KnE Life Sciences
UASC Life Sciences 2016
The UGM Annual Scientific Conference Life Sciences 2016
Volume 2019

Conference Paper

Effect Short–Term Biochar Application on Ultisol of Bengkulu, Indonesia

Priyono Prawito

Department of Soil Science, College of Agriculture, University of Bengkulu, Jl WR Supratman, Bengkulu 38371, Indonesia

Abstract

Most studies of biochar on agriculture were conducted in relatively short time period and generally showing positive effect. Couple studies however indicated that biochar application need long term to effect on both soil properties as well as plant growth and production. The purpose of this study was to evaluate the effect of short–term biochar application on Ultisol properties in Bengkulu. Research has been conducted on Ultisol in Kota Niur, Talang Empat, Bengkulu, Indonesia, since March 2013 to May 2014. The study was arranged in completely randomized block design with four treatments namely: A0 (control without biochar); A1 (burned biomass presence on each plot); A2 (wood charcoal of 120 t · ha, and A3 (coconut cell charcoal of 120 t · ha^{-1}). All the treatments were repeated 12 times resulting in 48 experiment units. The recorded soil properties including bulk density, soil porosity, soil aggregate stability, water holding capacity, field soil moisture, air dried soil moisture, soil pH, organic C, available N, P and K, as well as cation exchange capacity. All data were statistically analyzed using analysis of variance, F test with $P < 0.05$. All significant difference variables were analyzed using Duncan Multiple Range Test at $P < 0.05$. The result showed that two years application of 12 ton · ha^{-1} · yr^{-1} biochar did not significantly affect all soil properties studied, except available K. Coconut cell biochar showed best effect on available K (0.65 me · 100 g^{-1}) compare with control (0.30 me · 100 g^{-1}), burned existing biomass (0.39 me · 100 g^{-1}), and wood biochar (0.33 me · 100 g^{-1}).

Keywords: Bengkulu, Biochar, Charcoal, Short-term biochar application, Ultisol.

Corresponding Author:
Priyono Prawito
priyono@unib.ac.id

Received: 10 November 2018
Accepted: 6 January 2019
Published: 10 March 2019

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the UASC Life Sciences 2016 Conference Committee.

1. Introduction

Charcoal is simply carbon–rich product resulting from heating processes of organic materials such as wood, coconut shell, and other agricultural waste, without or with limited air. The process heating is also called as pyrolysis. Within the last decades, study on the role of charcoal agriculture or biochar has significantly increased, in line with increasing concern and tread of global warming, climate change, and environment degradation. Charcoal utilization is powerful approach to provide many problems solving such as food security, fuel scarcity, environment deterioration, and global warming in a simple and practical way. Charcoal approach is an ancient as well as the most recent technology utilized in human history. Further, due to it's important and strategies of utilizing charcoal on agriculture or biochar, it's said that the biochar approach is the single most important innovation for humanity's environmental future [1].

1.1. Role of biochar on global warming mitigation

Climate change due to increasing green house gasses (GHGs) has became significant concerned in the last couple decades. It is indicated that increasing GHGs in the atmosphere will end up in catastrophic event in the near future. It provides clear and strong justification to take action on reducing GHGs emission and increasing GHGs sequestration. Three most important GHGs related to agriculture or any activities on soil are carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Soil is both the source as well as the sink of these GHGs. Among them, CO_2 is the most abundance in the atmosphere [1]. Human activities contributing to N_2O to the atmosphere more than 3 Gt carbon dioxide equivalents (CO_2 e) or about 8 % of global emission, in 2004, where agriculture was responsible for 42 % of the total emission [2].

The role of charcoal or biochar in mitigating global warming is through reducing GHGs emission or increasing GHGs sink in soil. As the global warming potential of $CH_4$is 25 times, and N_2O is 298 times of equivalent mass of CO_2, taking little action on reducing CH_4 and N_2O emission or increasing their sink could be of significant benefit to the environment [3]. Previous study by incorporating biochar or charcoal derived from agriculture waste into Typic Hapludand in laboratory experiment and reported that N_2O emission from charcoal treated soil was reduced up to less than 15 % compare to the N_2O emission of charcoal untreated soil [4]. It was reported from their field experiment that application of charcoal capable of reducing N_2O emission from soil up to 15 mg $N_2O \cdot m^{-2}$ in the initial year [5]. They also noted that application of charcoal shown increasing soil pH; cations exchange capacity (CEC), potassium availability (K), as well as water retention in the soil [6]. It is also noted that the quality of the charcoal itself has significantly affect its role in controlling N_2O and CH_4 emission and sequestration. It was reported from their laboratory experiment that manure derived charcoal made in high temperature reduced N_2O emission to 0 %, while the manure derived charcoal made in low temperature has emitted N_2O gas 100 % compare to charcoal untreated soil [5]. Besides reduction on N_2O emission, they also reported that application of charcoal made from caliandra, could completely suppressed the CH_4 emission from soil [6].

Physically, charcoal surface is heterogeneous consisted of defect structure and complex metallic and organic compounds. The highly porous of charcoal has been shown to adsorb N_2O, CH4 and also CO_2 as well as substrate for N_2O production including NH_4^+ and NO_3^-. On the soil surface, charcoal adsorbs more sun energy than soil due to its darker color, causing higher temperature, than the surrounding micro environment, it may induce reaction rates.

1.2. Biochar stability in soil

Biochar/charcoal stability is one of many important aspects of biochar characteristics. Stability shows how long biochar is survived in soil system with minimum or without degradation. The more the biochar survive in soil system the better the biochar stability is. It means that the C applied in soil will remain in soil system for long time; means reduced C emission from soil system to the atmosphere. It is the purpose of managing GHGs to mitigate climate change. Other positive value of the biochar stability is how long the presence of biochar in soil system provides benefit to enhance soil properties and water quality. Previous studies showed that charcoal were very stable in soil environment. Charcoal has been found more than 10 000 yr as residues from forest fire [7, 8]. Early research of carbon dating found that biochar in “Terra Preta” soils of Amazon range from 500 yr to 7 000 yr BP, it is more than 7 000 yr to 9 000 yr until now [9, 10]. Although study of biochar has continuously in progressed, information on what is the residence time of biochar has not been widely agreed. It was suggested mean residence times of 1 300 yr to 2 600 yr under the dry land conditions of Northern Australia. The charcoal mean residence time vary with charcoal material as well as the soil environment condition where the biochar presence [11]. Despite of its debate on the methodology to determine the biochar residence time, the great age of biochar in soil studies and many archeological finding of biochars are proof of its stability in soil system.

1.3. Role of biochar on Agriculture

Study on the effect of biochar application in soil to crop productions have been conducted in many countries with various climates during the last couple decades [12–16]. It has been reported that application of rice husk charcoal on soil developed from volcanic ash parent material in Indonesia, increased root nodule formation, plant growth and yield of soybean [12]. Blackwell et al. also reported that the residual effect of charcoal application still detected until the tenth rotation especially for corn [12]. Similar result also reported by other study that application of charcoal also increased nodule formation, mycorrhizal infection rates and the spore number of soybean planted in volcanic ash soil [12.]

Effect of charcoal application on maize and sorghum productions have also been reported that charcoal application increased colonization of roots by mycorrhizal fungi, reduced exchangeable Al, increased yield up to 30 %, 51 %, and 100 %, reduced soil acidity and increased K uptakes. The studies have been conducted in various country and climates such as Kenya, Australia, Colombia, and Indonesia [13, 17, 18].

Incorporating biochar of 0.79 t $\cdot$ ha^{-1} into an Oxisol in Brazil capable of increasing 115 % to 320 % rice biomass. The charcoal was made from wood in local kilns, which was traditionally managed for long time [15]. Other study conducted in Australia indicated that charcoal application of: 6 t $\cdot$ ha^{-1} and 1.5 t $\cdot$ ha^{-1} banded fertilizer into Haplix Xerosol increase 3 kg $\cdot$ ha^{-1} to 400 kg $\cdot$ ha^{-1} wheat yield.

Increasing agriculture production as effected by charcoal application in line with increasing soil nutrient transformation shown by increasing P and N uptake by plants. Despite its significant effect on nutrient transformation, the mechanism of how the stimulation of nitrification is still in the subject of on going debate. Most studies of biochar on agriculture was conducted in relatively short time period ranging from one to couple years, showing various result with general trend that biochar has positive effect on soil quality, plant growth and production. Couple studies however indicated that charcoal application need long term to effect on both soil properties as well as plant growth and production. Previous studied of Cheng [19] also confirm that significant microbial-induced changes take place in biochar in the long term and that the initial abiotic oxidation could facilitate further microbial oxidation.

This information that relatively different from most charcoal studied is of important information for further studied. The purpose of this study was to evaluate the effect of short-term biochar application on Ultisol properties in Bengkulu.

2. Materials and Methods

Data in this paper were apart of long-term biochar application in palm oil plantation established on Ultisol of Bengkulu starting in 2012. The same plots were used for multi year's biochar application, by applying of 12 ton $\cdot$ ha^{-1} biochar per year or burning the biomass as well as chopping the biomass on the existing plots. In this particular paper, data has been collected from March 2013 to May 2014. Research was arranged in completely randomized block design with four treatments utilizing four difference biochars, they were: A_0 (control without biochar); A_1 (burned biomass presence on each plot); A_2 (wood charcoal of 12 ton · ha^{-1}), and A_3 (coconut cell charcoal of 12 ton · ha^{-1}). All treatments were repeated 12 times resulting in 48 experiment units.

Soil properties were recorded and used as variable in statistical analyses. The recorded soil physical properties including Bulk density (gravimetric method), Soil porosity (calculated based on BD and particle density method), soil aggregate stability (wet sieving method), water holding capacity (gravimetric method), field soil moisture (gravimetric method), and air-dried soil moisture (gravimetric method). The chemical soil properties were Soil pH (pH H_2O 1:2.5 measured with pH mater), Organic C (Walkey and Black method), Available N (wet destruction, Kjeldahl method), P (Bray I) and K (flame photometer), as well as cation exchange capacity.

All data were statistically analyzed using analysis of variance (ANOVA), F test with $P < 0.05$. All significant difference variables were analyzed using *Duncan Multiple Range Test* (DMRT) at $P < 0.05$.

3. Result and Discussion

Most biochar application did not significantly affect soil physical as well as chemical properties except available K. Resume of statistical analyses of all soil properties studied were presented in Table 1.

Table 1: Resume of calculated F values on soil properties involved in the study of biochar application in Ultisol of Bengkulu.

No	Variable	Calculated F
1	Bulk Density	0.42 ^{ns}
2	Soil Porosity	1.67 ^{ns}
3	Aggregate stability	0.95 ^{ns}
4	Water holding capacity	0.50 ^{ns}
5	Field soil moisture	0.37 ^{ns}
6	Air dried soil moisture	1.62 ^{ns}
7	Soil pH	0.73 ^{ns}
8	Organic C	2.75 ^{ns}
9	Available N	3.67 ^{ns}
10	Available P	0.39 ^{ns}
11	Available K	5.15 *
12	Cation exchange capacity	1.15 ^{ns}

ns: no significant different; *: significantly different at $P < 0.05$.

Among the 12 soil properties, only soil available K was significantly affected by application of biochar in this study. Further analysis utilizing Duncan Multiple Range Test showed that coconut cell biochar was the best charcoal in this study (0.65 me · 100 g^{-1}) compare with control (0.30 me · 100 g^{-1}), burned existing biomass (0.39 me · 100 g^{-1}), and wood biochar (0.33 me ·100 g^{-1}) (Table 2).

Table 2: Duncan's Multiple Range Test on available K in the study of biochar application in Bengkulu.

No	Treatment	Average available K (me 100 · g^{-1})
1	Control (without biochar)	0.30 ^{b}
2	Burned Existing Biomass	0.39 ^{b}
3	Wood Biochar (12 t · ha^{-1})	0.33 ^{b}
4	Coconut Cell Biochar (12 t · ha^{-1})	0.65 ^{a}

^{a,b}: Numbers followed by the same letter indicate that there are no significant different on Duncan's Multiple Range Test at $P < 0.05$.

Application of 12 t · ha^{-1} biochar did not affect most of recorded soil variables. It is probably insufficient amount to give significant effect to the recorded soil parameters. Studied conducted by Christophe reported that application of 11 t · ha^{-1} charcoal in Amazonian soils did not give significant effect on CEC due to insufficient amount of added charcoal [20]. Beside it insufficient amount, addition of fresh biochar could have contributed to its minimum effect on some soil properties. Lehmann indicated that fresh biochar has lower CEC than the aged biochar [21]. Effect of biochar application on soil water holding capacity (WHC) has also been studied. It indicated that application of biochar did not significantly affect soil WHC, except for soil with sandy texture. Literature study of Glaser reported that application of biochar even reduces WHC on soil with clayey texture [20].

Application of biochar was expected to have significant effect on micro-environment through increasing solar energy adsorbed by the added biochar, which in turn capable of increasing soil temperature and microbial activities. This process was not detected in this study, most likely because the plots studied were under 3 yr old of oil palm vegetation, where their canopy overshadow most of the plots. Besides its oil palm canopy, the application of the biochar was incorporated in the top soil up to 10 cm depth, therefore most part of applicated biochar were inside the soil surface therefore the biochar has no effect on solar radiation adsorption.

Besides comparing among treatments to determine the best biochar application in this study, some data were also compared with the previous data, from previous study in the same plots. It was to evaluate if there was any change after a year of biochar application. Some selected data were presented in Table 3. Although statistical analyses were not performed on this data set, Table 3 shows that no parameter has significant change after one year of biochar application. It suggested that sufficient amount of biochar as well as sufficient time were required to enhance soil properties.

TABLE 3: Comparison of some selected soil properties between the first and the second years of Biochar applicated Ultisol in Kota Niur Bengkulu.

Soil Parameters$	A0		A1		A2		A3	
	Year I	Year II	Year I	Year II	Year I	Year II	Year I	Year II
Bulk Density ($g \cdot m^{-3}$)	1.08	1.07	1.08	1.02	1.04	1.06	1.00	1.01
Soil Porosity	0.54	0.57	0.53	0.54	0.48	0.48	0.56	0.53
Soil Permeability	0.17	0.18	0.27	0.11	0.25	0.05	0.06	0.05
Water Holding Capacity	0.76	0.78	0.79	0.85	0.79	0.77	0.85	0.77
Soil pH	4.00	5.03	4.03	4.98	4.00	5.05	4.07	4.98
Organic-C	29.5	29.5	37.6	37.6	25.5	25.5	34.3	34.3
Available K	0.29	0.39	0.39	0.47	0.33	0.46	0.65	0.54

Source: Rostalina and Prawito [22]. A0 = Control (without biochar); A1 = Burned Existing Biomass; A2 = Wood Biochar (12 ton $\cdot$ ha^{-1}); A3 = Coconut Cell Biochar (12 ton $\cdot$ ha^{-1}).

4. Conclusions

Short–term application of biochar in Ultisol of Bengkulu did not affect most of selected soil properties. Among those selected soil properties (bulk density, soil porosity, soil aggregate stability, water holding capacity, field soil moisture, air dried soil moisture, soil pH, organic C, available N, P and K, and cation exchange capacity) only available K was affected by biochar application. Coconut cell biochar showed best effect on available K (0.65 me 100 $\cdot$ g^{-1}) compare with control (0.30 me $\cdot$ 100 g^{-1}), burned existing biomass (0.39 me ·100 g^{-1}), and wood biochar (0.33 me $\cdot$ 100 g^{-1}). To use biochar as soil amendment, sufficient amount of biochar as well as time period should be considered.

Acknowledgments

Thanks and appreciation credited to Pevi, Atri, Bayu Gatra, and Renita, for their data collection in the first year of these experiments. Thanks, and appreciation also extended to Tia, Vitri, and Vera for their contribution on both field and laboratory data collection in the second year of these experiments. Special thank send to Junar for his serious and meticulous work nurturing these field experiments.

References

[1] Lehmann J, Stephen J. (Eds). Biochar for environment management: Science and technology. Earthscan: Publishing for a Sustainable Future. London, Sterling, VA; 2009. p. 8–9. http://www.biochar-international.org/projects/book

[2] Denman KL, Brasseur G, Chidthaisong A, Ciais P, Cox PM, Dickinson RE, Hauglustaine D, et al. Coupling between changes in the climate system and biogeochemistry. In: Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (Eds). Cambridge University Press, Cambridge, UK; 2007. p. 499–587. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7.html

[3] Zwieten LV, MacKenzie MD, Gundale MJ. Biochar and emission of non-CO_2 greenhouse gases from soil. In: Biochar for environment management: Science and technology. Lehmann J, Stephen J. (Eds). Earthscan: Publishing for a Sustainable Future. London, Sterling, VA; 2009. p. 227–243. http://www.biochar-international.org/projects/book

[4] Yanai Y, Toyota K, Okazaki M. Effects of charcoal addition on N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments. Soil Science and Plant Nutrition 2007; 53:181–188. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1747-0765.2007.00123.x

[5] Rondon MA, Molina D, Hurtado M, Ramirez J, Lehmann J, Major J, Amezquita E. Enhancing the productivity of crops and grasses while reducing greenhouse gas emissions through biochar amendments to unfertile tropical soils. In: 18th World Congress of Soil Science, 9–15 July, Philadelphia, USA; 2006. p. 138–168. https://www.ldd.go.th/18wcss/techprogram/P16849.HTM

[6] Rondon M, Ramirez JA, Lehmann J. Greenhouse gas emissions decrease with charcoal additions to tropical soils. In: 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration in Agriculture and Forestry. Soil Carbon Center, Kansas State University, United States Department of Agriculture, Baltimore, MD, USA; 2005. p. 208. http://www.biochar-international.org/node/924

[7] Krull ES, Swanston CW, Skjemstad JO, McGowan JA. Importance of char-coal in determining the age and chemistry of organic carbon in surface soils. Journal of Geophysical Research; 2006; 111: G04001 https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2006JG000194

[8] Preston CM, Schmidt MWI. Black (pyrogenic) carbon: A synthesis of current knowledge and uncertainties with special consideration of boreal regions. Biogeosciences

2006, 3:397–420. https://www.biogeosciences.net/3/397/2006/

[9] Glaser B, Haumaier L, Guggenberger G, Zech W. The “Terra Preta” phenomenon: A model for sustainable agriculture in the humid tropics. Naturwissenschaften 2001; 88: 37–41. https://link.springer.com/article/10.1007/s001140000193

[10] Neves EG, Petersen JB, Bartone RN, Silva CAD. Historical and sociocultural origins of Amazonian Dark Earths. In: Amazonian Dark Earths: Origin, properties, management. Lehmann J, Kern DC, Glaser B, Woods WI, (Eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands; 2003. p. 29–50. https://link.springer.com/chapter/10.1007%2F1-4020-2597-1_3

[11] Lehmann J, Skjemstad JO, Sohi S, Carter J, Barson M, Falloon P, Coleman K, et al. Australian climate-carbon cycle feedback reduced by soil black carbon. Nature Geoscience 2008; 1:832–835. https://www.nature.com/articles/ngeo358

[12] Blackwell P, Riethmuller G, Collins M. Biochar application in soil. In: Biochar for environment management: Science and technology. Lehmann J, Stephen J. (Eds). Earthscan: Publishing for a Sustainable Future. London, Sterling, VA; 2009. P. 207–226. http://www.biochar-international.org/projects/book

[13] Yamato M, Okimori Y, Wibowo IF, Anshori S, Ogawa M. Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea, peanut and soil chemical properties in South Sumatra, Indonesia. Soil Science and Plant Nutrition 2006; 52:489–495. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1747-0765.2006.00065.x

[14] Steiner C. Teixeira WG, Lehmann J, Nehls T, Luis J, de Macedo LV, Blum WEH, Zech W. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered central Amazonian upland soil. Plant and Soil 2007; 291: 275–290. https://link.springer.com/article/10.1007/s11104-007-9193-9

[15] Nehls T. Fertility improvement of a terra firme oxisol in Central Amazonia by charcoal applications. [MSc Thesis]. University of Bayreuth, Germany. (2002). p. 343-357. https://www.researchgate.net/publication/236611396_Fertility_improvement_of_a_Terra_Fir _oxisol_in_Central_Amazonia_by_charcoal_application

[16] Blackwell P, Shea S, Storer P, Solaiman Z, Kerkmans M, Stanley I. Improving wheat production with deep banded oil mallee charcoal in Western Australia. In: Proceedings of the International Agrichar Conference, Terrigal, NSW Australia, May 2007. P. 17. http://biochar-international.org/images/Blackwell_-_Improving_Wheat_Production_with_Mallee_Charcoal.pdf

[17] Rondon M, Molina D, Ramirez J, Amezquita E, Major J, Lehmann J. Enhancing the productivity of crops and grasses while reducing greenhouse gas emissions through bio-char amendments to unfertile tropical soils. Poster presented at the

World Congress of Soil Science, Philadelphia, PA, 9–15 July 2006; p.1–19. https://www.ldd.go.th/18wcss/techprogram/P16849.HTM

[18] Van Zwieten L, Kimber S, Sinclair K, Chan KY. Downie A. Biochar: Potential for climate change mitigation, improved yield and soil health. In: Proceedings of the New South Wales Grassland Conference, NSW, Australia 2008; p. 30–33. http://grasslandnsw.com.au/news/wp-content/uploads/2009/07/Van-Zweiten-Kimber-Sinclair-Chan-Downie-2008.pdf

[19] Cheng CH, Lehmann J, Thies JE, Burton SD. Stability of black carbon in soils across a climatic gradient, Journal of Geophysical Research, 2008; 113; G02027. http://adsabs.harvard.edu/abs/2008JGRG..113.2027C

[20] Christophe S, Teixeira WG, Lehman J, Nehl T, Vasconcelos dMJL, Blum WEH, Zech W. Long term effect of manure, charcoal and mineral fertilization on crop production and fertility on a high weathered Central Amazonian upland soil. Plant and Soil 2007; 291 (2): 275–290. https://www.researchgate.net/publication/225161728_Long_term_effects_of_manure_charc
_and_mineral_fertilization_on_crop_production_and_fertility_on_a_highly_weathered_Cer
_Amazonian_upland_soil

[21] Lehmann J. Bio energy in the black. Front Ecol Environ 2007; 5(7): 381–387. https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/15409295%282007%295%5B381%3ABITB%5D2.0.CO%3B2

[22] Rostalina P, Prawito P. Pemanfaatan biochar untuk perbaikan kualitas tanah dengan indikator tanaman jagung dan padi gogo pada sistem lahan tebang bakar. [Utilization of biochar for soil quality improvement with indicator of corn and paddy plant on slash land system]. Naturalis: Jurnal Penelitian Pengelolaan sumberdaya alam dan lingkungan 2012; 1 (3): 179–188. [in Bahasa Indonesia]. http://repository.unib.ac.id/1377/