



Improvement of Soil Pore Distribution and Soil Moisture Content using Organic Matter Addition Technology

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ABSTRACT

Background: Coffee plants in Sumbermanjing Wetan are commonly cultivated on dry lands that rely solely on rainfall as the source of water input that eventually makes them susceptible to climate change. The deficiency of organic material and water availability for these plants poses a significant challenge for coffee farmers in Sumbermanjing Wetan. Therefore, a research was conducted to investigate the addition of various organic matter through biopore infiltration holes in coffee plantations with the following objectives: i) to analyze the impact of applying organic matter on the distribution of soil pores and ii) to examine the effect of organic matter application on soil moisture content.

Methods: The research was carried out in the Smallholder Coffee Plantation of Argotirto Village, Sumbermanjing Wetan District, Malang Regency. A randomized block design was implemented with five treatment groups, which included the control (P1), two biopore holes + manure (P2), two biopore holes + compost (P3), two biopore holes + green manure (P4) and surface-applied manure (P5), each repeated three times. The observed variables included the percentage of soil organic matter, pore distribution, available water capacity and soil moisture content.

Result: The findings indicated that addition of organic matter in biopore infiltration holes enhanced soil organic material content, where treatment P4 (two biopore holes + green manure) exhibiting the highest soil organic material values in the first and third months after the application. The application of organic matter increased soil porosity in all treatments, where treatment P4 (two biopore holes + green manure) showing the highest available water capacity. This suggests that the utilization of organic matter can improve soil aggregation, thus increasing porosity and available water capacity. Consistently, soil water content at a depth of 40-60 cm tended to increase in the third month following biopore infiltration holes application, indicating that the addition of organic matter through biopore infiltration holes can enhance soil moisture at subsoil.

Key words: Biopore, Coffee plantation, Organic matter, Soil moisture, Soil pore.

INTRODUCTION

Indonesia, well-known for cultivating both coffee and palm oil, ranks as the world's fourth-largest coffee producer, boasting a total output of 794,800 tons in 2022 (BPS, 2022). One of the prominent coffee-producing regions in Indonesia is located in the Sumbermanjing Wetan District, East Java. Coffee cultivation in Sumbermanjing Wetan primarily occurs in rain-fed lands, reliant solely on rainfall as the primary water source. This dependence on rainwater makes rain-fed lands particularly vulnerable to climate variations. Rainfall frequency is a pivotal factor in rain-fed systems as it signifies how often the soil is replenished with water. However, not all rainfall quantities prove effective for plant growth (Sohoulande *et al.*, 2019). The water that plants can utilize is referred to as Plant Available Water Content (PAWC). PAWC represents the maximum water contained within a soil profile that can be supplied to plants, being the difference of moisture levels between field capacity and permanent wilting point (He *et al.*, 2022), residing within the mesopores of the soil. Water availability is influenced by various factors, including rainfall, soil physical quality and soil organic matter. Soils with poor water retention capabilities result in limited water absorption by plants (Silva *et al.*, 2015).

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Soil organic matter comprises of organisms, remnants of plants and animals and decomposed organic material. Soil organic matter plays a crucial role in nutrient storage, enhance infiltration and increase available water capacity (Cotching, 2018). Soil organic is correlate positively with available water capacity (Rawls *et al.*, 2003; Hanuf *et al.*, 2021; Tang *et al.*, 2022; Khoirunnisak *et al.*, 2023). Organic material can increase the number of functional oxygen

groups that play a role in binding water (Zhou *et al.*, 2020). Indirectly, soil organic matter can boost soil aggregation processes, increase soil porosity and consequently lead to enhanced available water capacity (Guhra *et al.*, 2022). Previous research indicates that in dryland coffee cultivation in South Malang, the organic C level is relatively low, less than 1% (Khoirunnisak *et al.*, 2023). Therefore, there is a need to implement technology to increase soil organic matter.

Biopore holes are infiltration structures made at the soil surface to a specific depth, designed to accommodate rainfall runoff and serve as sites for the decomposition of organic matter (Permatasari, 2015), where the organic matter can enhance soil porosity (Kumar *et al.*, 2023). The application of biopore holes can reduce surface runoff, minimize nutrient loss and increase water storage capacity, soil porosity, available water capacity and soil infiltration capacity (Soemarno *et al.*, 2021). Several studies have been carried out regarding on biopore holes application in dryland areas (Umasugi *et al.*, 2018; Aji *et al.*, 2020; Soemarno *et al.*, 2021; Fuady *et al.*, 2022). However, research on organic matter addition using various technologies, especially in the Sumbermanjing Wetan District, remains limited. The novelty of this research compared to previous studies is the use of biopore hole technology to enhance soil organic matter in coffee plantation in Sumbermanjing Wetan. Consequently, the objective of this study was to examine impact of adding different organic matter through biopore holes in coffee plantations, with the following objectives: i) to analyze the impact of organic matter application on soil porosity (soil pore distribution) and ii) to assess the impact of organic matter application on soil moisture content.

MATERIALS AND METHODS

This research was conducted in the Smallholder Coffee Plantation of Argotirto Village, Sumbermanjing Wetan District, Malang Regency, East Java, Indonesia, located between 8.2411-8.1443 S and 112.4031-112.4634 E. The Sumbermanjing Wetan District is situated at an elevation of 598 meters above sea level, experiencing an average temperature ranging from 22.5 to 26.2°C (BPS, 2022). The soil type at the research location is Inceptisol, with Typic Humudepts suborder (Saraswati *et al.*, 2022). The coffee variety cultivated in this area is Robusta coffee (*Coffea canephora*) that is 2 years old with *Gliricidia sepium* plants as shade. The research was conducted between March and July 2023. Soil samples were analyzed at the Chemistry and Soil Physics Laboratory, Faculty of Agriculture, Universitas Brawijaya.

Experimental design

This research was carried out using an experimental method with a randomized block design (RBD) consisting of 5 treatments and 3 replications. The applied treatments were as follows: control (P1), 2 biopore holes + manure (P2), 2 biopore holes + compost (P3), 2 biopore holes + green manure (P4) and surface-applied manure (P5). Biopores are made using a drilling machine with a hole diameter of 12 cm and a depth of 40 cm, with 2 holes per plant (Fig 1). Compost and manure were applied at a rate of 3 kg per biopore hole, while green manure was applied at a rate of 1 kg of *Gliricidia* sp. leaves per biopore hole (following the recommendation of Egodawatta *et al.* (2012). That organic matter were inserted into the 12 cm diameter biopore holes at a depth of 40 cm, which were created using a drilling machine.

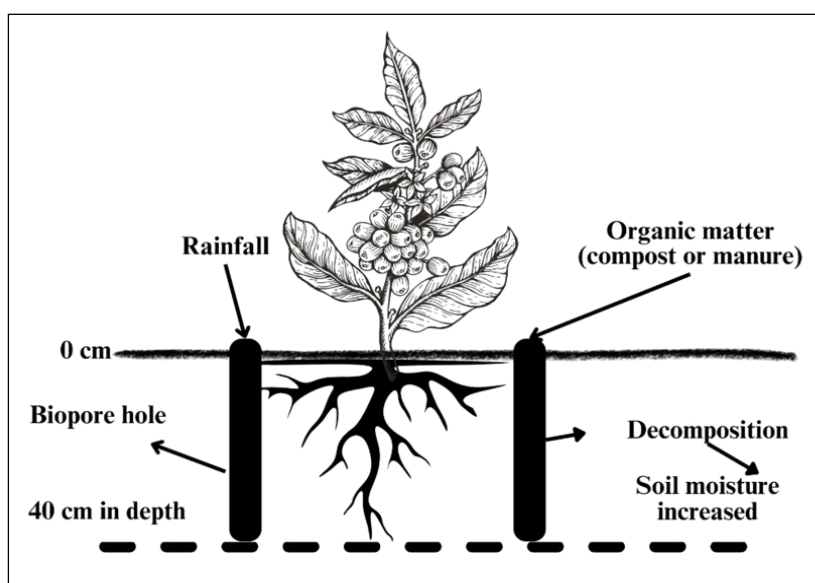


Fig 1: Illustration of biopore hole.

Data collection

Soil sampling was carried out at three distinct depths: 0-20 cm, 20-40 cm and 40-60 cm. Data were collected in the first, second and third months after treatment. The variables measured in this study were soil organic matter, soil pore distribution and soil moisture content. Soil organic matter analysis was performed using disturbed soil samples and the Walkey and Black method. Soil moisture content was analyzed using gravimetric method. Soil pore distribution was categorized into: i) total pores (total porosity), shown by water at pF 0; ii) macropores (air capacity), shown by pF 0 - pF 2; iii) mesopores (available water content), shown by pF 2 - pF 4.2; and iv) micropores (unavailable moisture), shown by pF 4.2 (Jim and Ng, 2018).

Soil water retention determines the soil's capacity to hold water and is related to the availability of soil water for plant growth (Tang *et al.*, 2022). Soil water retention was analyzed using the sandbox method and a pressure plate apparatus at matric potentials (pF 0, pF 1, pF 2 and pF 4.2). Available water capacity was calculated based on the difference in water content between field capacity (pF 2; 0.03 MPa) and permanent wilting point (pF 4.2; 1.5 MPa) conditions (Ghassemi-Golezani and Farhangi-Abri, 2021).

Soil characteristics before application

Table 1 provides the soil properties prior to the application of treatment. The soil texture at the research site was predominantly clayey, with sand content at 10.83%, silt at 12.50% and clay at 76.67%. Clayey soil texture has good water retention capabilities, but the available water capacity (within mesopores) was relatively low, at 0.07 cm³ cm⁻³.

Data analysis

The collected data were analyzed for variance at a 95% confidence level ($\alpha=5\%$). In cases of significant differences, Duncan's post hoc tests were performed. All analyses were conducted using SPSS 25 for Windows.

RESULTS AND DISCUSSION

Soil organic matter after application

Soil organic matter increased after the biopore holes application compared to which before the application. The biopore holes application significantly increased soil organic matter content in the first and second months (Table 2). In the first month, treatment P4 (2 biopore holes + green manure) produced the highest soil organic matter value at 2.65% and significantly differed from treatment P1 (control), which produced the lowest soil organic matter content at 1.69%. In the second month, treatment P3 (2 biopore holes + compost) had the highest soil organic matter content at 2.66%, significantly differed from treatment P1 (control), which had the lowest soil organic matter content at 1.72%. These results show that the application of organic fertilizer technology in the soil can increase soil organic matter. Long-term input of organic materials into coffee plantations can result in the highest soil carbon stock

compared to coffee plantations without organic matter input (Laekemariam, 2020). Organic matter is an essential factor in soil fertility. The decomposition process that occurs makes nutrients available for plants (de Rebello *et al.*, 2019).

The soil organic matter values in the third month decreased for all treatments. The treatment with the lowest value was P5 (surface-applied manure) at 1.13% and the highest was P4 (2 green manure holes) at 1.66% (Table 2). The soil organic matter analysis in the third month showed a decrease in values for all treatments compared to which the second month. This could be attributed to the process of organic matter decomposition over time, resulting in a reduction in the sequestration of soil organic carbon (Geng *et al.*, 2024). Additionally, the low soil carbon content could also be attributed to soil microorganisms utilizing carbon as an energy source during the decomposition process (Gurmu, 2019).

The effect of organic matter application on soil pore distribution

The biopore holes application significantly increased macropores in the soil in the second month (Table 2). However, in the first and third months, the treatment had no significant effect on macropores. Generally, the application of organic matter in all treatments increased the value of soil macropores, with the highest value of macropores found in treatment P3 (2 biopore holes + compost). Macropores in the soil, also known as air capacity, function as aeration sites in the soil. Higher values of macropores indicate that soil compaction processes are not taking place (Mondal and Chakraborty, 2022). However, the water retained in soil pores cannot be utilized by plants as it is susceptible to loss through gravitational processes (Jim and Ng, 2018).

The application of biopores did not result in a significant impact on mesopores in the soil in the first and third month after application, but mesopores increased after biopore holes application (Table 2). Mesopores provide water that can be utilized by plants, as the water in mesopores is bound with moderate energy that can still be absorbed by plant roots. Conversely, the soil matrix provides sufficient capillary

Table 1: Soil characteristics before application.

Soil characteristics	Nilai
Soil organic carbon (%)	0.53
Soil organic matter (%)	0.91
Soil texture	Clay
Soil bulk density (g/cm ³)	0.92
Soil particle density (g/cm ³)	2.46
Total soil porosity (cm ³ /cm ³)	0.62
Macro pore (cm ³ /cm ³)	0.27
Meso pore (cm ³ /cm ³)	0.06
Micro pore (cm ³ /cm ³)	0.28
pF 0 (cm ³ /cm ³)	0.62
pF 1 (cm ³ /cm ³)	0.52
pF 2 (cm ³ /cm ³)	0.34
pF 4.2 (cm ³ /cm ³)	0.28

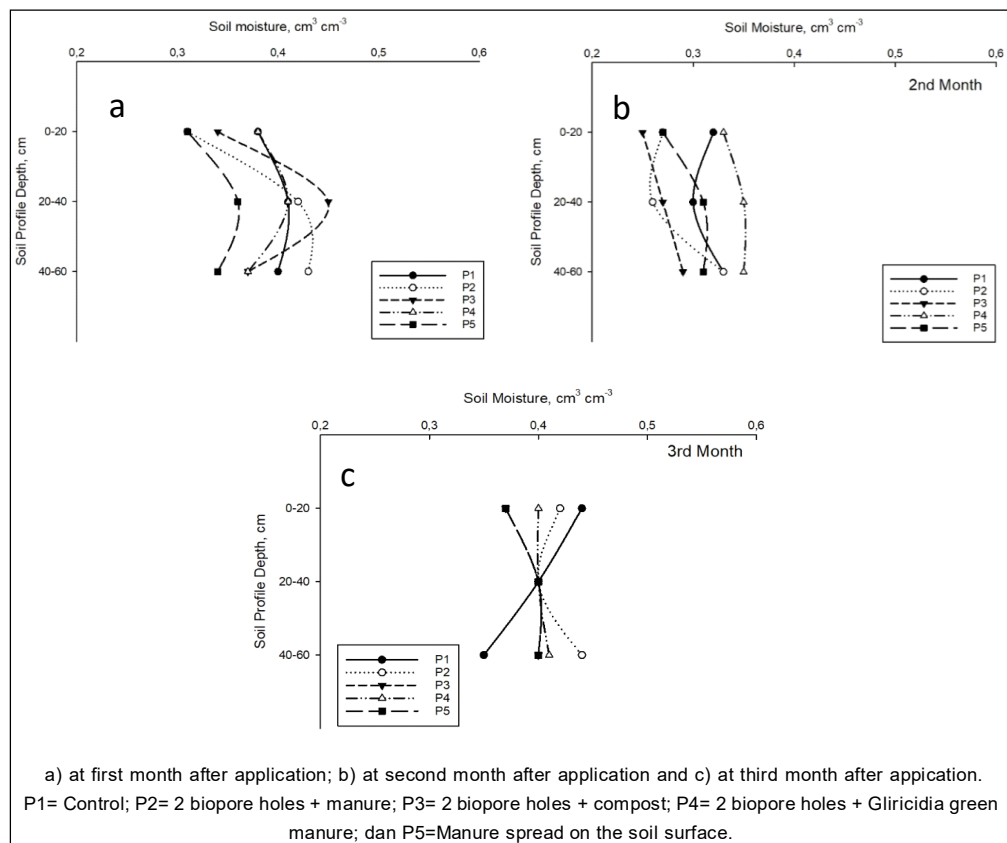


Fig 2: The curve of soil moisture content after the application at different observation months.

The application of biopore holes is more effective in increasing soil porosity in the lower layers, leading to increased water storage in the subsoil layer.

CONCLUSION

The application of biopore holes can increase the soil organic matter content, with treatment P4 (2 biopore holes + green manure) having the highest organic matter content in the first and third months after application, at 2.65% and 1.66%, respectively. Meanwhile, treatment P3 (2 biopore holes + compost) had the highest organic matter content in the second month at 2.66%. This indicates that the addition of organic matter such as green manure or compost is effective in increasing soil organic matter. However, in the third month, the organic matter content decreased, likely due to the use of carbon sources by microorganisms for further decomposition. Soil organic matter plays a role in increasing soil porosity, with all treatments having higher total pore content compared to before the treatment. The application of biopore holes also increases available water capacity in all treatments, with treatment P4 (2 biopore holes + green manure) having the highest available water capacity. Consistent with soil moisture content, treatment P4 (2 biopore holes + green manure) tends to have the highest soil moisture content, especially in the second month. Kebaruan dari penelitian ini yaitu teknologi These results indicate that the application of biopore holes can be

used as an effort to increase water storage in the soil. This study was only conducted for three months after the biopore holes application, so significant changes in soil physical properties were not observed. It is recommended to conduct further research in the following year to assess the effect of biopore holes application on soil physical properties.

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Conflict of interest

All authors declare that they have no conflict of interest.

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