Advance Journal of Food Science and Technology 9(7): 539-545, 2015
DOI: 10.19026/ajfst.9.1962
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: March 25, 2015 Accepted: April 22, 2015 Published: September 05, 2015

Research Article

Effects of Biochar on Chemical Properties of Three Types of Soil and Nutrient Uptake of Maize under Drought Stress

[1, 2]ThiHuong Nguyen, [1]Yanan Tong, [3, 4]NhuTrung Luc and [1]Cheng Liu
[1]College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, Shaanxi, China
[2]Department of Natural Resources and Environment of Laocai 330100, Vietnam
[3]Institute of Soil and Water Conservation, Northwest A&F University, Yangling 712100, Shaanxi, China
[4]Department of Agricultural and Rural Development of Laocai 330100, Vietnam

Abstract: This study was conducted to determine the effects of biochar on the chemical properties of three types of soils and the nutrient uptake and yield of the maize plant grown on the soils. The experimental results are as follows: (i) In Loess soil, when the biochar application rate was 15 t/ha, the soil chemical properties was barely improved, but the nutrient uptake of maize was obviously improved. The amount of biochar application was at 30 t/ha, the result was just on the contrary and 60 t/ha application of biochar performed a poor effect on the soil chemical properties as well as on the nutrient uptake of maize. (ii) In sandy soil, when the application of biochar reached to 15 t/ha, there were not remarkable effects on soil chemical properties and moderate promoting effect on nutrient uptake of maize. Additionally, the biochar application at a rate of 30 t/ha led to a small effect on the both, but 60 t/ha amount made a significant improvement in both. (iii) In loessal soil, applying 15 t/ha biochar to soil had a moderate effect on chemical properties' improvement, but the promotional effect on nutrient uptake of maize is poor. When the amount of biochar application was at 30 t/ha, soil chemical properties were significantly improved but the effect on nutrient uptake of maize was moderate. However, 60 t/ha biochar application obviously improved nutrient uptake of maize, but the effect of chemical properties improvement was poor.

Keywords: Arid soil, biochar, chemical properties, maize, nutrient uptake

INTRODUCTION

Biochar is a kind of carbon mixture got through pyrolysis and carbonization of organic matter under hypoxia circumstance, with highly aromatic components, good biochemistry and thermal stability. Researchers get to know it from black soil in Amazon basin, South American (Grossma *et al*., 2010). The studies indicated that applying biochar in soil is favorable to form water stable aggregate, to decrease soil volume weight and to increase soil aeration (Steiner *et al*., 2007; Laird *et al*., 2010). Moreover, for the high porosity, large surface area and negative charges and high charge density, application of the biochar could improve soil Cation Exchange Capacity (CEC) (Laird *et al*., 2010), influence the base saturation, decrease soil pH (Van *et al*., 2010) and reduce nutrient leaching, so as to improve fertility efficiency (Chan *et al*., 2007). In addition, biochar can increase the biological activity of soil by providing living environment and suitable water and nutrient conditions for microorganism in soil (Lehmann *et al*., 2011).

Until now, there were many researches pointed out that biochar has positive effects on soil properties improvement and crop nutrient uptake capacity and crop yeild (Liu *et al*., 2012; Major *et al*., 2009). However, most of researches about the soil improvement and yield increasing effects were conducted under suitable environment and a small number of researches about the biochar effects on soil properties and plant growth were conducted under stress environment. Although, soil properties have significant effects on biochar function (Laird *et al*., 2010; Lehmann and Joseph, 2009; Schulz and Glaser, 2012), there is a wide spread dispute on its effects on soil improvement and crop yield. Therefore, the effects of applying biochar to different areas should be further studied specifically.

Drought is one of the most common natural disasters in Northwest China. Water deficiency would decrease fertilizer efficiency and increase soil solution

Corresponding Author: Yanan Tong, College of Natural Resources and Environment, Northwest A&F University, Yangling Shaanxi 712100, China

concentration which hinder plant root growth and inhibit plant nutrient uptake and decrease crop yield. However, biochar can improve soil water retention (Kimetu and Lehmann, 2010) and improve soil nutrient effectiveness and promote plant nutrient uptake to some degree. Therefore, applying biochar to dry soil can recover physical, chemical and biological properties of soil and crop nutrient level (Oguntunde *et al*., 2008; Huang *et al*., 2011). But it still needs to be studied about the effect of applying biochar to arid agricultural areas in Northwest China. In order to provide theoretical basis for applying biochar to agriculture in arid areas, three kinds of common agricultural soils such as loess soil, sandy soil and loessal soil in Northwest areas were taken and as a crop maize were considered which one of widely planted crops. Then, as research subjects, this paper studies the effects of biochar on three types of soils' chemical properties and on the nutrient uptake and yield of the maize planted in theses soils.

MATERIAL AND METHODS

Studied materials: The loess soil was collected from the 3rd experimental station of Northwest A&F University, Yangling, China and the sandy soil was collected from the farmer fields in Weihe riversides, Yangling, China. The studied loessal soil is from Fangjiahe village, of Yan'an, China. Then, the basic chemical properties of the soils were measured using 0-20 cm depth soil samples and given in Table 1. As a planting material Zhengdan 958 maize cultivar was used for our experiment. The studied biochar, bought from Shangqiu Sanli New Energy Co., Ltd. Henan, China, was produced with pyrolysis of wheat straw at 350-550°C. Prior to experiments, biochar material was ground and passes through a 2 mm sieve to obtain homogenized sample. Next, the basic properties of biochar were measured and given in Table 2.

Pot experiment: Three treatments and two types of control experiments (without biochar under drought stress and suitable moistened) were conducted for each soil. In treatments, biochar was applied to soil with 3 levels (15 t/hm^2, 30 t/hm^2 and 60 t/hm^2), respectively. Moreover, each soil types were applied nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) fertilizer (urea, single superphosphate and potassium chloride for each) as the basic fertilizer, with the amount of 360 kg N/ha, 120 kg P_2O_5 /ha and 150 kg K_2O/ha, respectively (1.44 g N, 0.48 g P_2O_5, 0.6 g K_2O for each pot). After mixing up the soil with biochar and fertilizers, the mixture was put in the planting pots with 28 cm in diameter, 38 cm in height, 12 kg soil (converted to the dry soil quantity) for each pot. Each processing experiment had 8 pots, a half of which were controlled as containing 60% of the maximum field capacity as the suitable soil moisture and the other 4 pots of which were controlled containing 40% of the maximum field capacity as drought stress. From June 2nd, 2014 to October 5th, 2014, maize were planted (one plant per pot). From the beginning to the maize maturity, soil moister content was detected regularly and water was supplemented according to the water loss.

Index measurement: To measure the weight of maize, cut off the maize ears from the base of stem by scissors and wrap them in clean paper. Then, placed them in a oven for 30 min at 105°C and baking at 65°C to gain a constant weight. Subsequently, the harvested plants and grains are tested for nutrient content. Further, the soils in the planting pots were cleaned with removing the plant residues and mixing the soil up. Next, soil samples were sieved through a 1 mm sieve for testing chemical properties. For testing the soil pH, glass electrode method was adopted, with water soil ratio being 2.5:1. The method of sodium acetate-flame photometry was exploited to test the Cation Exchange Capacity (CEC). The Sulfuric acid and potassium dichromate external heating method was utilized for determining Total Organic Carbon (TOC). The 1 mol/L KI extraction-flow analyzer was used for available nitrogen in the soil. Molybdenum antimony anti-colorimetric method and ultraviolet spectrophotometer were carried out to test available phosphorus. The available K was obtained by 1 mol/L NH_4OAc extraction-flame analyzer. After the soil sample was observed a constant volume then: digested with sulfur-catalyst and the content of total N were tested by automatic intermittent chemical analyzer (Cleverchem 200); digested with nitric acid, perchloric acid and hydrofluoric acid, the content of total P were tested by automatic intermittent chemical analyzer and consequently total K was measured by flame photometer.

After digested the plant samples with H_2SO_4-H_2O_2, they (plant/gain) were analyzed by automatic intermittent chemical analyzer (Cleverchem 200) to test the content of total N and total P and then flame photometer was used to measure the content of total K.

Table 1: The basic chemical properties of the topsoils (0-20 cm)

	pH	Organic matter %	CEC cmol/kg	Available nutrient contents of soil K mg/kg	N mg/kg	P mg/kg
Loess soil	7.68	2.32	22.58	193.24	39.45	6.75
Sandy soil	8.29	1.08	9.79	53.54	22.56	8.17
Loessal soil	8.26	1.44	11.12	145.25	33.38	4.35

Table 2: The basic properties of biochar

pH	CEC cmol/k	Organic carbon g/kg	Total N g/kg	Total P g/kg	Total K g/kg	Ash content %
10.35	21.75	465	5.91	0.62	25.03	20.51

Data processing: All data were processed with MS Office 2010 and IBM SPSS 20.0: T-test was performed to analyze the significant difference between the values of soil and maize indexes under arid and suitable moisture controlled conditions. For the samples with different amounts of biochar application at the same moisture condition, data were analyzed using one-way ANOVA. The least significant difference method was carried out for multiple comparison. For all statistical analysis, p-value with $p \leq 0.05$ was considered as significant level.

The biochar has different degrees of effects on indexes of arid soil chemical properties and nutrient uptake of maize. Therefore, to evaluate the overall improvement effects of applying biochar on the above two indexes, the principal component analysis was performed to apply the arid soil with biochar. The increasing rates of all indexes of soil chemical properties and nutrient uptake of maize were compared with the controlled samples which were analyzed by descending factor analysis method. The F value which refers to the comprehensive principal component was evaluated as the overall effects of biochar application. The higher F-values indicate the more significant effects of applying biochar to improve the soil chemical properties and nutrient uptake of maize.

RESULTS AND ANALYSIS

Effects of biochar application on three types of soils chemical properties under drought stress: Under drought treatment (Table 3), the content of organic matter and total P in loess soil was significantly decreased compared with control sample. But the content of available nitrogen was considerably increased. The chemical properties of sandy soil were not changed greatly. Among the three tested soils, loessal soil was the most sensitive to the drought

Table 3: Effects of biochar on the chemical properties of soils under drought stress

Soil type	Biochar t/ha	Soil moisture content %	Organic matter %	CEC cmol/kg	TOC mg/kg	Soil available nutrient content N mg/kg	P mg/kg	K mg/kg	Total soil nutrients content N g/kg	P g/kg	K g/kg
Loess soil	0	60	2.48	70.66	5.86	47.51	7.52	174.44	1.31	0.56	14.35
		40	2.23*c	69.87b	6.10a	65.30*c	6.91b	215.28d	1.32a	0.44*b	14.30b
	15	40	2.53bc	114.53a	5.45a	70.66b	7.86b	305.12c	1.36a	0.51a	15.60a
	30	40	2.96ab	114.66a	4.30a	75.27a	10.11a	431.71b	1.26a	0.57a	14.98ab
	60	40	3.25a	110.24a	5.73a	69.15b	7.86b	576.68a	1.39a	0.52a	15.18ab
Sandy soil	0	60	1.19	49.57	5.21	12.68	5.77	33.56	0.44	0.58	7.84
		40	1.05c	49.84c	4.70a	13.69a	6.16a	35.60c	0.46c	0.55a	7.43b
	15	40	1.31bc	70.27a	4.57a	7.11bc	5.82a	62.14c	1.05a	0.47b	7.87b
	30	40	1.65b	69.61b	4.21a	5.55c	6.16a	123.40b	0.61b	0.52a	7.80b
	60	40	2.05a	49.18d	4.74a	8.46b	6.82a	368.41a	0.57bc	0.52a	8.92a
Loessal soil	0	60	1.21	15.66	6.05	23.55	4.85	84.60	0.75	0.25	11.61
		40	1.20c	16.44*a	4.49*a	28.10*b	4.78b	82.56c	0.43*c	0.25b	11.93a
	15	40	1.62b	16.70a	4.05a	35.75a	4.91b	174.44b	0.57bc	0.37a	11.91a
	30	40	1.90a	15.13b	3.64a	23.66c	5.90a	292.87a	0.87a	0.21b	11.68a
	60	40	1.71b	16.18a	4.38a	11.03d	5.77a	305.12a	0.65b	0.28b	11.77a

*: Refers that drought treated soil properties has significant difference compared with the control one; The lower-case letters stand for the soil chemical properties varying when the amount of biochar application is different and p<0.05; The soil moisture content is represented by the percentage of maximum field capacity; CEC is short for cation exchange capacity and TOC for total organic carbon

Table 4: The effects of applying biochar on soils' chemical properties under drought stress

Biochar t/ha	FC %	Loess soil Plant g/kg N	P	K	Grain g/kg N	P	K	Sandy soil Plant g/kg N	P	K	Grain g/kg N	P	K
0	60	8.00	0.05	27.67	6.68	0.09	2.28	2.97	0.11	12.60	6.13	0.14	3.11
	40	7.53b	0.06a	28.51c	6.97c	0.09b	2.24ab	4.28*a	0.09*a	8.72*d	9.11*a	0.10*b	2.57a
15	40	6.67b	0.07a	38.77a	9.33a	0.10ab	2.58a	3.67ab	0.09a	25.91b	8.27c	0.10b	2.73a
30	40	9.03a	0.06a	35.67b	7.45bc	0.07c	1.92b	3.12b	0.06b	20.15c	7.78d	0.12a	2.98a
60	40	9.10a	0.06a	35.00b	8.18b	0.11a	1.95b	3.43b	0.08ab	36.83a	8.81b	0.11ab	3.26a

Biochar t/ha	FC %	Loessal soil Plant g/kg N	P	K	Grain g/kg N	P	K
0	60	4.77	0.04	26.36	10.68	0.12	2.60
	40	4.52a	0.05*b	24.95d	10.74a	0.15*c	2.75b
15	40	3.81b	0.07a	30.36c	8.32b	0.09d	2.29c
30	40	3.88b	0.07a	35.58b	10.10a	0.19a	2.20c
60	40	4.53a	0.06b	38.59a	10.23a	0.16b	3.39a

*: Refers that drought treated nutrient content has significant difference compared with the controll one; The lower-case letters stand for the content of nutrient varying when the amount of Biochar application is different and p<0.05; The soil moisture content is represented by the percentage of maximum field capacity

treatment that its TOC and total N content were significantly reduced and its cation exchange capacity and available nitrogen content were remarkably increased.

By adding biochar, all three types of soil chemical properties were changed (Table 3). In arid loess soil, 15 t/ha biochar application did not show a significant difference in soil organic matter content, but 30-60 t/ha biochar application increased the organic matter content by 33-46%. The amount of applying biochar ranging from 15 t/ha to 60 t/ha could significantly increase the cation exchange capacity and the content of total P, available nitrogen and also available K. However, different biochar applying amounts just showed indistinctive effects on CEC and total P content, while 30 t/ha biochar application had the highest effect on improving available K content (15% increased). As the increase of the amount of applied biochar, the available K content was increased by 101-168%. Additionally, when the application amount of biochar reaching to 15 t/ha, the total K content of the soil significantly increased by 9%.

In arid sandy soil, the content of organic matter, available K and total P were remarkably increased due to the application of 30-60 t/ha biochar. The incremental effects of biochar on organic matter and available K contents increased with the increasing biochar applying amounts. As to the total K content of the soil, only when the application reached to 60 t/ha, is it significantly increased by 20%. The cation exchange capacity and total N content of the arid sandy soil were gradually declined when increase the amount of biochar application. Even when the application reached to 60 t/ha, biochar significantly reduced the cation exchange capacity by 1%. Therefore, it is worthwhile to note that biochar greatly reduces the content of available nitrogen content and when the application reaches to 30 t/ha, the nitrogent content reduces by 59%.

In arid loessal soil, the biochar application led to increase in the contents of organic matter and total N, the former increasing the most significantly as the application reaches to 30 t/ha while the latter increasing the most significantly when the application reaches to 30-60 t/ha. The application of 30-60 t/ha biochar significantly enhanced available phosphorus and total P content, but the effect on the latter is weaken as the amount of biochar increased. When the biochar application amount was at 15 t/ha, the content of available nitrogen was significantly increased. Then, available nitrogen content was reduced with increasing the amount of biochar application and the large amount of biochar application caused to great decline the available nitrogen content.

Effects of applying biochar to three types of soils on nutrient uptake of maize under drought stress: Under drought stress, the nutrient uptake of maize presented significant difference in three types of soils (Table 4). The experimental results show that in loess soil, the drought had no considerable effects on nutrient uptake of maize. But in sandy soil, the N content of both maize plant and the grains were higher than the control, while the P and K content of plant and P content of the grains were lower than the control. In loessal soil, among all tested plants and grains, only phosphorus of plants and gains was significantly higher than the controll.

In the arid loess soil added with biochar, when the amount of application reached to 30-60 t/ha, N content of the plants was significantly increased, while 15-60 t/ha application increased potassium content of the plants, but the most significant increase in plant K content (36%) occurred only when the application reaches to 15 t/ha. Besides, both applying 15 t/ha and 60 t/ha biochar can increase the content of N in maize grains. Applying biochar 30 t/ha reduced the phosphorus content of the maize grains, but 60 t/ha biochar application had shown opposite result.

In the arid sandy soil added with biochar, when the amount of application reached to 30-60 t/ha and 30 t/ha, both nitrogen and phosphorus content of the plants were significantly reduced. The 15-60 t/ha biochar application greatly increased the potassium content of the plants and the incremental effects enhanced with the increasing biochar application amount. In contrast, the same amount of application of 15-60 t/ha significantly reduced the nitrogen content of the maize grains and the large reduction of nitrogen content was observed when the application reached at 30 t/ha. Only 30 t/ha application of biochar significantly increased the phosphorus content of maize grains.

Applying biochar to the arid loessal soil, when the amount reached to 15-30 t/ha, the nitrogen content of plants is significantly reduced but the phosphorus content increased. Consequently, the potassium content was also increased. Under the condition that the amount was 15 t/ha, the nitrogen content of the maize grains was significantly reduced. While 30 t/ha amount of application greatly reduced phosphorus content of maize grains, 30-60 t/ha greatly increases it. What is similar to the effect on the potassium content of the maize grains that 15-30 t/ha amount of application significantly reduces it but 60 t/ha increases it.

The overall effect of applying biochar: Considering that biochar has different degrees of effects on indexes of arid soil chemical properties and nutrient uptake of maize, this study carried out the method of principal components analysis to comprehensively analyzes the increasing rate of the soil chemical properties and maize nutrient uptake indexes values comparing with the CK values. The results show as followings (Table 5) in loess soil, 15 t/ha application of biochar had poor effect on improving soil chemical properties but it had

Table 5: The comprehensive principal value F of the increasing rate comparing the soil chemical properties and nutrient uptake of maize applied with biochar with the controll samples

	Loess soil		Sandy soil		Loessal soil	
Biochar t/ha	Soil chemical properties	Nutrient uptake	Soil chemical properties	Nutrient uptake	Soil chemical properties	Nutrient uptake
15	-1.36	2.08	-1.10	0.32	0.65	-1.72
30	1.85	-1.44	-1.14	-1.47	1.94	0.21
60	-0.50	-0.64	2.25	1.16	-2.15	1.52

significant promoting effect on nutrient uptake of maize, while 30 t/ha application was observed opposite result and 60 t/ha application obtained both effect moderately. In sandy soil, the effects on improving soil chemical properties were poor and on promoting nutrient uptake of maize were in the medium level, when the application of biochar reaches to 15 t/ha, but both two effects were poor when the amount reaches to 30 t/ha, while both effects were significant when the amount reached to 60 t/ha; in loessal soil, applying biochar 15 t/ha to soil improved soil chemical properties moderately and poorly promoted maize nutrient uptake, but when the application was at 30 t/ha, the soil chemical properties was efficiently improved whereas the maize nutrient uptake was only moderately improved, while 60 t/ha application greatly promoted the maize nutrient uptake and poorly improved the soil chemical properties.

CONCLUSION AND DISCUSSION

The experimental results showed that drought stress has caused decreasing the organic matter and total P content in loess soil. However, it increased the available nitrogen content in loess soil. Further, drought stress declined the TOC and total N content while increased the cation exchange capacity and the content of available nitrogen in loessal soil, but there was no significant effects on the soil properties of sandy soil. In most cases, applying biochar to the arid soil has positive effect in improving cation exchange capacity and organic matter content of the soil, which is similar to the findings of Liang *et al.* (2006). The reason is that biochar has a large surface area and is rich in oxygen-containing groups (carboxyl and hydroxyl for example), oxidization of which can increase the number of such groups. Moreover, the large amount of negative charges carried by these groups make a high cation exchange capacity of the biochar (Deenik *et al.*, 2010). Besides, the carbon content of the biochar can be as high as 40-75% and most of them exist in the irregular layered aromatic ring structure with a high biological stability, all of which significantly increase the organic matter content of the soil (Schmidt and Noack, 2000). However, there are some cases in this study that the application of biochar greatly decreased the cation exchange capacity of soil. The reason may be the changes of soil organic matter properties caused by the application of biochar and the specific mechanism needs further studies to explain (Deenik *et al.*, 2010).

The findings of this study prove that applying biochar is a efficient way to supplement the available K of soil, which is similar to the findings of Chan *et al.* (2007). Because potassium in biochar has a high effectiveness, application of the biochar can directly supply the available K of soil and indirectly reduce the leaching loss (Tryon, 1948). However, as the supplement of available nitrogen and phosphorus of soil, biochar has a little effect. The reason for the limited supplementary effect might be the reduction of efficacy of nitrogen and phosphorus during the break and preparation process of biochar (Bagreev *et al.*, 2001; Tsai *et al.*, 2006). But in several cases, biochar supplements some available phosphorus of soil. This finding similar with the results of Tryon (1948) study. It has the possibility that by absorbing the phosphate anion of soil, biochar reduces leaching loss (Lehmann and Rondon, 2006) and promotes the releasing of organic phosphorus of soil (Lehmann and Joseph, 2009). Different types of soil and different amount of application lead to different significant effects on the available nitrogen. In loess soil, the amount of application of biochar ranging 15-60 t/ha can increase the content of available nitrogen, which is same to the findings of Ding *et al*. (2010). And the reason is in the similar mechanic manner of available phosphorus. But in sandy and loessal soil, the same findings of Laird *et al.* (2010) is that biochar application causes the significant reduction of the available nitrogen content, even a small amount. There are two possible reasons to explain this phenomenon First is that the biochar accelerates the leaching loss of available nitrogen (Laird *et al*., 2010) (this also explains why biochar has different effects on available nitrogen in different soils. Soils have different water holding capacity, because of the significant differences among the 3 types of studied soils). Second is applying a large amount of biochar to soils, the ratios of Carbon/Nitrogen (C/N) and Carbon/Phosphorus (C/P) are greatly increased that forces microorganisms extensively use the nitrogen therefore, it leads to the loss of available nitrogen. Overall, for being rich in the content of phosphorus, nitrogen and potassium, the biochar has a wide supplementary effect on the total nutrient.

Biochar has complicated effects on nutrient uptake of maize and the effects vary obviously in different soils. Overall, in loess soil, it has positive effect in promoting the nutrient uptake of maize by applying 15 t/ha amount of biochar, while 30 t/ha amount makes the opposite result and 60 t/ha amount performs it in the medium level. In sandy soil, 15 t/ha amount of application of biochar has medium effect in promoting the nutrient uptake of maize and 30 t/ha amount has meager effect, while 60 t/ha amount greatly promotes it. In loessal soil, 15 t/ha amount of biochar application poorly promotes the nutrient uptake of maize, 15 t/ha amount shows moderate effect and 60 t/ha amount was observed significant effect. Interestingly, for some cases, biochar application promotes the maize in taking up some nutrient in nitrogen, phosphorus and potassium, which is similar to the findings of Van *et al*. (2010) and Asai *et al*. (2009). However, for the other cases, the results are just on the contrary. This is because the biochar is closely related to the effectiveness of nutrients of soil and the nutrient in the biochar itself (Lehmann *et al*., 2003). It is noticeable that under some circumstances, even applying the same amount of biochar to the same type of soil, the content of nutrient in plants and grains has different responses. Such finding shows that biochar also has a certain influence on the nutrient distribution process, because the biochar changes the living environment of the microorganisms of soil, which further affects the properties of root-microorganism symbiotic system (Blackwell *et al*., 2010) and the secretion of plant hormone (Spokas *et al*., 2010). But the specific mechanism still needs further studies for explanations.

ACKNOWLEDGMENT

This research work was supported by Support proje ct: MOST China: 2012BAD05B03. The authors sincerely thank the anonymous reviewers and editors for this manuscript.

REFERENCES

Asai, H., B.K. Samson, H.M. Stephan, K. Homma, K. Songyikhangsuthor *et al*., 2009. Biochar amendment techniques for upland rice production in Northern Laos: 1. Soil physical properties, leaf SPAD and grain yield [J]. Field Crops Res., 111(1/2): 81-84.

Bagreev, A., T.J. Bandosz and D.C. Locke, 2001. Pore structure and surface chemistry of adsorbents obtained by pyrolysis of sewage-derived fertilizer [J]. Carbon, 39: 1971-1979.

Blackwell, P., E. Krull, G. Butler, H. Allan and S. Zakaria, 2010. Effect of banded biochar on dryland wheat production and fertiliser use in southwestern Australia: An agronomic and economic perspective [J]. Australian J. Soil Res., 48(7): 531-545.

Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie and S. Joseph, 2007. Agronomic values of green waste biochar as a soil amendment [J]. Australian J. Soil Res., 45: 629-634.

Deenik, J.L., A.T. McClellan and G. Uehara, 2010. Biochar volatile matter content effects on plant growth and nitrogen transformations in a tropical soil [J]. Soil Sci. Soc. Am. J., 74: 1259-1270.

Ding, Y., Y.X. Liu, W.X. Wu, D.Z. Shi, M. Yang and Z.K. Zhong, 2010. Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. Water Air Soil Poll., 213 (1/4): 47-55.

Grossma, J.M., B.E. O'Neill, S.M. Tsai, B. Liang, E. Neves *et al*., 2010. Amazonian anthrosols support similar microbial communities that differ distinctly from those extant in adjacent, unmodified soils of the same mineralogy [J]. Microb. Ecol., 60: 192-205.

Huang, C., L. Liu and M. Zhang, 2011. The effects of biochar on properties of red earth and growth of ryegrass [J]. Zhejiang Uni. J., 37(4) : 439-445.

Kimetu, J.M. and J. Lehmann, 2010. Stability and stabilisation of biochar and green manure in soil with different organic carbon contents. Australian J. Soil Res., 48(7): 577-585.

Laird, D.A., P. Fleming, D.D. Davis, R. Hortonb, B. Wangc *et al*., 2010. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil [J]. Geoderma, 158 (3/4): 443-449.

Lehmann, J., J.P. Da Silva, C. Steiner, T. Nehls, W. Zech *et al*., 2003. Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central amazon basin: Fertilizer, manure and charcoal amendments [J]. Plant Soil, 249(2): 343-357.

Lehmann, J. and M. Rondon, 2006. Bio-char Soil Management on Highly Weathered Soils in the Humid Tropics [M]. In: Uphoff, N., A.S. Ball, E. Fernandes *et al*. (Eds.), Biological Approaches to Sustainable Soil Systems. CRC Press, Boca Raton, pp: 517-530.

Lehmann, J. and S. Joseph, 2009. Biochar for Environmental Management Science and Technology [M]. Earthscan, Ltd., London, UK.

Lehmann, J., M.C. Rillig, J. Thies, C.A. Masielloc, W.C. Hockadayd *et al*., 2011. Biochar effects on soil biota-A review [J]. Soil Biol. Biochem., 43: 1812-1836.

Liang, B., J. Lehmann, D. Solomon, J. Kinyangi, J. Grossman, B. O'Neill, J.O. Skjemstad, J. Thies, F.J. Luizáo, J. Petersen and E.G. Neves, 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J., 70(5): 1719-1730.

Liu, J., H. Schulz, S. Brandl, H. Miehtke, B. Huwe *et al*., 2012. Short-term effect of biochar and compost on soil fertility and water status of a dystric cambisol in NE germany under field conditions [J]. J. Plant Nutr. Soil Sci., 175: 698-707.

Major, J., C. Steiner, A. Downie and J. Lehmann, 2009. Biochar Effects on Nutrient Leaching [C]. In: Lehmann, J. and S. Joseph (Eds.), Biochar for Environmental Management Science and Technology. Earthscan, London, pp: 271-287.

Oguntunde, P.G., B.J. Abiodun, A.E. Ajayi *et al*., 2008. Effects of charcoal production on soil physical properties in Ghana [J]. J. Plant Nutr. Soil Sci., 171: 591-596.

Schulz, H. and B. Glaser, 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment [J]. J. Plant Nutr. Soil Sci., 175: 410-422.

Schmidt, M.W.I. and A.G. Noack, 2000. Black carbon in soils and sediments: Analysis distribution, implications and current Challenges [J]. Glob. Biogeochem. Cyeles, 14(3): 777-794.

Spokas, K.A., J.M. Baker and D.C. Reicosky, 2010. Ethylene: Potential key for biochar amendment impacts [J]. Plant Soil, 333(1/2): 443-452.

Steiner, C., W.E.H. Blum, W. Zech, W.G. Teixeira, J. Lehmann *et al*., 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered central amazonian upland soil [J]. Plant Soil, 291(1/2): 275-290.

Tryon, E.H., 1948. Effect of charcoal on certain physical, chemical and bio-logical properties of forest soils [J]. Ecol. Monog., 18: 81-115.

Tsai, W.T., M.K. Lee and Y.M. Chang, 2006. Fast pyrolysis of rice straw, sugarcane bagasse and coconut shell in an induction-heating reactor [J]. J. Anal. Appl. Pyrol., 76: 230-237.

Van, Z.L., S. Kimber, S. Morris, K.Y. Chan, A. Downie, J. Rust, S. Joseph and A. Cowie, 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant Soil, 327(1/2): 235-246.