© 2024 Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP
JURNAL ILMU LINGKUNGAN
Volume 22 Issue 1 (2024): 163-174 ISSN 1829-8907

Application of Compost and Manure in the Biopore Infiltration Hole to Improve Saturated Hydraulic Conductivity (SHC) of Soil in the Coffee Root Zone

Lailatul Fitria[1*], Kurniawan Sigit Wicaksono[2], Soemarno[3]

[1]Postgraduate Program in Soil and Water Management, Faculty of Agriculture, Brawijaya University, Jl. Veteran, Malang 65145, Indonesia; email: lailatul.elf407@gmail.com
[2,3]Soil Department, Faculty of Agriculture, Brawijaya University, Jl. Veteran, Malang 65145, Indonesia

ABSTRACT

Kopi merupakan salah satu sumber devisa utama di Indonesia. Faktor penyebab fluktuasi produksi kopi adalah perubahan iklim, kepadatan tanah yang tinggi, bahan organik yang kurang sehingga menyebabkan akar kopi tidak mampu menyerap air dan unsur hara secara optimal. Pergerakan air tanah diukur dengan konduktivitas hidrolik jenuh yang merepresentasikan kemampuan tanah untuk meneruskan air. Aplikasi kompos dan pupuk kandang pada lubang resapan biopori (BIH) merupakan teknologi yang efektif dalam mengurangi limpasan permukaan dan pengelolaan sampah organik, serta perbaikan karakteristik tanah. Penelitian ini dilakukan dengan menggunakan Rancangan Acak Kelompok dengan empat perlakuan dan empat ulangan. Perlakuannya adalah P1 sebagai kontrol (tanpa BIH), P2 (BIH tanpa kompos), P3 (BIH+kompos), dan P4 (BIH+pupuk kandang kambing). Analisis data dilakukan dengan uji F (ANOVA), dan dilanjutkan dengan uji Beda Nyata Terkecil (BNT) pada taraf 5%, apabila terdapat perbedaan yang signifikan. Pengamatan karakteristik tanah dilakukan setiap dua bulan sekali pada tiga kedalaman zona perakaran, yaitu 0-20 cm, 20-40 cm, dan 40-60 cm. Sedangkan pengamatan *auger hole* pada kedalaman 0-30 cm dan 0-60 cm. Variabel penelitian meliputi tekstur tanah, berat isi tanah, Konduktivitas Hidraulik Jenuh tanah oleh *Auger-Hole*, Bahan Organik Tanah (BOT), pH, Kapasitas Tukar Kation (KTK), dan hasil kopi. Hasil penelitian menunjukkan bahwa perlakuan BIH dengan pupuk kandang kambing memberikan hasil terbaik yang diukur dengan peningkatan konduktivitas hidrolik jenuh tanah hingga 40%. Hasil kopi tertinggi terdapat pada perlakuan BIH dan pupuk kandang kambing menjadi 3,29 t ha^{-1}.

Kata Kunci: Auger hole, BIH, Hydraulic Conductivity, Zona perakaran, Perkebunan kopi

ABSTRACT

Coffee is one of the primary sources of foreign exchange in Indonesia. The factors causing fluctuations in coffee production are climate change, high soil density, less organic material, which causes coffee roots to be unable to absorb water and nutrients optimally. The soil water movement measured by saturated hydraulic conductivity which represents the soil ability to transmit water. The application of compost and manure in the biopore infiltration hole (BIH) is an effective technology in reducing surface-runoff and organic wastes management, as well as soil characteristics improvement. This study was conducted using a Randomized Block Design with four treatments and four replications. The treatments were P1 as control (without BIH), P2 (BIH without compost), P3 (BIH+compost), and P4 (BIH+goat manure). Data analysis was carried out using the Ftest (ANOVA), and continued with Least Significant Difference (LSD) test at 5% level, when there was a significant difference. Observations of soil characteristics were carried out every two months in three depth of root zone, 0-20 cm, 20-40 cm, and 40-60 cm. While the observation of the Auger hole at a depth of 0-30 cm and 0-60 cm. Research variables include soil texture, soil bulk density, Saturated Hydraulic Conductivity of soil by Auger-Hole, Soil Organic Matter (SOC), pH, Cation Exchange Capasity (CEC), and coffee yield. Results showed that treatment of BIH+goat manure gave the best results, measured by improving soil hydraulic conductivity up to 40%. The highest coffee yield was found in the BIH+manure treatment to 3.29 t ha^{-1}.

***Keywords*:** Auger hole, BIH, Hydraulic Conductivity, Root zone, Coffee plantation

Citation: Fitria, L., Wicaksono, K. S., dan Soemarno. (2024). Application of Compost and Manure in the Biopore Infiltration Hole to Improve Saturated Hydraulic Conductivity (SHC) of Soil in the Coffee Root Zone, Jurnal Ilmu Lingkungan, 22(1), 163-174, doi:10.14710/jil.22.1.163-174

1. Introduction

Coffee is one of the main commodities that support Indonesian economy. The Directorat General of Estate Crops (2020) stated that there were fluctuations in coffee production, especially in 2017-2019 of 717,962 tons, 756,051 tons, and 752,511 tons, respectively. One of reasons for this fluctuation in coffee production is coffee areas which has also fluctuated from 2013-2019. Furthermore, causes of the low coffee production is climate change which is currently happening to cause problems with the water availability to supply the needs of plants in the vegetative and generative growth stages. Efforts to increase coffee production are based on several factors such as fluctuating rainfall, soil fertility, productive land area, water stress, and temperature that can have an impact on coffee productivity (Harahap et al., 2019; Iskandar et al., 2019). One of measurements of the soil water movement in saturated state are also called the soil saturated hydraulic conductivity. The low value of the soil saturated hydraulic conductivity represents an increasingly inhibited soil water movement. This causes plant roots to be unable to absorb nutrients and water optimally to meet their metabolic needs. Soil organic matter affects nutrient availability and soil physical conditions. If the physical condition of soil is good, it will have an impact on nutrient supply and the movement of soil water will also be good (Aranda et al., 2015; Castellini & Ventrella, 2012; Iwasaki et al., 2017).

One of the applications of compost and manure is the biopore infiltration hole (BIH) technology. This is the effective technology in reducing runoff, as well as soil and water conservation (Mulyawati, 2021). This BIH can also be filled with organic wastes, compost or manure which functions to support communities of soil organisms, and in the end, can improve soil quality. Earthworms and soil fauna in these BIH will form burrows or tunnels into surrounding soil which can accelerate movement of soil solution into the soil (Gaiser et al., 2013; Khusna et al., 2020).

Efforts to overcome problems that have been described above are by applying compost and manure in the biopore infiltration hole (BIH). The biopore infiltration hole technology will increase the movement of soil-solution into surrounding soils (Khusna et al., 2020; Watiniasih, 2016). This research focuses on effects of compost and manure application in the BIH on soil saturated hydraulic conductivity and its impact on the coffee yield.

2. Materials and Methods

The research was conducted at Agro Techno Park Jatikerto, which is located at Dusun Cupak, Jatikerto Village, Kromengan District, Malang Regency. The topography of this area which is about 390 m above sea level. Geographically, Jatikerto Village is located at 7°21'-7°31' south latitude and 110°10'-111°40' east longitude, with average of an annual air temperature of 25°C-30°C. The research was carried out from September 2020 to February 2022. Agro Techo Park Jatikerto (ATP Jatikerto) is one of the coffee-producing locations in the Malang Regency area. The coffee cultivars are Robusta and Excelsa (Liberica) coffee. In the actual conditions in the research area, are dominated by the clayey soils. The soil order found at the research site is Alfisols. This causes the value of soil bulk density are high (Table 1.), and the saturated hydraulic conductivity (SHC) are relatively slow (Table 1.)

The field experiment was designed in the Randomized Block Design (RBD) with four treatments and four replications, and tree sample of coffee tree in each treatment plot. The treatments used were P1 as control (without BIH), P2 (BIH only), P3 (BIH+compost), P4 (BIH+goat manure). Each treatment was repeated four times to produce 16 experimental plots. Measurement of SHC (Soil Hydraulics Concuctivity) with the auger hole method were carried out at two depths of each treatment resulting in 32 units of the auger hole. Measurement of soil properties were carried out every two months in tree depth of soil in root zone of coffee tree, namely 0-20 cm, 20-40 cm, and 40-60 cm.

Data obtained were then analyzed using analysis of variance (Ftest) at 5% level and then it is continued with a further analysis using the Least Significant Difference (LSD 5%) test. Correlation analysis was conducted to determine correlation among the soil characteristics.

2.1 Soil Characteristics

The characteristics of the soil before application showed that at the study site, the texture of the soil was clay, which resulted in high soil density. This can be seen from the value of the bulk density which ranges from 1.24 g cm^{-3} to 1.31 g cm^{-3} with very high criteria. This also affects other parameters (Table 1.) such as the value of the saturated hydraulic conductivity (SHC) from slow to very slow and also low organic matter content.

3. Results and Discussion

Application of compost and manure in BIH can improve soil quality in terms of soil physics chemistry, and soil biology. This causes an increase in coffee beans yields.

3.1 Soil Physical Properties

Making these biopore infiltration holes can provide input for rainwater infiltration into the soil and become groundwater that can be utilized by plants. Therefore, rainwater conservation can be done by making biopore infiltration holes. The use of leaf litter (or compost) as a filler for BIH provides the benefit of reducing the volume of household waste disposal to water disposal sites.

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

Table 1. Characteristics of Soil Sample Before BIH Applications

No	Characteristics	Sample Depth 0-20 cm		Sample Depth 20-40 cm		Sample Depth 40-60 cm	
		Value of Analysis	Criteria	Value of Analysis	Criteria	Value of Analysis	Criteria
1.	pH (H_2O)*	5,6	Moderately Acid	5,6	Moderately Acid	5,5	Moderately Acid
2.	CEC*	24,70 me 100 g^{-1}	Medium	32,21 me 100 g^{-1}	High	36,11 me 100 g^{-1}	High
3.	Organic-C (SOC)*	0,77%	Very Low	0,81%	Very Low	0,50%	Very Low
4.	SHC (K-sat)**	0,28 cm h^{-1}	Slow	0,24 cm h^{-1}	Slow	0,16 cm h^{-1}	Slow
5.	% Sand	16,07	-	10,64	-	7,32	-
6.	% Silt	17,10	-	17,66	-	16,78	-
7.	% Clay	66,83	-	71,69	-	75,90	-
8.	Soil Texture**	Clay	-	Clay	-	Clay	-
9.	BD**	1,24 g cm^{-3}	High	1,29 g cm^{-3}	High	1,31 g cm^{-3}	High
10.	PD**	2,35 g cm^{-3}	-	2,31 g cm^{-3}	-	2,33 g cm^{-3}	-
11.	Porosity**	47,2%		44,1%		43,8%	

Remarks: *) Source from Soil Research Institute (2009); **) Source from J R Landon (1986). CEC: Cation Exchange Capasity; SHC: Saturated Hydraulic Conductivity; BD: Bulk Density; PD: Particle Density

Results of variance analysis (Table 2) show that application of compost and manure in BIH suggested significant effects on the soil bulk density. At the observation of 120 DAA, the treatment of BIH+compost (P3) and BIH+manure (P4) had a significant effects on soil bulk density at a depth of 0-20 cm and 20-40 cm. This indicates that a decrease of soil bulk density occurred over a certain period. Observations at 180 DAA and 240 DAA showed that the BIH+compost treatment (P3 and P4) had a significant effect on bulk density at all soil depths compared with control treatment (P1). Results of Cahyono et al. (2017) study suggested that application of compost and manure over a certain time have resulted in decrease of soil bulk density. The value of soil bulk density is strongly influenced by the increase of soil porosity. In this case, compost and manure increases the portion of meso and macro pores due to significantly enhanced soil aggregation and stabilization of the soil aggregates due to activities of various types of soil organisms There are several advantages of using organic fertilizers (materials) compared to inorganic fertilizers. This organic fertilizer (material) not only supplies several plant nutrients but can also improve soil characteristics. The results of the study prove that the application of organic fertilizers can improve soil characteristics, such as available water capacity (Herawati et al., 2021; Li et al., 2021), soil aggregation, and soil structure (Cao et al., 2021; De Notaris et al., 2021; Iwasaki et al., 2017), soil bulk density, permeability & soil hydraulic properties (Li et al., 2021; Valentine et al., 2012), soil penetration resistance; soil chemical properties such as cation exchange capacity, soil buffer capacity, nutrient retention; and soil biological properties such as soil microbial activity and development.

Porosity represents the amount of water that can seep in, but not how fast or how well it absorbs. The results of the analysis of variance showed that the application of composted biopore infiltration holes was proven to increase the percentage of soil porosity (Table 3.). The decrease in the value of bulk density (Table 2.) is in line with the increase in soil porosity. The results showed that the improvement of soil quality in terms of soil physics between parameters was very continuous so that it would affect the chemical characteristics of the soil and crop yields. The best results were found in the BIH+compost treatment of 67.74%, this can happen because, in biopore infiltration holes containing organic matter, soil fauna will work to make small holes from the bottom layer to the soil surface layer. If the application of biopore infiltration holes is carried out on a large scale and permanently, it will be one solution to the problem of land degradation.

The combination of biopore infiltration hole technology with organic fertilizer has been proven to improve soil quality. Khusna et al. (2020) suggested that the use of biopore infiltration holes (BIH) by inserting organic matter into the biopore holes can add nutrients to the soil to increase soil fertility. They have conducted a study to evaluate the use of biopore in increasing soil fertility in Gambiran, Besole Village, Besuki District, Tulungagung Regency. The level of soil fertility was measured by field observations and analysis of soil samples. The results showed that the use of biopore can increase soil fertility in karst area. The saturated hydraulic conductivity of soil represents flow rate of a liquid (soil solution) in soil. In the application of compost and manure in BIH, it is proven to be able to improve value of saturated hydraulic conductivity of soil from very slow to moderate criteria (Table 4.).

Results of variance analysis (Table 4.) showed that application of compost and manure in BIH suggested significant effects on soil characteristics. In the control treatment (P1), the SHC value showed very slow criteria at 60 DAA in all treatments, then SHC increased significantly up to 120 DAA, 180 DAA, and 240 DAA become the moderate criteria. However, treatment of BIH+compost (P3) did not significantly different with the BIH+manure (P4). Activities of soil organisms has an important role in improving soil pores so that it affects SHC value of soil. At 240 DAA observations, SHC value increased at all of soil depths (Table 4.). Application of compost and manure in BIH increased activities of soil organisms and increases availability of nutrients in the soil. This triggers increasing of SHC values of a dense soils in coffee

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

fields. In line with the research of Fitria & Soemarno (2022) explained that application of organic fertilizers tends to reduce soil density and it results in higher value of soil permeability. The magnitude of the soil permeability rate is also influenced by soil aggregates stability and content of soil organic matter. Soil hydraulic conductivity is a function of groundwater pressure, soil moisture content, and soil moisture retention. Soil hydraulic properties are needed to understand water balance, irrigation, and transport processes. Therefore, the saturated hydraulic properties of the soil surface affect precipitation and snowmelt into runoff and groundwater storage. Soil hydraulic conductivity is indispensable for designing water control structures, groundwater storage facilities, and run off forecasting.

Siltecho et al. (2015) suggest that adequate water management is necessary to improve the efficiency and sustainability of agricultural systems when water is scarce or water is abundant, especially in relation to land use change. In order to quantify, predict, and ultimately control water and solute transport into the soil (mass flow), it is necessary to determine the hydraulic properties of the soil precisely. Many alternative fields and laboratory techniques are available. Mulyawati (2021) conducted research on the use of biopore infiltration holes (BIH) as a form of flood mitigation by absorbing some rainwater into the ground through the BIH. Based on the soil permeability values measured in the BIH, it can be interpreted that soil texture greatly determines the value of soil permeability. The difference in the value of soil permeability is also influenced by soil structure and soil porosity.

Table 2. Effect of Treatment on Soil Bulk Density

Treatments	Soil Bulk Density (g cm^{-3})					
	60 DAA			120 DAA		
	Soil depth: 0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	1,19^{a}	1,23^{a}	1,33^{a}	1,22^{b}	1,25^{b}	1,25^{a}
P2 (BIH)	1,17^{a}	1,26^{a}	1,27^{a}	1,18^{b}	1,24^{b}	1,27^{a}
P3 (BIH+Compost)	1,21^{a}	1,23^{a}	1,27^{a}	1,09^{a}	1,11^{a}	1,25^{a}
P4 (BIH+ Manure)	1,19^{a}	1,22^{a}	1,24^{a}	1,13^{a}	1,10^{a}	1,22^{a}
Treatments	Soil Bulk Density (g cm^{-3})					
	180 DAA			240 DAA		
	Soil depth: 0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	1,29^{b}	1,26^{b}	1,33^{b}	1,25^{c}	1,23^{c}	1,24^{c}
P2 (BIH)	1,26^{b}	1,26^{b}	1,29^{b}	1,05^{b}	1,13^{b}	1,23^{c}
P3 (BIH+Compost)	1,03^{a}	0,94^{a}	0,80^{a}	0,80^{a}	0,82^{a}	0,89^{a}
P4 (BIH+ Manure)	1,03^{a}	0,94^{a}	0,78^{a}	0,78^{a}	0,82^{a}	0,92^{b}

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. DAA: Days After Application; BIH: Biopore Infiltration Hole.

Table 3. Effect of BIH to Porosity

Treatments	Porosity (%)					
	60 DAA			120 DAA		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	43,67^{a}	36,33^{a}	40,43^{a}	38,87^{a}	42,95^{a}	44,23^{a}
P2 (BIH)	40,38^{a}	39,59^{a}	42,84^{a}	41,05^{a}	41,72^{a}	41,51^{a}
P3 (BIH+Compost)	42,73^{a}	38,67^{a}	36,60^{a}	46,73^{b}	47,60^{ab}	44,46^{a}
P4 (BIH+ Manure)	39,93^{a}	38,93^{a}	33,92^{a}	42,40^{ab}	47,25^{ab}	45,54^{a}
Treatments	Porosity (%)					
	180 DAA			240 DAA		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	41,79^{a}	44,57^{a}	42,29^{a}	41,93^{a}	45,10^{a}	45,96^{a}
P2 (BIH)	35,78^{a}	38,50^{a}	35,47^{a}	46,15^{b}	44,57^{a}	38,59^{a}
P3 (BIH+Compost)	54,29^{ab}	55,53^{b}	51,53^{b}	67,74^{c}	61,26^{b}	59,02^{b}
P4 (BIH+ Manure)	47,97^{ab}	55,75^{b}	54,54^{b}	64,51^{c}	61,54^{b}	59,33^{b}

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. DAA: Days After Application); BIH: Biopore Infiltration Hole.

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

Table 4. Effect of Treatment on Soil Hidraulics Conductivity

Treatments	Soil hydraulics conductivity (m day^{-1}) in Auger Hole							
	60 DAA		120 DAA		180 DAA		240 DAA	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
P1 (Control)	1,24^{a}	0,88^{a}	4,69^{a}	3,04^{a}	5,05^{a}	3,16^{a}	5,18^{a}	3,29^{a}
P2 (BIH)	1,76^{ab}	0,94^{ab}	4,74^{ab}	3,05^{ab}	5,66^{ab}	3,34^{b}	5,27^{ab}	3,62^{a}
P3 (BIH+Compost)	2,14^{b}	1,06^{b}	4,75^{b}	3,05^{b}	7,97^{b}	3,66^{c}	8,13^{b}	4,83^{ab}
P4 (BIH+ Manure)	2,50^{b}	1,12^{b}	5,02^{c}	3,06^{b}	9,15^{c}	3,82^{c}	10,23^{b}	5,17^{b}

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. DAA: Days After Application; BIH: Biopore Infiltration Hole

3.2 Soil Chemical Properties

The application of biopore infiltration holes in addition to affecting the physical characteristics of the soil also affects the chemical characteristics of the soil. The results of the analysis of variance showed that biopore infiltration holes were able to improve soil quality in terms of chemistry. The results of the analysis of the various effects of BIH treatment on soil pH showed a significant effect (Table 5). It can be seen that the BIH+manure treatment showed the highest soil pH results. Manure is the result of composting from the rest of animal manure, in this case, goat manure. Microorganism activity in goat manure is considered higher than in compost produced from organic waste. This is because the organic matter contained in the biopore infiltration hole affects the presence of H+ ions in the soil. As the amount of exchangeable H+ increases, the concentration of basic nutrients (cations) usually decreases as uptake by plants increases. The desired range of soil pH for optimal plant growth varies among plant species. While some plants grow best in a soil pH range of 6.0-7.0; others grow well in slightly acidic soil conditions. Soils become acidic when basic elements such as calcium, magnesium, sodium, and potassium held by soil colloids are replaced by hydrogen ions. Soils formed under conditions of high annual rainfall are more acidic than soils formed under drier climatic conditions. Intensive farming in the long term with nitrogen fertilizers can also result in soil acidification.

The results of the analysis of variance showed that the application of biopore compost affected the cation exchange capacity (Table 6.). The value of CEC is influenced by the organic matter content of the soil and the percentage of clay. The cation exchange capacity represents the number of cations that the soil can absorb and exchange (Solly et al., 2020). The results showed that the addition of organic matter was able to increase the value of soil cation exchange capacity, but with increasing depth the value of CEC decreased (Table 9.). This is because the percentage of organic matter will decrease with increasing soil depth. As a result, high oxygen concentrations in biopore can affect the microbial activity and nutrient uptake by roots which are limited by oxygen deficiency in dense soil layers. In line with the research results of (Prameswari et al., 2015) that the results of the analysis of the soil bases content showed that the exchange Ca content in the soil was very low (< 2 mg/100 g), the Ca exchange content tended to increase after one year of treatment. The CEC value of the soil at the skid trail location was lower than that in the natural forest (11.06 meq/100 g), and the CEC of the soil in the BIH treatment (19.87 meq/100 g) was higher than that of the soil in the natural forest.

Research by Domingues et al. (2020) mentions that the addition of organic matter will increase the load negative so that it will increase cation exchange capacity. Cation exchange capacity demonstrates the soil's ability to hold cations and process decomposition of organic matter is the source of negative ground charge. Clay content has the same effect. The finer the soil fraction, the more surface area particles, so it has a higher CEC. In addition, (Fitria & Soemarno, 2022) also discuss the results of their research that an increase in soil pH has the potential to increase the CEC value of the soil, this result will affect the availability of nutrients in the soil.

Root growth in natural biopore is then related to the mobilization and nutrient cycle by rhizosphere microorganisms. On the other hand, earthworms transport organic matter from the soil surface into the biopore and coat the burrow walls with their mucus substance, and show high microbial activity (Uksa et al., 2015). As a result of these two processes, natural biopore have the potential to present a nutrient source zone, due to enhanced nutrient biological cycles and due to increased nutrient availability to plants. The ability of BIH to accelerate the decomposition process of organic matter has something to do with the ability of BIH to improve air and water systems which are very much needed by decomposer bodies to remodel organic matter in BIH. This is due to the ability of BIH to maintain aeration in the infiltration hole so that the soil fauna gets sufficient oxygen to carry out the decomposition process of organic matter.

The BIH structure with its biopore holes becomes a pathway for the movement of water (soil solution) and air into the surrounding soil so that there is sufficient organic matter, water, oxygen, and nutrients suitable for the development of plant roots and soil organisms.

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana

Table 5. Effect of Treatment on Soil pH

Treatments	Soil pH		
	Soil depth: 0-20 cm	20-40 cm	40-60 cm
P1 (Control)	5,6ᵃ	5,6ᵃ	5,5ᵃ
P2 (BIH)	5,7ᵃ	5,7ᵃ	5,6ᵃ
P3 (BIH+Compost)	5,9ᵇ	5,7ᵃᵇ	5,8ᵃ
P4 (BIH+ Manure)	6,0ᵇ	6,1ᵇ	6,0ᵇ

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. DAA: Days After Application; BIH: Biopore Infiltration Hole.

Table 6. Effect of Treatment on CEC

Treatments	CEC (me 100 g^{-1}) 60 DAA			120 DAA		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	24.79ᵃ	38.87ᵃ	36.14ᵃ	24.88ᵃ	32.29ᵃ	36.15ᵃ
P2 (BIH)	24.49ᵃ	41.05ᵃ	36.43ᵃ	25.22ᵃ	32.63ᵃ	36.59ᵃ
P3 (BIH+Compost)	26.23ᵃ	42.20ᵃᵇ	36.93ᵃ	27.48ᵇ	34.63ᵃ	38.22ᵃ
P4 (BIH+ Manure)	26.24ᵃ	46.72ᵇ	37.49ᵃ	27.49ᵇ	34.94ᵃ	38.72ᵃ
Treatments	**CEC (me 100 g^{-1}) 180 DAA**			**240 DAA**		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	25.02ᵃ	23,44ᵃ	23,76ᵃ	38,87ᵃ	32,53ᵃ	30,70ᵃ
P2 (BIH)	25.88ᵃ	27,93ᵃ	28,25ᵃ	41,05ᵃ	33,38ᵃ	31,78ᵃ
P3 (BIH+Compost)	29.59ᵇ	32,14ᵃᵇ	29,11ᵃ	46,72ᵇ	40,72ᵇ	33,74ᵃ
P4 (BIH+ Manure)	30.58ᵇ	33,00ᵇ	36,29ᵇ	42,20ᵃᵇ	41,43ᵇ	34,74ᵃ

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. DAA: Days After Application); BIH: Biopore Infiltration Hole.

Table 7. Effect of Treatment on Content of Soil Organic Carbon (SOC)

Treatments	SOC (%) 60 DAA			120 DAA		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	0,72ᵃ	0,92ᵃ	0,50ᵃ	0,77ᵃ	0,81ᵃ	0,58ᵃ
P2 (BIH)	0,60ᵃ	0,94ᵃ	0,58ᵃ	0,63ᵃ	0,69ᵃ	0,50ᵃ
P3 (BIH+Compost)	0,84ᵃ	1,10ᵃ	0,57ᵃ	1,29ᵇ	1,01ᵃ	0,52ᵃ
P4 (BIH+ Manure)	0,77ᵃ	1,09ᵃ	0,55ᵃ	1,23ᵃᵇ	1,12ᵃᵇ	0,64ᵃ
Treatments	**SOC (%) 180 DAA**			**240 DAA**		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
P1 (Control)	0,77ᵃ	0,82ᵃ	0,59ᵃ	0,77ᵇ	0,82ᵃ	0,58ᵃ
P2 (BIH)	0,55ᵃ	0,66ᵃ	0,51ᵃ	0,47ᵃ	0,69ᵃ	0,51ᵃ
P3 (BIH+Compost)	1,19ᵇ	0,96ᵃ	1,05ᵇ	1,99ᶜ	2,00ᶜ	1,01ᵇ
P4 (BIH+ Manure)	1,47ᵇ	1,23ᵃᵇ	0,89ᵃᵇ	2,11ᶜ	1,71ᵇ	1,14ᵇ

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. DAA: Days After Application); BIH: Biopore Infiltration Hole.

3.3 Coffee Productions

The results of the analysis of coffee yields variance (Table 8.) showed that the biopore compost treatment had a significant effect on the control treatment (P1). It is proven that the best coffee production is seen in the biopore+manure treatment (P4), which is 3,29 t ha^{-1}. This is in line with the results of the analysis of variance on the physical and biological characteristics of the soil, where the BIH+goat manure treatment was able to improve the optimal soil quality. Treatment P3 (BIH+compost) with P4 (BIH+goat manure) showed insignificant results, this was because both the application of organic matter in the form of compost and manure was able to improve soil quality, although the increase was different. Optimal water and nutrient requirements are very important for coffee plant production so the application of biopore compost technology, is proven to be able to significantly increase coffee production.

Biopores can facilitate nutrient uptake from the subsoil by increasing the density of root lengths in most soils or absorption of nutrients from the pore walls. Crop production must be based on living soils

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

and ecological processes. In addition, the high biopore density can facilitate the absorption of water and nutrients, especially in drought conditions, thereby contributing to increased stability of the cropping system, the overall goal of organic coffee plantation management. It is evident from the data analysis of variance (Table 8.) that the BIH application can optimize coffee production. The beneficial effects of biopore have been widely studied, on the one hand, they provide a preferential pathway for root growth, especially in dense subsoils, because the presence of natural biopore can reduce soil penetration resistance and improve soil aeration (Gaiser et al., 2013; Valentine et al., 2012). Simple indicators of crop and cultivation performance across a wide range of soil types and management are needed to design and test sustainable planting practices.

3.4 Relationship between Parameters

The results of the correlation test at the end of the observation (240 DAA) were still parameters at a depth of 0-20 cm, 20-40 cm, and 40-60 cm (Table 9.). BIH application shows an effect in improving soil quality both in terms of soil physics and soil chemistry. At the top layer depth (0-20 cm), the saturated hydraulic conductivity showed a significant positive correlation with soil organic matter ($r=0.102^{**}$). The SHC value also showed a significant correlation with porosity, pH, and CEC in the soil ($r=0.917^{**}$; $r=0.837^{**}$; and $r=0.887^{**}$) and SHC shows a negative correlation with the value of BD ($r=-0.832^{**}$), which means that the higher the density of the soil, the slower the SHC (Table 9.). Saturated hydraulic conductivity is one indicator to determine the movement of water in the soil. So that if the SHC value is higher, then the movement of water in the soil will also be faster. One of the factors that affect the value of the saturated hydraulic conductivity of the soil is the presence of soil organic matter. This is related to the activity of microorganisms so that the application of biopore infiltration holes can increase soil porosity.

The saturated hydraulic conductivity of the soil showed a significant positive correlation with soil porosity, soil pH, and SOC at 20-40 cm ($r=0.932^{**}$; $r=0.855^{**}$; $r=0.928^{**}$) (Table 9.). It can be concluded that the increase in soil organic matter will affect the quality of the soil. Rong et al. (2016) also explained that the addition of organic fertilizers such as compost had a positive effect on C-Organic soil due to the release of organic carbon in the soil. In addition to chemical properties, the application of composting also affects the physical properties of the soil. Giving compost affects the porosity of the soil. This happens because, in compost, there is a decomposition process by microorganisms which ultimately has an impact on increasing the stability of soil aggregates.

In the lower layer (40-60 cm), there is a correlation between treatment parameters (Table 9.). Saturated hydraulic conductivity showed a significant positive correlation with soil organic matter ($r=0.747^{**}$). The SHC value also showed a significant correlation to soil porosity and pH ($r= 0.873^{**}$; $r=0.716^{**}$). Saturated hydraulic conductivity is one indicator to determine the movement of water in the soil.

So that if the SHC value is higher, then the movement of water in the soil will also be faster. One of the factors that affect the value of the saturated hydraulic conductivity of the soil is the content of soil organic matter.

Results of regression and correlation analysis showed that organic matter was able to improve the physical and chemical properties of the soil (Figure 1). Application of compost and manure can affect soil physical characteristics, soil chemistry, soil biology, improve nutrient availability in the root zone of plants, and plant growth (Getahun et al., 2022). The high content of soil organic matter is able to hold the available nutrients and available soil moisture. There are several advantages to using organic fertilizers (organic matter) compared to inorganic fertilizers. This organic fertilizer not only supplies a number of plant nutrients but can also improve soil physical characteristics (Fukumasu et al., 2022; Thai et al., 2022). Application of BIH technology is also promote application of organic wastes which is then used as organic fertilizer. The purpose of the addition of organic matter is to improve effectiveness of biopore that has been embedded in the soil (Lynch et al., 2022; Uksa et al., 2015; Wendel et al., 2022).

The difference in the results of the increase at a depth of 0-20 cm, 20-40 cm, and 40-60 cm was due to variations in the characteristics of the different soils. The application of biopore infiltration holes tends to be able to improve soil quality in the upper layer more optimally than in the lower layer (20-40 cm; 40-60 cm) so that in the upper layer, the soil density will decrease more optimally compared to the lower layer. This causes the impact of the application of biopore to decrease as the soil depth increases. Another factor that causes it is possible because, in the upper layer, the soil will get more organic matter intake from the fallen coffee leaves coupled with soil fauna activity which is dominated in the top layer of soil. The results of Priori et al. (2021) explained that the root system of plants will affect soil characteristics and fauna activity in the soil. Varied soil characteristics coupled with external factors such as rainfall, the input of organic matter, and temperature will affect the availability of water in the soil and crop production. Soil fertility indicators are used to determine the response to land management and cropping patterns. The results of the study explained that the density of soil on the cultivated land and root penetration was considered high. This represents the inhibition of water movement and faunal activity in the soil (Boizard et al., 2017; De Notaris et al., 2021; Priori et al., 2021; Yang et al., 2021). SHC values at depths of 0-20 cm, 20-40 cm, and 40-60 cm (Figure 2.) indicate that SHC has a close relationship with the total chlorophyll of coffee plants. This means that the increase in SHC value is in line with the increase in total chlorophyll in coffee

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

plants. This results in the process of photosynthesis in coffee plants.

Yang et al. (2021) explained that Chlorophyll has a direct effect on the process of photosynthesis, namely producing organic compounds as assimilates derived from inorganic compounds with the help of sunlight. These organic compounds are needed by a plant in its metabolic process (plant height, number of leaves, leaf area, and yield) (Adugna Debela Bote & Jan, 2016; Chalchissa et al., 2022; Damatta et al., 2008; Praxedes et al., 2006). This argument is proven in the research results, that the increasing value of SHC is in line with the increase in the production of coffee plants.

The results of the analysis show that the value of SHC has an effect on the production of coffee plants (Figure 3.). The increase in SHC value is in line with the increase in coffee beans yield. This means that the application of BIH with the addition of compost or goat manure was able to increase the yield of coffee beans compared to the BIH treatment (control). SHC is characterized by increased soil porosity, so plant roots are more optimal in absorbing soil moisture and available nutrients in the soil (Marín-Castro et al., 2017; Silva et al., 2021). This affects the metabolic process of the coffee plant as evidenced by the increase in leaf chlorophyll content (Figure 2.) so that the photosynthesis process will run optimally and coffee beans yield will increase (Adugna D Bote & Struik, 2011; Chemura et al., 2017; Mayoli & Gitau, 2012; Netto et al., 2005; Reis et al., 2009; Sudirman & Hartono, 2020).

This research certainly has limitations. The main limitations of these results study will be valuable on the interaction in the use of composted biopore technology on soil saturated hydraulic conductivity values. This research only considers a number of supporting soil data and not too many soil samples are taken because they adjust to the conditions of the available coffee grounds. In addition, the auger hole research method that used in this study is based on soil and vegetation conditions which are quite different from studies with similar topics and the limited number of recent sources that apply the same method so that the resulting data becomes variative.

Table 8. Effect of Treatment on the Coffee Yields

Treatments	Coffee Yields (t ha^{-1})
P1 (Control)	0,78^{a}
P2 (BIH)	1,19^{b}
P3 (BIH+Compost)	2,57^{c}
P4 (BIH+ Manure)	3,29^{d}

Remarks: Numbers in the same column followed by the same letter is not significantly different at LSD 5%. BIH: Biopore Infiltration Hole.

Table 9. Matrix Correlation of Soil Characteristics at the Soil Depth of 0-20 cm

	SHC	BD	Porosity	pH	CEC	SOC
			0-20 cm			
SHC	1					
BD	-0,832**	1				
Porosity	0,917**	-0,957**	1			
pH	0,837**	-0,896**	0,898**	1		
CEC	0,887**	-0,922**	0,912**	0,909**	1	
SOC	0,958**	-0,849**	0,935**	0,828**	0,870**	1
			20-40 cm			
SHC	1					
BD	-0,879**	1				
Porosity	0,932**	-0,960**	1			
pH	0,855**	-0,875**	0,847**	1		
CEC	0,334	-0,320	0,347	0,264	1	
SOC	0,928**	-0,894**	0,914**	0,794**	0,264	1
			40-60 cm			
SHC	1					
BD	-0,916**	1				
Porosity	0,873**	-0,887**	1			
pH	0,716**	-0,843**	0,755**	1		
CEC	0,485	-0,473	0,399	0,508*	1	
SOC	0,747**	-0,861**	0,795**	0,781**	0,267	1

Notes SHC: Saturated Hydraulics Conductivity; BD: Bulk Density; CEC: Cation Exchange Capacity; SOC: Soil Organic Carbon.
(*) Correlation is significant at the 0.05 level (2-tailed test)
(**) Correlation is significant at the 0.01 level (2-tailed test)

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

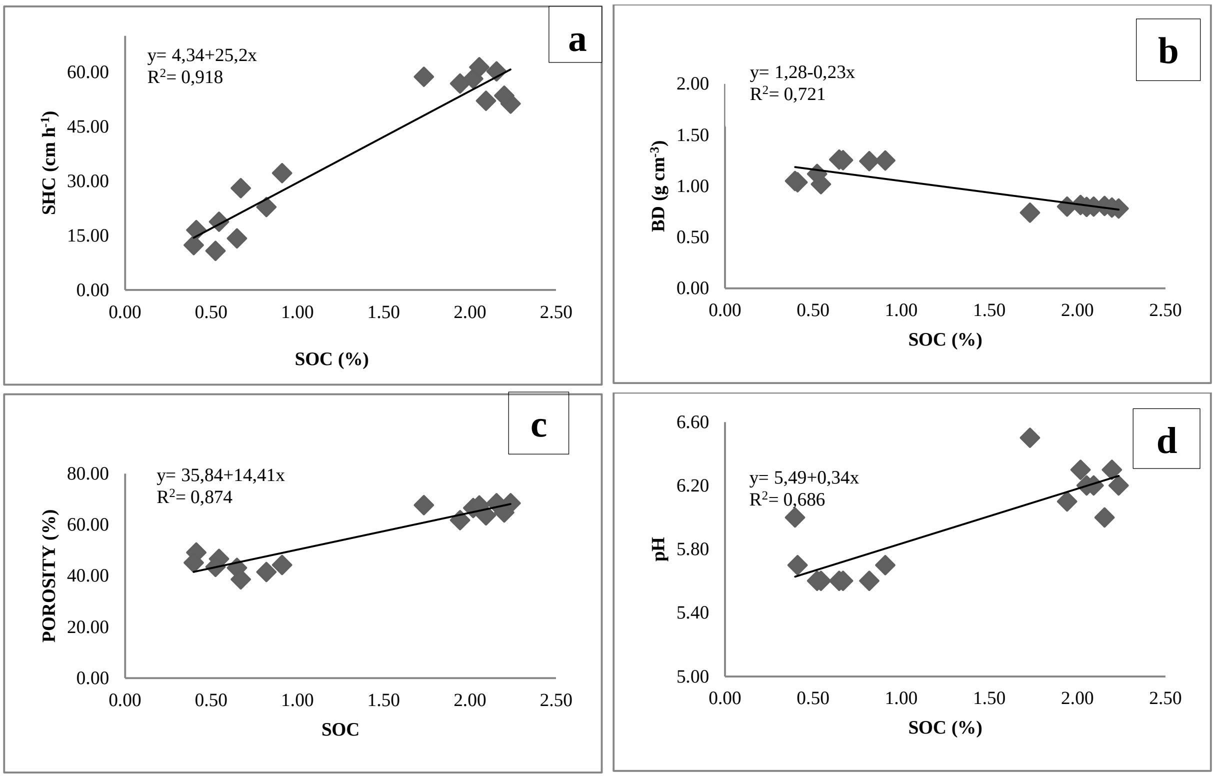

Figure 1. Relationship of SOC and Soil Characteristics; (a). Saturated Hydraulic Conductivity of soil (SHC); (b). Bulk Density (BD); (c). Soil Porosity; (d). Soil pH

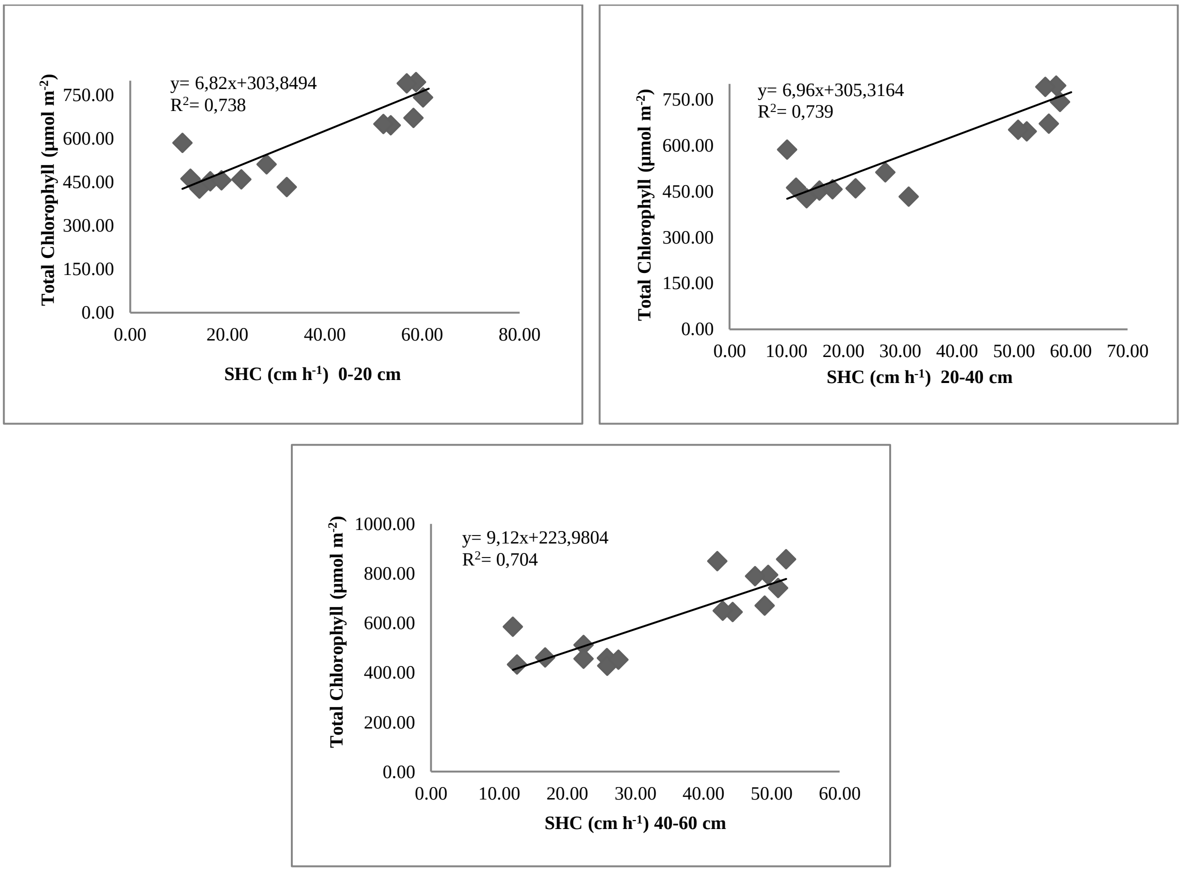

Figure 2. Relationship between total chlorophyll of coffee tree and SHC (Saturated Hydraulics Conductivity of soil)

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

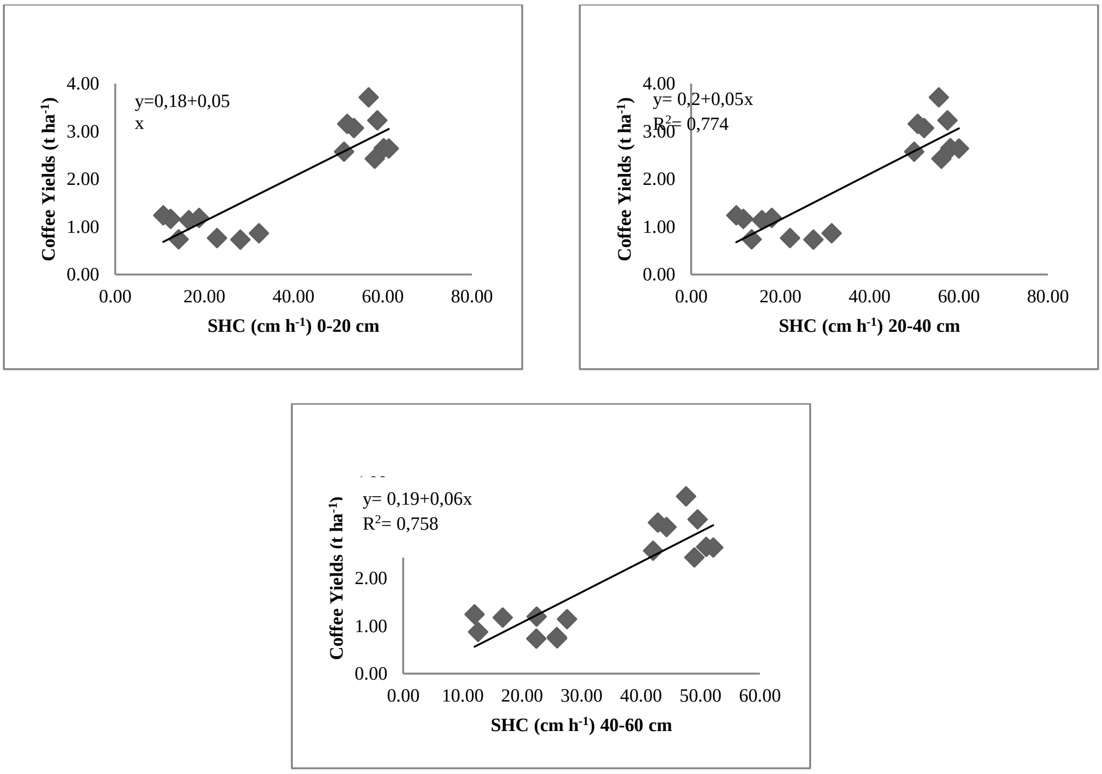

Figure 3. Relationship between Coffee beans Yields and SHC (Saturated Hydraulics Conductivity of soil)

4. Conclusion

Compost and manure application in the biopore infiltration holes (BIH) can improve value of the saturated hydraulic conductivity of soil. The best results are seen in the treatment of BIH+goat manure. Results showed that application of BIH+manure improved soil characteristics such as soil porosity, soil organic carbon, soil pH, and soil CEC. Coffee beans yield after application of treatment also showed very significant increase. The highest coffee beans yield was 3,29 t ha^{-1} in the BIH+goat manure treatment.

Acknowledgements

The authors would like to thank Agro Techno Park Jatikerto, Malang Regency for allowing the implementation of this research. This research was funded by Doctoral and Professor Grant from the Faculty of Agriculture, Universitas Brawijaya, with the decree No 2338/UN10.F04/PN/2020.

References

Aranda, V., Macci, C., Peruzzi, E., & Masciandaro, G. (2015). Biochemical activity and chemical-structural properties of soil organic matter after 17 years of amendments with olive-mill pomace co-compost. *Journal of Environmental Management*, *147*, 278–285. https://doi.org/https://doi.org/10.1016/j.jenvman.2014.08.024

Boizard, H., Peigné, J., Sasal, M. C., de Fátima Guimarães, M., Piron, D., Tomis, V., Vian, J.-F., Cadoux, S., Ralisch, R., Tavares Filho, J., Heddadj, D., De Battista, J., Duparque, A., Franchini, J. C., & Roger-Estrade, J. (2017). Developments in the "profil cultural" method for an improved assessment of soil structure under no-till. *Soil and Tillage Research*, *173*, 92–103. https://doi.org/https://doi.org/10.1016/j.still.2016.07.007

Bote, Adugna D, & Struik, P. C. (2011). Effects of shade on growth , production and quality of coffee (Coffea arabica) in Ethiopia. *Journal of Horticulture and Forestry*, *3*(11), 336–341.

Bote, Adugna Debela, & Jan, V. (2016). Branch growth dynamics, photosynthesis, yield and bean size distribution in response to fruit load manipulation in coffee trees. *Trees*, *30*(4), 1275–1285. https://doi.org/10.1007/s00468-016-1365-x

Cahyono, P., Astuti, N. K., Purwito, & Rahmat. (2017). Mapping the rainfall distribution for irrigation planning in dry season at pineapple plantation , Lampung Province , Indonesia (Study case at Great Giant Pineapple Co . Ltd .) Mapping the rainfall distribution for irrigation planning in dry season at pin. *IOP Conf. Series: Earth and Environmental Science*, *129*(2018), 1–6. https://doi.org/10.1088/1755-1315/129/1/012017

Cao, S., Zhou, Y., Zhou, Y., Zhou, X., & Zhou, W. (2021). Soil organic carbon and soil aggregate stability associated with aggregate fractions in a chronosequence of citrus orchards plantations. *Journal of Environmental Management*, *293*, 112847. https://doi.org/https://doi.org/10.1016/j.jenvman.2021.112847

Castellini, M., & Ventrella, D. (2012). Impact of conventional and minimum tillage on soil hydraulic conductivity in typical cropping system in Southern Italy. *Soil and Tillage Research*, *124*, 47–56. https://doi.org/10.1016/j.still.2012.04.008

Chalchissa, F. B., Diga, G. M., Feyisa, G. L., & Tolossa, A. R. (2022). Impacts of extreme agroclimatic indicators on the performance of coffee (Coffea arabica L.) aboveground biomass in Jimma Zone, Ethiopia.

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

Heliyon, *8*(8), e10136. https://doi.org/https://doi.org/10.1016/j.heliyon.2022.e10136

Chemura, A., Mutanga, O., & Odindi, J. (2017). Empirical Modeling of Leaf Chlorophyll Content in Coffee (Coffea Arabica) Plantations With Sentinel-2 MSI Data: Effects of Spectral Settings, Spatial Resolution, and Crop Canopy Cover. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *10*(12), 5541–5550. https://doi.org/10.1109/JSTARS.2017.2750325

Damatta, F. M., Ronchi, C. P., Maestri, M., & Barros, R. S. (2008). Ecophysiology of coffee growth and production. *Braz. J. Plant Physiol*, *19*(4), 485–510.

De Notaris, C., Jensen, J. L., Olesen, J. E., Stumpf da Silva, T., Rasmussen, J., Panagea, I., & Rubæk, G. H. (2021). Long-term soil quality effects of soil and crop management in organic and conventional arable cropping systems. *Geoderma*, *403*, 115383. https://doi.org/https://doi.org/10.1016/j.geoderma.2021.115383

Directorat General of Estate Crops. (2020). *Statistik Perkebunan Unggulan Nasional 2019-2021*. Direktorat Jenderal Perkebunan, Kementerian Pertanian.

Domingues, R. R., Miguel, A. S., Spokas, K. A., Melo, C. A., Trugilho, P. F., Valenciano, M. N., & Silva, C. A. (2020). Enhancing Cation Exchange Capacity of Weathered Soils Using Biochar : Feedstock , Pyrolysis Conditions and Addition Rate. *Agronomy*, *10*(824), 1–17. https://doi.org/10.3390/agronomy10060824

Fitria, L., & Soemarno. (2022). Effects of Lime and Compost on Chemical Characteristics and Soil Hydraulic Conductivity of Alfisols at ATP Jatikerto Coffee Plantation. *Journal of Sustainable Agriculture*, *37*(1), 48–61. https://doi.org/http://dx.doi.org/10.20961/carakatani.v37i1.54010 Effects

Fukumasu, J., Jarvis, N., Koestel, J., Katterer, T., & Larsbo, M. (2022). *Relations between soil organic carbon content and the pore size distribution for an arable topsoil with large variations in soil properties*. *September 2021*, 1–15. https://doi.org/10.1111/ejss.13212

Gaiser, T., Perkons, U., Küpper, P. M., Kautz, T., Uteau-Puschmann, D., Ewert, F., Enders, A., & Krauss, G. (2013). Modeling biopore effects on root growth and biomass production on soils with pronounced sub-soil clay accumulation. *Ecological Modelling*, *256*, 6–15. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2013.02.016

Getahun, G. T., Kätterer, T., Munkholm, L. J., Rychel, K., & Kirchmann, H. (2022). Effects of loosening combined with straw incorporation into the upper subsoil on soil properties and crop yield in a three-year field experiment. *Soil and Tillage Research*, *223*, 105466. https://doi.org/https://doi.org/10.1016/j.still.2022.105466

Harahap, R. H., Humaizi, & Muda, I. (2019). Sustainable Management of Coffee Farms (Case in Karo Regency, North Sumatera Indonesia). *International Journal Civil Engineering and Technology (IJCIET)*, *9*(11), 2721–2731. http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=9&IType=11

Herawati, A., Mujiyo, Syamsiyah, J., Baldan, S. K., & Arifin, I. (2021). Application of soil amendments as a strategy for water holding capacity in sandy soils Application of soil amendments as a strategy for water holding capacity in sandy soils. *The 5th International Conference on Climate Change*, *724*(2021), 1–10. https://doi.org/10.1088/1755-1315/724/1/012014

Iskandar, B. S., Iskandar, J., Irawan, B., & Partasasmita, R. (2019). *The development of coffee cultivation in the traditional agroforestry of mixed-garden (dukuh lembur) to provide social-economic benefit for the Outer Baduy Community , South Banten , Indonesia*. *20*(10), 2958–2969. https://doi.org/10.13057/biodiv/d201026

Iwasaki, S., Endo, Y., & Hatano, R. (2017). Soil Science and Plant Nutrition The effect of organic matter application on carbon sequestration and soil fertility in upland fields of different types of Andosols. *Soil Science and Plant Nutrition*, *63*(2), 200–220. https://doi.org/10.1080/00380768.2017.1309255

J R Landon. (1986). *Booker Tropical Soil Manual* (pp. 58–102).

Khusna, N. I., Amin, S., Efrianinrum, F. Y., & Bashith, A. (2020). The effect of using biopore on soil fertility in karst area , District of Besuki , Tulungagung Regency. *IOP Conference Series : Earth and Environmental Science*, *485*(2020), 1–10. https://doi.org/10.1088/1755-1315/485/1/012066

Li, Y., Feng, G., Tewolde, H., Zhang, F., Yan, C., & Yang, M. (2021). Soil aggregation and water holding capacity of soil amended with agro-industrial byproducts and poultry litter. *Journal of Soils and Sediments*, *21*(2), 1127–1135. https://doi.org/10.1007/s11368-020-02837-3

Lynch, J. P., Schneider, H. M., Mooney, S. J., & Strock, C. F. (2022). Future roots for future soils. *Plant, Cell, & Environment*, *September 2021*, 620–636. https://doi.org/10.1111/pce.14213

Marín-Castro, B. E., Negrete-Yankelevich, S., & Geissert, D. (2017). Litter thickness, but not root biomass, explains the average and spatial structure of soil hydraulic conductivity in secondary forests and coffee agroecosystems in Veracruz, Mexico. *Science of The Total Environment*, *607–608*, 1357–1366. https://doi.org/https://doi.org/10.1016/j.scitotenv.2017.07.064

Mayoli, R. N., & Gitau, K. M. (2012). The Effects Of Shade Trees On Physiology Of Arabica Coffee. *Journal of Horticultural Science*, *6*.

Mulyawati, I. (2021). *COMMUNITY EMPOWERMENT AT NANGGERANG VILLAGE IN REDUCING POTENTIAL*. *3*(1), 251–253. https://doi.org/10.33068/iccd.Vol3.Iss1.352

Netto, A. T., Campostrini, E., Oliveira, J. G. de, & Bressan-Smith, R. E. (2005). Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. *Scientia Horticulturae*, *104*(2), 199–209. https://doi.org/https://doi.org/10.1016/j.scienta.2004.08.013

Prameswari, D., Supriyanto, Saharjo, B. H., Wasis, B., & Pamoengkas, P. (2015). Aplikasi lubang resapan biopori dan Cross Drain untuk Rehabilitasi di Jalan

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP

Sarad. *Jurnal Penelitian Hutan Dan Konservasi Alam*, *12*(2), 177–189.

Praxedes, S. C., DaMatta, F. M., Loureiro, M. E., G. Ferrão, M. A., & Cordeiro, A. T. (2006). Effects of long-term soil drought on photosynthesis and carbohydrate metabolism in mature robusta coffee (Coffea canephora Pierre var. kouillou) leaves. *Environmental and Experimental Botany*, *56*(3), 263–273. https://doi.org/https://doi.org/10.1016/j.envexpbot.2005.02.008

Priori, S., Pellegrini, S., & Vignozzi, N. (2021). Soil Physical-Hydrological Degradation in the Root-Zone of Tree Crops : Problems and Solutions. *Agronomy*, *11*(68), 1–27. https://doi.org/https://doi.org/10.3390/agronomy 11010068

Reis, A. R., Favarin, J. L., Malavolta, E., Júnior, J. L., & Moraes, M. F. (2009). Photosynthesis, Chlorophylls, and SPAD Readings in Coffee Leaves in Relation to Nitrogen Supply. *Communications in Soil Science and Plant Analysis*, *40*(9–10), 1512–1528. https://doi.org/10.1080/00103620902820373

Rong, Y., Yong-zhong, S. U., Tao, W., & Qin, Y. (2016). Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. *Journal of Integrative Agriculture*, *15*(3), 658–666. https://doi.org/10.1016/S2095-3119(15)61107-8

Siltecho, S., Hammecker, C., Sriboonlue, V., Clermont-Dauphin, C., Trelo-ges, V., Antonino, A. C. D., & Angulo-Jaramillo, R. (2015). Use of field and laboratory methods for estimating unsaturated hydraulic properties under different land uses. *Hydrol. Earth Syst. Sci.*, *19*, 1193–1207. https://doi.org/10.5194/hess-19-1193-2015

Silva, R. F. da, Severiano, E. da C., Oliveira, G. C. de, Barbosa, S. M., Peixoto, D. S., Tassinari, D., Silva, B. M., Silva, S. H. G., Dias Júnior, M. de S., & Figueiredo, T. d'Aquino F. R. (2021). Changes in soil profile hydraulic properties and porosity as affected by deep tillage soil preparation and Brachiaria grass intercropping in a recent coffee plantation on a naturally dense Inceptisol. *Soil and Tillage Research*, *213*, 105–127. https://doi.org/https://doi.org/10.1016/j.still.2021.105127

Soil Research Institute. (2009). *ANALISIS KIMIA TANAH , TANAMAN , AIR , DAN PUPUK*.

Solly, E. F., Weber, V., Zimmermann, S., Walthert, L., Hagedorn, F., Schmidt, M. W. I., & Solly, E. F. (2020). A Critical Evaluation of the Relationship Between the Effective Cation Exchange Capacity and Soil Organic Carbon Content in Swiss Forest Soils. *Frontiers in Forest and Global Change*, *3*(98), 1–12. https://doi.org/10.3389/ffgc.2020.00098

Sudirman, A., & Hartono, J. S. S. (2020). Study on the amount of chlorophyll content and leaf area of Robusta coffee plants with shade trees and fertilizer application in Hanakau Sukau West Lampung. *International Conference on Agriculture and Applied Science (ICoAAS)*, *November*, 43–45. https://doi.org/https://doi.org/10.2581/icoaas.v1i1.2002

Thai, S., Davídek, T., & Pavlů, L. (2022). Causes clarification of the soil aggregates stability on mulched soil. *Soil and Water Research*, *2022*(2), 91–99. https://doi.org/https://doi.org/10.17221/151/2021-SWR

Uksa, M., Schloter, M., Kautz, T., Athmann, M., Köpke, U., & Fischer, D. (2015). Spatial variability of hydrolytic and oxidative potential enzyme activities in different subsoil compartments. *Biology and Fertility of Soils*, *51*(4), 517–521. https://doi.org/10.1007/s00374-015-0992-5

Valentine, T. A., Hallett, P. D., Binnie, K., Young, M. W., Squire, G. R., Hawes, C., & Bengough, A. G. (2012). Soil strength and macropore volume limit root elongation rates in many UK agricultural soils. *Annals of Botany*, *110*(2), 259–270. https://doi.org/10.1093/aob/mcs118

Watiniasih, I. P. C. N. A. A. G. R. D. N. L. (2016). DEKOMPOSISI SAMPAH JANUR KELAPA (Cocos nucifera L.) DAN NIBUNG (Oncosperma tigillarium (Jack) Ridl.) DALAM LUBANG RESAPAN BIOPORI. *SIMBIOSIS*, *4*(2). https://ojs.unud.ac.id/index.php/simbiosis/article/view/28754/17872

Wendel, A. S., Bauke, S. L., & Amelung, W. (2022). Root - rhizosphere - soil interactions in biopores. *Plant and Soil*, *475*(2022), 253–277. https://doi.org/10.1007/s11104-022-05406-4

Yang, X., Lu, M., Wang, Y., Wang, Y., Liu, Z., & Chen, S. (2021). Response Mechanism of Plants to Drought Stress. *Horticulture*, *7*(50), 1–36. https://doi.org/https://doi.org/10.3390/horticulturae7030050

© 2024, Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP