International Journal of Plant & Soil Science
13(6): 1-7, 2016; Article no.IJPSS.30888
ISSN: 2320-7035

SCIENCEDOMAIN *international*
www.sciencedomain.org

Forms and Levels of Phosphorus in a Strongly Weathered Acid Soil in Ghana: The Contribution of Corn Cob Biochar

B. A. Osei[1*]

[1]*Department of Soil Science, University of Cape Coast, Cape Coast, Ghana.*

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/IJPSS/2016/30888
Editor(s):
(1) Artemi Cerda, Department of Geography, University of Valencia, Spain.
Reviewers:
(1) Wafula Nelson Wekha, Kenyatta University, Kenya.
(2) Okuo James, University of Benin, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/17475

Original Research Article

Received 6th December 2016
Accepted 28th December 2016
Published 10th January 2017

ABSTRACT

Different rates of corn cob biochar were applied to a strongly weathered acid soil as an amendment. The impact of the amendment on levels and forms of phosphorus (P) was determined. The biochar was applied to the soil at a rate of 0, 26, 52, 78 and 150 t ha^{-1}. The amended soil was incubated in a greenhouse for a period of 1 – 8 weeks. Sub samples of the unamended/control and amended soils were taken at periods of 2, 4, 6 and 8 weeks and then analysed for pH, total P, Bray – 1 P and water – extractable P. Significant improvements were recorded in the pH of the amended soil. The application rate of 150 t ha^{-1} recorded the highest increase in pH (78.4%) while the lowest change (64.9%) was recorded by the application rate 52 t ha^{-1}. The total P decreased as the rate of amendment increased, implying that total P was mineralized as the amount of carbon in the amendment increased. This resulted in the increase in available P. The yield of lettuce (*Lactuca sativa*) generally increased with rate of biochar application but the P content in the shoot of the plant was less than the optimum.

Keywords: P availability; strongly weathered acid soil; corn cob biochar.

**Corresponding author: E-mail: bosei@ucc.edu.gh;*

1. INTRODUCTION

Soil is a key component of the Earth system. It controls the cycles of the Earth System such as the erosional, hydrological, biological and geochemical cycles. Soil also provides food and fibre, other resources and services [1,2,3]. Phosphorus is a very component of the cycle of nutrients [4,5,6] and biochar can act as a buffer in the soil system [7,8,9,10]. Phosphorus (P) is a highly reactive element, and as such, does not exist in the elemental form in the soil. Soil pH has a profound influence on the quantity of P available to plants at any point in time and the amount of P that is precipitated. Phosphorus is most readily available between the pH range of 5.5 and 6.5 [11]. At pH below 4, soil P forms compounds with aluminium and iron oxides, making it unavailable to plants. Phosphorus also forms compounds with calcium when soil pH is above 7 rendering it unavailable to plants [12]. Strongly weathered acid soils contain high concentration of iron and aluminium oxides and hydroxides which aid P fixation and renders it unavailable to crops [13].

Biochar stimulates the activity of a variety of agriculturally important soil microorganisms because of its high pH. Biochar has the ability to neutralize acidity of strongly weathered tropical soils. The addition of biochar to agricultural soils has received much attention due to the apparent benefits to soil quality and enhanced crop yields, as well as the potential of gaining carbon credits by carbon sequestration [14]. When applied to these soils P availability will be enhanced [15]. The objectives of the study are twofold, namely;

i. To evaluate the influence of biochar application on pH of a strongly weathered acid soil and
ii. To determine the effect of biochar amendment on P availability, and its resultant concentration in a test crop (lettuce).

2. MATERIALS AND METHODS

2.1 Soil Sampling and Preparation

Soil samples were collected from 0 – 30 cm depth at Ainyinase in the Western Region of Ghana. The soil samples were taken from the upper 30 cm of the soil profile. Twenty soil cores were taken and then bulked. The samples were air-dried and passed through a 2 mm sieve. The chemical and physical properties of the soil are summarized in Table 1.

2.2 Biochar

Biochar was prepared from corn cob. Properties of the corn cob biochar are presented in Table 2.

2.3 Pot Experiment and Biochar Amendment

The pot experiments were carried out in a green house, under controlled environmental conditions in a complete randomized design. The area of the pot was 0.772 m^2. Lettuce seeds were nursed in a seed box. After two weeks, the seedlings were strong enough so they were transplanted into the pots that had been treated with the various biochar amendments (0, 26, 52, 78 and 150 t ha^{-1}) and incubated for 8 weeks. The lettuce shoots were harvested after 30 days of transplanting. The soils samples in the pots were kept moist at 60% field capacity during the growth of the lettuce.

Another set of amended soils were incubated in the greenhouse for 0 – 8 weeks. Within the eight weeks incubation period, samples were taken fortnightly from the pots. These samples were used for post treatment laboratory analyses of soils (water soluble P, Bray 1- P and total P).

Table 1. Chemical and physical of the soil (0 – 30 cm)

Parameter	Value (± SD)	Method
pH	3.7 ±0.02	Glass Electrode pH meter
Organic carbon (%)	0.8 ±0.02	Walkley-Black method
Total P (mg/kg)	400 ±0.02	H_2SO_4 – H_2O_2 digest
Total nitrogen (%)	0.1 ±0.02	Kjeldahl method
Bray – 1 P (mg kg^{-1})	3.6 ±0.05	Bray – 1 extraction
Water soluble P (mg kg^{-1})	0.5 ±0.02	Water – extraction
ECEC ($cmol_c/kg^{-1}$soil)	2.8 ±0.05	Exchangeable acidity + Exchangeable base summation method
Bulk density (Mg/m^3)	1.3 ±0.01	Core sampler
Soil texture	Sandy loam	Hydrometer method

Table 2. Some properties of biochar

Parameter	Value (± SD)	Method
pH	9.8 ±0.01	Glass electrode method
Total N (%)	0.5 ±0.02	Kjeldahl method
Total C (%)	95.1 ±0.02	Furnace at 450ºC method
Total P (%)	0.02 ±0.02	H_2SO_4 – H_2O_2 digest

Total P content of the lettuce was determined by the dry ashing method. Ground plant sample (0.5 g) was weighed into a crucible and kept in a furnace at a temperature of 450ºC overnight. The sample was allowed to cool and 5 ml of 1.0 M HCl was added. The suspension was evaporated to dryness on a hot plate. Ten (10) ml of 1.0 M HCl was added and filtered into a 50 ml volumetric flask. The flask was topped up to the mark with 0.1 M HCl. The P content in the filtrate was determined by a spectrophotometer.

2.4 Statistical Analysis

The data that were obtained were subjected to analysis of variance (ANOVA) by using Genstat 12.1 version [16] statistical package. Treatment means were compared by the least significance difference (LSD) method at P = 0.05.

3. RESULTS AND DISCUSSION

3.1 Effects of Biochar on Some Soil Chemical Properties

3.1.1 Soil pH

Soil pH is an important soil property that affects the growth of most plants. Table 3 shows how the application of biochar affected the pH of the soil over the 2, 6 and 8 weeks incubation period.

The pH of the control (0 t ha^{-1}) soil remained extremely acidic throughout the 8 weeks period whereas the pH of the various treatments kept increasing over the period. Even though there was an appreciable increase in pH in 26 t ha^{-1} and 52 t ha^{-1} treatments, levels of pH were not within the range as described by [17] to be optimum for plant growth. However, within the first two weeks of treatment, the pH of rate 78 t ha^{-1} was observed to rise from 3.7 to 5.6 (Table 3) and finally to an optimum pH level of 6.4 (Table 3). From the week 2 to the week 8, the highest pH levels were recorded in treatment 150 t ha^{-1}. The soil pH increased from the initial level of 3.7 to 5.9 and 6.3 in the second and fourth weeks respectively, and then increased to 6.6 (Table 3). When the rate of biochar was increased from 78 t/ha to 150 t/ha, there was an advantage of only a 3.1% increase in soil pH making it highly uneconomical to apply biochar at such a high rate (150 t ha^{-1}).

During the period of the experiment all amendments that were used in the study resulted in an increase in the soil pH. It was observed at the end of the experiment that, 150 t ha^{-1} caused the highest increase in soil pH (78.4%) while biochar 26 t ha^{-1} recorded a 63.8% increase in soil pH.

The pH of biochar used as amendments was high (Table 2) and the increase in pH could have been as a result of the pH of the amendments influencing the initial soil pH to increase [17]. Biochar is known to have a high CEC therefore, increase in soil pH could have also been as a result of the release of basic cations from the amendments which displaced and replaced hydrogen and aluminium ions at the exchange sites [18].

Statistically, significant differences existed between the control soil (0 t ha^{-1}) and all the other treatments. With exception of 78 t ha^{-1}, there were significant differences between 150 t ha^{-1} and all the other treatments.

Soil pH directly affects the growth and development of plants in that the availability of all plant nutrients is pH dependent therefore soil pH increases with biochar amendment could potentially contribute positively to growth and development of crops.

3.1.2 Bray-1 extractable phosphorus and biochar application

The concentration of Bray 1 extractable P is a fairly good indicator of the phosphorus supplying capacity of a soil [19]. Bray 1 extractable P which is a measure of plant available P, is a determinant of the critical P limits based on soil test crop calibration study [20].

An increasing trend in Bray I extractable phosphorus was observed in the set of treatments involving biochar with increasing rate of biochar application. However, significant differences were not observed in treatments 150 t ha^{-1} and 78 t ha^{-1}.

Extractable phosphorus increased as the incubation period progressed. With this trend existing within the treatments, the highest available phosphorus concentration of 12.5 mg kg^{-1} (Table 4) was observed in 150 t ha^{-1} rate while 26 t ha^{-1} rate increased the initial soil available phosphorus from 3.36 to 5.41 mg kg^{-1} (Table 4). This result is in line with reports of [21,22] which state that biochar contains a large amount of phosphorus therefore its application to the soil may release soluble phosphorus into the soil which is necessary for the enhancement of phosphorus availability.

Table 3 shows that all the treatments that were used in the study resulted in increases in soil pH. Increasing soil pH reduces the activities of aluminium and iron which would have otherwise formed compounds with phosphorus thus making phosphorus more available [23]. This could have explained the increase in extractable P.

3.1.3 Effects of biochar on water soluble phosphorus

In this study, it was found that all the treatments improved the levels of water soluble phosphorus of the soil. During the incubation period, it was observed that concentrations of water soluble phosphorus increased greatly in the second week after treatment and transplanting however the concentration decreased in the 4, 6 and 8 weeks (Table 5).

Despite this decreasing trend observed in water soluble phosphorus (Table 5), the least water soluble concentration (as was observed in 26 t ha^{-1}) was about 3.3 mg kg^{-1} (140.7% reduction) which was higher than the unamended soil (0.58 mg kg^{-1}).

Among the treatments the effect of biochar rate on soluble P level was not consistent. For instance, increase in water soluble P in 52 t ha^{-1} was higher (8.71 mg kg^{-1}) than 78 t ha^{-1} which was of 5.54 mg kg^{-1} (Table 5). Amending the soil with 150 t ha^{-1} biochar caused the water soluble concentration to rise to 10.09 mg kg^{-1} that was almost double the effect (82.1%) of applying biochar at 78 t ha^{-1}.

The increase in the water soluble and available phosphorus is in line with a report by [24] that biochar may improve available P in soils; both directly through phosphorus addition from water soluble phosphorus contained in biochar and/or indirectly through impact on soil chemical, physical and/or biological processes. Biochar may also increase microorganism activities through addition of carbon [25].

Increase in soil pH as was observed in this study as a result of the applications of the amendments employed in the study, might cause microbial activities to increase in the soil [26]. The increase in microbial activities [27] and phosphatase activity which may release phosphorus into the soil [28] resulting in increased phosphorus availability to plants.

3.1.4 Changes in total soil phosphorus by biochar application

Soil total phosphorus is a sum of all the forms of phosphorus in the soil [29]. Table 6 gives an overview of how total phosphorus levels in the soil were affected by the amendments.

Table 3. Influence of rate of biochar amendment on soil pH as affected by incubation period

Rate of application	Soil pH							
(t ha^{-1})	Week 2	(± SD)	Week 4	(± SD)	Week 6	(± SD)	Week 8	(± SD)
0	3.7	0.01	3.7	0.02	3.7	0.01	3.7	0.01
26	5.3	0.05	5.9	0.06	6.1	0.02	6.0	0.03
52	5.4	0.08	5.5	0.06	6.2	0.01	6.1	0.02
78	5.6	0.05	5.8	0.01	6.4	0.05	6.2	0.03
150	5.9	0.01	6.3	0.01	6.6	0.01	6.5	0.01

Table 4. Effects of biochar amendments on soil bray-1 extractable phosphorus as affected by incubation period

Rate of application	Bray – 1 P (mg kg^{-1})							
(t ha^{-1})	Week 2	(± SD)	Week 4	(± SD)	Week 6	(± SD)	Week 8	(± SD)
0	3.4	0.06	3.6	0.02	3.5	0.01	3.5	0.01
26	4.4	0.01	4.7	0.02	5.4	0.01	5.1	0.03
52	7.1	0.03	8.1	0.02	8.6	0.01	8.5	0.01
78	10.0	0.01	10.5	0.01	11.7	0.01	10.6	0.01
150	12.5	0.02	12.5	0.01	12.5	0.02	12.1	0.02

Table 5. Effects of biochar amendments on water soluble phosphorus as affected by incubation period

Rate of application (t ha^{-1})	Water soluble P (mg kg^{-1})							
	Week 2	(± SD)	Week 4	(± SD)	Week 6	(± SD)	Week 8	(± SD)
0	0.6	0.08	0.6	0.08	0.6	0.08	0.6	0.05
26	3.3	0.21	5.5	0.46	3.3	0.11	3.2	0.10
52	8.7	0.52	4.9	0.30	8.7	0.01	8.5	0.02
78	5.5	0.06	5.7	0.18	5.5	0.04	5.4	0.13
150	10.1	0.20	9.2	0.11	8.6	0.03	8.6	0.02

Table 6. Effects of biochar amendments on soil total phosphorus as affected by incubation period

Rate of application (t ha^{-1})	Total phosphorus (mg kg^{-1})							
	Week 2	SD (±)	Week 4	SD (±)	Week 6	SD (±)	Week 8	SD (±)
0	400	0.002	400	0.002	400	0.001	400	0.002
26	200	0.001	200	0.001	200	0.001	200	0.002
52	200	0.001	100	0.001	200	0.003	200	0.001
78	280	0.001	100	0.001	200	0.001	200	0.001
150	200	0.001	100	0.001	200	0.001	200	0.002

According to [30], phosphorus may be deficient in soils even though the total phosphorus concentration in the soil may be high. For the control soil, 400 mg kg^{-1} of total P was present (Table 1) in the soil but only 3.61 mg kg^{-1} (9.03%) was present in available form. It can be observed that the concentrations of total phosphorus in the soil decreased as the weeks of incubation progressed (Table 6). The reduction in the amount of total phosphorus could be as a result of mineralisation of phosphorus. Mineralization of phosphorus increases as the amount of carbon in the soil increases [31]. This implies that more phosphorus is made available for plant growth and microbial activity [30]. This is evident in the increment of soil available phosphorus and water soluble phosphorus as depicted in Tables 4 and 5. At the end of the study, the soil total phosphorus of all treatments reduced by 50%.It was observed that no significant differences existed among the various treatments at 95% confidence interval.

3.1.5 Effect of biochar amendment dry yield and P content of shoot of lettuce

The dry matter yield and total P content of lettuce shoot are presented in Table 7.

The control treatment did not record any yield as the seedlings died in the course of the experiment. This could be attributed to the acid nature of the soil as lettuce is known to be very sensitive to low soil pH. It was also observed that increasing biochar rate of application generally resulted in an increase in the yield of lettuce. According to [32] the optimum level of P in lettuce shoot is 0.5%. The biochar amendment could not supply the optimum P to the test crop.

Table 7. Dry matter yield of lettuce and total P content of lettuce shoot

Biochar (t ha^{-1})	Dry matter yield (t ha^{-1})	P content in lettuce shoot (%)
0	NA	NA
26	2.5 ± 0.01	0.19
52	2.0 ± 0.02	0.25
78	2.7 ± 0.30	0.22
150	3.2 ± 0.10	0.13

NA = Not Applicable

4. CONCLUSION

Significant increase in pH was observed after biochar addition to the soil. Biochar therefore has the potential to be used as a liming material in an acid soil. Total P was mineralized into available P (bray 1 – P and water – soluble P) as biochar was added to the soil. Corn biochar have potential in improving P availability in strongly weathered acid soils.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Brevik EC, Cerda A, Mataix-Solera J, Pereg L, Quinton JN, Six J, Van Oost K. The interdisciplinary nature of SOIL. SOIL. 2015;1:117-129.
DOI: 10.5194/SOL-1-117-2015
2. Keestra SD, Bouma J, Wallinga J, Tittonell P, Cerda A, Montanarella L, Quiton JN, Pachepsky Y, van der Putten WH, Bardgett RD, Moolenaar S, Mol G, Jansen B, Fresco LO. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. SOIL. 2016;2:111-128.
DOI: 10.5194/soil-2-111-2016,2016
3. Mol G, Keesstra SD. Editorial: Soil science in a changing world. Current Opinions in Environmental Sustainability. 2012;4:473-477.
4. Mamedov AI, Bar-Yosef B, Levkovich I, Rosenberg R, Silber A, Fine P, Levy GJ. Amending soil with sludge, manure, humic acid, orthophosphate and phytic acid: Effects on infiltration, runoff and sediment loss. Land Degrradation and Development. 2016;27(6):1629-1639.
5. Shen Zhang G, Cha Li J. Distribution of inorganic phosphorus in profiles and particle frctions of Anthrosols across an established riparian buffer and djacent cropped area at the Dian lake (China). Solid Earth. 2016;7(1):301-310.
DOI:http://dx.doi.org/10.5194/se-7-301-2016
6. Mahmoud E, Abd El-Kader. Heavy metal immobilization in contaminated soils using phosphogypsum and rice straw compost. Land Degradation and Development. 2015;26(8):819-824.
7. Munoz MA, Guzman JG, Zornoza R, Moreno F, Faz A, Lal R. Effects of biochar and marble mud on mine waste properties to reclaim tailing ponds. Land Degradation and Development. 2016;27(4):1227-1235.
DOI: 10.1002/ldr.2521
8. Drake JA, Cavagnaro TR, Cunningham SC, Jackson WR, Patti AF. Does biochar improve establishment of tree seedlings in saline sodic soils? Land Degradation and Development. 2016;27(1):52-59.
DOI: 10.1002/ldr.2374
9. Coomes OT, Miltner BC. Indigenous charcooal and biochar production: Potential of soil improvement under shifting cultivation systems. Land Degradation and Development; 2016.
DOI: 10.1002/ldr.2500
10. Paz-Ferreiro J, Mendez A, Tarquis AM, Cerda A, Gasco G. Preface: Environmental benefits of biochar. Solid Earth. 2014;5(2): 1301-1303.
DOI: 10.5194/se-5-1301-2014
11. Brady NC, Weil RR. Soil acidity. The nature and properties of soils. Upper Saddle River, NJ: Prentice Hall. 2002;363-412.
12. Peltzer DA, Wardle DA, Allison VJ, Baisden WT, Bardgett RD, Chadwick OA, Walker LR. Understanding ecosystem retrogression. Ecological Monographs. 2010;80(4):509-529.
13. Malavolta E, Kliemann HJ. Desordens nutricionais no cerrado. Piracicaba, SP Brasil. 1985;136.
14. Berek AK, Hue N, Ahmed A. Beneficial effects of biochar to correct soil acidity. The Food Provider. 2011;1-3.
15. Kimetu JM, Lehmann J. Stability and stabilization of biochar and green manure in soil with different organic carbon contents. Australian Journal of Soil Research. 2010;48:577-585.
16. Genstat. Genstat discovery (3rd ed). Genstat Procedure Library Release PL15.2. London, VSN Internationa Ltd; 2008.
17. Rowell DL. Soil science: Methods and applications. Singapore: Longman Publication Ltd. 1994;327.
18. Fox RH. Selection for phosphorus efficiency in corn 1. Communications in Soil Science & Plant Analysis. 1978;9(1): 13-37.
19. Reuter DJ, Dyson CB, Elliott DE, Lewis DC, Rudd CL. An appraisal of soil phosphorus testing data for crops and pastures in South Australia. Animal Production Science. 1995;35(7):979-995.
20. Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Agronomic values of green waste biochar as a soil amendment. Soil Research. 2008;45(8): 629-634.
21. Atkinson CJ, Fitzgerald JD, Hipps NA. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. Plant Soil. 2010;337:1-18.
22. Clark RB, Flores CI, Gourley LM. Mineral element concentrations in acid soil tolerant and susceptible sorghum genotypes. Communications in Soil Science & Plant Analysis. 1988;19(7-12):1003-1017.

23. DeLuca TH, MacKenzie MD, Gundale MJ. Biochar effects on soil nutrient transformations. Biochar for Environmental Management: Science and Technology. 2009;251-270.
24. Zimmerman AR. Abiotic and microbial oxidation of laboratory produced black carbon (biochar). Environmental Science & Technology. 2010;44(4):1295-1301.
25. Fuentes JP, Bezdicek DF, Flury M, Albrecht S, Smith JL. Microbial activity affected by lime in a long-term no-till soil. Soil and Tillage Research. 2006;88(1): 123-131.
26. Liptzin D, Silver WL. Effects of carbon additions on iron reduction and phosphorus availability in a humid tropical forest soil. Soil Biology and Biochemistry. 2009;41(8):1696-1702.
27. Trasar-Cepeda MC, Carballas T, Gil-Sotres F, De Blas E. Liming and the phosphatase activity and mineralization of phosphorus in an andic soil. Soil Biology and Biochemistry. 1991;23(3):209-215.
28. Powell JM, Jackson-Smith DB, Satter LD, Bundy LG. Whole-farm phosphorus management on dairy farms. In Proceedings of the 2002 Wisconsin Fertilizer, Aglime, and Pest Management Conference, Madison, WI. 2002;13-24.
29. Snowball K, Robson AD. Nutrient deficiencies and toxicities in wheat: A guide for field identification. Mexico, DF, CIMMYT; 1991.
ISBN: 968-61 27-48-8.
30. Available:http://www.ctahr.hawaii.edu/maui (Accessed on 14th February, 2014)
31. Busman L, Sands G. Agricultural drainage publication series: Issues and answers. University of Minnesota Extension Bulletin. 2002;7740.
32. Valenzuela JA. U. S. Patent No 5, 145, 001. Washington DC. US Patent and Trademark office; 1992.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17475