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Changes in Soil Physical Properties Following Applications of Vermicompost Superimposed with Liquid Organic Fertilizer

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ABSTRACT

Soil properties play essential roles in transmitting and holding precipitation water; therefore, they determine the amount of plant-available water in the soil profile. The study aimed to compare the size distributions of Andept soil pores following four-year applications of vermicompost and liquid organic fertilizer (LOF). The experiment was done from 2016 to 2019. The five doses of vermicompost (5, 10, 15, 20, and 25 Mg ha^{-1}) set as the main factor, supplemented with 0 and 100 percent concentrations of LOF as a sub-factor, were arranged in a split-plot design with three replicates. Results showed that adding LOF decreased slow-drainage pores significantly when combined with 10 Mg ha^{-1} of vermicompost. However, the pore changes by LOF were not significant when applied to other doses of vermicompost. Applying vermicompost and LOF lowered the slow-drainage pores by increasing soil organic carbon and reducing soil particle density. The findings suggest that vermicompost and LOF act as soil ameliorants to reduce water loss by drainage from soil profiles. The study highlights the importance of soil properties in determining plant-available water in the soil profile.

Keywords: Ameliorant, drainage pores, organic fertilizers, water loss

INTRODUCTION

Pore size distributions are much more important than the total pore fraction of soils because the former controls many aspects of water and other characteristics of soils. Pore size distribution can also be attributed to the physical quality indicator of soils because of its relation to soil structural stability and root penetration to the deeper soil layers (Shahab et al., 2013). The distributions of pores at various sizes play one of the most pronounced roles in determining the adsorption capacity of water by soils and other porous media. A study by Zangiabadi et al. (2020) proved that pore size distributions of light-texture soil may be used as an indicator for the upper limit of plant available water at the 0.33 bar of pressure or the equivalent pore diameters of smaller than 100 µm. Another work by Rahayu et al. (2019) proved that increases in pore sizes relating to water retention may promote the growth of Kentucky bluegrass in the sand media. Soil pore size distributions and their continuity provide the path of water movement in the soil and control the redistribution of rainfall water to the lower layers in the soil profile.

Authors choose different limits of pore sizes to describe the function of soil porosity in agricultural and non-agricultural fields of work. Greenland (1977) describes soil pore sizes greater than 500 µm as air-filled porosity, 50-500 µm as the drainage pores, and 0.5-50 µm as the water-available pores. Other authors determine 9-300 µm (De Leenheer, 1977; Sudirman et al., 2006) and 30-300 µm (Francis et al., 1988) as the limits of drainage pores, but they all use 0.2 µm as the smallest size for water-available pores. Lately, Zaffar and Lu (2015) have promoted five classes of pore sizes for clay soils, including macropores (>75 µm), mesopores (30-75 µm), micropores (5-30 µm), ultra-micropores (0.1-5 µm) and cryptopores (0.007-0.1 µm). Differences in the functional limits of soil pore sizes found in previous studies could be related to variations in the physical characteristics of study soils, such as texture and organic carbon content.

The pore-size distributions of agricultural soils are influenced internally by the composition of solid phases, including organic matter and mineral components. Fine clay soils are dominated by tiny water-holding pores (Chen et al., 2020), while coarse sand and rock fragments increase the water and air-transmitting pores of soils (Li et al., 2021). Total porosity could be very high due to grass and shrub roots, dominated by large, elongated pores caused by freeze-thaw circles, or shallow and less connected in high clay content (Zhao et al., 2020). Similarly, Hermawan et al. (2020) found that sand and clay fractions have good relations to the proportions of pore diameters of less than 100 µm, but no significant relations were found to the pore sizes of less than 0.2 µm. Changes in pore size distribution can also be due to changes in the interlayer, inter particular, and interaggregate pores of swelling and shrinking soils (Shi et al., 2017). The pore size distributions in the soil are also changed by external factors related to land use practices in the agricultural land. Jensen et al. (2020), for example, reported that a change of land use systems from grassland period to arable land decreases the proportion of plant-available water and structural void ratio. They also concluded that it is faster to lose than to develop an ideal pore size distribution and a complex soil structure by land management practices. Therefore, conducting a deeper study on soil pore size behavior is necessary when subject to management practices.

Organic farming is well known as an excellent agricultural cultivation practice that can promote organic carbon content and soil structure status, particularly in the upper layers. Changes in soil structure can be determined by measuring the aggregate stability during organic farming and relating the stability with the variation of organic carbon (Shahin and Khater, 2020). Structural stability is the key to other soil physical characteristics, including the size distribution and stabilization of pore spaces in soils. The roles of organic farming in stabilizing soil aggregates and pore spaces involve the temporal stabilization by the fine plant roots and the long-term binding by exudates from the decomposition of organic materials in the soil (Chaney and Swift, 1984). Removing organic matter may reduce the 50-100 µm macropores volume and increase <5 µm micropores of clay soils (Zaffa and Lu, 2015). Therefore, it is essential to study the direct effects of long-term organic farming practices on the porosity and size distributions of pore space in the soil.

The study aimed to compare the size distributions of Andept soil pores following four-year applications of vermicompost and liquid organic fertilizer (LOF). It was assumed that at least one variable of pore size distributions would be influenced significantly by the four-year practices of organic farming.

MATERIALS AND METHODS

The study was conducted in a long-term experimental farm in Rejang Lebong Regency, Bengkulu Province, located about 1054 m above sea level and at the geographic coordinates of 30° 27’ 36.88" S and 102° 36’ 53.19" E. The experiments were arranged in a split-plot design with three replicates. The treatments were five doses of vermicompost set as the main factor, and supplemented with 0 and 100 percent concentrations of liquid organic fertilizer (LOF) as a sub-factor. The sites were established in 2016 and planted with the sweet corn-ground nut-sweet corn rotations until 2019. The crop rotations were a part of the Closed Agriculture Production System (CAPS) Project run by the University of Bengkulu, aiming to evaluate the adaptation of a newly assembled variety of sweet corn to an organic farming system and to monitor the improvement of soil fertility.

Undisturbed and disturbed soil samples were collected from each experimental unit at 0-20 cm depth in July 2020 for laboratory analysis. Weeds growing in the research sites were removed from the soil surface to provide proper spaces for soil sampling. About 5 cm thickness of surface soils was also removed, and then undisturbed soil samples were taken using the stainless-made cores of 7.4 by 4.0 cm in height and width. Both ends of the cores were covered with plastic to secure the samples and brought to the laboratory to determine water-filled distributions of soil pores. Therefore, pore size distributions determined in this study represented the pore characteristics at depths of about 5 to 10 cm. Disturbed samples were taken from the same points using a shovel and put in plastic bags for texture and organic carbon analysis using the pipet and Walkley and Black methods, respectively (Gee and Bauder, 1986).

The pore size distributions were analyzed by determining the amount of water collected from the samples using the Pressure Plate Apparatus set at the pressure of 0.01, 0.1, 0.33, and 15 atm. Under equilibrium conditions, the volumetric water content remaining at each pressure was equaled to the proportions of pores with diameters smaller than 300, 30, 10, and 0.2 µm, respectively. Based on their functions in soils, the pores with 30-300 µm diameters were attributed as the fast-drainage pores, the 10-30 µm diameters as the slow-drainage pores, the 0.2-10 µm as the water-available pores, and the <0.2 µm as

Table 1. Summary of F values for the effects of vermicompost and LOF.

Variables	F Values			Coefficient of Variance (%)
	Vermicompost	Liquid Organic Fertilizer	Interaction	
Bulk density	1.19 ns	1.95 ns	0.63 ns	5.21
Particle density	6.16*	0.15 ns	0.65 ns	2.58
Total porosity	2.31 ns	1.93 ns	0.15 ns	3.60
Fast-drainage pores	1.58 ns	1.72 ns	1.08 ns	21.36
Slow-drainage pores#	4.37*	5.18*	4.17*	5.58
Water-available pores	0.80 ns	0.03 ns	1.39 ns	25.92
Field-water content	8.66*	0.24 ns	0.92 ns	7.34
Organic carbon	21.55*	1.64 ns	1.48 ns	7.80

Remarks: * and ns showed significant ($P<0.05$) and not significant effects (Pe”0.05), respectively, while # indicated data transformation of ($\sqrt{X+1}$).

the non-available pores of water (Sudirman et al., 2006). Determination of pore size distribution using the pressure method was more widely used compared to other techniques, such as the thin section and X-ray computed tomography (CT) scan (Rachman, 2015; Zhao et al., 2020). Pore size distribution data was then analyzed using the analysis of variance (F test) followed by Duncan's tests to evaluate the significance of mean differences among factors.

RESULTS AND DISCUSSION

Characteristics of soil porosity can be expressed as the total proportion of pore space occupying the soil, called soil porosity, and the distribution of pore space at different sizes. Unlike total porosity, which shows only the total pore space in soils, pore size distribution indicates the proportion of pore sizes with different functions in the soil (Table 1). Pore size distribution is one of the most pronounced physical characteristics because it controls the plant water availability in the soil profile. There are three phases of soil pore size distribution about the water status, namely water drainage and water storage pores. When precipitation occurs, water falls to the soil surface and fills the pores; it will drain soon through macropores due to the gravitation effect. Fast drainage pore sizes of 30-300 µm in diameter will be needed to drain the excessive water from the soil profile.

Meanwhile, slow drainage sizes of 10-30 µm exist in the upper boundary of available water at pore sizes of 0.2-10 µm (Figure 1). Increases could follow decreases in the proportion of slow-drainage

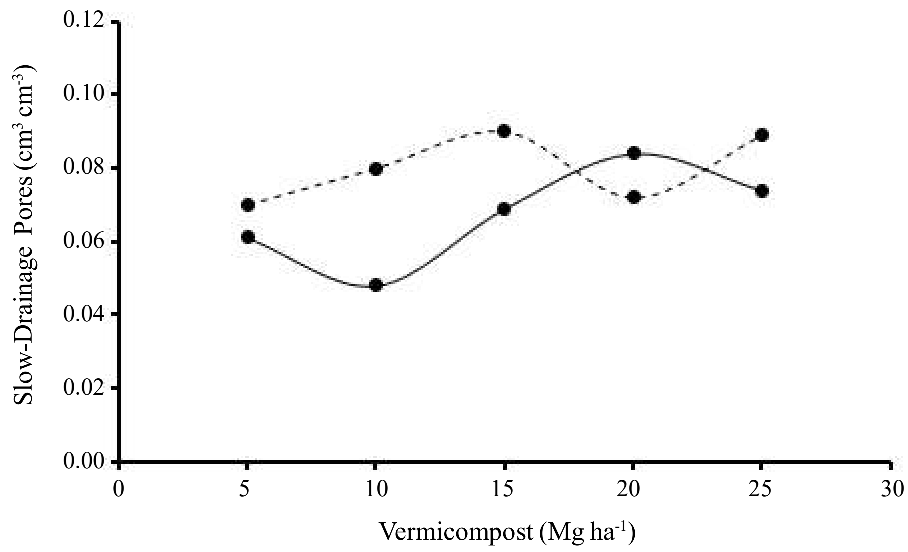

Figure 1. Effects of Liquid organic fertilizer dependence of vermicompost on slow-drainage pores. - -●- -: No LOF, —●— : LOF 100 %.

pores in the proportion of smaller pore sizes of 0.2-10 μm. Although the 10 μm pore size as the upper boundary of available water is questionable by Logsdon (2019), especially when the plant grows in the field, increases in pore sizes of 0.2-10 μm may increase the amount of water that soils can store.

In the current study, applying 10 Mg ha^{-1} vermicomposting resulted in the lowest slow-drainage pores and particle density compared to 5, 15, 20, and 25 Mg ha^{-1} doses when superimposed with liquid organic fertilizer (Figure 2). Less draining pores following vermicompost application indicated that organic fertilizers might sustain agricultural practices in the study area regarding water use efficiency by crops. Including organic input to reduce water loss from the crop production area would also help cope with disturbances due to climate change, mainly other disturbances of farms (Perrin et al., 2020). The findings suggested that the long-term organic farming practice in the study area might lead to other benefits from increased organic matter content with organic fertilizer application. A similar result has been reported by Shahin and Khater (2020) that long-term organic farming increased soil organic matter significantly in sandy soils.

Values of plant water availability in the loamy sand study soil were 0.03 to 0.05 cm^3 cm^{-3} higher compared to finer soil compositions in the nearby soils (Table 3). The coarse study soil contained lower field capacity pores by 0.04 to 0.05 cm^3 cm^{-3} but also much lower permanent wilting point pores by 0.1 to 0.13 cm^3 cm^{-3} compared to the finer adjacent soils, as reported by Hermawan et al. (2020). The particle size dependence of plant water availability, as found in the current study, was similar to the Claim in a US Patent that soil water retention was highest when the proportion of 0.05-2.0 mm particles was more significant than 50% (Bais and Jan, 2021).

The studied soil could supply water to the plant when the soil water content was as low as 0.16 cm^3 cm^{-3}, while other finer soils could not supply water at the water content of 0.26 to 0.29 cm^3 cm^{-3}. Soil organic matter, usually associated with available soil water content, was much lower in the current study (Table 2) and, therefore, was not the reason for differences in soil water availability between three adjacent soils.

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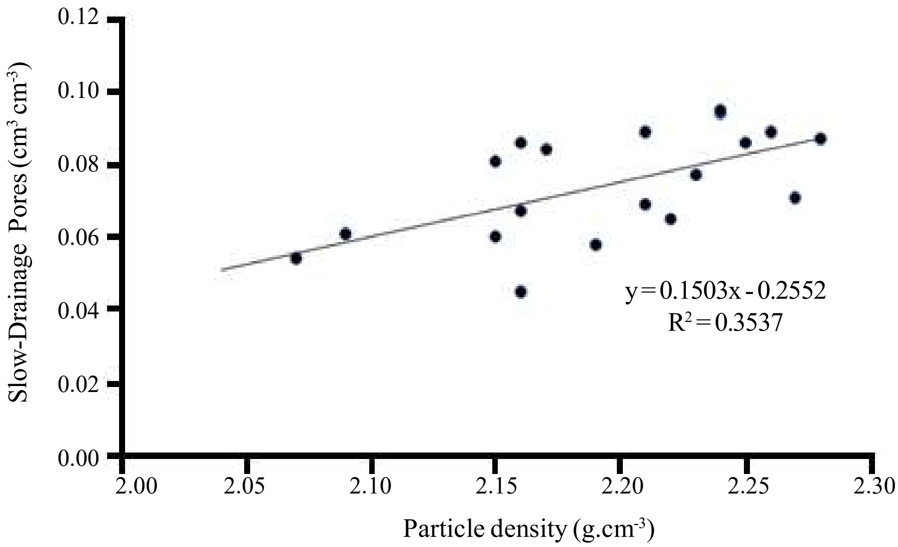

Figure 2. A correlation between particle density and slow-drainage pores.

Table 2. Averages of soil organic content under vermicompost and LOF treatments.

Treatments	Soil organic content (%)
Vermicompost 5 Mg ha^{-1}	2.00a
Vermicompost 10 Mg ha^{-1}	2.21c
Vermicompost 15 Mg ha^{-1}	2.82b
Vermicompost 20 Mg.ha^{-1}	2.41c
Vermicompost 25 Mg.ha^{-1}	3.10a
No LOF	2.69
LOF 100%	2.77

decreases in the proportion of slow-drainage pores in the proportion of smaller pore sizes of 0.2-10 μm. Although the 10 μm pore size as the upper boundary of available water is questionable by Logsdon (2019), especially when the plant grows in the field, increases in pore sizes of 0.2-10 μm may increase the amount of water that soils can store.

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Table 3. Comparisons of average pore-size distributions between the study and other soils.

Parameters	Inceptisols (Study Soil)	Ultisols (Hermawan et al. 2020)	Entisols (Hermawan et al. 2020)
Texture	Loamy sand	Silty loam	Silt
Soil organic carbon (%)	3.20	6.59	6.13
Bulk density (g cm^{-3})	0.90	0.83	0.87
Particle density (g cm^{-3})	2.20	2.06	2.15
Total porosity (cm^3 cm^{-3})	0.59	0.60	0.60
Fast-drainage pores (cm^3 cm^{-3})	0.17	0.13	0.16
Slow-drainage pores (cm^3 cm^{-3})	0.07	0.05	0.04
Field capacity pores (cm^3 cm^{-3})	0.37	0.44	0.45
Permanent wilting point pores (cm^3 cm^{-3})	0.16	0.26	0.29
Water-available pores (cm^3 cm^{-3})	0.21	0.18	0.16

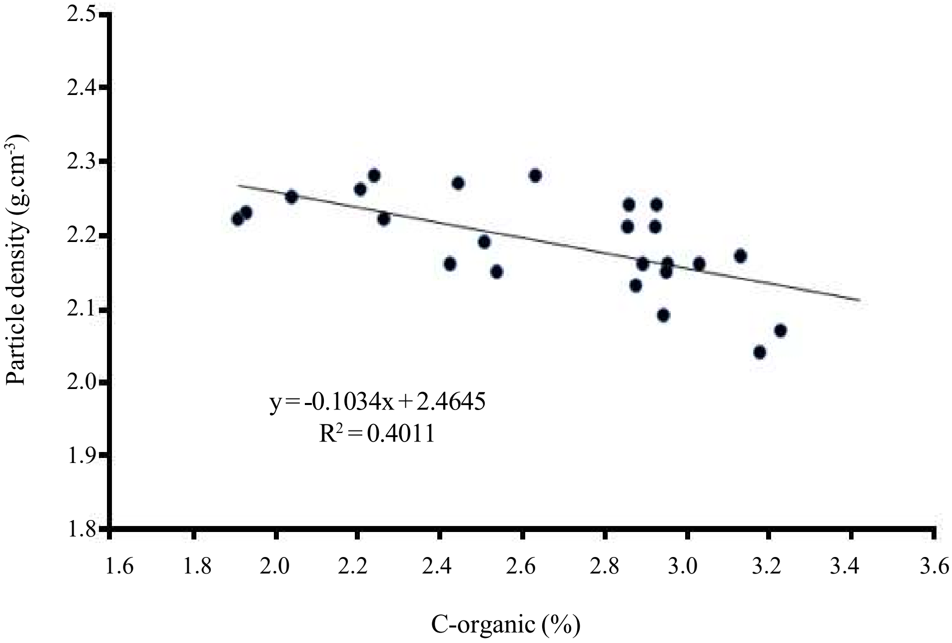

Figure 3. A correlation between soil organic carbon and particle density.

CONCLUSIONS

Application of liquid organic fertilizer (LOF) decreased the proportion of slow-drainage pores significantly when superimposed to 10 Mg ha^{-1} of vermicompost. However, the pore changes by LOF were not pronounced when applied with lower or higher doses of vermicompost. Applying vermicompost and LOF reduced the proportion of slow-drainage pores by increasing soil organic matter and decreasing soil particle density (Figure 3). The findings suggest that vermicompost and LOF act as soil ameliorants to reduce water loss through slow-drainage pores at the soil profiles.

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