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Changes of Soil Physical and Chemical Characteristics of Vertisol by Organic Matter and Sands Applications

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ABSTRACT

Vertisol has a clay texture, high micropores, and high water and nutrient absorption ability. The high water content of Vertisol causes the air to decrease, thus inhibiting root development. Stretching of the Vertisol structure is expected to increase soil porosity and reduce ion and water absorption. This study examines interactions between organic matter and percent sand on soil porosity and nutrient availability. The study was arranged according to a factorial Completely Randomized Design (CRD), repeated three times. The first factor was seven kinds of organic matter (control, cow dung + banana peel compost, cow dung + leaf litter compost + compost water hyacinth + cow dung, humin, humic acid, and biochar. The application doses are respectively for each treatment: humic acid and humin 20 kg ha^{-1}, biochar 1 Mg ha^{-1}, compost+manure fertilizer 15 Mg ha^{-1}. Changes in soil chemical characteristics were evaluated against pH, C-org, and Available-P, while changes in soil physical characteristics were evaluated against bulk density, particle density, and soil porosity. The results showed that the combination of organic matter and percent sand could improve the physical and chemical characteristics of the soil. Bulk density (BD), particle density (PD), and soil porosity increased with the addition of sand. The organic matter significantly correlated with improving soil properties was humic acid, humin, biochar, compost, and manure, with the best percentage of sand at 20%.

Keywords: Characteristics, organic matter, sands, soil, vertisol

INTRODUCTION

Vertisols is black and fertile soils, derived from various parent materials, dominated by smectite clay minerals, and charasterize by crack formation during dry season. The color matrix of Vertisols varies, and the cation exchange capacity was high with pH's range from 5.5 to 7.4. The high content of Ca++, Mg++ should be consider for management Vertisols for food plantation (Prasetyo, 2017). Clay minerals of the vertisol mainly consists of montmorillonite group (Rajamuddin et al., 2013)

The soil pH in KCl of the incubated soils ranged from 7.6 to 7.9 and 7.5 and 7.9 to 8.3 pH in H2O, Electrical conductivity obtained ranged from 2.88 to 4.21 dS m^{-1}. Electrical potentials ranged from -31.45 to -63.04. The Point Zero Charge of soils correlated positively with the properties of the soils and the biochar rates.The addition of biochar to soils modified the PZC, increased the pH, electrical conductivity (ECe) and cation exchange capacity (CEC) of the soils. (Odiamehi et al., 2021).

Application of organic soil amendment and phosphorus fertilizer could improve soil chemical properties, P uptake, P absorption efficiency and maize yield in Vertisols until the second planting season. The combination of maize stover biochar and applying phosphorus fertilizer (P3-T2) significantly increased the P uptake, P absorption efficiency from 27.75% to 28.65%, and maize yields renge from 6.92 Mg ha-1 to 6.92 Mg ha^{-1} (Matheus et al., 2023)

Several alternatives have been made to overcome these obstacles. Applying organic matter can improve the soil's physical, chemical, and biological properties (Surya et al., 2017). Sources of organic matter from agricultural waste can be used as a source of nutrients plant's needs, reducing the use of chemical fertilizers (Simatupang, 2019). Organic matter applied to Vertisol can increase soil Organic-C, Available-P, Total-N, Available-K, cation exchange capacity, soil temperature, and soil moisture (Harsono, 2012). A healthy rhizosphere environment also encourages plant root growth due to increased nutrient availability so that the amount of nutrients absorbed by plants increases and improves plant growth. In addition to the application of organic matter, the addition of sand fraction can increase the porosity of Vertisol. The addition of 20% sand increased the stability of the vertisol aggregate from a value of 37.14% to 44.36% and reduced the soil's stability from 23.33 cm to 19.08 cm (Dulur et al., 2015).

The organic material used in this research comes from waste. Waste is residual material produced from production activities both on a household, industrial, and mining scale (Satriawi et al., 2020). Sources of organic matter used are banana peels and leaf litter and utilize the many weeds commonly found in the research location, namely water hyacinth. Banana peel waste can be used as an organic fertilizer because it contains Ca, P, Mg, Na, and S (Nasution et al., 2014).

Agricultural waste in the form of leaf litter can be used as organic material by composting; this is because compost is categorized as an organic soil enhancer that is useful for improving the quality and physical, chemical, and biological properties of the soil (Widowati et al., 2022). Water hyacinth weeds have a chemical composition of 78.47% organic matter, 21.23% Organic-C, 0.28% Total-N, 0.0011% Total-P, and 0.016% Total-K potential to be used as organic fertilizer needed by plants to grow (Simatupang, 2019). Other materials used as soil enhancers include humic acid, humin, and biochar. Humates can stimulate soil microorganisms more efficiently to break down organic matter, increase soil moisture, and chelate micronutrients, especially Fe (Mindari et al., 2018). Humin is a component of organic matter that regulates soil's capacity to hold water, improving soil structure, soil stability, and ion exchange (Saidy, 2018). Biochar can be formed through the combustion of biomass (biochar as pyrolysis of biomass), scrubbing, or composting; it is assumed that it is effective in storing carbon. The determinants of charcoal quality include density, humidity, the size of the wood pieces, and the final carbonization temperature (Mindari et al., 2018).

Adding various sources of organic matter is expected to improve Vertisol's physical and chemical properties. This study examines interactions between organic matter and percent sand on porosity and nutrient availability of the soil.

MATERIALS AND METHODS

Time and Place

This research was conducted from July to October 2022 in the greenhouse and land resource laboratory of the Faculty of Agriculture, University of Pembangunan Nasional "Veteran" East Java.

Research methods

The study was arranged according to a factorial, completely randomized design (CRD). The first factor is seven types of organic matter, including control (without organic matter, b0), 15 Mg ha^{-1} of banana peel compost + cow dung (10:1) (b1), 15 Mg ha^{-1} (leaf litter compost) (b2), 15 Mg ha^{-1} compost water hyacinth + cow dung (1:1) (b3), 20 kg ha^{-1} humic acid (b4), 20 kg ha^{-1} humin (b5), and 1 Mg ha^{-1} biochar (b6). The second factor is three levels of sand supply, namely 0% (p0), 20% (p1), and 40% (p2). Each treatment combination was repeated three times and total of 21 treatment combinations.

Research Implementation

Preparation of Treatment Media and Organic Materials

Organic materials derived from banana peels, cow dung, leaf litter, and water hyacinth are composted for four weeks. Humic acid and humin were extracted from leaf compost with 0.1 N KOH in a ratio of 1:10. Biochar is made through the pyrolysis of rice husks. The medium used was Vertisol and samples were taken from Bojonegoro at 0 - 20 cm depth. Vertisol samples were taken to the laboratory and then crushed and sieved through a 2 mm sieve; then weighed according to the treatment and then put into polybags with a capacity of 7.8 kg.

Application of Organic Matter and Sand

Polybags that already contain planting media were mixed with sand and organic materials according to the experimental design. The media applied to the treatment was incubated for one week. Soil sub-samples were taken one week after incubation (WAI) and analysed for the physical and chemical characteristics of the soil.

Observation

Parameters observed included the soil's physical and chemical properties after applying organic matter and sand. The physical characteristics of the soil were evaluated against the bulk density (BD) and particle density (PD) using gravimetric and volumetric methods. Calculate soil porosity with the formula 1-(BD/PD) x 100%. Soil chemical characteristics were evaluated for pH, Electrical Conductivity (EC), Redox values by electrometric method, Organic-C by Walkey and

Black method, Available-P by Olsen method, and Cation Exchange Capacity (CEC) by NH_4OAc pH 7 method.

Data Analysis

Data obtained from applying various types of organic matter and sand percentage were tabulated with Microsoft Excel and analysed for variance (ANOVA) with the F test significance level of 5% using SPSS version 22. Suppose the calculated F value is greater than the F table or siq. <0.05, then the Honest Significant Difference (HSD) test was carried out with a significance level of 5%. The observation variable correlation test is used to determine the closeness relationship between the observed variables.

RESULTS AND DISCUSSION

Soil Chemical Characteristic

The results of descriptive statistical analysis and Anova after one week of application of various types of organic matter and the percentage of sand to the chemical characteristic of pH, EC, Redox, Available-P, and Organic-C from Vertisols, respectively, are presented in Table 1 and Table 2.

The soil chemical characteristic analysis showed that Vertisol is classified as alkaline because the soil pH is > 7.0. The EC value of the soil is classified as good to very good for cultivation and includes standard soil grade for agriculture. Soil organic carbon content is low to moderate humic content. The CEC value of the soil is classified as very low to low. Analysis of variance interactions between organic matter and sands only showed a significant effect on the Organic-C of the soil. There was an interaction between organic matter and sands on the soil c-organic, while the other soil characteristics were not significant.

There was a significant interaction between adding various organic matter and sand to the Bojonegoro vertisol during one week of incubation on the Organic-C content. However, there was no interaction between the two other soil characteristics. Organic matter alone significantly affected pH, redox, Available-P, and soil CEC but did not affect soil EC. The application of sand significantly impacts soil CEC (Table 2).

Organic matter types affected redox potential, pH, available P, and cation exchange capacity of soil. The changes are varied depending on the organic matter sources. The potential redox value is related to the humidity of the material and the media. It is higher in the labile organic matter application (banana peel compost and leaf compost) compared to stable organic matter (humic acid, humin and biochar). The average soil pH value is also higher than the control. The highest of soil available P was in the banana peel compost application. The

Table 1. Soil chemical characteristics after application of various types of organic matter and percentage of sands.

	Descriptive Statistics*					
	Minimum		Maximum		Mean	Std. Deviation
pH	7.64		8.01		7.88	.08
EC ($\mu S\ cm^{-1}$)	313.70	(Vg)	562.9	(G)	404.30	46.34
Redox	-77.50		-60.50		-66.94	4.36
P-available (mg kg^{-1})	5.19	(L)	37.96	(M)	15.82	7.59
C-Org (%)	.74	(Lh)	2.76	(Mh)	1.41	.37
CEC (cmol kg^{-1})	16.08	(Vl)	37.70	(L)	24.89	5.16

*Lh= low humic, Mh moderat humic, L=low, M=moderate, Vl=very low, G=good, Vg=very good)

Table 2. Anova of Soil Chemical Characteristics 1 week application of organic matter and sands.

Source	df	pH		EC		Redox		P-available		CEC		C-org	
		F	Sig(*)	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
OM	6	21.48	0.00	1.26	0.30	43.32	0.00	15.58	0.00	1.10	0.38	3.97	0.00
Sand	2	2.15	0.13	2.31	0.11	3.01	0.06	3.21	0.05	62.15	0.00	4.01	0.03
OM * Sand	12	0.58	0.84	0.38	0.96	1.77	0.09	0.50	0.90	1.38	0.21	8.59	0.00

*sig < 0.05

soil cation exchange capacity is not different in all applications (Table 3).

Soil Physical Characteristics

The soil physical characteristics were evaluated through the value of specific gravity and the unit weight ranged which were between 1.1-1.46 g.cm^{-3} and 2.2, – 2.79 g.cm^{-3} respectively with an average of 1.33 g.cm^{-3} and 2.46 g.cm^{-3}. Soil porosity is classified as low to medium with a range of 36% - 53.64%. The change in porosity was likely due to the loosening of the bonds between particles by organic matter (Table 4).

The combination of various types of organic matter and the percentage of sand affects the physical characteristics of the soil, but there is no interaction between the both. The effect of the sand percentage is greater than that of organic matter, as presented in Table 5.

The application of percentage of sands has a significant effect on bulk density and particle density on Vertisols (Table 5) but did not significant on the porosity of the soil. Meanwhile, the type of organic matter has a significant effect on the porosity of the soil. The optimum percentage of sand for changes in bulk density, particle density, and porosity is about 40% (Table 6). The particle density of soil is influenced by the addition of the percentage of sand, where the more significant the percentage of sand, the particle density of the soil increases. The bulk density of the soil also changes with the addition of the percentage of sand and the optimum at 40% application.

Table 3. HSD analysis of type of organic matter on pH, Redox, P-available, and CEC.

Type of Organic Matter	Redox (mV)	pH	P-available (ppm)	CEC (cmol kg^{-1})
B0	-66.03b	7.85b	11.67a	25.73
B1	-73.03a	7.95c	29.87c	26.17
B2	-72.18a	7.97c	15.20b	22.98
B3	-63.22c	7.77a	14.76b	24.73
B4	-62.29c	7.84b	15.94b	25.05
B5	-65.41bc	7.86b	11.32a	25.16
B6	-66.39b	7.93c	12.00ab	23.69
HSD 5%	1.14	0.03	2.94	tn

Bo=control, B1= 15 kg ha^{-1} (banana peel + cow dung,(10:1), B2= 15 kg ha^{-1} leaf litter , B3= 15 kg ha^{-1} Water hyacinth + cow dung (1:1)), B4= 20 kg ha^{-1} Humic acid , B5= 20 kg ha^{-1} Humin, and B6=1 Mg ha^{-1} Biochar.

Tabel 4. Soil physical characteristic after application of various types of organic matter and percent sand.

Soil Physic	Mean	Lower Bound	Upper Bound	Median	Variance	Std. Deviation	Minimum	Maximum
BD (g.cm^{-3})	1.33	1.30	1.35	1.33	0.01	0.08	1.10	1.46
PD (g cm^{-3})	2.46	2.41	2.50	2.45	0.02	0.14	2.20	2.79
Porosity (%)	45.91	44.81	47.01	46.73	12.49	3.53	36.37	53.64

Table 5. Analysis of Soil Physical Characteristics 1 week after application of Organic Matter and Sands.

Source	db	Bulk Density		Particle Density		Porosity	
		F	Sig.	F	Sig.	F	Sig.
Organic Matter (OM)	6	2.104	.096	6.39	.001	4.188	.006
Sand	2	38.23	.000	83.78	.000	.375	.692
OM * Sands	12	1.619	.161	1.990	.081	1.707	.137

OM=Type of organic matter

Table 6. Type of organic matter and percentage of sand on bulk density, particle density, and porosity of soil.

Treatment	Porosity	Particle Density	Bulk Density
Sands			
P0 (0%)	46.37 a	2.33 c	1.25 c
P1 (20%)	45.46 a	2.43 b	1.33 b
P2 (40%)	45.90 a	2.60 a	1.40 a
Organic Matter			
Control (B0)	43.23 bc	2.38 b	1.35a
Manure+ compost banana (B1)	42.37 c	2.37 b	1.37a
Manure+ compost EG (B2)	47.16 abc	2.45 ab	1.30a
Compost (B3)	46.70 abc	2.47ab	1.32a
Humic acid (B4)	45.77 abc	2.49 a	1.35a
Humin (B5)	48.59 a	2.52 a	1.29a
Biochar (B6)	47.55 abc	2.51 a	1.32a

Table 7 shows that the correlation between bulk density and particle density is significantly positive but negative correlation with soil porosity. The porosity value will affect the bulk density. The higher the percentage of sand added will increase the pore space of the soil. Particle density is significantly positively correlation with soil porosity; this indicates that the arrangement of the type and number of particles will determine its pores. Adding sand particles to Vertisol can loosen the arrangement of the existing particles, thereby increasing the porosity of the soil. Redox has a significant negative correlation with the pH of H_2O and Available-P, which means that conditions of reduction or lack of oxygen cause pH to drop/acid. Reduction occurs when there is a lack of oxygen; this is often found in Vertisols due to the high micropores due to the large amount of clay that composes soil particles. The reduction also causes available P to decrease by 4 - 20% (17.28 - 13.64 ppm), presumably due to P adsorption by acid cations, which causes its availability to decrease. The EC value does not correlate with any indicators; it is suspected that adding organic matter and sand does not change the salt content in the soil. The CEC value is not correlated with the measured indicators, but adding sand will decrease the soil CEC in an effective linear manner. Giving sand 40% reduces CEC by 20 - 35%. (30.19 - 20.06 Cmol kg^{-1}).

RESULTS AND DISCUSSION

The best combination treatments for soil characteristics are 20 % sand and humin (p1b5). Applying organic matter significantly affects the pH, Redox, and Available-P. Sand application only has a significant effect on CEC. The soil's EC value is still unaffected due to adding organic matter and sand (Figure 1). The same thing was obtained by Lin et al. (2020) that organic matter significantly

Table 7. Matrix Correlation (Pearson).

	PD	Porosity	pH H_2O	Redox	EC	CEC	P-available
Bulk density (BD, g cm^{-3})	.436**	-.618**	.037	-.008	-.056	.068	.058
Particle Density (PD, g cm^{-3})	C	.437**	-.182	.205	-.056	.095	.124
Porosity (%)		1	-.177	.169	.002	.015	.075
pH H_2O			1	-.648**	.029	.063	.184
Redox (mV)				1	.117	-.024	-.415**
EC (mS cm^{-1})					1	.048	.099
CEC (Cmol kg^{-1})						1	.229

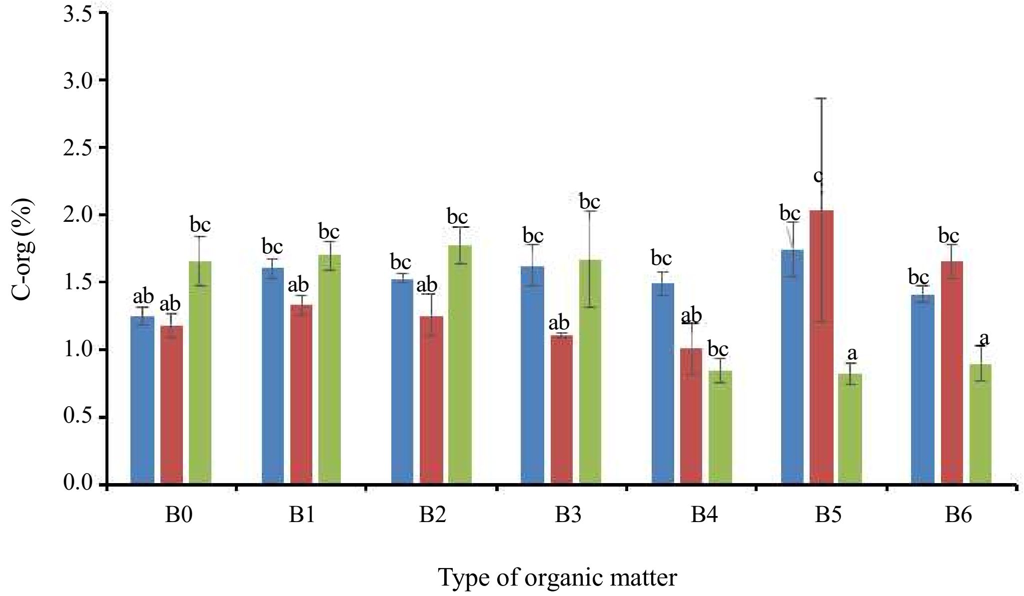

Figure 1. Effect of organic matter and sand on C-organic of soil. P0: ■, P1: ■, P2: ■.

affected soil pH and redox value. This fact is caused by the release of H^+ from organic matter, which contributes to the concentration of H^+ in the soil, thus affecting the pH value of the soil. The decomposition of organic matter from water hyacinth decreased the highest pH by 0.08, while humic acid (HA) and humin had no significant effect. Humic acid is a derivative of stable organic matter with carboxylic, phenolate, amine, and quinone groups that play an essential role in ion absorption. Applying humic acid in the soil absorbs the ions present in the soil and precipitates or chelates them. Giving compost leaves, banana peels, and biochar increases the pH of the soil. Overall the soil was reduced and highest on applying compost and banana peels.

Adding compost and humic acid changed the redox of the soil slightly. Adding humin and biochar almost did not change the soil redox; it was suspected that organic matter was relatively stable and had no significant reaction. The reshuffling of organic matter will produce organic compounds. So, organic materials that play a more critical role in soil redox are still unstable. The magnitude of the potential and the role of organic compounds affect the dynamics of the soil's chemical properties, especially the soil's redox conditions (Putri, 2010).

The application of both significantly affects the Organic-C value of Vertisol. The addition of sand (p0) has a high C-organic value compared to the sand treatment, respectively 20% and 40% of sand

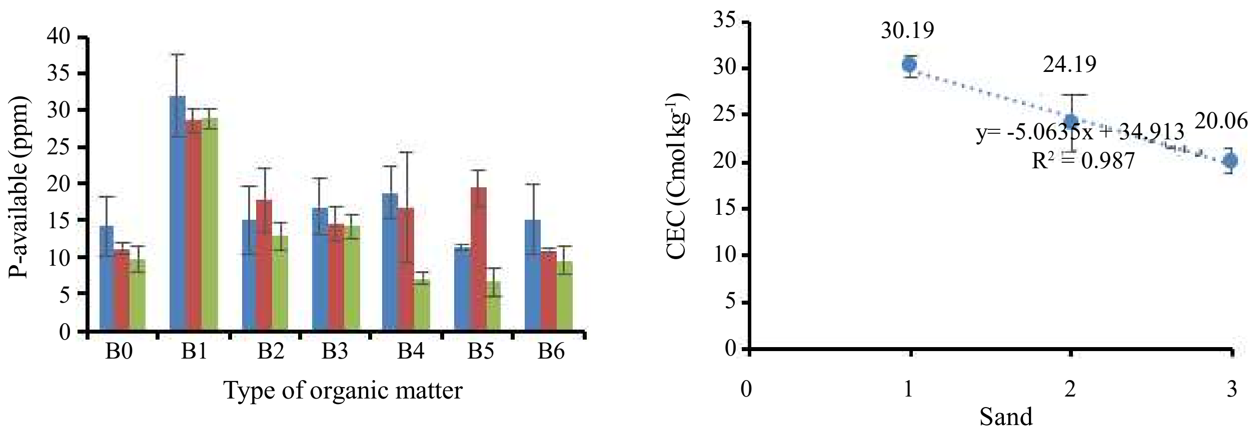

Figure 2. Effect of type of organic matter on P-available and sands on CEC. P0: ■, P1: ■, P2: ■.

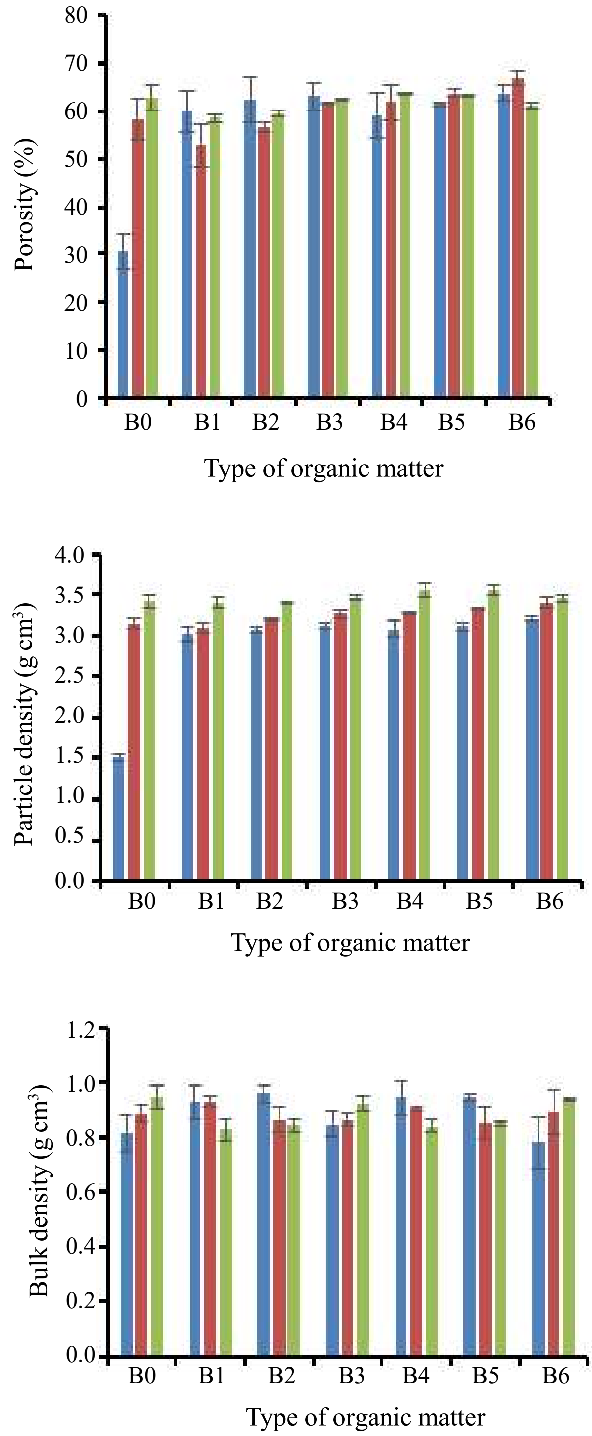

Figure 3. Effect of type of organic matter on bulk density, particle density, and porosity of soil. P0: ■, P1: ■, P2: ■.

(p1 and p2). Applying the sand fraction to Vertisol could reduce the soil's organic matter content. The higher the percentage of sand given, the lower the C-organic content in the soil. Soils that have a high sand content will have the property of being easier to pass water and rapid decomposition of organic matter; this causes low levels of C-organic in soils with a high sand fraction. The treatment that contributed the highest soil C-organic content was found in the treatment of cow dung + compost of banana peel (b1).

Table 2 explains that the application of sand only significantly affected the soil CEC. In contrast, the treatment of organic matter significantly affected the P-available, Redox, C-organic, and soil pH (Figure 2). The same thing is supported by the research of Kolambani and Widowati. (2022), which explained that applying organic matter to the soil significantly affected Available-P nutrients. The soil Available-P depends on (1) the amount and type of soil minerals, (2) soil pH, (3) the influence of cations, (4) the influence of anions, (5) the level of P saturation, (6) organic matter, (7) time and temperature, and (8) flooding (Hanum, 2013). The cow dung + compost of banana peel (b1) treatment had the highest P-available content compared to other organic matter treatments. The result is in line with the high value of Organic-C in the treatment cow dung + compost of banana peel (b1).

Bulk density is the soil mass-to-particle volume ratio, including soil pores, expressed in g cm-3 (Kurnia et al., 2006). Figure 3 shows that the 40% sand treatment without adding organic matter (p2b0) gave the highest bulk density value compared to other treatments. The factor affecting the high value of bulk density is the presence of low organic matter content (Saputra et al., 2018 [Belum ada pada References]) following the study's results, where the highest bulk density was due to no addition of organic matter. The soil's bulk density reflects the soil density level, where the greater the value of the bulk density of the soil, the denser the soil, and the lower the porosity of the soil (Chaudhari et al., 2013).

Giving 40% sand treatment has significantly affected the soil's bulk density, particle density, and porosity (Table 6). Adding sand particles to Vertisols can loosen the arrangement of the existing particles, thereby increasing the porosity of the soil (Lubis et al., 2013). The higher the percentage of sand in the soil, the more pore space between the soil particles, and the more it can facilitate the movement of air and water.

The interaction of organic matter and sand increases Organic-C. The addition of sand has a high Organic-C value compared to the sand treatment, respectively 20% and 40% of sand (p1 and p2). The higher the percentage of sand given, the lower the C-organic content in the soil. Adding sand fraction to Vertisol increased the soil pores, so the decomposition process occurred faster, reducing the soil Organic-C. On the other hand, it will be easier to pass water, so the drainage will be faster.

The treatment that contributed the highest soil Organic-C content was found in the treatment of water hyacinth compost and manure.

CONCLUSIONS

Vertisol has high nutrient content, but water and air management could be better because the soil particles are too tightly bound. Applying organic matter and sand is expected to loosen particle bonds to increase porosity. The application of various organic matter and sand for one week has significantly affected the Organic-C Vertisol, and there is an interaction between the two variables. The highest value of organic C in the humin and sand treatment was 20%. Applying organic matter Applying organic matter alone affects the soil's pH, redox, CEC, and Available-P. Giving sand up to 40% significantly affects CEC, bulk density, particle density, and soil porosity. The higher the sand application will increase the decomposition reaction depending on the quality, but the optimal dose of sand is 20%.

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REFERENCES

Chaudhari PR, DV Ahire, VD Ahire, M Chakravarty, and S Maity. 2013. Soil bulk density as related to soil texture, organic matter content, and available total nutrients of Coimbatore soil. I*nt J Scientific and Research Publication* 3: 1-8.

Dulur NWD, IGM Kusnarta and W Wangiyana. 2015. Aplikasi pasir dan pupuk kandang pada bedeng permanen untuk perbaikan sifat tanah dan pertumbuhan padi di lahan vertisol tadah hujan lombok. *J Agroteksos* 25: 102-108. (in Indonesian).

Hanum C. 2013. Growth, yield, and seed quality of soybean with organic and phosphorus fertilizer application. *J Agron Indonesia* 41: 209-214.

Harsono P. 2012. Mulsa organik: pengaruhnya terhadap lingkungan mikro , sifat kimia tanah dan keragaan cabai merah di tanah vertisol Sukoharjo pada musim kemarau. *J Hortikultura Indonesia* 3: 35-41. (in Indonesian).

Kolambani FU and Widowati. 2022. Changes in chemical properties of three soil types after application of biochars and organic fertilizers for two years. *J Degrades and Mining Lands Management* 9: 3715-3724. doi: https://doi.org/10.15243/jdmlm.2022.094.3715

Kurnia U, F Agus, A Adimihardja and A Dariah. (2006). Sifat fisik tanah dan metode analisisnya. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Bogor. 282 p.

Lin Y, AN Campbell, A Bhattacharyya, N Didonato, AM Thompson, MM Tfaily, PS Nico, WL Silver and J Pett-ridge. 2020. Differential effects of redox conditions on the decomposition of litter and soil organic matter. Biogeosciences 17: 25 p. doi: 10.1101/2020.08.21.262246.

Lubis AT, Z Nasution and Sarifuddin. 2013. Pengaruh air laut , zeolit dan pasir vulkan terhadap status hara pada tanah gambut serta pertumbuhan padi sawah. *J Online Agroekoteknologi* 2: 13-25. (in Indonesian).

Matheus R, D Kantur and MK Salli. 2023. Utilization of organic soil amendments and phosphorus fertilizer to improve chemical properties of degraded dry land Vertisol and maize yield. *J Degraded and Mining Lands Management* 10: 4297-4304. doi: https://doi.org/10.15243/jdmlm.2023.102.4297.

Mindari W, P E Sasongko, U Khasanah and P Pujiono. 2018. Rasionalisasi peran biochar dan humat terhadap ciri fisik-kimia tanah. *Folium: J Ilmu Pertanian* 2: 34-42. doi: https://doi.org/10.1016/j.nec.2013.02.001. (in Indonesian).

Nasution FJ, L Mawarni and M Meiriani. 2014. Aplikasi Pupuk Organik Padat Dan Cair Dari Kulit Pisang Kepok Untuk Pertumbuhan Dan Produksi Sawi (*Brassica Juncea* L.). *Agroekoteknologi* 2: 1029-1037. (in Indonesian).

Odiamehi OV, KC Uzoma, L Mubarak, AA Kwalam and HD Wakili. 2021. Effects of poultry biochar on electrochemical properties of an alfisol and vertisol of Northern Nigeria. *Indonesian J Innovation and Applied Sciences (IJIAS)* 1: 200-207. doi: https://doi.org/10.47540/ijias.v1i3.288.

Prasetyo BH. 2017. Perbedaan sifat-sifat tanah vertisol dari berbagai bahan induk. *J Ilmu-Ilmu Pertanian Indonesia* 9: 20-31. doi: https://doi.org/10.31186/jipi.9.1.20-31.

Putri DS. 2010. Pengelolaan kadar lengas tanah vertisol dan pemanfaatan pupuk kandang sapi yang diperkaya untuk meningkatkan serapan fe dan hasil padi beras merah 'segreng.' [Skripsi], UNS-F Pertanian Jur Ilmu Tanah, Surakarta. (in Indonesian).

Rajamuddin, U. A., Lopulisa, C., Husni, H., & Nathan, M. (2013). Mineralogy and micromorphology characteristic of vertisol lying on limestone parent rocks at jeneponto district of South Sulawesi Province, Indonesia. *Int J Agr Syst (IJAS)*1: 92-97.

Saidy AR. 2018. Bahan organik tanah: klasifikasi, fungsi dan metode studi. In *Banjarmasin: Lambung Mangkurat University Press*.

Satriawi W, EW Tini and A Iqbal. 2020. Pengaruh pemberian pupuk limbah organik terhadap pertumbuhan dan hasil tanaman mentimun (*Cucumis Sativus* L.). *J Penelitian Pertanian Terapan* 19: 115-120. doi: https://doi.org/10.25181/jppt.v19i2.1407.

Simatupang MI. 2019. Pemberian kompos eceng gondok dan poc limbah udang terhadap pertumbuhan dan produksi tanaman kedelai (Glycine Max L. Merr). [Skripsi], Universitas Muhammadiyah Sumatera Utara. (in Indonesian).

Surya JA, Y Nuraini and Widianto. 2017. Kajian porositas tanah pada pemberian beberapa jenis bahan organik di perkebunan kopi robusta. *J Tanah Dan Sumberdaya Lahan* 4: 463-471. (in Indonesian).

Widowati T, N Nuriyanah, L Nurjanah, SJR Lekatompessy and R Simarmata. 2022. Pengaruh bahan baku kompos terhadap pertumbuhan dan produksi cabai merah keriting (Capsicum annuum L.). *Jurnal Ilmu Lingkungan* 20: 665-671. doi: https://doi.org/10.14710/jil.20.3.665-671. (in Indonesian).