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Role of Rice Husk Biochar in Improving Soil Physical Properties of ex Gold-Mined Soil

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ABSTRACT

Mining causes destructive soil properties, especially soil texture, water retention, and transmission. Applying biochar is the best way to improve soil physical properties. A glasshouse experiment was conducted to evaluate the role of biochar on soil physical properties based on a Completely Randomized Design (CRD) with four replicates. The research comprised six treatments (0, 4, 8, 12, 16, 20 t biochar ha^{-1}). The results showed that the ex-gold-mined soil had coarse soil texture (sandy loam), high Bulk Density (BD) (1.43 g cm^{-3}), low Total Soil Pores (TSP) (46.45%), low soil organic matter (SOM) content (1.27 %), very fast hydraulic conductivity (198.8 cm h^{-1}). After biochar incubation, SOM increased (to 3.11%), soil BD decreased (to 1.16 g cm^{-3}), TSP increased (to 54.17 %), water retention increased (at pF 1.0, 2.0, 2.54, and 4.2), plant available water (PAW) increased (into 8.33 %), and hydraulic conductivity decreased (into 24.70 cm h^{-1}). However, applying 20 t biochar ha^{-1} still needs to bring the soil physical properties of the ex-gold-mined soil back into suitable soil for farming land.

Keywords: Liquid organic fertilizer, upland rice, synthetic zeolite

INTRODUCTION

Illegal gold mining has been conducted in Dharmasraya Regency since the last decade. It has polluted the soil and river water on which the tailing was disposed. Soil properties of ex-gold mined soil are highly degraded. It does not only degrade chemical and biological but also soil physical properties. Soil physical properties such as texture became very coarse; soil BD was very high, and total soil pores and the amount of plant available water decreased (Yulnafatmawita et al., 2018; 2020).

In order to be able to reuse for agriculture, the ex-mined soil must be ameliorated. Some types of organic matter, such as manure and compost, should be added to improve soil properties. Another amendment material that is quite popular lately is biochar. Biochar could improve soil chemical properties (Yulnafatmawita et al., 2020; Ethik et al., 2021; Solfianti 2021), soil biological properties (Dermiyati et al., 2017; Nurbaity et al., 2019), and soil physical properties (Yulnafatmawita et al., 2021; Prakongkep et al., 2021; Gelardi et al., 2021; Fu et al., 2021).

For soil physical properties, biochar can increase soil OM content, water retention, and plant available water of fine textured soil (Yulnafatmawita et al., 2021). Biochar has porous structure large specific surface area (Leng et al., 2021; Fu et al., 2021). Then, Prangkokep et al. (2021) stated that biochar was found to initiate the soil aggregation process in clay-textured soil. Compared to manure, biochar was more effective in reducing some metal elements in the soil solution of paddy soil (Yulnafatmawita et al., 2020). Chen et al. (2018) found that the dose and characteristics of biochar applied as a soil amendment would determine the rate of soil hydraulic conductivity.

Herath et al. (2013) reported that after 295 days of incubation, biochar could increase soil aggregate stability under two contrasting soils, Alfisol and Andisol. It also increased water retention at each matric potential of the soil water. Biochar application could improve the available water content of coarse-textured soils (Glab et al., 2016) and increase aggregate stability (Baiamonte et al., 2019).

Application of biochar into three soil orders, Entisol, Ultisol, and Luvisol (Santos et al., (2022), also increased the capacity of those soils to hold water and reduced the hydrophobicity (Adhikari et al., 2022). It was suggested that biochar can be used as soil ameliorant across soil textures, especially problematical soils.

Ex-gold-mined land was considered problematical soil since it can cause environmental pollution, either soil or water pollution *in situ* and *ex-situ*, and it cannot be used for farming activities. Therefore, an effort is needed to improve the land for the farming areas as it was before. The use of biochar as a soil amendment is promising. Among the soil fertility determinant, soil physical properties are the main factor to be improved before the chemical and biological recovery of the soil. Based on that condition, this research was conducted to improve the soil physical properties of ex-gold-mined soil by using rice husk biochar as a soil amendment.

MATERIALS AND METHODS

This research was a pot experiment conducted in the glasshouse. The soil samples were taken from ex-gold-mined area in Dharmasraya Regency. Disturbed and undisturbed soil samples were taken from the area of ex-gold-mined soil. The area was initially farmed land, especially for oil palm and rubber tree plantations. However, the area could no longer be used for farming after being mined. The illegal gold mining practice in Dharmasraya was conducted traditionally, so the miner needed to put the disposal of the waste properly.

The soil sample was brought to the Soil Science, Faculty of Agriculture, Andalas University laboratory. The soil was air-dried and sieved with a 2-mm sieve. The soil was sampled to measure soil water content and correct the soil moisture content. The 2-mm disturbed soil samples were analyzed for soil texture (sieve and pipette method) and soil organic matter (wet oxidation method). In contrast, the undisturbed soil samples were analyzed for the soil BD, TSP, and hydraulic conductivity. Biochar was derived from rice husk and processed using the soil pit method Herviyanti et al. (2020). The water content of the biochar was also determined for water content correction needed in the calculation. Amount of biochar used based on the oven dry weight calculation.

This experiment consisted of 6 treatments (A = 0 Mg biochar ha^{-1}; B = 4 Mg biochar ha^{-1}; C= 8 Mg biochar ha^{-1}; D=12 Mg biochar ha^{-1}; E = 16 Mg biochar ha^{-1}; and F = 20 Mg biochar ha^{-1}) with four replicates. A total of 24 experimental units were allocated based on a Completely Randomized Design (CRD) in the glasshouse.

After being treated and mixed thoroughly, the soil and biochar mix was watered until field capacity, put into a pot, and closely incubated for two weeks. After the two-week incubation, the soil was planted with two certified sweet corn seeds in each pot. Then, the crops were maintained by applying synthetic fertilizers (Urea, KCl, TSP) as recommended and spraying pesticides to control pests and diseases. After the crop was harvested, soil samples were taken to analyze the soil physical properties.

Soil parameter analyzed after corn was harvested (16 weeks after incubation) was BD and TSP using a gravimetric method, hydraulic conductivity using the constant head permeameter, OM content using the wet oxidation method, and soil water potential using pressure and membrane plate apparatus. The soil data collected were

Table 1. Initial properties of ex-gold-mined soil in Dharmasraya.

Parameter	Value	Criteria
Bulk density (g cm^{-3})	1.43	High$^{1)}$
Total Soil Pore (% volume)	46.45	Low $^{1)}$
Void ratio (e)	0.87	
Hydraulic Conductivity (cm per jam)	198.80	Very Fast$^{1)}$
Organic matter (%)	1.27	Very Low$^{2)}$
Texture		
Sand (%)	88.45	
Silt (%)	9.28	Sand
Clay (%)	2.27	

Lembaga Penelitian Tanah 1979, Balai Penelitian Tanah 2005.

statistically analyzed for the variance and then continued using HSD at a 5% level of significance by JMP Pro 14.0.

RESULTS AND DISCUSSION

Data from laboratory analyses for initial soil properties are presented in Table 1, and soil physical properties after biochar application in Table 2. After biochar application, the results of soil water potential analysis are presented in Figures 1 and 2, and Tables 3 and 4. The correlations between biochar and soil organic matter and some soil physical properties can be seen in Figures 3 and 4.

Initial Soil Physical Properties

This ex-gold-mined soil had awful soil physical properties. It had a very coarse soil texture (>88% sand particles). Therefore, it had a very high soil bulk density (BD) and a fast hydraulic conductivity rate. Coarse soil texture on the top of ex-gold-mined soil could be derived from the coarse material in the subsoil, which was mixed with the topsoil. Sometimes, the materials on the soil surface were often from the parent materials or parent rock. Therefore, the ex-gold-mined land consisted of subsoils. When sampling undisturbed soil using metal core, the non-soil materials (particles > 2 mm) were

Table 2. Physical properties of ex-gold-mined soil 16 weeks after biochar application

Biochar Dose (Mg ha^{-1})	OM (%)	BD (g cm^{-3})	TSP (%)	Hydr. Cond. (cm h^{-1})	Void Ratio
Bio-0	1.48 f	1.36 a	48.68 c	78.90 a	0.95 d
Bio-4	2.62 e	1.24 b	52.33 b	34.37 b	1.10 c
Bio-8	2.68 de	1.20 bc	52.76 b	32.37 bc	1.12 bc
Bio-12	2.74 c	1.19 bc	53.29 ab	30.14 d	1.14 b
Bio-16	2.88 b	1.18 c	53.90 ab	27.69 e	1.17 a
Bio-20	3.12 a	1.17 c	54.17 a	25.16 f	1.18 a

Note: data in the column followed by the same small letter was not significantly different by HSD at a 5% level of significance.

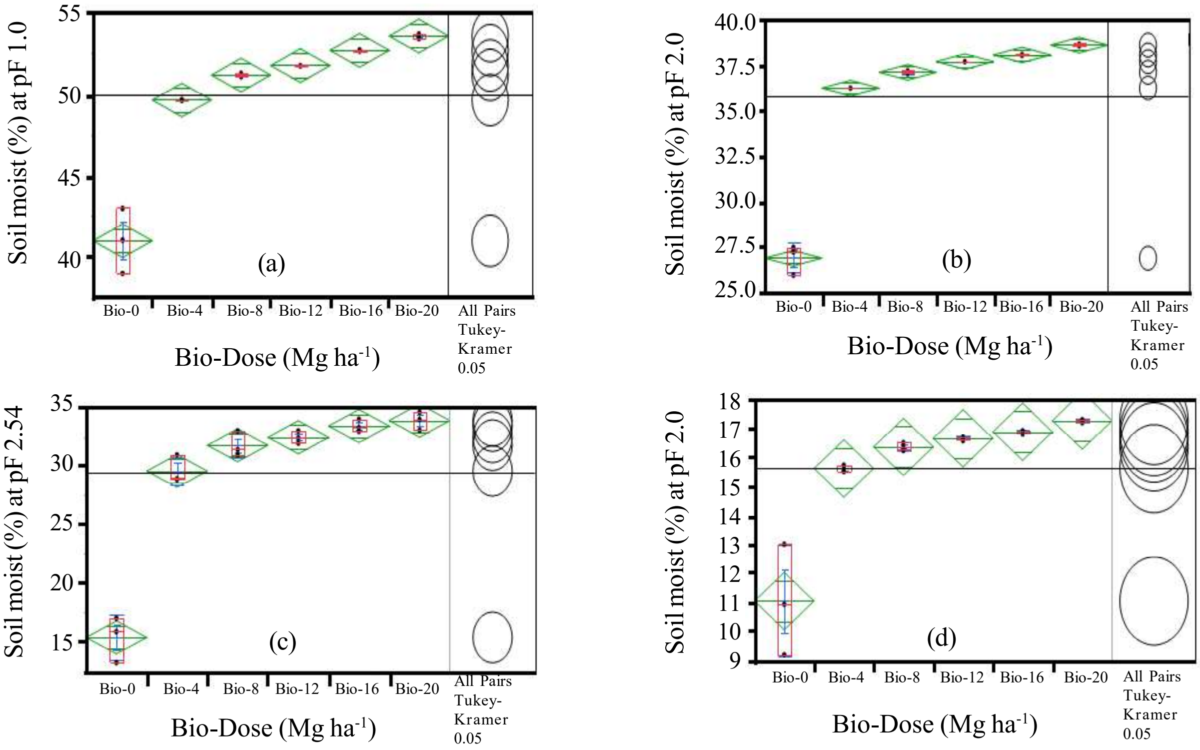

Figure 1. Soil water retention at pF 1.0 (a), 2.0 (b), 2.54 (c), and 4.2 (d) of ex-gold-mined soil after biochar application.

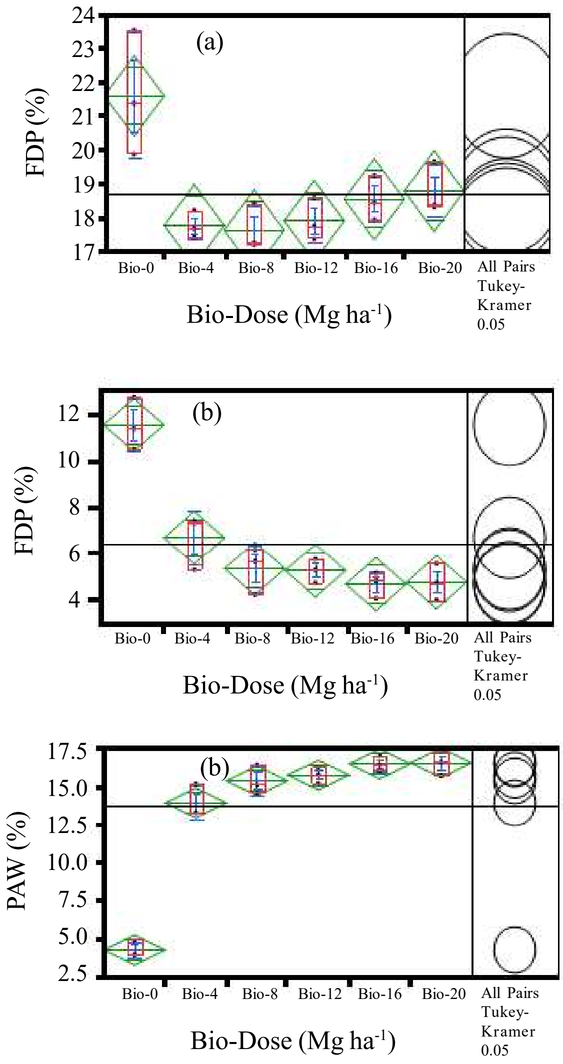

Figure 2. The pore of fast drainage (FDP) (a), pore of slow drainage (SDP) (b), and plant available.

also included. Therefore the soil BD became very high (1.43 Mg m^{-3}). Murtinah and Komara (2021) also reported high soil BD (1.42 g cm^{-3}) on the top 10 cm soil depth of ex-coal mined land after 20 years of rehabilitation at PT Kaltim Prima Coal, Sangatta, Indonesia. Since total soil pore (TSP) inversely relates to the soil BD, the TSP value of the ex-gold mined soil became low (46.45%). The results agreed with those reported by Yulnafatmawita et al. (2020), that sand particle percentage positively correlated to the soil BD and negatively to the TSP.

Then, very low clay (<3%) content combined with low SOM and a large portion of non-soil material caused water easy to pass the soil column. Therefore, the soil hydraulic conductivity rate was high-speed (198.8 cm h^{-1}). The low clay percentage and SOM will also cause the soil water retention to be relatively low. It meant the soil could not provide enough water for plant growth, so it was unsuitable for crop growth. The same trend was also found in ex-gold-mined soil in Sijunjung (Yulnafatmawita et al., 2020), especially the soil organic matter and soil total porosity was lower, and the bulk density was higher than those of the original soil. At the same time, the ex-gold-mined soil in this research location (Dharmasraya) was very coarse (<3% clay particles). A large percentage of sand particles creates more macropores, causing the soil easy to transmit water under saturated conditions and hard to retain water in the vadose zone. As stated by Chen et al. (2018), the hydraulic conductivity of ex-mined soil was determined by the soil characteristics besides the amendment applied.

Soil Physical Properties after Biochar Application

Based on Table 2, the application of rice husk biochar significantly affected soil OM content, bulk density, total soil porosity, hydraulic conductivity, and void ratio of the ex-gold mined soil. Increasing the amount of biochar applied from 4 to 20 t ha^{-1} significantly increased the soil OM content. At 20 t ha^{-1} biochar application, the soil OM content increased by 111% more than the control (0 t ha^{-1} biochar application). It was due to the OC content of biochar added to the soil. It agreed with the data resulted by Yulnafatmawita et al. (2021) that increasing biochar applied increased the soil OM content of Ultisols from 1.14% (without biochar application) to 2.41% (at treatment 9:1 of soil:biochar volume ratio).

As the biochar dose applied increased, the soil bulk density became decreased. It can be explained that the biochar has a much lower mass than that of mineral material. Therefore, the dry weight of the soil per unit volume became lower than that without biochar application (0 Mg ha^{-1}). Inversely related to the soil BD, the total soil porosity increased by increasing biochar application. It was due to the high pore percentage contained within biochar. Chen et al. (2018) and Yang et al. (2022) also reported decreasing soil BD due to biochar application. Applying biochar derived from wheat straw decreased the soil BD by 74% (from 1.42 g cm^{-3} to 1.05 cm^{-3}) as its application increased from 1% to 5%, respectively. Nurida and Jubaedah (2019) reported that applying biochar combined with compost still decreased the soil BD of Ultisols during the second planting season in Taman Bogo East Lampung. Then, Yang et al. (2021) also found that the total average porosity of biochar was 82.44% (for rice straw) and 78.32% (for canola stalk). High

Table 3. Water retention of ex-gold mined soil after biochar application.

Biochar Dose (Mg Ha^{-1})	pF 1.0	pF 2.0	pF 2.54	pF 4.2
	………………………………%………………………………			
Bio-20	53.62 a	38.67 a	33.89 a	17.30 a
Bio-16	52.74 ab	38.13 a	33.43 a	16.91 a
Bio-12	51.81 abc	37.76 ab	32.48 ab	16.68 a
Bio-8	51.23 bc	37.17 bc	31.80 ab	16.39 a
Bio-4	49.69 c	36.30 c	29.60 b	15.64 a
Bio-0	41.03 d	26.92 d	15.35 c	11.05 b

Note: Data followed by the same small letter in the column is not significantly different by HSD 5%

total soil pore contributed to high soil void ratio, the volume ratio between space and solid material in the soil. The void ratio increased by 39% (from 0.85 to 1.18), making the soil light and porous.

Based on the data, the hydraulic conductivity rate of soil under 0 t ha-1 (Table 2) was much lower than that of the initial soil (Table 1). It was because the ex-gold-mined soil was sieved, and the large materials (>2 mm in diameter particles) were discarded before being incubated. Therefore, the macropores decreased compared to the initial soil, and the soil hydraulic conductivity also decreased. Then, the biochar application significantly decreased the soil hydraulic conductivity compared to soil without biochar application (control, 0 Mg ha^{-1}). It could be explained that biochar having a high specific surface area (SSA) will cause some water to be retained. Consequently, the rate of water passing the soil column (the hydraulic conductivity of the soil) became lower. Compared to without biochar application (0 Mg ha^{-1}), the soil hydraulic conductivity decreased by 56-68 % as the biochar was applied up to 20 t ha^{-1}. It was also found by Gelardi et al. (2021) that biochar decreased soil hydraulic conductivity by 64-80% in sandy and silt loam soils.

Soil Water Potential After Biochar Application

Figure 1 shows that biochar application increases water retention of ex-gold-mined soil. Biochar application significantly increased soil water content at different pF values (Table 3). The amount increased by increasing biochar application from 4 to 20 Mg ha^{-1} compared to the 0 Mg biochar ha^{-1}. It was due to the characteristics of biochar having high SSA and a high pores percentage. Biochar pores can hold more water. Therefore, the amount of water retained at each pF value increased with the increase in total soil porosity. As Herath et al. (2013) found, applying biochar increased the water retention at wilting point, field capacity, and saturated water content of two contrasting soils, Alfisols and Andisols, after a 295-days incubation. Furthermore, Nurida and Jubaedah (2019) reported that applying biochar combined with compost to Typic Kanhapludults increased plant available water in the third planting season of corn.

Figure 2 described that biochar application highly affected the pore distribution of ex-gold-mined soil. Biochar application decreased slow (SDP) and fast drainage pore (FDP) but increased plant available water (PAW) compared to treatment 0 t biochar

Table 4. The pore distribution of ex-gold mined soil after biochar application.

Biochar Dose (Mg Ha^{-1})	SDP	FDP	PAW
	……………%……………………		
Bio-20	4.78 b	18.81 b	16.59 a
Bio-16	4.70 b	18.57 b	16.52 a
Bio-12	5.28 b	17.92 b	15.79 ab
Bio-8	5.37 b	17.65 b	15.42 ab
Bio-4	6.70 b	17.79 b	13.96 b
Bio-0	11.57 a	21.64 a	4.30 c

Note: Data followed by the same small letter in the column is not significantly different by HSD 5%

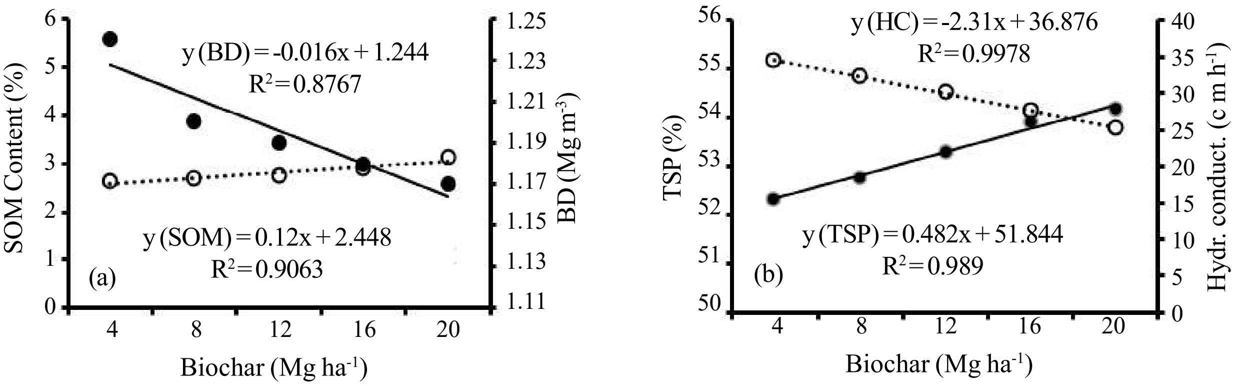

Figure 3. Correlation between biochar doses and soil organic matter and bulk density ▨ : SOM, ▨ and between biochar and total soil porosity and hydraulic conductivity ▨ : TSP, ▨ : Hydr. Cond (b).

ha^{-1}. It was caused by increasing water retention due to biochar application. The amount of biochar applied from 4 to 20 Mg ha^{-1} significantly increased the pore percentage for plant available water (Table 4). However, there was no significant difference between FDP and SDP. The pore percentage for FDP or macropores tended to increase, and SDP tended to decrease by biochar addition to the soil since the biochar also contains a high amount of macropores.

In Figure 3a, it is shown that biochar doses positively correlated to SOM content ($R^2 = 0.9063$, $r=0.95$) and negatively to soil BD ($R^2 = 0.8767$, $r=-0.94$). It meant that about 90% of the increase in SOM was due to biochar which still contains OC. Then, about 88% of the decrease in soil BD was also affected by biochar since it has very lightweight for a unit volume.

Figure 2b shows a high correlation between biochar dose, soil TSP, and hydraulic conductivity. Biochar positively correlated to total soil porosity ($R^2 = 0.989$, $r=0.99$) and negatively correlated to hydraulic conductivity ($R^2 = 0.9978$, $r=-0.99$). The hydraulic conductivity rate was much lower than that at the initial soil condition. Hydraulic conductivity continuously decreased up to 20 t ha^{-1} applied. However, the rate of hydraulic conductivity was still higher than that biochar of ideal soils for agriculture. More biochar or organic matter was needed to reduce the hydraulic conductivity rate and increase water retention.

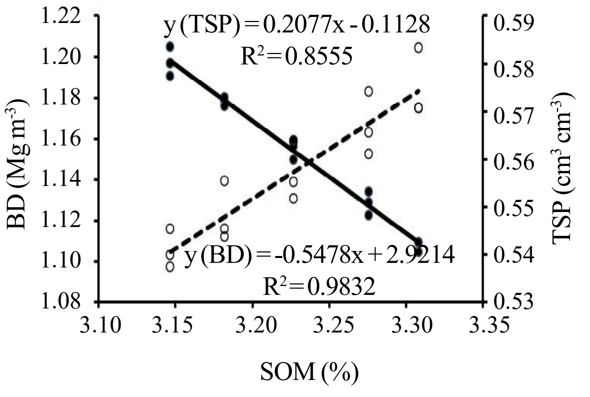

Figure 4. Correlation between SOM content and the soil BD as well as the TSP.

Figure 4 showed a highly negative correlation between SOM content and soil BD ($R^2=0.9832$; $r=-0.99$) and a high positive correlation between SOM and the TSP ($R^2=0.8555$; $r=0.92$). SOM derived from biochar highly contributed to the soil BD and the TSP. Biochar (Figures 2a and 2b) and SOM showed the same effect on soil BD and TSP.

CONCLUSIONS

Applying biochar improved some physical properties of ex-gold-mined soil with coarse soil texture, low OM content and TSP, high BD, and very high soil hydraulic conductivity. A noted result of this research was that application of 20 t biochar ha^{-1} was able to reduce hydraulic conductivity from very high (from 198.80 cm h^{-1} at initial soil condition and from 78.90 cm h^{-1} at 0 t biochar ha^{-1} application after 16 weeks incubation) into 25.16 cm h^{-1} on very coarse textured soil. It also increased soil water retention at pF 1.0, 2.0, 2.54, and 4.2, as well as PAW, and decreased the percentage of fast (FDP) and slow drainage pore (SDP).

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REFERENCES

Adhikari S, W Timms and MAP Mahmud. 2022. Optimizing water holding capacity and hydrophobicity of biochar for soil amendment – A review. 2022. *Sci Total Environ* 851: 158043. doi: https://doi.org/10.1016/j.scitotenv.2022.158043.

Baiamonte G, G Crescimanno, F Parrino and C De Pasquale. 2019. Effect of biochar on the physical and structural properties of sandy soil. *CATENA* 175: 294-303. doi: https://doi.org/10.1016/j.catena.2018.12.019.

Chen C, R Wang, J Shang, K Liu, MK Irshad, K Hu and E Arthur. 2018. Effect of biochar application on hydraulic properties of sandy soil under dry and wet conditions. *Vadose Zone J* 17: 180101. doi https://doi.org/10.2136/vzj2018.05.0101.

Dermiyati, A Karyanto, A Niswati, JL Raja, S Triyono and NVA Harini. 2017. The activity of Soil microorganisms during the growth of sweet corn (*Zea Mays* Saccharata Sturt) in the second planting time with the application of fertilizers and biochar. *J Trop Soils* 22: 37-45. doi: http://dx.doi.org/10.5400/jts.2017.v22i1.37-45).

Ethik A P W, B Mulyanto, Asmarhansyah, I G M Subiksa and Agus F. 2021. Application of ameliorants for ex-tin mining soil improvement and increasing corn (*Zea mays*) yield. IOP Conf Series: *Earth and Environmental Science* 648 (2021) 012187

Fu G, X Qiu, X Xu, W Zhang, F Zang, and C Zhao. 2021. The role of biochar particle size and application rate in promoting the hydraulic and physical properties of sandy desert soil. *Catena* 207: 105607.

Gelardi DL, IH Ainuddin, DA Rippner, JE Patiño, MA Najm and SJ Parikh. 2021. Biochar alters hydraulic conductivity and impacts nutrient leaching in two agricultural soils. *Soil J* 7: 811-825. doi https://doi.org/10.5194/soil-7-811-2021.

Glab T, J Palmowska, T Zaleski and K Gondek. 2016. Effect of biochar application on soil hydrological properties and physical quality of sandy soil. *Geoderma* 281: 11-20. doi https://doi.org/10.1016/j.geoderma.2016.06.028.

Herath HMSK, MC-Arbestain, and M Hedley. 2013. Effect of biochar on soil physical properties in two contrasting soils: An Alfisol and an Andisol. *Geoderma* 209-210: 188-197. doi: https://doi.org/10.1016/j.geoderma.2013.06.016

Herviyanti H, A Maulana, Y Yulnafatmawita and R Ryswaldi. 2020. Characteristics of biochar derived from different types of feedstock and methods. Indonesia Focus ASPIRA. University of Pittsburgh.

Leng L, Q Xiong, L Yang, H Li, Y Zhou, W Zhang, S Jiang, H Li and H Huang. 2021. An overview of engineering the surface area and porosity of biochar. *Sci The Total Environ* 763: 144204.

Murtinah V and LL Komara. 2021. Soil physical properties development in post-coal mining rehabilitation area in East Kutai District, East Kalimantan, Indonesia. *Adv Biol Sci Res* 11: 397-402. doi: https://doi.org/10.2991/absr.k.210408.065

Nurbaity A, G C Uratel, and J S Hamdani. 2019. Mycorrhiza Enhanced Protein and Lipid Contents of Potatoes Grown on Inceptisol with Addition of organic matter. *J Trop Soils* 24: 129-133.

Nurida NL and Jubaedah. 2019. Biochar-based soil amendment formulation for improvement upland acidic soil in East Lampung: soil properties and maize (*Zea Mays*) yield. *J Trop Soils* 24: 33-41.

Prakongkep N, RJ Gilkes, W Wisawapipat, P Leksungnoen, C Kerdchana, T Inboonchuay, E Delbos, L-J Strachan, P Ariyasakul, C Ketdan and C Hammecker. 2021. Effects of biochar on properties of tropical sandy soils under organic agriculture. *J Agric Sci* 13: 1-17.

Santos JA, MIS Gonzaga, WM Dos Santos, AJ da Silva. 2022. Water retention and availability in tropical soils of different textures amended with biochar. *Catena* 219: 106616. doi: https://doi.org/10.1016/j.catena.2022.106616.

Solfianti M, Herviyanti, TB Prasetyo and A Maulana. 2021. Pengaruh aplikasi biochar limbah kulit pinang dosis rendah terhadap sifat kimia inceptisol. *J Agrikultura* 32: 77-84.

Yang C, J Liu and S Lu. 2021. Pyrolysis temperature affects pore characteristics of rice straw and canola stalk biochars and biochar-amended soils. *Geoderma* 397: 115097. doi: 10.1016/j.geoderma.2021.1150

Yang X, Q Sun, J Yuan, S Fu, Y Lan, X Jiang, J Meng, X Han and W Chen. 2022. Successive corn stover and biochar applications mitigate N_2O emissions by altering soil physicochemical properties and N-cycling-related enzyme activities: A five-year field study in Northeast China. *Agric Ecosyst Environ* 340: 108183. doi: https://doi.org/10.1016/j.agee.2022.108183

Yulnafatmawita, Z Zakir, Refdinal and E Farda. 2021. The effects of biochar and manure on some soil characteristics and growth of garlic (*Allium sativum* L.) on Ultisols. *IOP Conf Series: Earth and Environmental Science* 741: 012033

Yulnafatmawita Y, S Yasin and L Maira. 2018. Physical properties of paddy soil as affected by irrigation polluted by physical properties of paddy soil as affected by irrigation polluted by gold mine tailing. A case study in Dharmasraya, West Sumatra, Indonesia. *Int J Civil Engin and Tech* (IJCIET) 9: 1886-1897.

Yulnafatmawita, S Yasin, EF Kurnia and ZA Haris. 2020. Impact of gold mining on physical properties of inceptisols in Muaro Sijunjung, West Sumatra Indonesia. *IOP Conf Series*: *Earth and Environmental Science* 515: 012041.