AF-842
[1-7]

RESEARCH ARTICLE Indian Journal of Agricultural Research

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

Afifatul Khoirunnisak[1], Sugeng Prijono[2], Lenny Sri Nopriani[2], Tiara Kemeta[3], Andi Moch Faisal[3] **10.18805/IJARe.AF-842**

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).

[1]Faculty of Agriculture, Brawijaya University, Malang 65145, East Java, Indonesia.
[2]Department of Soil Science, Faculty of Agriculture, Brawijaya University, Malang 65145, East Java, Indonesia.
[3]Faculty of Agriculture, Brawijaya University, Malang 65145, East Java, Indonesia.

Corresponding Author: Sugeng Prijono, Department of Soil Science, Faculty of Agriculture, Brawijaya University, Malang 65145, East Java, Indonesia. Email: spj-fp@ub.ac.id

How to cite this article: Khoirunnisak, A., Prijono, S., Nopriani, L.S., Kemeta, T. and Faisal, A.M. (2024). Improvement of Soil Pore Distribution and Soil Moisture Content using Organic Matter Addition Technology. Indian Journal of Agricultural Research. DOI: 10.18805/IJARe.AF-842.

Submitted: 20-11-2023 **Accepted:** 21-05-2024 **Online:** 11-06-2024

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.

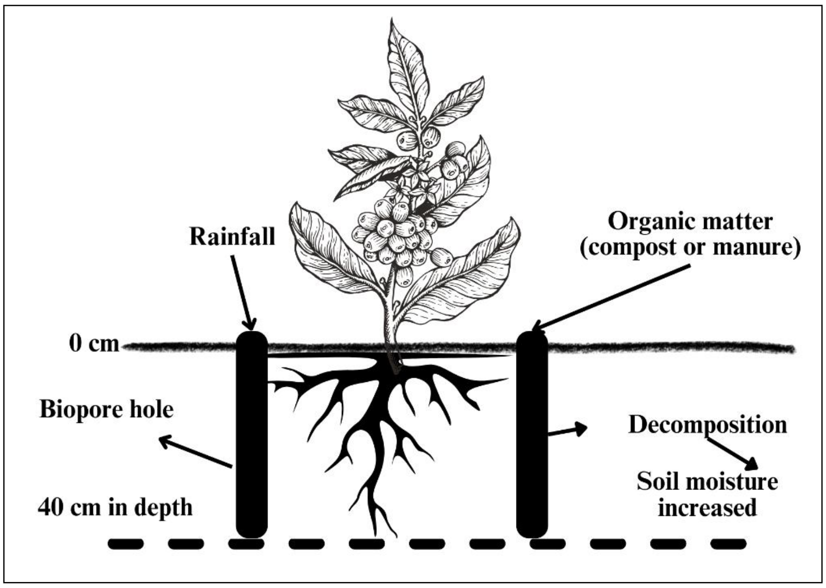


Fig 1: Illustration of biopore hole.

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-Abriz, 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 $cm^3\ cm^{-3}$.

Data analysis

The collected data were analyzed for variance at a 95% confidence level (α=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

action to retain water opposite to gravitational forces, keeping it available for plant roots (Jim and Ng, 2018). Treatment P4 (2 biopore holes + green manure) had the highest mesopore value in the third month after the application. This aligns with research results (Barreto *et al*., 2012) showing that the application of *Gliricidia* sp. biomass to the soil can enhance physical properties of the soil, including increased soil aggregate stability and an impact on increased available water capacity.

After biopore holes application, micropores tended to remain constant and decrease in the second month after application. Micropores hold hygroscopic moisture and help maintain soil moisture for soil organisms. However, the water in micropores is strongly bound by the soil matrix and is not absorbable by plant roots (Jim and Ng, 2018). The application of organic matter to biopore holes increased total pores in the second and third months after application (Table 2) compared to which before the application (Table 1). In the first month, treatments P2, P3 and P4 had the highest total pores, significantly differed from treatment P5. Total pores increased in the second and third months after application. This indicates that the application of biopore holes can increase the total soil porosity. Soil organic matter acts as a binding agent to form soil aggregates (Guhra *et al*., 2022), with the result of an increase in soil porosity (Singh *et al*., 2023).

The effect of soil organic matter on soil moisture content

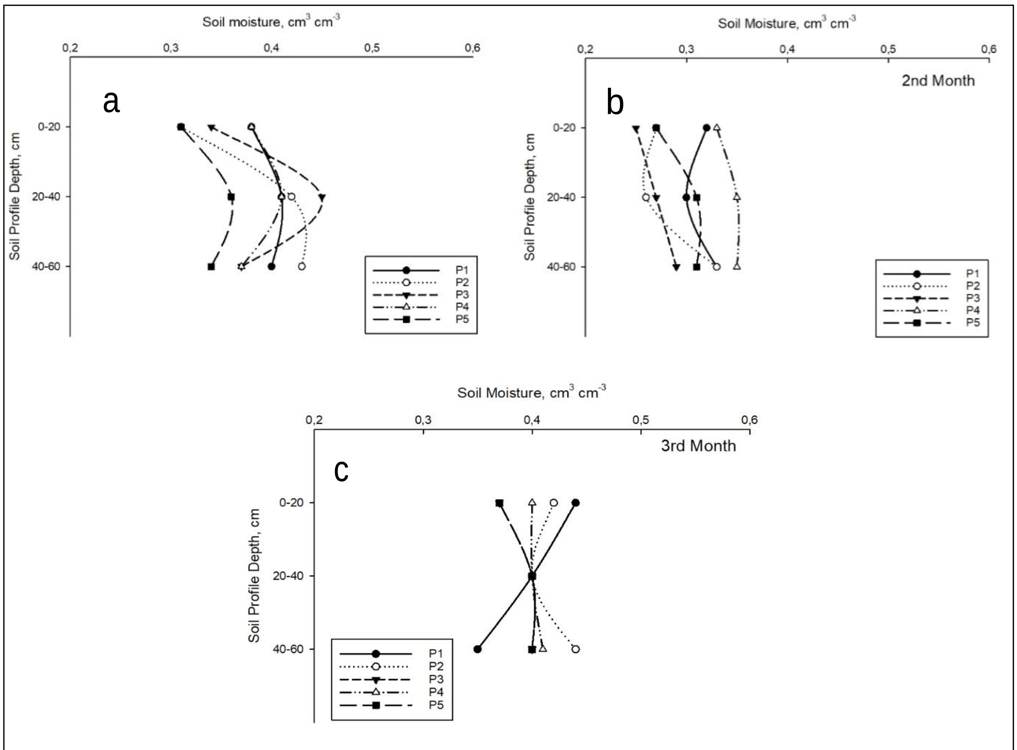
The soil moisture content fluctuates with soil depth and time after the biopore holes application (Fig 2). In some treatments (all treatments in the first month; P4, P3, P5 in the second and third months), the soil moisture content at the topsoil (0-20 cm) is lower than at other depths. This is likely due to higher water usage (transpiration) and evaporation at the soil surface, especially during the dry season. This is in line with the statement by Silva *et al*. (2015) that topsoil is more vulnerable to water loss via evaporation caused by solar radiation and wind effects near the soil surface. Additionally, changes in soil moisture content near the topsoil can be caused by water uptake by plant roots.

Soil moisture content decreased in the second month and increased in the third month after the application of organic matter. This indicates that the application of organic matter leads to increased soil aggregation, thereby increasing soil porosity and resulting in increased water storage in soil pores (Panagea *et al*., 2021); Hanuf *et al*., 2021; Saraswati *et al*., 2022). In the second month, treatment with 2 biopores + green manure (P4) had the highest soil moisture content at each depth. The green manure used was *Gliricidia*, which has high N content and a low C/N ratio, making it easy to decompose. As mentioned by Mohammed *et al*. (2023), *Gliricidia* biomass can enhance soil structure by elevating organic matter levels. This can improve soil water retention and increase nutrient availability for plants. Soil moisture content at a depth of 40-60 cm is higher in all treatments compared to the control treatment. The

Table 2: Soil characteristics after application.

Treatment	Soil organic matter (%)			Soil pore distribution											
				Macropore (cm/cm³)			Mesopore (cm/cm³)			Micropore (cm³ cm³)			Total Pore (cm³ cm³)		
	Month														
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
P1	1.69a	1.72a	1.40	0.22a	0.22 a	0.19	0.11	0.13ab	0.13	0.27b	0.19	0.27	0.60ab	0.54a	0.60
P2	1.90ab	2.28ab	1.63	0.27ab	0.25 ab	0.20	0.10	0.12ab	0.13	0.27ab	0.19	0.28	0.63b	0.56ab	0.62
P3	2.20ab	2.66b	1.53	0.28b	0.30 b	0.22	0.09	0.11a	0.12	0.27ab	0.20	0.27	0.64b	0.60b	0.61
P4	2.65b	1.99ab	1.66	0.24ab	0.22 a	0.19	0.13	0.14b	0.14	0.26ab	0.21	0.28	0.62b	0.57ab	0.61
P5	2.30ab	2.18ab	1.13	0.23ab	0.25 ab	0.19	0.10	0.13ab	0.13	0.24a	0.19	0.25	0.58a	0.57ab	0.58

Information: P1= Control; P2= 2 biopore holes + manure; P3= 2 biopore holes + compost; P4= 2 biopore holes + green manure; dan P5= manure spread on the soil surface. Numbers accompanied by different letters in the same column indicate a statistically significant difference based on the Duncan's test at a 5% significance level.



a) at first month after application; b) at second month after application and c) at third month after appication. P1= Control; P2= 2 biopore holes + manure; P3= 2 biopore holes + compost; P4= 2 biopore holes + Gliricidia green manure; dan P5=Manure spread on the soil surface.

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

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.

ACKNOWLEDGEMENT

This study was funded by Professor Grant from the Faculty of Agriculture, Brawijaya University, Malang (Contract Nr. 4744.19/UN10.F04/PN/2023).

Conflict of interest

All authors declare that they have no conflict of interest.

REFERENCES

Aji, T.G., Sutopo, N. and Palupi, N.E. (2020). Biopore infiltration holes to enhance water storage capacity in the root zone of mandarin orange (*Citrus reticulata*). Journal Hortikultura. 30(1): 41. https://doi.org/10.21082/jhort.v30n1.2020.p41-46 [Indonesian].

Barreto, A.C., Chaer, G.M. and Fernandes, M.F. (2012). Soil and Tillage Research Hedgerow pruning frequency effects on soil quality and maize productivity in alley cropping with Gliricidia sepium in Northeastern Brazil. Soil and Tillage Research. 120: 112-120. https://doi.org/10.1016/j.still.2011.11.010.

BPS. (2022). Indonesian Coffee Statistics (Sub Direktorat Statistik Tanaman Perkebunan (ed.). BPS-Statistics Indonesia [Indonesian].

Cotching, W.E. (2018). Organic matter in the agricultural soils of Tasmania, Australia - A review. Geoderma, 312(October 2017), 170-182. https://doi.org/10.1016/j.geoderma.2017.10.006.

de Rebello, T.R., Bortolozo, F.R. and Parron, L.M. (2019). Organic matter content in riparian areas of soil composed of woody vegetation and grass and its effects on pesticide adsorption. International Journal of Recycling of Organic Waste in Agriculture. 8(1): 67-72. https://doi.org/10.1007/s40093-018-0229-3.

Egodawatta, W.C.P., Sangakkara, U.R. and Stamp, P. (2012). Impact of green manure and mineral fertilizer inputs on soil organic matter and crop productivity in a sloping landscape of Sri Lanka. Field Crops Research. 129: 21-27. https://doi.org/10.1016/j.fcr.2012.01.010.

Fuady, M.J.F., Yuniwati, I., Aprilio, D., Indraloka, A.B. and Yudha, I.G.N.A.S.P.D. (2022). Mplementation of Biopore-Sludge Fertilization System for Ecofarming Practices Among Farmers in Bayu Village, Songgon District, Banyuwangi. PaKMas*:* Jurnal Pengabdian Kepada Masyarakat. 2(1): 145-151. https://doi.org/10.54259/pakmas.v2i1.833 [Indonesian].

Geng, J., Tan, Q., Lv, J. and Fang, H. (2024). Assessing spatial variations in soil organic carbon and C:N ratio in Northeast China's black soil region: Insights from Landsat-9 satellite and crop growth information. Soil and Tillage Research, 235(September 2023). https://doi.org/10.1016/j.still.2023.105897.

Ghassemi-Golezani, K. and Farhangi-Abriz, S. (2021). Plant available water holding capacity of soil under chemically modified biochars. Rhizosphere, 21 (December 2021), 100469. https://doi.org/10.1016/j.rhisph.2021.100469.

Guhra, T., Stolze, K. and Totsche, K.U. (2022). Pathways of biogenically excreted organic matter into soil aggregates. Soil Biology and Biochemistry, 164(October 2021), 108483. https://doi.org/10.1016/j.soilbio.2021.108483.

Gurmu, G. (2019). Soil organic matter and is role in soil health and crop productivity Improvement. Journal of Agricultural Science and Research. 7(7): 475-483. https://doi.org/10.14662/ARJASR2019.147.

Hanuf, A.A., Prijono, S. and Soemarno. (2021). Improvement of soil available water capacity using biopore infiltration hole with compost in a coffee plantation. Journal of Degraded and Mining Lands Management. 8(3): 2791-2799. https://doi.org/10.15243/jdmlm.

He, D., Oliver, Y., Rab, A., Fisher, P., Armstrong, R., Kitching, M. and Wang, E. (2022). Plant available water capacity (PAWC) of soils predicted from crop yields better reflects within-field soil physicochemical variations. Geoderma. 422: 115958. https://doi.org/10.1016/j.geoderma.2022.115958.

Jim, C.Y. and Ng, Y.Y. (2018). Porosity of roadside soil as indicator of edaphic quality for tree planting. Ecological Engineering, 120(February). 364-374. https://doi.org/10.1016/j.ecoleng.2018.06.016.

Khoirunnisak, A., Prijono, S. and Wicaksono, K.S. (2023). The role of coffee agroforestry on available water capacity and root length density in smallholder plantation. Biodiversitas. 24(1): 55-61. https://doi.org/10.13057/biodiv/d240108.

Kumar, Y.S.S., Reddy, P.V.R., Babu, D.V., Nayak, S.B., Vishnuvardhan, K.M., Rao, E.S.V.N. and Raghavendra, T. (2023). Effect of fourteen years of long term organic and inorganic fertilization on productivity, soil quality and grain quality of rice (*Oryza sativa* L.). Indian Journal of Agricultural Research. 57(2): 178-183. https://doi.org/10.18805/IJARe.A-5954.

Laekemariam, F. (2020). Carbon stock, sequestration and soil properties among fields in smallholder farms in southern Ethiopia. Environmental Systems Research. 9(1). https://doi.org/10.1186/s40068-020-00176-3

Mohammed, A.L., Nartey, E.K., Addai, F., Arthur, S. and Bawah, E. (2023). Effect of gliricidia sepium leafy biomass and npk (15:15:15) fertiliser on the growth and yield of tomato, *Solanum lycopersicum* (L.). Journal of Applied Life Sciences and Environment. 56(2(194)/2023): 273-288. https://doi.org/10.46909/alse-562100.

Mondal, S. and Chakraborty, D. (2022). Global meta-analysis suggests that no-tillage favourably changes soil structure and porosity. Geoderma. 405(September 2021), 115443. https://doi.org/10.1016/j.geoderma.2021.115443.

Panagea, I.S., Berti, A., Èermak, P., Diels, J., Elsen, A., Kusá, H., Piccoli, I., Poesen, J., Stoate, C., Tits, M., Toth, Z. and Wyseure, G. (2021). Soil water retention as affected by management induced changes of soil organic carbon: Analysis of long-term experiments in europe. Land. 10(12). https://doi.org/10.3390/land10121362.

Permatasari, L. (2015). Biopore infiltration hole: "one day for biopore" as an alternative to prevent floods. International Journal of Advances in Science Engineering and Technology. 3(2): 6-9.

Rawls, W.J., Pachepsky, Y.A., Ritchie, J.C., Sobecki, T.M. and Bloodworth, H. (2003). Effect of soil organic carbon on soil water retention. Geoderma. 116(1-2): 61-76. https://doi.org/10.1016/S0016-7061(03)00094-6.

Saraswati, L., Prijono, S. and Prasetya, B. (2022). Influence of various soil and water conservation methods on the moisture balance at coffee plant root zone. Indian Journal of Agricultural Research. 56(3): 325-330. https://doi.org/10.18805/IJARe.AF-703.

Silva, B.M., Oliveira, G.C., Serafim, M.E., Silva, É.A., Ferreira, M.M., Norton, L.D. and Curi, N. (2015). Critical soil moisture range for a coffee crop in an oxidic latosol as affected by soil management. Soil and Tillage Research. 154: 103-113. https://doi.org/10.1016/j.still.2015.06.013.

Silva, B.M., Santos, W.J.R. dos, Oliveira, G.C. de, Lima, J.M. de, Curi, N. and Marques, J.J. (2015). Soil moisture space-time analysis to support improved crop management. Ciência e Agrotecnologia. 39(1): 39-47.

Singh, M., Jaswal, A., Sarkar, S. and Singh, A. (2023). influence of integrated use of organic manures and inorganic fertilizers on physio-chemical properties of soil and yield of *kharif* maize in coarse loamy typic haplustept soil. Indian Journal of Agricultural Research. 1-6. https://doi.org/10.18805/ijare.a-6034.

Soemarno, Nurin, Y.M., Yunita, D.M. and Hanuf, A.A. (2021). Application of biopore infiltration hole with compost to increase phosphorus in robusta coffee plantations. Agrotechnology Research Journal. 5(1): 49-55. https://doi.org/10.20961/agrotechresj.v5i1.46623 [Indonesian].

Sohoulande, C.D.D., Stone, K., Szogi, A. and Bauer, P. (2019). An investigation of seasonal precipitation patterns for rainfed agriculture in the Southeastern region of the United States. Agricultural Water Management. 223(April): 105728. https://doi.org/10.1016/j.agwat.2019.105728.

Tang, K., Li, F.Y., Jaesong, S., Liu, Y., Sun, T., Liu, J., Gao, X. and Wang, Y. (2022). Soil water retention capacity surpasses climate humidity in determining soil organic carbon content but not plant production in the steppe zone of Northern China. Ecological Indicators, 141(July), 109129. https://doi.org/10.1016/j.ecolind.2022.109129.

Umasugi, B., Prijono, S., Soemarno and Ariffin (2018). Improvement of soil moisture storage in clove plantation land using biopore technology and organic material litters. J. Degrade. Min. Land Management. 5(53): 2502-2458. https://doi.org/10.15243/jdmlm.

Zhou, H., Chen, C., Wang, D., Arthur, E., Zhang, Z., Guo, Z., Peng, X. and Mooney, S.J. (2020). Effect of long-term organic amendments on the full-range soil water retention characteristics of a Vertisol. Soil and Tillage Research. 202(February): 104663. https://doi.org/10.1016/j.still.2020.104663.