilizer sources of N, P and K were urea, SSP and MoP, respectively. Full doses of P and K were applied as basal, 50% of the N was applied as basal and 25% at crown root initiation (CRI) stage and remaining 25% at grain filling stage. Single-distilled water was used for irrigation throughout the growing period maintaining field water capacity and appropriate plant protection measures were also followed. The yield of wheat and uptake of P by plant parts were determined at maturity. Plant parts were washed, oven dried and weighed. Estimation of P in plant samples was carried out by vanadomolybdo-phosphoric yellow colour method. The available P content of the harvested soil was also analyzed.

2.5 Statistical Analysis

One-way analysis of variance (ANOVA) was performed for data derived from all the experiments using statistical analysis system (version 9.2, SAS Institute Inc., Cary, North Carolina, USA). Significant effects of various treatments in both incubation and greenhouse experiments were analysed using *t-test* [12].

3. RESULTS AND DISCUSSION

3.1 Effect of Biochar on pH and Other Properties of Soil

Results shows that soil pH significantly increased with increase in biochar application rate (from 0 to 60 g kg^{-1}), lime addition and incubation period (Table 1). The highest pH attained was 7.72 and 7.61 for 60 g kg^{-1} rice and wheat biochar, respectively in 120 days whereas the lime increased the pH up to 6.73. This may because the lime was added half of the lime requirement. Biochars and lime application caused the significant rapid increase of soil pH within the first 15 days of incubation. Within the first 15 days pH increased by 0.45, 0.76 and 1.24 units with addition of rice biochar at 10, 20 and 60 g kg^{-1} whereas for same doses of wheat biochar the pH increased by 0.56, 0.85 and 1.38 units, respectively. Thereafter the pH changes were gradually lowered down. Wheat biochar was found more effective to increase pH than rice biochar at 10 g kg^{-1} application rate. Addition of 10 g kg^{-1} rice biochar increased pH 0.45, 0.48, 0.66, 0.77, 0.82, 0.91, 0.94 and 1.05 units from the initial pH in 15, 30, 45, 60, 75, 90, 105 and 120 days, respectively where as for the wheat biochar the corresponding pH increase was 0.56, 0.75, 0.84, 0.93, 1.09, 1.15, 1.24 and 1.38 units. However, at the higher doses i.e., at 20 g kg^{-1} and 60 g kg^{-1} the effect of each biochar was almost comparable. Overall unit increase of soil pH per unit increase of biochar application was significantly higher in wheat biochar than rice biochar. This may be due to the higher pH of wheat biochar (7.69) than the rice biochar (7.52).

Higher $CaCO_3$ content of biochar and release of base cations was suggested as responsible for increase of soil pH [6]. Al saturation of acid soil also might be decreased during incubation and resulted the increase of pH upon addition of biochar [13]. The result is also consistent with previous studies that incorporation of biochar significantly increased the pH of acidic soils [14].

Analysis of variance (Table 2) showed that incubation period (F, 84.81; Pr>F, <.0001), and application rate (F, 281.05; Pr>F, <.0001) had significant effects ($p < 0.05$) on the pH of this acidic soil. But replications did not show significant effect. It was observed from the Tukey test ($\alpha = 0.05$) that there was not much significant difference between the rice and wheat biochar at the same corresponding doses. However, there was significantly sharp increase of pH on addition of biochar over the control in all incubation time range.

Addition of both biochars and lime decreased down the exchangeable acidity on completion of 120 days incubation period than the control unamended soil (Fig. 1). The exchangeable acidity decreased more for the lime addition followed by rice biochar at application rate of 60 g kg^{-1}. However, the wheat biochar was found more efficient to decrease the exchangeable acidity at the lower doses than the rice biochar. As this exchangeable acidity was measured for incubated soil and soil-biochar mixtures after the completion of 120 days of incubation period when the pH of the samples was significantly increased, the precipitation of soluble and exchangeable Al^{3+} ions as insoluble hydroxyl Al-species at the higher pH condition may be responsible for such decrement of exchangeable acidity [15]. Apart this, the release of base cations from biochars incorporated in acidic soil participate in exchange reactions and replace the exchangeable Fe^{3+} and Al^{3+} and H^+ on the soil surface and thereby decrease the soil exchangeable acidity.

The CEC of the incubated soil increased upon addition of both biochars and lime than the control soil where no amendment was added (Fig. 2). The CEC value increased gradually with increased doses of both biochar. The rice biochar was found to increase more CEC than wheat biochar and lime. However, the maximum CEC was recorded for rice biochar @ 60 g kg^{-1}. Such increase of CEC for biochar and lime addition may be due to the increase of soil pH on completion of incubation period which possibly made the soil surface more negative [16]. The increased CEC of soil-biochar mixtures may also be due to slow oxidation of biochar materials during incubation which oxygenate the functional groups present at biochar surface and also enhance the formation of organo-mineral complexes [17]. In general, the biochars have high charge density per unit surface than soil [18]. Incorporation of biochar in soil increases the charge density of biochar mixed soil and thus, may enhance the CEC or cation sorption capacity of soil.

3.2 Effect of Biochar on Phosphorus Nutrition of Wheat

Findings from the greenhouse experiment shows that the uptake of phosphorus by different plant parts increased significantly with addition of both biochar over control (Table 3). The rice biochar at 0.5%, 1% and 2% of soil (*w/w*) significantly increased total P content of leaves over control by 33.62%, 55.17% and 72.84% respectively and wheat biochar increased it was 26.15%, 29.08% and 52.01% respectively. It was observed that the total P content in shoot of wheat increased more than that of in leaves. In shoot P content was increased by 93.5%, 108.3%, and 132.5% for rice biochar and 58.4%, 76.5% and 98.2% for wheat biochar over control. In root the P content significantly increased 79.84%, 99.24% and 135.4% for the rice biochar and 72.88%, 94.16% and 118.2% for wheat biochar over control. Rice biochar was found more effective for P uptake by wheat crop than wheat biochar. This difference might be due to differences in the ability of these biochars to supply P to the growing plant [19]. The increased uptake of P by plant parts with increased doses of biochars might be attributed to release of more P due to solubilization of Fe/Al-phosphate compounds with increased pH for biochar application. The biochar itself contain and supply the phosphorus to the soil. The application of biochar with an additional application of fertilizer increased soil pH, organic C and exchangeable cations, and subsequently, this resulted in an increased P uptake [20]. This may also have resulted in increased available phosphorus status in pot soil at harvest.

The increased yield of the wheat (Fig. 3) may be due to the release of more P from soil with increased doses of biochar addition in this acidic soil. The acid neutralizing capacity or liming effect of biochars has also been considered as the major mechanism by which productivity of wheat might be increased [21]. Furthermore, the lower temperature biochar as used in present

Table 1. Effect of biochar on soil pH in laboratory incubation studies

Treatments	pH							
	Number of days in incubation							
	15	30	45	60	75	90	105	120
T_1 Control (0 g kg^{-1} soil)	5.07_e	5.07_e	5.07_f	5.07_e	5.07_d	5.09_e	5.08_e	5.09_f
T_2 Rice biochar (10 g kg^{-1} soil)	5.52_{cd}	5.55_d	5.73_{ed}	5.84_d	5.89_c	5.98_d	6.01_d	6.12_e
T_3 Rice biochar (20 g kg^{-1} soil)	5.83_{cb}	5.95_{cb}	6.14_{cb}	6.32_b	6.55_b	6.72_b	6.94_b	7.23_c
T_4 Rice biochar (60 g kg^{-1} soil)	6.31_a	6.45_a	6.63_a	7.03_a	7.23_a	7.38_a	7.46_a	7.72_a
T_5 Wheat biochar (10 g kg^{-1} soil)	5.63_{cb}	5.82_c	5.91_{cd}	6.00_c	6.16_c	6.22_{cd}	6.31_c	6.45_d
T_6 Wheat biochar (20 g kg^{-1} soil)	5.92_b	6.13_b	6.25_b	6.43_b	6.62_b	6.88_b	7.12_b	7.35_{bc}
T_7 Wheat biochar (60 g kg^{-1} soil)	6.45_a	6.58_a	6.82_a	7.13_a	7.32_a	7.45_a	7.52_a	7.61_{ba}
T_8 lime (4 g kg^{-1} of soil)	5.24_{ed}	5.42_d	5.65_e	5.83_{cd}	6.14_c	6.38_c	6.51_c	6.73_d
SE (m)	0.067	0. 043	0.047	0.042	0.070	0.051	0.057	0.063
CD (0.05)	0.335	0.218	0.236	0.214	0.352	0.257	0.286	0.317
CV (%)	2.024	1.291	1.363	1.202	1.919	1.371	1.503	1.624

Note: Different letters in the same column represents significant differences by Tukey's test at α = 0.05. Means with the same letter are not significantly different

Table 2. ANOVA for the data of effect of biochar on soil pH using general linear model (GLM) procedure

Source	Degrees of freedom	Mean square	F value	Pr > F
Incubation period	7	3.27932394	84.81	<.0001
Replication	2	0.00563345	0.15	0.8645
Treatment	7	10.86660370	281.05	<.0001

Table 3. Effect of biochar on phosphorus uptake by different plant parts after harvest and residual phosphorus content in soil

Treatment	Total P in wheat leaves (mg kg^{-1})	Total P in wheat shoots (mg kg^{-1})	Total P in wheat roots (mg kg^{-1})	Residual phosphate in soil (mg kg^{-1})
T_1 Control (0 g kg^{-1} soil)	1160	1001.6	885	16.2
T_2 Rice biochar (5 g kg^{-1} soil)	1550	1938.3	1591.6	43.6
T_3 Rice biochar (10 g kg^{-1} soil)	1800	2086.6	1763.3	59.8
T_4 Rice biochar (20 g kg^{-1} soil)	2005	2328.3	2083.3	67.5
T_5 Wheat biochar (5 g kg^{-1} soil)	1463.3	1586.6	1530	33.1
T_6 Wheat biochar (10 g kg^{-1} soil)	1613.3	1768.3	1718.3	38.1
T_7 Wheat biochar (20 g kg^{-1} soil)	1763.3	1985	1930	50.0
SE (m)	55.13	33.47	39.17	3.79
SE (d)	77.96	47.3	55.4	5.36
CD (0.05)	168.83	102.5	119.98	11.60
CV (%)	5.88	3.19	4.13	14.47

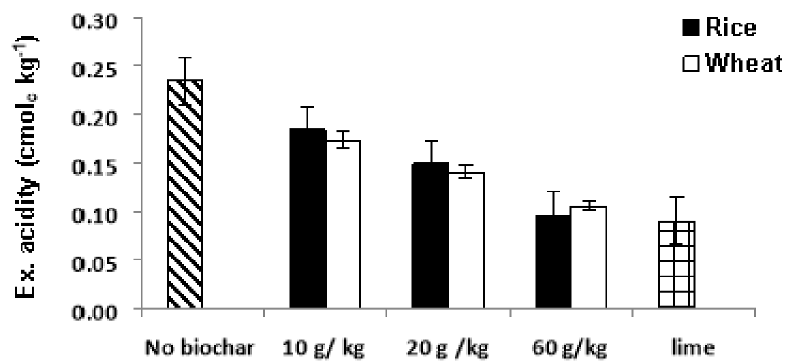

Fig. 1. Effect of biochar and lime on exchangeable acidity of soil
Error bars indicate standard error of mean-SEm

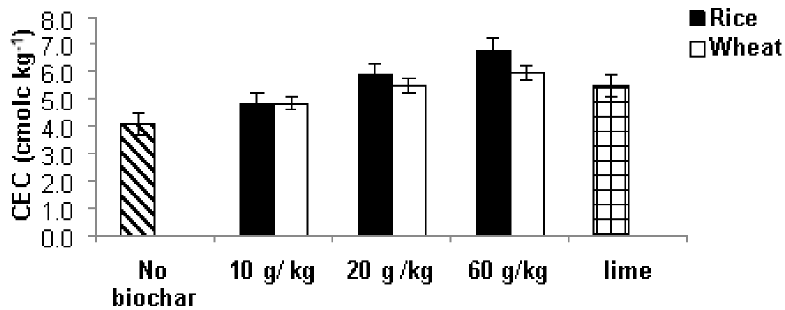

Fig. 2. Effect of biochar and lime on CEC of soil
Error bars indicate standard error of mean-SEm

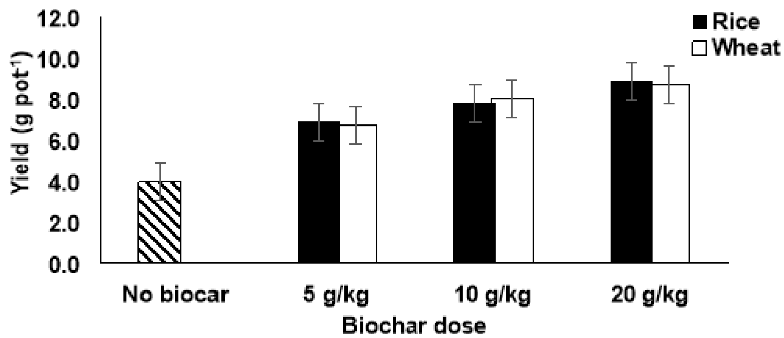

Fig. 3. Effect of rice and wheat biochar on yield of wheat
Error bars indicate standard error of mean-SEm

study increased the crop yield due to their higher available nutrient contents that provide a greater contribution to soil fertility [4].

4. CONCLUSION

Results from incubation study demonstrated the effectiveness of both rice and wheat biochars in ameliorating soil acidity which increased the pH and CEC of the acidic soil and lowered down the exchangeable acidity. Wheat biochar was more found effective for increase of pH and decrease of exchangeable acidity. However, CEC increased more for the biochar derived from rice. Soil application of biochar in higher doses (>21 Mg ha^{-1}) may have similar effect as lime in acid soil amelioration. Both the biochars exhibited positive effect on phosphorus uptake by the different plant parts as well as yield of wheat in the greenhouse experiment due to the dissolution and subsequent release of phosphorus from fixed source of Fe/Al phosphate compounds. Further inherent P content of both biochars might also have contributed to the increased P uptake by wheat. The incorporation of these highly carbonaceous biochar materials in soil can induce ameliorating effect on the soil acidity and improve the bioavailability of phosphorus.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Lehmann J, Joseph S. Biochar for environmental management: Science and technology. Earthscan Publications Ltd. London; 2009.
2. Harris P. On charcoal. Inter Sci Rev. 1999;24(4):301-306.
3. Singh B, Singh BP, Annette LC. Characterisation and evaluation of biochars for their application as a soil amendment. Aus J. Soil Res. 2010;48(7): 516-525.
4. Steinbeiss S, Gleixner G, Antonietti M. Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biol Biochem. 2009;41(6):1301–1310.
5. Van Zwieten LS, Kimber A, Downie KY, Chan A, Cowie R, Wainberg R, et al.

Papermill char: Benefits to soil health and plant production. In Proceedings of the Conference of the International Agrichar Initiative, 30 April- 2 May, 2007. Terrigal, NSW, Australia; 2007.

6. Chintala R, Mollinedo J, Schumacher TE, Malo DD, Julson JL. Effect of biochar on chemical properties of acidic soil. Arch Agron Soil Sci. 2014;60(3):393-404.
7. Shen Q, Hedley M, Arbestain MC, Kirschbaum MUF. Can biochar increase the bioavailability of phosphorus? J. Soil Sci Plant Nutri. 2016;16(2):268-286.
8. Wang T, Camps-Arbestain M, Hedley M. The fate of phosphorus of ash-rich biochars in a soil-plant system. Plant Soil. 2014;375(1-2):1–14.
9. Joseph SD, Camps-Arbestain M, Lin Y, Munroe P, Chia CH, Hook JV, et al. An investigation into the reactions of biochar in soil. Aus J. Soil Res. 2010;48(7):501-515.
10. Farina MPW, Channon PA. A field comparison of lime requirement indices for maize. Plant Soil. 1991;134(1):127–135.
11. Sumner ME, Miller WP. Cation exchange capacity and exchange coefficients. In Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Editors. Methods of soil analysis. Part 3: Chemical Methods. SSSA Book Series 5. Madison (WI): SSSA. 1996;1201-1230.
12. Tukey JW. The collected works of John W. Tukey VIII. Multiple Comparisons: 1948–1983. New York, USA: Chapman and Hall; 1994.
13. Yuan JH, Xu RK. The amelioration effects of low temperature biochar generated from nine crop residues on an acidic ultisol. Soil Use Manage. 2011;27(1):110–115.
14. Streubel JD, Collins HP, Garcia-Perez M, Tarara J, Granatstein D, Kruger CE. Influence of contrasting biochar types on five soils at increasing rates of application. Soil Sci Soc Am J. 2011;75(4):1402–1413.
15. Ritchie GSP. Role of dissolution and precipitation of minerals in controlling soluble aluminium in acid soils. Ad. Agron. 1994;53(1):47–83.
16. Steiner C, Teixeira WG, Lehmann J, Nehls T, Macêdo JLV, Blum WEH, et al. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil. 2007;291(1):275–290.
17. Glaser B, Haumaier L, Guggenberger G, Zech W. The Terra Preta phenomenon -a model for sustainable agriculture in the humid tropics. Naturwissenschaften. 2001; 88(1):37–41.
18. Liang BL, Solomon J, Kinyangi D, Grossman J, O'Neill, Skjemstad B, et al. Black carbon increases cation exchange capacity in soils. Soil Sci Soc Am J. 2006;70(5):1719–1730.
19. Madiba OF, Solaiman ZM, Carson JK, Murphy DV. Biochar increases availability and uptake of phosphorus to wheat under leaching conditions. Bio Fert Soil. 2016;52(4):439–446.
20. Chan KY, Van Zwieten, Meszaros I, Downie A, Joseph S. Agronomic values of green waste biochar as a soil amendment. Aus J Soil Res. 2007;45(8):629–634.
21. Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust S, et al. Effects of biochar from slow pyrolysis papermill waste on agronomic performance and soil fertility. Plant Soil. 2010;327(1-2):235–246.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/57823