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Research Article
Effect of Durian Shell (DS) Biochar on Growth and Yield of Field Grown Chilli (*Capsicum annuum* L.)

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Abstract

Background and Objective: Most of the previous research on biochar amendment to soil reported improvement in soil bio-physical properties. Durian shell availability and its management is a key issue in Asian region, therefore, its conversion to biochar can be viewed as a potential strategy. The application of durian shell biochar (DSB) may improve nutrient availability and water holding capacity for supporting growth and yield of crop. **Materials and Methods:** The experiments were conducted to improve soil fertility, plant growth and yield of field grown chilli, by applying different amount of durian shell biochar. The experiment was conducted in the dry lands of Kambu Subdistrict, Kambu, Kendari, Southeast Sulawesi on a randomized block design with 5 replications from May, 2018 until August, 2018. Biochar treatment consisted of 3 doses of durian shell biochar: no durian shell biochar (control), 0.5 kg m^{-2} durian shell biochar and 1 kg m^{-2} durian shell biochar. Soil moisture, soil hardness, plant height, shoot dry weight, number of fruits and fruit weight were measuring during the study. **Results:** The results showed that durian shell biochar increased soil nutrient content and decreased soil hardness. Durian shell biochar significantly affected plant height, shoot dry weight, number of fruits and fruits weight. However, dose of biochar application did not showed significant effect on growth and yield. **Conclusion:** The findings suggest that the conversion of durian shell biomass to biochar and its application to agricultural field can be a better approach for managing this waste in the Asian region.

Key words: Biochar, *Capsicum annuum* L., durian shell, soil fertility, yield

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Chili (*Capsicum annum* L.) is one of the horticultural commodities that received a lot of attention because it has a very high economic value and is widely used for food needs and demands by people in Asia, so the needs of chili continue to increase every day. High demand for chilli some times is not fulfilled by the availability of supplies[1]. Productivity and the quality of chilli in Indonesia is still low[2] with a national harvest area of 123, 404 ha and a national production reaching[3] of 8.47 t ha^{-1}, with a national production reaching of 6.45 t ha^{-1}, while, the potential productivity of chilli to reach[4] up to 20 t ha^{-1}.

The low productivity of chilli plants is due to, among others, poor land quality and improper cultivation techniques. One of the efforts to increase the growth and productivity of chili plants is the need for improved techniques of cultivation technology, one of which is the application of biochar. Reported by Yang *et al.*[5] biochar prepared from biomass and solid wastes such as agricultural and forestry waste, livestock and poultry manure. In Indonesia the potential use of biochar is quite large, considering that raw materials such as coconut shells, rice husks and other plants are quite available[6].

Biochar produced by the lack oxygen conditions through pyrolysis of agricultural and forestry wastes is a material with well-developed pore structure, large specific surface area, abundant oxygen-containing functional groups and excellent adsorption performance[7,8]. Biochar is composed of aromatic carbon rings so that it is more stable and durable in the soil[9]. Biochar has high levels of carbon sequestration as reported by Santi and Goenadi[10], a very stable carbon (C)-rich material not only capable of improving physical and chemical soil properties but also increasing soil C storage on a large scale[11,12] and biochar is considered as a more stable nutrient source than others[13].

The addition of organic material in the form of biochar in the soil, can increase the activity of microorganisms that play a role in recycling organic matter and stabilize soil aggregates[14,15]. Biochar applications have the ability to bind and store CO_2 from the air to prevent it from being released in the atmosphere and increase pH in acid soils[16] , increase soil CEC[17], provide nutrients N, P and K as well as biochar to maintain soil moisture so high water holding capacity and can increase plant growth and production[18]. The results of research by Nisa[19], stated that the application of biochar at a dose of 10 t ha^{-1} can increase the soil pH value from an initial condition of 6.78-7.40% or increase to 9.14%. While the results of the study performed by Kurniawan *et al.*[20] stated the provision of biochar with a dose of 5 t ha^{-1} gives a high value of the fresh weight of leaves and stems of sugarcane and is not significantly different from the application of biochar 10 t ha^{-1}. The response of plants to biochar, among others, is determined by the type of plant and soil type.

Research on the application of biochar to chilli plants has not been done much thus, it is necessary to do further research on the effect of biochar on the growth and production of chili plants. This study aims to determine the effect of Durian Shell biochar on the growth and production of chili plants.

MATERIALS AND METHODS

A field experiment was conducted in experimental station of Agricultural Faculty, Haluoleo University, Kampus Hijau Anduonohu, Kendari during the months May-August, 2018. The experimental site was located at an altitude of 25 m above the mean sea level with geographic coordinate 4°4'45" SL, 122°33'42" EM, with annual rainfall was 100-468 mm (Fig. 1). The soil was consisted of 37% sand, 44% silt and 19% clay and their chemical properties shown in Table 1. The mean daily temperature varied from 22-32°C and the relative humidity ranged from 62-92%.

The initial soil properties of experimental site are presented in the Table 1.

The experimental design was a randomized block design with three levels of DS biochar (i.e., B0 = Without biochar as a control, B1 = 0.5 g of DS biochar m^{-2} and B2 = 1 g of DS biochar m^{-2}) in five replications.

The detailed characteristics of biochar used in this experiment are presented in Table 2.

Biochar and land preparation, treatment and field maintenance: Biochar was produced from durian shell (DS) by using a drum kiln Dsb cocoa pod husk Pembuatan biochar, in which carbonization was done within 4-6 h[21,22]. The hot DS biochar produced after pyrolysis was quenched with distilled

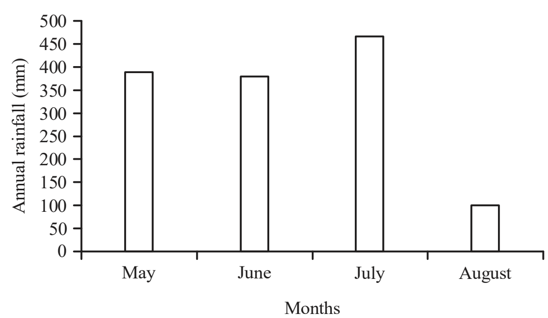

Fig. 1: Annual rainfall during the experimental period

Table 1: Chemical properties of the experimental soil

Chemical properties	Values
pH (in H_2O)	6.50
pH (in KCl)	5.81
C (%)	1.65
N (%)	0.07
P_2O_5 (mg/100 g), Extract HCl 25%	19.00
P_2O_5 (ppm), Olsen/Bray	70.00
K_2O (mg/100 g), Extract HCl 25%	26.00
K_2O (ppm), Olsen/Bray	35.00
Ca (me/100 g)	6.51
Mg (me/100 g)	5.54
K (me/100 g)	0.07
Na (me/100 g)	0.11
Kapasitas Tukar Kation (me/100 g)	6.30

Table 2: Chemical properties of Ds biochar

Chemical properties	Values
pH	12.30
Organic C (%)	30.00
N-total (%)	0.36
P_2O_5 (%)	0.78
K_2O (%)	0.47
Mg (ppm)	3429.00
Na (ppm)	1610.00
Kapasitas Tukar Kation (me/100 g)	41.65

water, collected, air-dried, crushed and sieved through a 2 mm sieve before being used[22]. DS biochar was collected and carried to Laboratory to measure its chemical properties.

Land was cleared from grass, remaining plant roots and all other materials. Soil processing is done twice, namely the first tillage was done at a depth of 15-20 cm using a hoe or reversing the soil. After that, a second soil management was carried out until there are no more lumps of soil, then plots were made with a size of 3.5×1.4 m as the experimental unit. The whole experimental field was divided into 5 blocks each containing 3 plots. The distance between block was 80 cm and the distance of beds in a block was 50 cm. Soil sampling from each plot was performed at 15 cm soil depth by using drill soil to look for the existing soil fertility.

The seeds used were hybrid keriting chili seeds of Lado variety. Before doing the nursery, the chilli seeds were soaked for 24 h using hot water at 30°C. Further, the chilli seeds that were floating and still sinking were separated. The sinking chilli seed were used for seeding, then drain on a tissue and air dry until it is completely dry.

Chilli seedlings were raised on seedlings plastic bag with a dimension of 6×8 cm size which had been filled with seedling media of dry top soil and manure (1:1) at the plastic lid whose dimension was 3×1 m. Healthy, uniform and 3 weeks old seedlings were transplanted at spacing of 60 cm between rows and 40 cm between plants. There were 6 seedlings in each row and 18 plants/plots. The seedlings were watered after transplanting. Fertilizer (SP36) was applied for the experimental plots at rate of 200 kg ha^{-1} at transplanting time and NPK fertilizer was applied at rate of 200 kg ha^{-1} at 21 days after transplanting.

Different rates of DS biochar were applied at 2 weeks after seedling transplanting at a rate based on the treatments. The maintenance including weeding, watering, pest and disease control were applied for all the plots. Weeding was done manually by using a hoe and watering was done by springking on each plot equal to 4 mm unless it rained. Pest and disease control was carried out by using pesticides.

The soil hardness, soil temperature and soil moisture were monitored at the depth of 10 cm below the surface by using a soil hardness tester, soil temperature measured and by gravimetric method, respectively. Plant height and shoot dry weight were determined at the first harvest time. Three samples of the plant were removed from the plot and sent to the laboratory in order to obtain their shoot dry weight. Fruit number and fresh fruit weight were collected during 4 harvest time. At the last harvest time, three soil samples were taken at the depth of 15 cm below the surface from each plot at random position and mixed to measure organic C, nitrogen, phosphorus, potassium, calcium and cation exchange capacity (CEC).

Statistical analysis: Statistical analysis was performed using analysis of variance. The data of different growth, yield and soil parameters were analyzed by 2 way analysis of variance (2-way ANOVA), if the ANOVA indicated significant at the $p<0.05$ level, then least significance differences (LSD) at 0.05 level of significance was applied.

RESULTS

Durian shell (DS) biochar significantly influence soil hardness and soil temperature as shown in Table 3. DS biochar under different rates was statistically similar on soil hardness and soil moisture, however, soil temperature did not show significant variation with the rate of biochar application. DS biochar was insignificantly influence soil moisture.

DS biochar increased carbon, nitrogen, phosphorus, potassium, calcium contents and CEC as shown in Fig. 2 and 3. The application of 0.5 kg m^{-2} of DS biochar increased carbon and nitrogen contents by 90 and 14%, respectively as compared to the control, whereas the application of 1 kg m^{-2} of DS biochar increased carbon and nitrogen contents 95 and 29%, respectively as compared to the control (Fig. 2a and b).

The application of 0.5 kg m^{-2} of DS biochar increased the phosphorus content by 215% as compared to control,

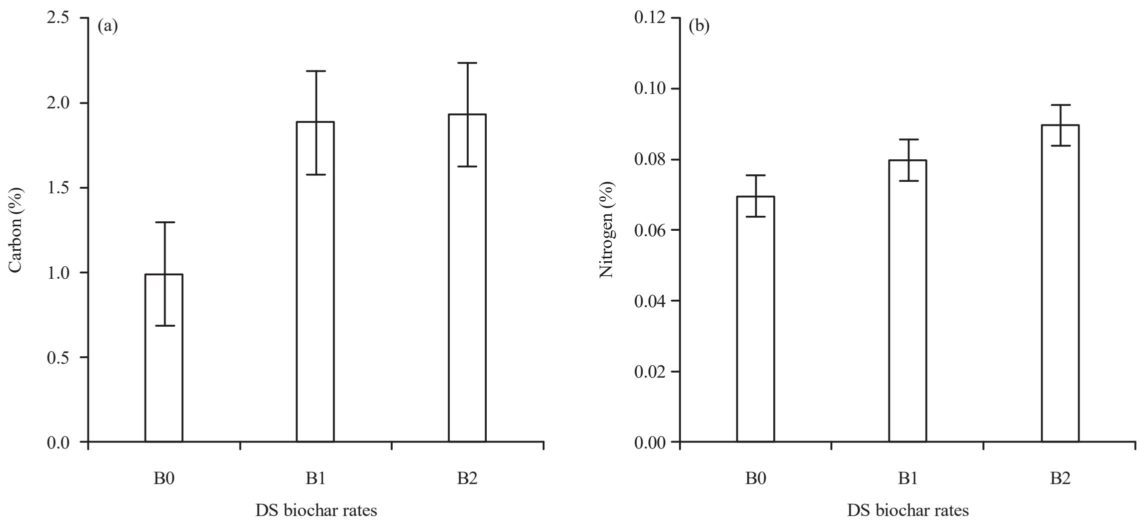

Fig. 2(a-b): Effect of DS biochar on (a) Carbon and (b) Nitrogen contents

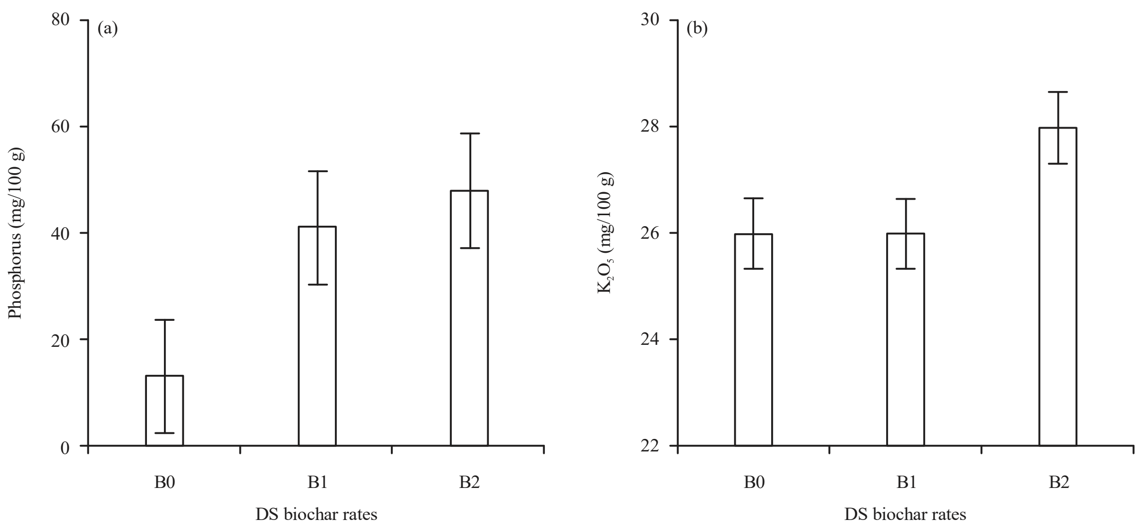

Fig. 3(a-b): Effects of DS biochar on (a) Phosphorus and (b) Potassium content

Table 3: Effect of different DS biochar on soil hardness, soil moisture and soil temperature

Treatments	Soil hardness (kg m^{-2}) (%)	Soil moisture (%)	Soil temperature (kg m^{-2} % °C)
Without biochar	13.62^{a}	9.08^{tn}	30.30^{b}
0.5 kg DS biochar m^{-2}	10.02^{b}	10.85^{tn}	30.38^{b}
1 kg DS biochar m^{-2}	9.87^{b}	10.72^{tn}	30.92^{a}

Values in the same column with different superscript letters are significantly different according to LSD test at $p<0.05$ for each variable

whereas the application of 1 kg m^{-2} of DS biochar increased the phosphorus and potassium content by 269 and 8%, respectively as compared to the control (Fig. 3a and b).

The application of 0.5 kg m^{-2} of DS biochar increased calcium content and CEC by 5 and 43%, respectively as compared to the control and the application of 1 kg m^{-2} of DS biochar increased the calcium content and CEC by 12% and 49%, respectively as compared to the control (Fig. 4a and b).

DS biochar significantly influence plant height, shoot dry weight, fruit number and fresh fruit weight as shown Table 4. DS biochar under different rates was insignificantly different but significantly different from control on plant height and fruit number. Table 4 also showed that soil treated with 0.5 kg m^{-2} was insignificantly different from soil treated with 1 kg m^{-2} in plant height and fruit number. Table 2 also showed that soil treated with 0.5 kg DS biochar m^{-2} was in significantly different from control, however, significantly different from soil treated with 0.5 kg DS biochar m^{-2} on shoot dry weight and fresh fruit weight.

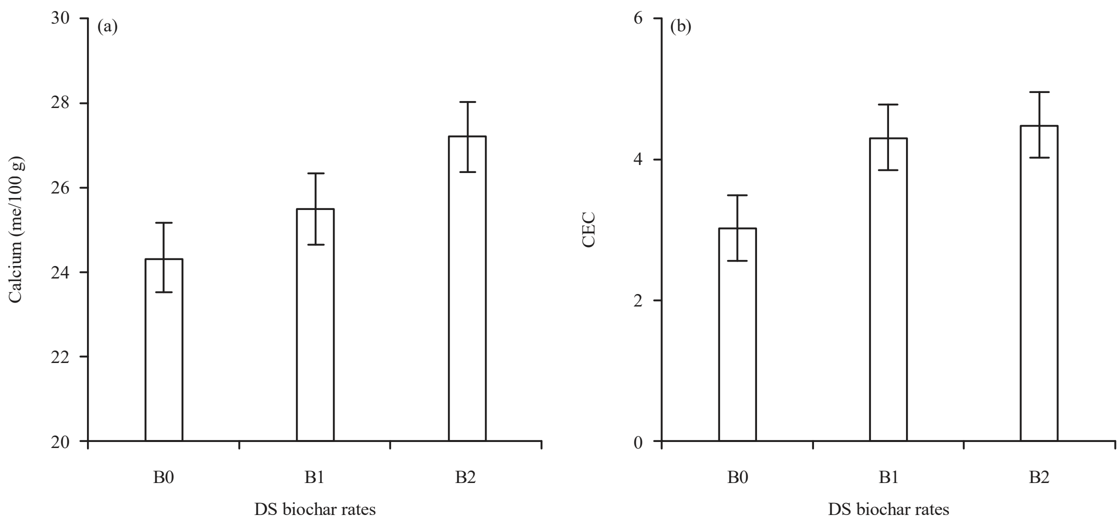

Fig. 4: Effects of DS biochar on (a) Calcium content and (b) CEC

Table 4: Effects of durian shell (DS) biochar on the growth and yield of field grown chilli

	Application rates			
Treatments	Plant height (cm)	Shoot dry weight (g)	Fruit number	Fresh fruit weight (g)
Without biochar	51.41^{b}	11.56^{b}	29.08^{b}	91.04^{b}
0.5 kg DS biochar m^{-2}	54.91^{a}	13.35^{ab}	37.43^{a}	108.3^{ab}
1 kg DS biochar m^{-2}	55.78^{a}	14.87^{a}	41.28^{a}	119.2^{a}

Values in the same column with different superscript letters are significantly, different according to LSD test at $p<0.05$ for each variable

DISCUSSION

Durian shell biochar significantly influence soil hardness as shown in Table 1. This result is in accordance with the findings of Laird *et al.*[23] and Jones *et al.*[24], who observed application of biochar can decrease the bulk density of soils. Soil treated with 0.5 kg DS biochar m^{-2} and 1 kg DS biochar m^{-2} decrease the soil hardness by 36 and 38%, respectively, than the control (Table 3) may be due to differences in their bulk density. Bulk density decreases with increase in rate of biochar application[25,26]. Further, Rogovska *et al.*[27], indicated that the rate of compaction decreased with increasing biochar application biochar significantly influence soil temperature as also shown Table 3. An increased amount of DS biochar was followed by an increase in soil temperature. Similar results showed that biochar increased soil temperature as reported by Bahrun *et al.*[22], Glaser *et al.*[28], possibly due to its color, biochar is expected to change in the albedo of the soil surface dan increase the capture of radiation.

Table 1 also showed that DS biochar was insignificantly influenced the soil moisture. However, many researches had reported that biochar application to soil increase pore aeration and water availability[29], improve soil structure[30] the soil's ability to retain moisture[31-33] .Soil treated with 0.5 kg m^{-2} was insignificantly different with control (without biochar) in soil moisture. The statistically similar on soil moisture of the soil treated with 0.5 kg DS biochar m^{-2}, 1 kg DS biochar m^{-2} and control is difficult to explain. A probable reason for this can be high frequency and daily rain fall during the crop season (Fig. 1).

DS biochar significantly influence plant height and shoot dry weight as shown Table 4. The tallest plant height and the highest shoot dry weight were obtained from the plot treated with 1 kg DS biochar m^{-2}, these could be due to the fact that biochar decreased soil hardness and modified the soil properties (Fig. 3). Biochar addition may cause significant decrease in bulk density as reported by Laird *et al.*[23], Jones *et al.*[24], Chen *et al.*[34]. This decreased bulk density may improve porosity and soil water holding capacity[23,35] and facilitating biomass gain[36]. Another way biochar may affect plant growth is through biochar-changes in soil nutrient conditions[37-39].

In general, DS biochar application increased fruit number and fresh fruit weight of field grown chilli. Biochar amended soil was generally characterized by a higher content of C, P, N, K, Ca and CEC than in the control plot. Table 4 showed that the positive effect of biochar on yield of chilli was possibly due to the nutrient ameliorating effects. This result was in conformity with the findings of Farrell *et al*.[40], who reported that the addition of biochar of N, P, K and Mg and higher grain yield. Table 4 showed that an increase in number and fresh fruit weight with increasing biochar rates. The application 0.5 kg m^{-2} of DS biochar increased fruit number and fresh fruit weight 29 and 19%, respectively as compared to the control without biochar, whereas the application 1 kg m^{-2} of DS biochar increased fruit number and fresh fruit weight by 42 and 31%, respectively as compared to the control without biochar (Table 4). This result was in agreement with findings of Spokas *et al*.[41] that amendment of soils with biochar under certain circumstances, significantly improve crop yield. Further, Kraska *et al*.[42] reported on winter rye that incorporation of biochar into the soil at the rate of 20 and 30 t ha^{-1} caused significant increase in the soil content of total C as well as of available P, K, Mg, Fe and B, relative to the control without biochar. Likewise, Lehmann *et al*.[43] found that addition of high rates biochar in the tropical environments have been associated with the increased plant uptake of P, K, Ca, Zn and Cu. As found from our results that DS biochar increased carbon, nitrogen, phosphorus, potassium, calcium and CEC reaching up to 95, 29, 269, 8, 12 and 49%, respectively, compared with control without biochar as shown in Fig. 1, 2 and 3 as results, plant growth and yield of chilli increased due to biochar amendment. This is consistent with the previous studies that application of biochar to soil help improve yield and its components of the crops[14,44-46].

CONCLUSION

The results showed that durian shell biochar increased soil nutrient and decreased soil density. Durian shell biochar significantly affected plant height, shoot dry weight, number of fruits and fruits weight, however, there is no significant difference between amount of durian shell biochar (0.5 and 1 kg m^{-2}) on growth and yield of field grown chilli.

SIGNIFICANCE STATEMENT

This study discovers the possible effect of durian shell biochar that can be beneficial for soil amendment, growth and yield of chilli. This study will help the researcher to uncover the critical area of the improvement of low soil nutrient and yield of chilli by application of different rate of durian shell biochar that many researchers were not able to explore. Thus, a new theory on the possibility of durian shell biochar for improving soil fertility and yield of chilli may be arrived at.

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REFERENCES

1. Estrades, C. and M.I. Terra, 2012. Commodity prices, trade and poverty in Uruguay. Food Policy, 37: 58-66.
2. Soelaiman, V. and A. Ernawati, 2013. Growth and development of *in vitro* curly pepper (*Capsicum annuum* L.) in some concentration BAP and IAA. Bul. Agrohorti, 1: 62-66.
3. Kementerian Pertanian Republik Indonesia, 2017. Produksi, luas panen dan produktivitas hortikultura di Indonesia. Diakses 4 Maret 2017. http://pertanian.go.id/indikator/tabel-2-prod-lspn-prodvitas-horti.pdf
4. Syukur, M., R. Yunianti and R. Dermawan, 2017. Budidaya Cabai: Panen Setiap Hari. PT. Penebar Swadaya, Jakarta, Pages: 148.
5. Yang, X., S. Zhang, M. Ju and L. Liu, 2019. Preparation and modification of biochar materials and their application in soil remediation. Applied Sci., Vol. 9, No. 7. 10.3390/app9071365.
6. Nurida, N.L., A. Rachman and Sutono, 2012. [The potential of biochar soil amendment in restoring degraded soils and increasing yield of maize in typic Kan Hapludults Lampung]. Buana Sains, 12: 69-74, (In Indonesian).
7. Ahmad, M., A.U. Rajapaksha, J.E. Lim, M. Zhang and N. Bolan *et al*., 2014. Biochar as a sorbent for contaminant management in soil and water: A review. Chemosphere, 99: 19-33.
8. Godlewska, P., H.P. Schmidt, Y.S. Ok and P. Oleszczuk, 2017. Biochar for composting improvement and contaminants reduction. A review. Bioresour. Technol., 246: 193-202.
9. Putri, V.I., Mukhlis and Hidayat, 2017. Application of different types of biochar to improve chemical properties of ultisolsoil and growth of maize. J. Agroekoteknol. FP, 5: 824-828.
10. Santi, L.P. and D.H. Goenadi, 2010. The use of bio-char as bacterial carrier for aggregate stabilization in ultisol soil from Taman Bogo-Lampung. Menara Perkebunan, 78: 52-60.
11. Sohi, S.P., E. Krull, E. Capel-Lopez and R. Bol, 2010. A review of biochar and its use and function in soil. Adv. Agron., 105: 47-82.

12. Kookana, R.S., A.K. Sarmah, L. van Zwieten, E. Krull and B. Singh, 2011. Biochar application to soil: Agronomic and environmental benefits and unintended consequences. Adv. Agron., 112: 103-143.
13. Chan, K.Y., L. van Zwieten, I. Meszaros, A. Downie and S. Joseph, 2007. Agronomic values of greenwaste biochar as a soil amendment. Aust. J. Soil Res., 45: 629-634.
14. Ahmed, F., M.S. Islam and M.T. Iqbal, 2017. Biochar amendment improves soil fertility and productivity of mulberry plant. Eurasian J. Soil Sci. Int., 6: 226-237.
15. Widiastuti, M.M.D., 2016. Analysis benefit cost ratio of biochar in agriculture land to increase income household in Merauke Regency. J. Penelitian Sosial Ekonomi Kehutanan, 13: 135-143.
16. Solaiman, Z.M. and H.M. Anawar, 2015. Application of biochars for soil constraints: Challenges and solutions. Pedosphere, 25: 631-638.
17. Tambunan, S., E. Handayanto and B. Siswanto, 2014. Effect of application of fresh and biochar organic materials on availability of P in soil in South Malang dry land. J. Tanah Sumberdaya Lahan, 1: 85-92.
18. Endriani, Sunarti and Ajidirman, 2013. Pemanfaatan biochar cangkang kelapa sawit sebagai soil amandement ultisol sungai Bahar-Jambi. J. Penelitian Univ. Jambi: Seri Sains, 15: 39-46.
19. Nisa, K., 2010. Effect of N, P, K and biochar fertilization on soil chemical properties, nutrient absorption and yield of paddy rice. Ph.D. Thesis, Universitas Syiahkuala, Malang.
20. Kurniawan, A., B. Haryono, M. Baskara and S.Y. Tyasmoro, 2016. The effects of biochar application to planting media on the growth of sugarcane seeds (*Saccharum officinarum* L.). J. Produksi Tanama, 4: 153-160.
21. Pari, G., H. Raliadi and S. Komarayati, 2013. Biochar for forestry and agricultural production. Proceeding of the National Workshop on Biochar for Food Security: Learning from Experiences and Identifying Research Priorities, February 4-5, 2013, Bogor, West Java, Indonesia, pp: 5-10.
22. Bahrun, A., M.Y. Fahimuddin, L.O. Safuan, L.M.H. Kilowasid and R. Singh, 2018. Effects of cocoa pod husk biochar on growth of cocoa seedlings in Southeast Sulawesi-Indonesia. Asian J. Crop Sci., 10: 22-30.
23. Laird, D., P. Fleming, B. Wang, R. Horton and D. Karlen, 2010. Biochar impact on nutrient leaching from a Midwestern agricultural soil. Geoderma, 158: 436-442.
24. Jones, B.E.H., R.J. Haynes and I.R. Phillips, 2010. Effect of amendment of bauxite processing sand with organic materials on its chemical, physical and microbial properties. J. Environ. Manage., 91: 2281-2288.
25. Mankasingh, U., P.C. Choi and K.V. Ragnarsdottir, 2011. Biochar application in a tropical, agricultural region: A plot scale study in Tamil Nadu, India. Applied Geochem., 26: S218-S221.
26. Zhang, A., R. Bian, G. Pan, L. Cui and Q. Hussain *et al*., 2012. Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. Field Crops Res., 127: 153-160.
27. Rogovska, N., D. Laird, R. Cruse, P. Fleming, T. Parkin and D. Meek, 2011. Impact of biochar on manure carbon stabilization and greenhouse gas emissions. Soil Sci. Soc. Am. J., 75: 871-879.
28. Glaser, B., L. Haumaier, G. Guggenberger and W. Zech, 2001. The Terra Preta phenomenon: A model for sustainable agriculture in the humid tropics. Naturwissenschaften, 88: 37-41.
29. Sutono, S. and N.L. Nurida, 2012. The water holding capacity of biochar in sandy soil fraction. Int. J. Penelit., 12: 45-52.
30. Glaser, B., J. Lehmann and W. Zech, 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. Biol. Fertil. Soils, 35: 219-230.
31. Singh, R., J.N. Babu, R. Kumar, P. Srivastava, P. Singh and A.S. Raghubanshi, 2015. Multifaceted application of crop residue biochar as a tool for sustainable agriculture: An ecological perspective. Ecol. Eng., 77: 324-347.
32. Karhu, K., T. Mattila, I. Bergstrom and K. Regina, 2011. Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity-results from a short-term pilot field study. Agric. Ecosyst. Environ., 140: 309-313.
33. Laird, D.A., P. Fleming, D.D. Davis, R. Horton, B. Wang and D.L. Karlen, 2010. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geoderma, 158: 443-449.
34. Chen, X., G. Chen, L. Chen, Y. Chen, J. Lehmann, M.B. McBride and A.G. Hay, 2011. Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. Bioresour. Technol., 102: 8877-8884.
35. Briggs, C.M., J.M. Breiner and R.C. Graham, 2005. Contributions of pinus ponderosa charcoal to soil chemical and physical properties. Proceedings of the ASACSSA-SSSA International Annual Meetings, November 6-10, 2005, Salt Lake City, USA.
36. Kammann, C.I., S. Linsel, J.W. Goßling and H.W. Koyro, 2011. Influence of biochar on drought tolerance of *Chenopodium quinoa* Willd and on soil-plant relations. Plant Soil, 345: 195-210.
37. Dempster, D.N., D.B. Gleeson, Z.I. Solaiman, D.L. Jones and D.V. Murphy, 2012. Decreased soil microbial biomass and nitrogen mineralisation with *Eucalyptus* biochar addition to a coarse textured soil. Plant Soil, 354: 311-324.
38. Dempster, D.N., D.L. Jones and D.V. Murphy, 2012. Organic nitrogen mineralisation in two contrasting agro-ecosystems is unchanged by biochar addition. Soil Biol. Biochem., 48: 47-50.

39. Taghizadeh-Toosi, A., T.J. Clough, R.R. Sherlock and L.M. Condron, 2012. Biochar adsorbed ammonia is bioavailable. Plant Soil, 350: 57-69.
40. Farrell, M., L.M. Macdonald, G. Butler, I. Chirino-Valle and L.M. Condron, 2014. Biochar and fertiliser applications influence phosphorus fractionation and Wheat yield. Biol. Fertil. Soils, 50: 169-178.
41. Spokas, K.A., J.M. Novak and R.T. Venterea, 2012. Biochar's role as an alternative N-fertilizer: Ammonia capture. Plant Soil, 350: 35-42.
42. Kraska, P., P. Oleszczuk, S. Andruszczak, E. Kwiecinska-Poppe and K. Rozylo *et al*., 2016. Effect of various biochar rates on winter rye yield and the concentration of available nutrients in the soil. Plant Soil Environ., 62: 483-489.
43. Lehmann, J., J. Gaunt and M. Rondon, 2006. Bio-char sequestration in terrestrial ecosystems-a review. Mitigat. Adapt. Strat. Global Change, 11: 403-427.
44. Igarashi, T., 2002. Effectiveness of Soil Amendments Like Rice Husk Charcoal. In: Handbook for Soil Amendment of Tropical Soil, AICAF. (Eds.). Association for International Cooperation of Agriculture and Forestry, Tokyo, Japan, pp: 127-134.
45. Agboola, K. and S.A. Moses, 2015. Effect of biochar and cowdung on nodulation, growth and yield of soybean (*Glycine max* L. Merrill). Int. J. Agric. Biosci., 4: 154-160.
46. Gebremedhin, G.H., B. Haileselassie, D. Berhe and T. Belay, 2015. Effect of biochar on yield and yield components of wheat and post-harvest soil properties in Tigray, Ethiopia. J. Fertil. Pestic., Vol. 6, No. 2. 10.4172/2471-2728.1000158.