Media Konservasi, 29 (4) 540-549

RESEARCH ARTICLE

MEDIA KONSERVASI
SCIENTIFIC JOURNAL IN CONSERVATION OF NATURAL RESOURCES AND ENVIRONMENT

Article Info:
Received 17 May 2024
Revised 29 August 2024
Accepted 06 September 2024

Corresponding Author:
Zaitun Zaitun
Department of Agrotechnology, Agriculture Faculty, Universitas Syiah Kuala, Banda Aceh, Indonesia
E-mail: zaitundara@usk.ac.id

Improving the Physical Properties of Ex-Coal Mining Soil Planted with Sweet Corn (*Zea mays saccharata* L.) Using Pine Wood and Sawdust Biochar

Syakur Syakur [a,c], Darusman Darusman[a,c], Zaitun Zaitun[b,c,*], and Golda Meilani Siagian[a]

[a] Soil Science Department, Agriculture Faculty, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[b] Agrotechnology Department, Agriculture Faculty, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[c] Research Center for Biochar and Sustainable Tropical Forests, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia

Abstract

Biochar is a by-product produced from the combustion process without oxygen at high temperatures (100-800°C) for approximately one hour. The advantage of this biochar is that apart from having several distinctive properties such as being more efficient, cost-effective, and easy to obtain, it can also improve the soil physical properties and remove toxic contaminants in ex-coal mining soil. Through its large surface area, large pore size distribution, particle types and low density, biochar can influence soil porosity, soil consistency, improve soil aggregate stability values and increase water availability for plants by up to 130%. The research was carried out at the experimental site of the Agriculture Faculty, Universitas Syiah Kuala using planting media from ex-coal mining soil. This research used a factorial randomized block design with three replications. The first factor was the biochar feedstock consisted of pine wood and sawdust. The second factor was the biochar dosage consisted of 0, 10, and 20 tonnes ha^{-1}. The physical soil characteristic parameters observed were soil porosity, bulk density, and aggregate stability. The biochar characteristic parameters observed were biochar combustion results, biochar morphology, water holding capacity, and biochar bulk density. Sawdust biochar morphology showed relatively porous, had higher fixed C, higher water holding capacity and lower bulk density than pine wood biochar. Application of sawdust biochar was better in ex-coal mining soil. Pine wood and sawdust biochar can improve soil physical properties, especially soil porosity, but did not affect soil bulk density and soil aggregate stability. Biochar dosages of 10 and 20 tonnes ha^{-1} can improve soil porosity. However, to minimize costs, the biochar application at a dose of 10 tonnes ha^{-1} can be recommended.

Keywords: ex-mining soil, soil amendment, soil physical properties

1. Introduction

Coal mining in Indonesia is generally an open pit mining system that opens the topsoil and removes it from the excavation area. The coal is excavated and transported out. After the excavation process is complete, the holes resulting from the coal mine excavation are backfilled with the previous soil cover. However, there is a concern that the landfilling process is not appropriate, resulting in the topsoil being buried or mixed with other soil contaminated by dangerous heavy metals. This results in changes in the landscape, the quality of the landfill resulting from coal excavation becomes low, and the content of heavy metals which are dangerous in supporting the plant growth process.

Problems in the soil's physical properties due to mining are soil compaction making it difficult to cultivate. Land conditions like this can worsen the water system and aeration which will disrupt the plant roots' function and development. Apart from that, the topsoil layer becomes thin or even disappears, and the structure and porosity are damaged, causing the soil to be unable to store and absorb water when it rains, resulting in a high chance of erosion and a low carrying capacity for plant growth. Therefore, this land was included as problematic land or marginal land that was poor in nutrients and needed to be restored so that plants can grow well.

Regarding the problems above, researchers were focusing more on efforts to find environmentally friendly solutions, one was adding organic material to the soil. However, with the advent of new technology, the organic material input offered is biochar. Biochar is a by-product produced from the combustion process without oxygen at high temperatures

(100-800°C) for approximately one hour [1]. The advantage of biochar is that apart from having several distinctive properties such as being more efficient, cost-effective, and easy to obtain because it uses environmentally friendly materials, it can also suppress and remove toxic contaminants [2] and biochar is a potential soil amendment because it is able to restore degraded land [3].

Biochar has the ability to restore degraded land such as ex-mining land. Through its large surface area, large pore size distribution, particle types, and low density, biochar can influence soil pore space and soil consistency [4]. Another advantage of biochar is that it can improve the stability value of wet soil aggregates by up to 226% and increase water availability for plants by up to 130% [3,5].

This research applied biochar from environmentally friendly waste to improve the soil's physical properties due to coal mining activities. Some waste that was included in the environmentally friendly category were pine wood and sawdust. The aim of this research was to determine the interaction effect of biochar type and dosage on the soil's physical properties in sweet corn land.

2. Materials and Methods

The location of research at the experimental site of the Agriculture Faculty, Universitas Syiah Kuala with planting media from ex-coal mining soil. Soil samples were analysed at the Soil Physics Laboratory, Agriculture Faculty, Universitas Syiah Kuala, Banda Aceh. Analysis of biochar characteristics using scanning electron microscopy (SEM) was conducted at the Physical Instrumentation Analysis Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala.

This research used a Randomized Block Design with a 2 × 3 factorial pattern. The first factor was the type of biochar feedstock, consisted of two types (biochar from pine wood and biochar from sawdust raw materials). The second factor was dosage of biochar, consisted of three levels (0, 10, and 20 tonnes ha^{-1}) and three replications.

2.1. Biochar Production

Before producing the biochar, pine wood, and sawdust waste were dried in the sun until dry. Then each type of biochar feedstock was weighed then put into the combustion device. The sawdust was placed into a drum, while the pine wood was placed into a Kon-Tiki. This was different because pine wood has a harder raw material than sawdust, so it is less effective when burned in a drum. The burning process was at a temperature of 100-800°C for approximately one hour through incomplete combustion (pyrolysis) [1]. After the burning was complete, the biochars were dried in the sun until dry, then ground and sieved using a 2 mm sieve. Then 100 grams of each biochar was collected randomly and then composited to analyse the characteristics of the biochar.

2.2. Soil Sampling

Soil sampling was collected twice, sampling for pretreatment analysis and final analysis. Soil sampling for pretreatment analysis before the soil was incubated. The soil for analysis by taking aggregate soil. The final analysis was observed when the plants were 45 days after planting. The parameters for the soil physical properties were: (1) bulk density, (2) texture, (3) total porosity, and (4) aggregate stability.

The determination of bulk density was using the Clod method and calculated using the formula [6]:

$$Clod\ Density\ (\mathrm{g\ cm^{-3}}) = \frac{\mathrm{\rho w} \times Ms}{\mathrm{Mu - Ma + Mp - (Mp \times \rho w/\rho p)}} \quad (1)$$

ρw: Specific gravity of water at the temperature during measurement (g cm^{-3})
Ms: Weight of soil lumps in an oven-dry (g)
Mu: Weight of air-dried soil lumps (g)
Ma: Weight of soil lumps that have been coated with wax put into water (g)

Mp: Weight of wax layer in the air = weight of soil lumps covered with wax - weight of lumps before being coated with wax (g)

pp: Specific gravity of wax (≈ 0.8 g cm^{-3})

The determination of soil texture was used the dropper pipette method to determine the relative ratio of sand, dust, and clay. The results of the analysis of soil texture were expressed in %.

Analysis of soil porosity was expressed in % units and calculated using the formula [7]:

$$\text{Total Porosity (\%)} = \%\ H_2O\ \text{dry weight} \times \text{Soil bulk density} \quad (2)$$

The aggregate stability was calculated using the formula [8]:

$$\mathrm{AS} = \frac{1}{\mathrm{Xa} - \mathrm{Xb}} \times 100\% \quad (3)$$

AS: Aggregate stability.

Xa: Average diameter weight of dry sieving (g)

Xb: Average diameter weight of wet sieving (g)

2.3. Biochar Characteristic Analysis

Analysis of biochar characteristics was to determine the characteristics of each type of biochar feedstock. The biochar characteristic parameters were: (1) biochar combustion results, (2) biochar morphology, (3) water holding capacity, and (4) biochar bulk density. The biochar morphology was evaluated using scanning electron microscopy (SEM) analysis with a magnification of 10,000 times.

2.4. Planting Media Preparation

Soil as a planting medium was taken from an ex-coal mining area located in West Aceh District. The soil was air-dried and then sieved using a 5 mm diameter sieve. The soil water content was measured to determine the dry weight of the soil. Next, 20 kg of soil was weighed, then mixed and stirred with biochar according to the dosage for each treatment and put it in a pot. Then water was added at field capacity for an incubation process of 14 days.

2.5. Plant Planting

After the soil had been incubated for 14 days, sweet corn seeds of the Bonanza F1 variety were planted into experimental pots. Each planting hole at a depth of 3 cm was filled with two corn seeds per hole and then covered again with soil.

2.6. Fertilizer

This research used fertilizer as basic fertilizer to support the growth of sweet corn plants. Fertilizer application was done at 9 days after planting. Fertilizer doses used in this research were SP 36 (250 kg ha^{-1} or 1.49 g pot^{-1}), Urea (444 kg ha^{-1} or 2.28 g pot^{-1}), and KCl (400 kg ha^{-1} or 2.9 g pot^{-1}).

3. Results and Discussion

3.1. Soil Physical Properties Pre-treatment

The physical properties of ex-coal mining soil showed that ex-coal mining soil had a soil bulk density that was classified as high for agricultural land (1.4 g cm^{-3}), whereas for ideal soil it was around 1.0–1.20 g cm^{-3}, soil porosity was included in the poor category (31%), unstable aggregate stability was only around 25%, and soil texture was sandy loam (70% sand, 25%

silt, and 5% clay). Based on the analysis result of physical fertility of the ex-coal mining soil, it did not support the process of plant growth and development, so improvements were needed.

Table 1. Pre-treatment analysis of the physical properties of ex-coal mining soil

No	Parameters	Value	Category
1	Bulk density (g cm^{-3})	1.4	High
2	Porosity (%)	31	Poor
3	Soil aggregate stability (%)	25	Unstable
4	Texture		
	Sand (%)	70	Sandy loam
	Silt (%)	25	
	Clay (%)	5	

3.2. Biochar Characteristics

3.2.1. Biochar Combustion Results

The results of combustion biochar showed that the sawdust temperature value using the drum method was lower (125–230°C) and the biochar production results were higher, 24.0% of the weight of the feedstock compared to biochar from pine wood feedstock using the Kon-Tiki method (Table 2). The level of fixed carbon produced was higher (62.43%), because the drum method, apart from being easier and cheaper, also produces even combustion without ash, and was easy to grind. In accordance with the opinion of [9] the level of fixed carbon was influenced by the complete combustion or pyrolysis process so that the components of water, ash, and volatile matter will easily evaporate and affect the calculation of the level of fixed carbon. However, the disadvantage of the drum method was that the production process takes longer than the Kon-Tiki method.

Table 2. Time of combustion, yield ratio and fixed carbon under two types of burning instruments and of biomass waste

No	Waste	Instrument	Burning time (minute)	Raw material weight (kg)	Biochar weight (kg)	Temperature (°C)	Yield (%)	Fixed Carbon (%)
1	Sawdust	Drum	60	15	3.6	125-230	24.0	62.43
2	Pine wood	Kon-Tiki	50	50	13.7	604-868	27.4	53.04

This was different from the results of combustion pine wood biochar using the Kon-Tiki method which obtained a higher temperature (604 – 868°C) with biochar production 27.4% of the raw material weight. In the combustion process using the Kon-Tiki method, there were several problems, such as during the combustion process, monitoring and control were very necessary because the fire can burn big due to the air that can still enter the biochar burning furnace, causing the biochar raw material to easily become ash. This method can also produce uneven biochar burning conditions due to extinguishing the fire too quickly. High temperatures will result in high ash content [10] so that little biochar was produced. Apart from that, in the Kon-Tiki method, there was the influence of air which causes the combustion process to undergo oxidation. This was supported by research by Debby [11] which reveals that if combustion was carried out with direct air contact, less charcoal was produced and more ash was produced, so the fixed carbon content produced from pine wood biochar using the Kon-Tiki was lower at 53.04%.

3.2.2. Biochar Morphology

Sawdust biochar morphology with a magnification of 10,000 times showed relatively porous. The biochar surface morphology properties were influenced by the feedstock types and pyrolysis temperature [12] and if the pyrolysis temperature increases, more pores in biochar will be produced [13]. In the drum method, sawdust biochar has many meso-pore shapes and sizes between 6.631-9.497 micrometres, and the pore holes appear to be multiple. Based on the morphology of sawdust biochar using the drum method, there were varying distances between pores. If we look at the diameter of the pore holes, sawdust biochar using the drum method has a smaller surface area compared to the biochar surface area from pine wood because the pore size was bigger with a size of 6.631-9.497 micrometres Table 3.

The pore shape of pine wood biochar using the Kon-Tiki method has a uniform pore shape between 1.039 – 2.376 micrometres and the pore holes appear single, and some were multiple. However, sawdust biochar using the drum method and pine wood biochar using the Kon-Tiki method both have pore sizes that fall into the meso-pore class with a pore size criterion of 0.2 – 30 micrometres [14].

Based on its morphology, sawdust biochar using the drum method and pine wood biochar using the Kon-Tiki method both have distances between pores, but in sawdust biochar, the distance between pores was more uniform than in pine wood biochar. Nurida et al. [1] stated that the properties of biochar which are rich in micropores will be very useful if applied to sandy soils where the specific surface area of the soil is relatively limited.

Table 3. Biochar pore diameter

No	Biochar type	Pore diameter (µm)		Average
		Minimum	Maximum	
1	Pine wood	1.039	2.376	1.7075
2	Sawdust	6.631	9.497	8.0640

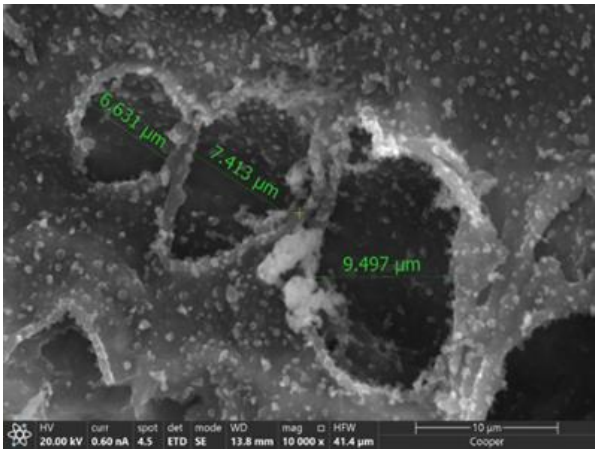

Figure 1. The pore diameter size of Sawdust Biochar with drum method.

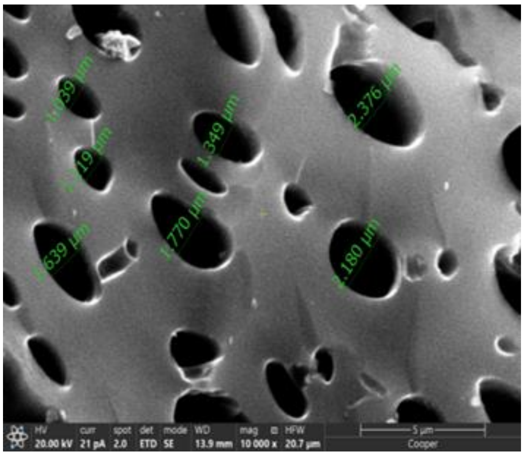

Figure 2. The pore diameter size of Pine Wood Biochar with Kon-Tiki Method.

3.2.3. Water Holding Capacity

Soil water holding capacity is the maximum amount of water that freely soil can hold, estimated after saturated soil has been allowed to drain without allowing its moisture to be depleted by evaporation [15]. It is generally recognized that the addition of biochar can increase the soil's ability to store and release water [16]. Through its large surface area, biochar can increase soil aggregation and reduce soil bulk density, which in turn can increase the number of soil pores, especially micropores which function to hold water [17].

Table 4. Biochar water holding capacity

No	Biochar type	Water holding capacity (%)
1	Pine wood	166.67
2	Sawdust	481.48

Sawdust biochar had a water-holding capacity value of 481.48%, while pine wood biochar had a water-holding capacity value of around 166.67% (Table 4). From several research results, the water holding capacity of biochar depend on type of feedstock and pyrolysis conditions which were responsible for the structure and surface area of the biochar product [18]. In addition, these factors also have a direct effect on biochar water absorption and help the soil retain water better if biochar is applied to the soil [19]. The higher water-holding capacity contained in biochar will enable moisture to be maintained in the soil although the effect appears to depend on the initial texture of the soil. Water holding capacity is generally at its optimum when the pores are large so this will also be related to soil porosity.

3.2.4. Biochar Bulk Density

The bulk density of biochar was also an important criterion for describing the physical quality of biochar. In general, the bulk density of biochar is lower than the bulk density of soil [20].

The bulk density value of sawdust biochar is lower (0.28 g cm^{-3}) compared to the bulk density of pine wood biochar with a value of 0.32 g cm^{-3} (Table 5). The weight value of the biochar content is in accordance with the Indonesian National Standard (SNI). SNI sets the weight of biochar in the granular form at around 0.44-0.55 g cm^{-3} while in powder form it is around 0.2-0.35 g cm^{-3} [21].

Table 5. Bulk density of two type biochar

No	Biochar type	Biochar bulk density (g cm^{-3})
1	Pine wood	0.32
2	Sawdust	0.28

This difference was caused by different raw materials, where biochar from sawdust has a larger pore diameter than pine wood. This statement is in accordance with the opinion of [22] who said that the bulk density of biochar depends on the raw materials used. If the biochar raw material has many particles and includes macro porosity within each particle and voids between particles, then the bulk density value of the biochar will be lower.

3.3. Effect of Pine wood and Sawdust Biochar Application on Soil Physical Properties

3.3.1. Soil Porosity

There was a significant effect of the biochar dose treatment on the percentage of soil porosity with the lowest average value found in the treatment of biochar 0 tonnes ha^{-1} (45.58%), while the highest average value of soil porosity percentage is found in the treatment of sawdust biochar with a dose of 20 tonnes ha^{-1} was 56.21% (Table 6). This was because sawdust biochar has more macro pores than pine wood biochar. This will have an impact on the absorption capacity of coal mine soil treated with sawdust biochar which is better able to retain water than soil treated with pine wood biochar so that water for plants becomes available. However, there was not significant effect between biochar dose on 10 tonnes ha^{-1} and 20 tonnes ha^{-1}. It can be concluded that a dose of 10 tonnes ha^{-1} was a dose that can be recommended. Several studies also report that the effectiveness of biochar application in improving soil water retention is clearly visible when applied to sand-textured soil [5,23].

Table 6. Average value of soil porosity due to the application of pine wood and sawdust biochar

Biochar type	Biochar dose (tonnes ha^{-1})			Average
	0	10	20	
	Soil porosity (%)			
Pine wood	45.58 a	51.86 b	52.88 b	50.11 a
Sawdust	45.58 a	52.31 b	56.21 b	51.37 a

The increase in soil porosity value was closely related to the decrease in soil bulk density value which has an impact on increasing the total soil porosity. This was also inseparable from the carbon contribution resulting from the application of biochar so that it has an impact on increasing soil C-organic, reducing the soil bulk density, and increasing the total porosity of the soil. On the other hand, biochar dosage also has a different effect on the amount of porosity. The higher dose of biochar affected higher total soil porosity, this is in line with [24] stated that soil porosity is influenced by the organic matter content, structure, and texture of the soil. Soil porosity is increased if organic matter is high.

Organic matter can act as an adhesive medium for soil fractions to form a better structure and granulation process. The soil structure which was initially dense will become crumblier due to the increase in the percentage of total space in the soil pores. Soils with a crumbly or granular structure have higher porosity than soils with a solid structure. Utilization of organic material in the biochar form was an action that can support soil carbon conservation [25]. Furthermore [26] stated that technological innovation to formulate and enrich soil organic matter was very necessary so that the effectiveness of organic matter as a soil amendment or organic fertilizer is higher and the required dose can be reduced.

3.3.2. Soil Bulk Density

The application of pine wood and sawdust biochar has no effect on the soil bulk density in the ex-coal mining soil. The highest average value of soil bulk density was in the treatment without biochar (1.25 g cm^{-3}) and the lowest average value was in the biochar treatment (1.24 g cm^{-3}) Table 7. However, when compared with the pre-treatment analysis of the ex-coal mining soil, the application of pine wood and sawdust biochar was able to reduce the soil bulk density 1.4 g cm^{-3} to 1.24-1.25 g cm^{-3}. This is also supported by an increase in the porosity value of ex-coal mining soil that has been applied with biochar, so it is suspected that the percentage of the number of macro pores in ex-mining soil that has been applied with biochar has decreased. In line with [27] statement that the total pore space of the soil is inversely proportional to the soil bulk density and is largely determined by the organic matter contained in the soil.

Table 7. Average value of soil bulk density due to the application of pine wood and sawdust biochar

Biochar type	Biochar dose (tonnes ha^{-1})			Average
	0	10	20	
	Bulk density (g cm^{-3})			
Pine wood	1.25	1.24	1.24	1.24
Sawdust	1.25	1.24	1.24	1.24

The soil C-organic treated with biochar was much higher compared to soil that had primary forest vegetation. Soil organic C will influence physical indicators such as bulk density, aggregate stability, and water retention, and also as an indicator of the quality of the soil itself [28]. This showed that the presence of biochar can make the soil loose and not dense.

3.3.3. Aggregate Stability

The application of biochar did not have a significant effect on aggregate stability in ex-coal mining soil Table 8. The highest average value of aggregate stability was obtained in sawdust biochar treatment with a dose of 20 tonnes ha^{-1}, while for pine wood biochar the highest value was found at a dose of 10 tonnes ha^{-1}. Meanwhile, the lowest average aggregate stability value was found in the sawdust biochar treatment with a dose of 10 tonnes ha^{-1}. On the other hand, the application of biochar can increase the aggregate stability value by 11.32% from the pre-treatment condition of 25% to 26-27%. Herath et al. [29] also stated that biochar as an amendment can increase soil aggregate stability by >17% and this increase is smaller, ranging from 4-16% from the control treatment.

Table 8. Average value of aggregate stability due to the application of pine wood and sawdust biochar

Biochar type	Biochar dose (tonnes ha^{-1})			Average
	0	10	20	
	Aggregate stability (%)			
Pine wood	26.53	26.80	26.65	26.66
Sawdust	26.53	26.54	27.19	26.75

It is suspected that the soil C-Organic has been treated with biochar decomposes optimally so that the population of microorganisms as granulation-stimulating agents in the soil did not work optimally. Subagyono et al. [30] also stated that aggregate stability is formed due to interactions between organic matter (C-Organic), microorganisms, and soil minerals which are also influenced by several factors such as raw materials of organic matter, decomposing processes, and the soil properties. Organic matter (C-Organic) has properties as an adhesive (cementing agent) so that soil aggregates become more stable and are not easily destroyed by hitting raindrops [31].

4. Conclusions

Sawdust biochar morphology showed relatively porous, had higher fixed C, higher water holding capacity, and lower bulk density than pine wood biochar. Application of sawdust biochar was better in ex-coal mining soil.

Pine wood and sawdust biochar can improve soil physical properties, especially soil porosity, but did not improve other soil physical properties such as soil bulk density and soil aggregate stability in ex-coal mining soil.

Biochar doses of 10 and 20 tonnes ha^{-1} can improve soil porosity. However, to minimize costs, the biochar application at a dose of 10 tonnes ha^{-1} can be used as a recommendation.

Author Contributions

SS: Supervision, Writing-Review, and Editing; **DD**: Writing-Original draft preparation, Conceptualization, Methodology; **ZZ**: Supervision, Writing-Review, and Editing; **GMS**: Data Collection, Software, Data Visualization, Writing-Review & Editing.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

We thank The Research and Community Service Institutions of Universitas Syiah Kuala for funding this research.

References

1. Nurida, N.L.; Rachman, A.; Sutono. Potential of Biochar Soil Improvement in Restoring Degraded Soil Properties and Increasing Corn Yields in Typic Kanhapludults Lampung. *J. Research and Development* **2012**, *12*, 69–74.
2. Oliveira, F.R.; Patel, A.K.; Jaisi, D.P.; Adhikari, S.; Hui, L.; Khanal, S.K. Environmental Application of Biochar: Current Status and Perspectives. *Bioresour Technol* **2017**, *246*, 110–122.
3. Blanco-Canqui, H. Biochar and Soil Physical Properties. A Review. *Analysis-Soil Physics and Hydrology* **2017**, *81*, 687–711.
4. Downie, A.; Crosky, A.; Munroe, P. Physical Properties of Biochar. In *Biochar for Environmental Management: Science and Technology*; Lehmann, J., Joseph, S., Eds.; 2009.
5. Atkinson, C.J.; Fitzgerald, J.D.; Hipps, N.A. Potential Mechanisms for Achieving Agricultural Benefits from Biochar Application to Temperate Soils: A Review. *Plant Soil* **2010**, *337*, 1–18.
6. Agus, F; Yustika, RD; Haryati, U. Determination of Specific Gravity of Soil Particles. In Undang Kurnia (Ed.). Physical Properties of Soil and Its Analysis Methods. Center for Agricultural Land Resources Research and Development. Agricultural Research and Development Agency. Ministry of Agriculture. **2006,** 25 – 34.
7. Tan, KH. Soil Sampling, Preparation, and Analysis. Second Edition. CRC Press Taylor and Francis Group. Boca Raton, FL **2005** 33487- 2742. 623 p.
8. Leenheer, L; De Boodt, M. Determination of Aggregate Stability by the Change in Mean Weight Diameter. Overdruk Uit Medelingen Van de Staat te Gent. International Symposium on Soil Structure, **1959** Ghent, 1958.
9. Basu, P. *Biomass Gasification and Pyrolisis, Practical Design and Theory*; Academic Press: Burlington (MA), 2010;

10. Prabowo, A.L. *Making Activated Carbon from Corn Cobs and Its Application for Adsorption of Cu, Pb, and Ammonia*. Undergraduate Thesis, Faculty of Engineering, University of Indonesia, Depok, 26 June 2009.
11. Debby, A. *Making Activated Carbon Nanopores from Durian Peel Waste for Lead (II) Heavy Metal Adsorbent*; Research Report, Faculty of Engineering, Setia Budi University, Surakarta, 30 January 2020.
12. Zaitun, Z.; Halim, A.; Sa'dah, N.; Cahyadi, R. Surface Morphology Properties of Biochar Feedstock for Soil Amendment. *IOP Conf. Ser. Earth and Environ. Sci.* **2022**, *951*, 12034, doi:10.1088/1755-1315/951/1/012034.
13. Mohanty, P.; Nanda, S.; Pant, K.K.; Naik, S.; Dalai, A.K. Evaluation of Physiochemical Development of Biochar Obtained from Pyrolysis of Wheat Straw, Timothy Grass and Pine Wood: Effect of Heating Rate. *J Anal Appl Pyrolysis* **2013**, *104*, 485–493.
14. Esmaeelnejad, L.; Shorafa, M.; Gorji, M.; Hosseini, S.M. Enhancement of Physical and Hydrological Properties of A Sandy Loam Soil Via Application of Different Biochar Particle Sizes During Incubation Period. *Spanish Journal of Agricultural Research* **2016**, *14*.
15. Dugan, E.; Robinson, J.S.; Verhoef, A.; Sohi, S. Biochar from Sawdust, Maize Stover and Charcoal: Impact on Water Holding Capacity (WHC) of Three Soils from Ghana. In Proceedings of the World Congress of Soil Science, Soil Solutions for A Changing World; 2010.
16. Novak, J.M.; Busccher, W.J.; Amonette, J.E.; Ippolito, J.A.; Lima, I.M. Biochar Impact on Soil-Moisture Storage in An Ultisol and Two Aridisols. *Soil Sci* **2012**, *177*.
17. Haynes, R.J.; Naidu, R. Influence of Lime, Fertilizer and Manure Applications on Soil Organic Matter Content and Soil Physical Conditions. A Review. *Nutr Cycl Agroecosyst* **1998**, *51*, 123–137.
18. Streubel, J.D.; Collins, H.P.; Garcia-Perez, M.; Tarara, J.; Granatstein, D.; Kruger, C.E.E. Influence of Contrasting Biochar Types on Five Soils at Increasing Rates of Application. *Soil Sci. Soc. Am. J.* **2011**, *75*, 1402–1413.
19. Ulyett, J.; Sakrabani, R.; Kibblewhite, M.; Hann, M. Impact of Biochar Addition on Water Retention, Nitrification and Carbon Dioxide Evolution from Two Sandy Loam Soils. *Eur. J. Soil Sci.* **2014**, *65*, 96–104.
20. Burrell, D.L.; Zehetner, F.; Rampazzo, N.; Wimmer, B. Long-Term Effect of Biochar on Soil Physical Properties. *Geoderma* **2016**, *282*, 96–102.
21. Jamilatun Characteristics of Activated Charcoal from Coconut Shell with Activation of H2SO4 with Temperature and Time Variations. In Proceedings of the National Symposium on Applied Technology (SNTT) 2; Yogyakarta, 2014.
22. Marry, G.S.; Sugumaran, P.; Niveditha, S.; Ramalakshmi, B. Production, Characterization and Evaluation of Biochar from Pod (Pisum Sativum), Leaf (Brassica Oleracea), and Peel (Citrus Sinensis) Wastes. *J. Recycl Org Waste Agricultural* **2016**, *5*, 43–53.
23. Suwardji; Utomo, W.H.; Sukartono Aggregate Stability After Application of Biochar in Sandy Clay Soil in Corn Planting in Dry Land, North Lombok District. *Buana Sains* **2012**, *12*, 61–68.
24. Hardjowigeno, S. *Soil Science*; Akademia Pressindo: Jakarta, 2007;
25. Glaser, B.; Lehman, J.; Zech, W. Ameliorating Physical and Chemical Properties of Highly Weathered Soils in The Tropics with Charcoals. A Review. *Biol Fertil Soils* **2002**, *35*, 219–230.
26. Dariah, A.; Sutono; Nurida, N.L. Use of Organic and Mineral Soil Improvers to Improve Soil Quality Typic Kanhapludults, Taman Bogo, Lampung. *Journal of Soil and Climate* **2010**, *3*.
27. Soepardi, G. *Soil Properties and Characteristics*; Department of Soil Sciences, Faculty of Agriculture, Bogor Agricultural Institute: Bogor, 1983;
28. Sombroek, W.; Ruivo, M.L.; Fearnside, P.M. Amazonian Dark Earths as Carbon Stores and Sinks. In *Amazonian Dark Earths: Origin, Properties, Management*; Lehmann, J., Ed.; Kluwer Academic Publishers: Dordrecht, 2003; pp. 125–139.
29. Herath, S.; Camps-Arbestain, M.; Hedley, M. Effect of Biochar on Soils Physical Properties in Two Contrasting Soils An Alfisol and An Andisol. *Geoderma* **2013**, *209–210*, 188–197.
30. Subagyono, K.; Haryati, U.; Talaohu, S.H. Water Conservation Technology in Dry Land Agriculture. In *Soil Conservation on Dry Sloping Land*; Purnomo, E.S., Ed.; Centre for Soil and Agroclimate Research and Development, R&D Agency, Agriculture Department, 2004; pp. 151–188.

31. Suriadikarta, D.A.; Prihatini, T.; Setyorini, D.; Hartatiek, W. Soil Organic Matter Management Technology. In *Dry Land Management Technology towards Productive and Environmentally Friendly Agriculture*; Centre for Soil and Agroclimate Research and Development: Bogor, 2002.