



Effects of Lime and Compost on Chemical Characteristics and Soil Hydraulic Conductivity of Alfisols at ATP Jatikerto Coffee Plantation

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Abstract

Coffee in Indonesia is currently one of the most important plantation commodities. Inappropriate management of coffee plantations causes low soil quality especially in smallholder coffee plantations, one of which is the density (compaction) of soil in coffee plantations that has a clayey texture. This study was aimed to analyze the effect of lime and compost application on the chemical characteristics and saturated hydraulic conductivity (SHC) of the soil. The experiment was carried out at Glasshouse Agro Techno Park (ATP) Jatikerto from September 2020-February 2021. Soil samples were taken from coffee gardens at a depth of 0-30 cm and 30-60 cm. The incubation study in the greenhouse used Factorial Complete Randomized Design with 12 treatments and 3 replications. Incubation was carried out for 8 weeks. Treatment factors include the depth of the soil sample (0-30 cm and 30-60 cm); compost (0 tons ha⁻¹, 10 tons ha⁻¹ and 20 tons ha⁻¹) and lime (0 tons ha⁻¹ and 2.5 tons ha⁻¹). Results showed that the treatment combination of 2.5 ton ha⁻¹ of lime and 20 ton ha⁻¹ of compost gave the best results measured by the availability of N and K nutrients and an increase in the SHC. However, results in this treatment were almost the same as treatment of 2.5 ton ha⁻¹ of lime and 10 ton ha⁻¹ of compost. The combination of compost and lime has a significant effect on improving the chemical characteristics of the soil and the SHC of the topsoil (0-30 cm) and the subsoil (30-60 cm).

Keywords: coffee plantation; compost; lime; soil chemical properties; soil hydraulic conductivity

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INTRODUCTION

Coffee is currently one of the main plantation commodities cultivated in Indonesia. Coffee plants are also a leading export commodity so that they can become a source of foreign exchange for the country. In 2011, Indonesia became a major producer of coffee 633,991 tons, which occupied the third position in the world after the State of Vietnam and Brazil of around. East Java is one of the centers of coffee production. According to the Ministry of Agriculture of East Java Province, the coffee plantation area is about 91,496 ha and 85.94% of these coffee areas are

smallholder coffee plantations with low average productivity (Ministry of Agriculture, 2021). At the provincial level, as recorded by the Ministry of Agriculture (2021), East Java showed a decline in coffee production growth to 23.82% in 2019. One of the coffee producers in East Java is Malang Regency. Coffee production in Malang Regency showed a decline of 31% from 2018 to 2019.

The low coffee production is caused, among others, by the non-optimal management of coffee plantations, particularly the management of soil fertility. Soil fertility management at the research site has not yet implemented sustainable agricultural practices. Farmers usually apply

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the inorganic fertilizers with the limited organic matter application. The inorganic fertilizers can increase the availability of nutrients for plants but harm the environment (Dewanto et al., 2017). These impacts include the declining soil quality in the form of physical and biological characteristics of soil (Supriyadi et al., 2021). Like other living things, coffee plants will also absorb nutrients based on the needs for their growth. Excess nutrients that are not absorbed will become residues in the soil and be exported into the surrounding environment. The use of inorganic fertilizers must consider the timeliness, dosage and application procedures.

Degradation of soil quality causes various kinds of problems. Improper management of coffee plantations can cause the soil to become compacted and harm root growth and the availability of soil moisture in the coffee root zone, as well as limited rainwater infiltration. This is following Purbajanti et al. (2019), who have reported that continuous fertilization using inorganic fertilizers can inhibit root growth, one of which is caused by the damage of soil aggregates (Gootman et al., 2020). The compacted soil can inhibit soil aeration and availability of soil moisture, as well as a higher soil penetration resistance. The indicator of limited infiltration and availability of soil moisture is the value of SHC (saturated soil hydraulic conductivity). Furthermore, the SHC value of soil is usually related to the rate of infiltration and percolation of water in the soil, surface runoff, soil porosity and soil density, soil permeability and drainage (Kuncoro et al., 2014). Several soil characteristics that affect the SHC value include soil texture, soil structure and aggregation, pore space ratio (porosity), water saturation level, trapped air and soil organic matter content (Elhakim, 2016). Research results by Viadé et al. (2011) and Mi et al. (2018) show that regardless of soil management practices, the spatial hydraulic characteristics of soils vary widely. The SHC measurements must therefore be carefully evaluated to ensure that these values are obtained accurately and are suitable for a particular use.

The analysis of soil samples in the Jatikerto ATP coffee plantation depicted that the soil had a clayey texture, the nutrient content was low and the soil bulk density was high (Table 2). Results of studies signify that application of compost and lime affects soil pH, soil CEC, soil organic matter,

nutrient availability in soil and soil aggregation (Hartati et al., 2012; Paradelo et al., 2015; Santri et al., 2019; Putra et al., 2020). Organic matter serves as a source of energy and food for soil organisms to increase their activities in the soil and the availability of plant nutrients (Elnasikh and Satti, 2017; Putra et al., 2020). Soil organic matter plays a very important role in holding available soil moisture (Hanuf et al., 2021), increases cation exchange capacity and nutrient availability and intensifies aeration and plant root development (Putra et al., 2020). The application of lime combined with compost can increase soil pH value, enhance the formation of crumb soil structure, affect the decomposition of soil organic matter and accelerate the formation of soil humic substances. Based on these phenomena, this study was conducted to analyze the effect of lime and compost interactions on some soil chemical characteristics and the SHC of the topsoil (0-30 cm) and the subsoil (30-60 cm) of the coffee garden, at ATP Jatiketo, Malang.

MATERIALS AND METHOD

Study location

The research was conducted at the glasshouse of the Agro Techno Park Jatikerto, Universitas Brawijaya, in Jatikerto Village, Kromengan Sub-district, Malang Regency. This area is located at 7°21'-7°31'S and 110°10'-111°40'E, with an average air temperature of 25°C -30°C. Laboratory analysis was carried out at the Laboratory of Soil Physics and Chemistry, Department of Soil Sciences, Agriculture Faculty, Brawijaya University. The glasshouse research incubation was carried out from September 2020 to February 2021.

Experimental design and data analysis

Soil samples were taken at a depth of 0-30 cm (topsoil) and 30-60 cm (subsoil). Compost fertilizer was produced by the Composting Center, Faculty of Agriculture, Brawijaya University, from organic wastes. The calcitic lime (CaCO₃) was 98.57% with a purity level of 100%, while the compost had a pH of 6.6, Organic-C 19.88%, K-exchangeable 1% and C/N ratio of 6%. Soil incubation experiment in glasshouse was carried out using a completely randomized factorial design with three factors and three replications; depth factors (0-30 cm and 30-60 cm), compost factors (0 tons ha⁻¹, 10 tons ha⁻¹ and 20 tons ha⁻¹)

and lime factors (0 tons ha⁻¹ and 2.5 tons ha⁻¹) (Table 1). The incubation experiment lasted for 8 weeks after the soil pH value are relatively stable and watering (addition of water) was carried out once a week by adding an amount of water until the soil reaches field moisture

capacity. Each pot with a size of 25 cm × 35 cm was filled with 5 kg of soil, lime and compost applied by mixing the soil evenly with the doses of lime and compost. Results of soil samples analysis before incubation are presented in Table 2.

Table 1. Code and description of treatment in the glasshouse incubation experiment

Code of Treatment	Description
K1M1C1	Soil sample at a depth of 0-30 cm without compost and lime (control)
K1M1C2	Soil sample at a depth of 0-30 cm + 2.5 tons ha ⁻¹ of lime
K1M2C1	Soil sample at a depth of 0-30 cm + 10 tons ha ⁻¹ of compost
K1M2C2	Soil sample at a depth of 0-30 cm + 10 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime
K1M3C1	Soil sample at a depth of 0-30 cm + 20 tons ha ⁻¹ of compost
K1M3C2	Soil sample at a depth of 0-30 cm + 20 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime
K2M1C1	Soil sample at a depth of 30-60 cm without compost and lime (control)
K2M1C2	Soil sample at a depth of 30-60 cm + 2.5 tons ha ⁻¹ of lime
K2M2C1	Soil sample at a depth of 30-60 cm + 10 tons ha ⁻¹ of compost
K2M2C2	Soil sample at a depth of 30-60 cm + 10 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime
K2M3C1	Soil sample at a depth of 30-60 cm + 20 tons ha ⁻¹ of compost
K2M3C2	Soil sample at a depth of 30-60 cm + 20 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime

Table 2. Characteristics of soil samples for incubation experiment

Soil characteristics	Soil sample at a depth of 0-30 cm		Soil sample at a depth of 30-60 cm	
	Value of analysis	Criteria	Value of analysis	Criteria
pH (H ₂ O)*	5.6	Moderately acid	5.5	Moderately acid
pH (KCl)*	4.5	-	4.3	-
Ca-exchangeable*	3.65 me 100 g ⁻¹	Low	4.67 me 100 g ⁻¹	Low
Mg- exchangeable*	1.08 me 100 g ⁻¹	Low	1.11 me 100 g ⁻¹	Low
K- exchangeable*	1.12 me 100 g ⁻¹	Medium	1.01 me 100 g ⁻¹	Medium
Na- exchangeable*	0.16 me 100 g ⁻¹	Low	0.17 me 100 g ⁻¹	Low
CEC*	22.23 me 100 g ⁻¹	Medium	32.50 me 100 g ⁻¹	High
BS*	27.03%	Low	21.42%	Low
Organic-C*	0.76%	Very low	0.50%	Very low
OM*	1.31%	Low	0.86%	Low
HC**	0.29 cm h ⁻¹	Slow	0.16 cm h ⁻¹	Slow
% Sand	18.24	-	5.80	-
% Silt	12.91	-	14.49	-
% Clay	68.85	-	79.71	-
Soil texture	Clay	-	Clay	-
BD***	1.07 g cm ⁻³	Medium	1.26 g cm ⁻³	High
PD***	2.50 g cm ⁻³	-	2.59 g cm ⁻³	-
Soil porosity***	57.2%	Less good	50.2%	Less good
pF 0	0.59	-	0.58	-
pF 2.5	0.39	-	0.38	-
pF 4.2	0.21	-	0.18	-

Note: CEC = Cation Exchange Capacity; BS = Base Saturation; OM = Organic matter; BD = Bulk Density; PD = Particle Density. (*) = Source from Soil Research Institute (2009); (**) = Sourced from Rusdi et al. (2015); (***) = Sourced from Soil Science Department UB (2018)

Observations pH (H₂O) and pH (KCl) were made every two weeks and observations at the end of the incubation period (8 weeks) included variables: SHC with a constant

head method, pH with pH meter, Organic-C with Walkley-Black method, base cations (K-exchangeable, Ca-exchangeable, Mg-exchangeable, Na-exchangeable) with Flame photometer and titration, CEC with Kjeldahl method and BS. Data analysis covered the variance analysis (F test) at 5% level and the further test using the DMRT (Duncan's Multiple Range Test) at 5% level, correlation analysis and simple linear regression with the SPSS program.

RESULTS AND DISCUSSION

Effects of lime and compost on soil characteristics

Soil pH

The application of lime and compost has a significant effect on the soil pH. Results of analysis of variance showed an interaction between soil sample depth, compost and lime doses (Table 3). It was proved that the combination of lime and compost can

increase the soil pH. Lime is used to increase the availability of nutrients in the soil. Increased pH in the soil is directly proportional to the increase in the availability of basic cations such as K, Ca, Mg and Na. Meanwhile, the levels of Al, Fe and Mn, which often bind basic cations, will decrease (Crusciol et al., 2011). The highest value of the actual pH was shown in the treatment of soil depth of 0-30 cm with the addition of 20 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime with a pH 6.8, while the lowest pH was found at control treatment (pH 5.6). The application of 20 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime demonstrated significant results among all of the treatments and the same with the treatment of 10 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime. The application of lime should be accompanied by the application of organic fertilizer because this improves soil reaction. pH value in the soil is determined based on the concentration of H⁺ and OH⁻ ions in the soil (Pasti et al., 2012). Results of soil analysis after the incubation period are presented in Table 3.

Table 3. Characteristics of soil chemistry

Treatment	Soil characteristics after incubation periods									
	H ₂ O	KCl	ΔpH(-)	K	Ca	Mg	Na	CEC	BS	Org-C
	me 100 g ⁻¹ soil						%		%	
K1M1C1	5.63 ^a	5.03 ^{ab}	0.60	1.06 ^c	5.34 ^a	2.37 ^a	1.39 ^{ab}	19.94 ^{ab}	45.34 ^a	0.68 ^{ab}
K1M1C2	6.36 ^{de}	5.15 ^{bc}	1.21	0.72 ^a	8.52 ^{de}	4.62 ^{bc}	1.80 ^{cd}	27.50 ^e	58.40 ^{bc}	0.77 ^b
K1M2C1	5.71 ^{ab}	4.98 ^{ab}	0.73	0.88 ^b	6.96 ^b	3.27 ^{ab}	1.49 ^{bc}	22.50 ^d	60.55 ^c	1.18 ^d
K1M2C2	6.57 ^e	5.34 ^c	1.23	1.02 ^{bc}	6.84 ^b	3.16 ^{ab}	1.88 ^d	26.25 ^e	48.47 ^{ab}	1.32 ^e
K1M3C1	6.07 ^c	4.87 ^a	1.21	1.33 ^d	9.37 ^e	5.42 ^c	1.66 ^{cd}	19.21 ^a	84.64 ^f	1.19 ^d
K1M3C2	6.77 ^f	5.28 ^c	1.49	1.15 ^c	9.71 ^e	5.21 ^{bc}	3.03 ^e	26.61 ^e	58.12 ^{bc}	1.13 ^{cd}
K2M1C1	5.75 ^b	4.96 ^{ab}	0.79	0.99 ^{bc}	5.68 ^a	2.92 ^{ab}	1.59 ^{bc}	19.94 ^{ab}	47.07 ^a	0.61 ^{ab}
K2M1C2	6.33 ^d	5.11 ^{bc}	1.22	1.00 ^{bc}	7.65 ^c	4.96 ^{bc}	1.68 ^{cd}	20.64 ^b	74.51 ^d	0.83 ^b
K2M2C1	5.75 ^b	5.09 ^b	0.66	1.02 ^{bc}	7.75 ^c	2.66 ^{ab}	1.22 ^{ab}	20.85 ^c	53.51 ^b	1.07 ^{cd}
K2M2C2	6.47 ^e	5.28 ^c	1.19	0.72 ^a	8.49 ^d	6.89 ^{cd}	1.80 ^{cd}	29.58 ^f	92.19 ^e	1.09 ^{cd}
K2M3C1	5.66 ^{ab}	5.22 ^{bc}	0.44	0.77 ^{ab}	6.54 ^b	3.75 ^b	1.44 ^{bc}	22.78 ^d	75.24 ^d	1.19 ^d
K2M3C2	6.57 ^e	5.70 ^d	0.86	0.83 ^{ab}	9.01 ^{de}	8.71 ^d	2.96 ^e	31.24 ^g	75.03 ^d	1.44 ^f

Note: K1M1C1 = Soil sample at a depth of 0-30 cm without compost and lime (control); K1M1C2 = Soil sample at a depth of 0-30 cm + 2.5 tons ha⁻¹ of lime; K1M2C1 = Soil sample at a depth of 0-30 cm + 10 tons ha⁻¹ of compost; K1M2C2 = Soil sample at a depth of 0-30 cm + 10 tons ha⁻¹ of compost + 2.5 tons ha⁻¹ of lime; K1M3C1 = Soil sample at a depth of 0-30 cm + 20 tons ha⁻¹ of compost; K1M3C2 = Soil sample at a depth of 0-30 cm + 20 tons ha⁻¹ of compost + 2.5 tons ha⁻¹ of lime; K2M1C1 = Soil sample at a depth of 30-60 cm without compost and lime (control); K2M1C2 = Soil sample at a depth of 30-60 cm + 2.5 tons ha⁻¹ of lime; K2M2C1 = Soil sample at a depth of 30-60 cm + 10 tons ha⁻¹ of compost; K2M2C2 = Soil sample at a depth of 30-60 cm + 10 tons ha⁻¹ of compost + 2.5 tons ha⁻¹ of lime; K2M3C1 = Soil sample at a depth of 30-60 cm + 20 tons ha⁻¹ of compost; K2M3C2 = Soil sample at a depth of 30-60 cm + 20 tons ha⁻¹ of compost + 2.5 tons ha⁻¹ of lime

The combination treatment of lime and compost was proved to have a significant

effect on the control treatment. Jaskulska et al. (2014) explained that in the liming process,

soil pH will increase according to the type and dose of lime. Besides that, soil acidity reflects the relative distribution of acidic cations (H^+ and Al^{3+}) and basic cations (Ca^{2+} , Mg^{2+} , K^+ and Na^+), with the capacity to neutralize acidic ions depending on the exchangeable Ca^{2+} and Mg^{2+} . When the number of exchangeable H^+ increases, the concentration of basic cations usually decreases due to an increase in the uptake of base cations by plants (James et al., 2016). The potential pH (pH KCl) was affected by the compost treatment at a dose of 20 tons ha^{-1} and 10 tons ha^{-1} of lime, compared to the control treatment (Table 3). This shows that the application of lime and compost significantly affect the potential pH of soil.

Delta pH (ΔpH)

The value of pH is obtained from the difference between pH H_2O and pH KCl. The ΔpH values of the soil sample depth 0-30 cm and 30-60 cm are presented in Table 3. The 0-30 cm depth of the soil sample and the 30-60 cm depth of the soil sample show a negative ΔpH value. It suggests that soil colloids have a negative charge that can adsorb basic cations (Supriyadi et al., 2021). Tesfaye et al. (2020) have also explained that a negative soil ΔpH value indicates that soil colloids have a net negative charge.

Base cations

Results of analysis of base cations on soil samples showed significant differences among treatments, interaction of soil depth, compost and lime significantly affect the basic cations in soil (Table 3). Treatment of 20 tons ha^{-1} of compost and 2.5 tons ha^{-1} of lime at a depth of 0-30 cm and 30-60 cm showed the highest K-exchangeable content. According to Viadé et al. (2011), liming has a positive effect on the K-exchangeable content in the soil. Soil organic matter increases alkaline cations and CEC by increasing the available negative charge, which raises the buffer capacity in the soil. Meanwhile, the lime application can increase alkaline cations in the soil (Zhang et al., 2015).

Treatment of 20 tons ha^{-1} of compost and 2.5 tons ha^{-1} of lime also exhibited the highest Ca-exchangeable content (Table 3). The main content of calcite lime is $CaCO_3$, when the compound is applied to the soil, the availability of Ca increases (Olego et al., 2021). The application of lime combined with compost on topsoil

and subsoil affects the concentration of H^+ and increases the availability of Ca in the soil.

The Mg-exchangeable content was influenced by the treatment of lime and compost on the topsoil and subsoil samples. Application of 20 tons ha^{-1} of compost and 2.5 tons ha^{-1} of lime showed higher significant results than the control treatment. Lime indirectly affects nutrient uptake by plants by affecting the exchange of Ca^{2+} and Mg^{2+} in the soil (Han et al., 2019). The Na-exchangeable content in soil is significantly affected by the application of lime and compost. Application of 20 tons ha^{-1} of compost and 2.5 tons ha^{-1} of lime result in a higher content of the soil Na-exchangeable than the control treatment. Results of this study are following those of other studies (Mijangos et al., 2010; Jaskulska et al., 2014; Paradelo et al., 2015).

Cation exchange capacity (CEC)

The research data depict that the treatment has a significant difference in soil CEC (Table 4). The treatment of 20 tons ha^{-1} of compost and 2.5 tons ha^{-1} of lime was significantly different from all other treatments. According to Neina (2019), the increase in soil pH is directly proportional to the increase in soil CEC and this is caused by the impact of liming, which rises the negative charge on organic colloids and mineral colloids in the soil. Other research results show that liming affects the negative charge on the surface of clay colloids and organic colloids (pH-dependent charge) and thus having an impact on soil CEC, adsorbed base cations and nutrient availability for plants (Nduwumuremyi et al., 2013; Chemedda et al., 2015).

Base saturation (BS)

The results of the analysis of variance showed significant effects of interaction soil depth, a dose of compost and a dose of lime (Table 3). In the analysis of base saturation, the treatment of 20 tons ha^{-1} of compost and 2.5 tons ha^{-1} of lime demonstrated a significant effect among other treatments. According to Masmoudi et al. (2020), base saturation is closely related to soil pH value and soil fertility. Low base saturation (< 25%) is an indication of acidic soil and poor base cations (Debnath et al., 2021; Mohammed et al., 2021; Ukabiala et al., 2021).

Soil organic matter (SOM)

The results of the analysis of variance showed that the interaction between the depth factor of the soil sample, compost and lime had

a significant effect on the SOM content (Table 3). The treatment of 10 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime indicated significant results compared to other treatments. This can happen because the compost contains a certain amount of Organic-C so that the application of compost increases the SOM content. According to Gribb et al. (2009), compost is yielded from the decomposition of organic matter into simpler compounds with the help of microorganisms. Compost is useful for reducing high soil density and increasing the ability of the soil to hold water. In addition, it can stimulate plant root growth (Dewilda et al., 2019). The other research results have explained that the addition of organic fertilizer (manure, compost, green manure) has

a positive effect on soil Organic-C (Yang et al., 2016; Kamran et al., 2018; Gautam et al., 2021; Lipiec et al., 2021; Yao et al., 2021).

Giving compost to the soil can increase the porosity of the soil so that it affects the SHC. Treatment of 20 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime showed significant results for all treatments (Table 4). The treatment of giving 20 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime showed significant results to the control treatment. Many researchers have found that the SHC is influenced by soil bulk density (BD), soil water content, soil porosity, distribution of soil texture, soil aggregation (soil structure), soil organic matter, CEC, alkaline cations and soil acidity (García-Gutiérrez et al., 2018).

Table 4. Effects of treatment on the SHC

Treatment	SHC
	SHC (cm h ⁻¹)
Soil sample at a depth of 0-30 cm (control)	11.62 ^a
Soil sample at a depth of 0-30 cm + 2.5 tons ha ⁻¹ of lime	23.16 ^b
Soil sample at a depth of 0-30 cm + 10 tons ha ⁻¹ of compost	25.47 ^{bc}
Soil sample at a depth of 0-30 cm + 10 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime	34.79 ^{bc}
Soil sample at a depth of 0-30 cm + 20 tons ha ⁻¹ of compost	49.33 ^c
Soil sample at a depth of 0-30 cm + 20 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime	46.70 ^d
Soil sample at a depth of 30-60 cm (control)	12.03 ^{ab}
Soil sample at a depth of 30-60 cm + 2.5 tons ha ⁻¹ of lime	15.72 ^{ab}
Soil sample at a depth of 30-60 cm + 10 tons ha ⁻¹ of compost	21.98 ^{ab}
Soil sample at a depth of 30-60 cm + 10 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime	28.75 ^{bc}
Soil sample at a depth of 30-60 cm + 20 tons ha ⁻¹ of compost	70.12 ^d
Soil sample at a depth of 30-60 cm + 20 tons ha ⁻¹ of compost + 2.5 tons ha ⁻¹ of lime	64.19 ^d

Relationship of SHC and soil characteristics

The value of SHC (permeability) is influenced by soil properties, such as porosity, pore space distribution, texture, structure, groundwater viscosity and other properties (Hillel, 2003; Dikinya et al., 2006; Elhakim, 2016). The size of the soil pores is very important in the rate of infiltration (movement of water into the soil) and the rate of percolation (movement of water through the soil). Soil permeability rate values can be grouped into some categories, from “very slow” to “very fast” (Rusdi et al., 2015).

The application of compost and lime to the soil can improve the chemical characteristics and increase the SHC of the soil. The increase in the SHC value of the topsoil was influenced by several parameters (Table 5). The SHC showed a significant correlation with the soil organic matter ($r = 0.685^{**}$). The SHC value was also

significantly correlated with the base saturation and the availability of basic cations in the soil ($r = 0.708^{**}$; $r = 0.757^{**}$; $r = 0.748^{**}$; and $r = 0.539^{**}$). SHC is one indicator to determine the movement of water in the soil. When the SHC value is higher, the movement of water in the soil will also be easier. One of the factors influencing the SHC value is the presence of soil organic matter. The correlation test results also signify that the SHC value has a positive correlation with soil pH ($r = 0.568^*$). This is related to the activity of microorganisms, in which the acid soil activities of microorganisms will decrease and the density of the soil is high so that it affects the SHC value of the soil. Mi et al. (2018) have reported that the application of organic matter to the soil can improve the quality of the soil assessed for its characteristics. Furthermore, in a study conducted by Li et al. (2021), it has been

concluded that a decrease in the percentage of organic matter in the soil resulted in an increase in soil density, such as soil bulk density, decreased soil porosity, aggregate stability and water content at the field moisture capacity.

The SHC showed a significant positive correlation with the Organic Matter and Organic-C of the soil ($r = 0.795^{**}$) at a depth of 30-60 cm (Table 6). This can be interpreted that the more soil organic matter, the faster the rate of soil permeability. This statement is directly proportional to research conducted by Tesfaye et al. (2020), which has concluded that the increase in soil organic matter will be directly proportional to the porosity of the soil that affects the rate of soil permeability. Soil aggregation

and soil structure greatly affect the soil SHC. The pores, size and continuity of pores also greatly influence the SHC. The flow of water through the soil mass is also sensitive to the presence of macropores, although they are few. In addition to the physical properties of the soil, several chemical properties of the soil and the nature of the solution flowing through the soil also influence the SHC. This chemical effect occurs when soil characteristics and soil solution promote swelling (volume development) and chemical dispersion of colloidal clay particles present in the soil, the combination of lime and compost treatment has a significant effect on the SHC values of soil samples from a depth of 0-30 cm and a depth of 30-60 cm.

Table 5. Correlation of SHC and characteristics of soil sample at a depth of 0-30 cm

Soil characteristics	SHC	pH H ₂ O	pH KCl	K	Ca	Mg	Na	CEC	SOM	C-Org	BS
SHC	1										
pH H ₂ O	0.568*	1									
pH KCl	0.083	0.723**	1								
K	0.203	0.487	0.733	1							
Ca	0.757**	0.612**	0.059	0.545*	1						
Mg	0.748**	0.546*	-0.017	0.603**	0.960**	1					
Na	0.539*	0.817**	0.557*	0.333	0.631**	0.551*	1				
CEC	0.099	0.767**	0.779**	0.471*	0.292	0.185	0.572*	1			
SOM	0.685**	0.362	0.117	-0.313	0.308	0.237	0.266	0.084	1		
C-Org	0.658**	0.362	0.117	-0.313	0.308	0.237	0.266	0.084	1.00**	1	
BS	0.708**	0.160	-0.413	0.285	0.784**	0.843**	0.262	-0.346	0.366	0.266	1

Note: (**) Significant at $p = 0.01$; (*) Significant at $p = 0.05$

Table 6. Correlation of SHC and characteristics of soil sample at a depth of 30-60 cm

Soil characteristics	SHC	pH H ₂ O	pH KCl	K	Ca	Mg	Na	CEC	SOM	C-Org	BS
SHC	1										
pH H ₂ O	0.079	1									
pH KCl	0.64**	0.66**	1								
K	0.346	0.65**	0.553*	1							
Ca	0.237	0.803*	0.737**	0.400	1						
Mg	0.482*	0.050	0.100	0.156	0.001	1					
Na	0.440	0.74**	0.862**	0.731**	0.584*	-0.11	1				
CEC	0.244	0.080	0.408	0.453	-0.097	-0.44	0.647**	1			
SOM	0.79**	0.375	0.826**	0.300	0.682**	0.281	0.566*	0.101	1		
C-Org	0.79**	0.375	0.826**	0.300	0.682**	0.281	0.566*	0.101	1.0**	1	
S	0.111	0.352	0.050	0.075	0.394	0.76**	-0.169	-0.783**	0.226	0.226	1

Note: (**) Significant at $p = 0.01$; (*) Significant at $p = 0.05$

The results of previous studies in various locations and conditions have shown that the effects of lime and compost on the SHC value of the soil appear through an indirect mechanism.

Soils dominated by sand particles tend to have relatively macropores (≥ 9 mm) so that the value of SHC is also large. Soils dominated by clay particles tend to have a higher content of

micropores (< 30 μm) and lower values of SHC. The size of the soil pores is very important related to the rate of infiltration (movement of water into the soil) and the rate of percolation (movement of water through the soil). Pore size and the number of pores are closely related to soil texture and structure and affect soil permeability (Yuan et al., 2018). Likewise, the type and degree of soil structure influence the SHC. Observations of soil texture, structure, consistency, color or mottling, bedding, visible pores and depth to impermeable layers such as parent rock and clay form the basis for deciding whether permeability measurements are representative (Singh et al., 2020). Some soil structural features such as diameter, length, width and the number of pores between soil aggregates can be used to predict the SHC of the soil. Soil aggregates are formed through physical, chemical and biological processes that take place in the soil. These

processes are influenced by human activity factors, such as soil tillage, the load on the soil surface due to the machinery and the application of fertilizer into the soil.

Relationship of pH (H₂O) and base cations

The results of correlation and regression tests of soil samples from a depth of 0-30 cm (Figure 1A) showed a significant positive correlation (p < 0.05). There is a significant relationship between pH (H₂O) and soil K content (Y = 0.03+0.19X; R² = 0.237*). The application of lime and compost significantly increases the availability of K in the soil. In soil samples from a depth of 30-60 cm (Figure 1B), it is known that results of correlation analysis between pH (H₂O) and soil K content show a significant positive correlation (Table 6; p < 0.05). The increase in the soil pH is followed by the increase in the soil K content (R² = 0.423*; Y = 0.2+0.23X).

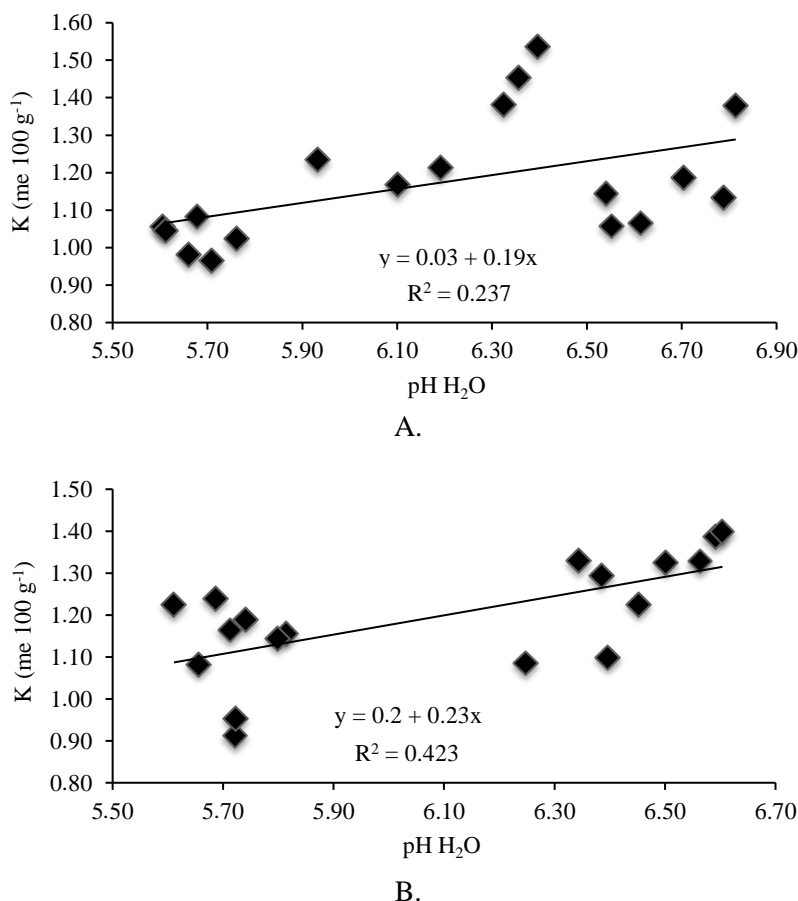


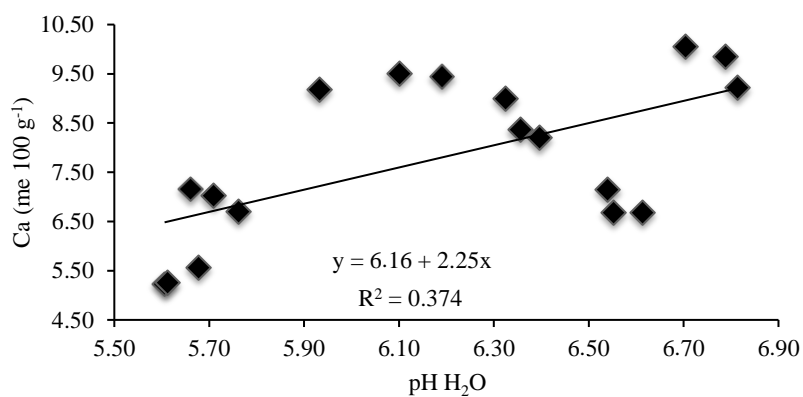
Figure 1. The relationship between the soil pH H₂O and the content of K in soil, (A) = Soil sample at a depth of 0-30 cm; (B) = Soil sample at a depth of 30-60 cm

The results of correlation and regression tests of soil samples from a depth of 0-30 cm

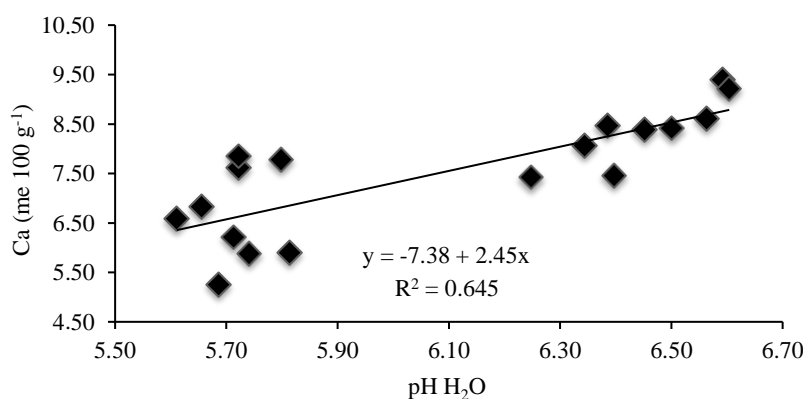
(Figure 2A) demonstrated a significant positive correlation (p < 0.05) between pH (H₂O) and

soil Ca content. This shows that soil pH increases the availability of Ca content ($R^2 = 0.374^*$; $Y = 6.16 + 2.25X$). In soil samples from a depth of 30-60 cm (Figure 2B), it is known that the results of correlation and regression tests between pH

H_2O and Ca content show a significant positive correlation (Table 6, $p < 0.05$). The increase in Ca content in the 30-60 cm layer of soil was directly correlated with the increase in soil pH (H_2O) ($R^2 = 0.645$; $Y = -7.8 + 2.45 X$).



A.

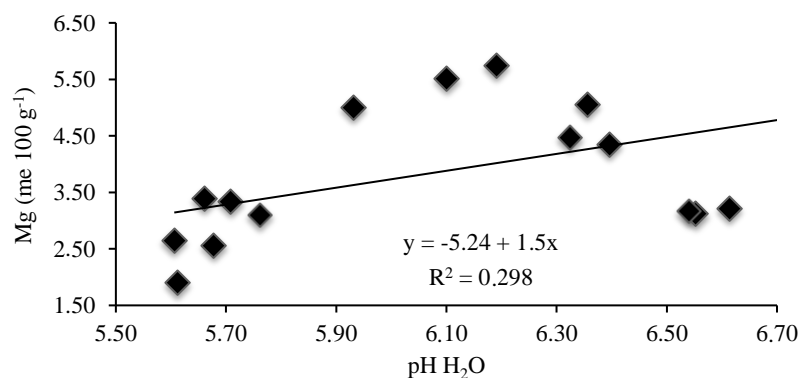


B.

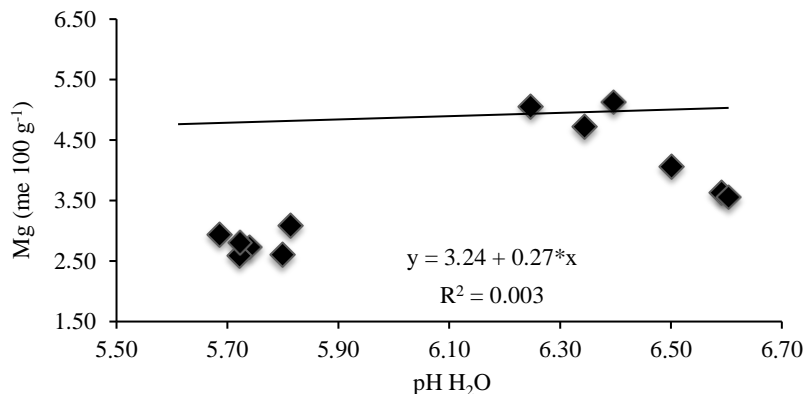
Figure 2. The relationship between the soil pH H_2O and the content of Ca in soil, (A) = Soil sample at a depth of 0-30 cm; (B) = Soil sample at a depth of 30-60 cm

Correlation and regression tests of soil samples from a depth of 0-30 cm (Figure 3A) showed a significant positive correlation ($p < 0.05$) between pH (H_2O) and soil Mg content ($R^2 = 0.298$; $Y = -$

$5.24 + 1.5 X$). In soil samples from a depth of 30-60 cm (Figure 3B), there is no significant correlation between pH (H_2O) and soil Mg content.



A.

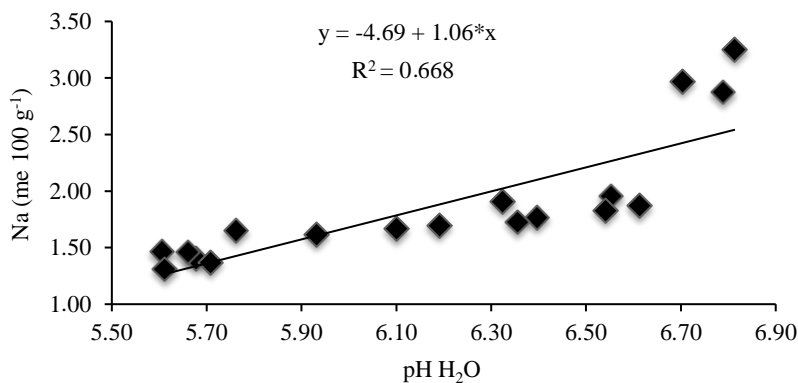


B.

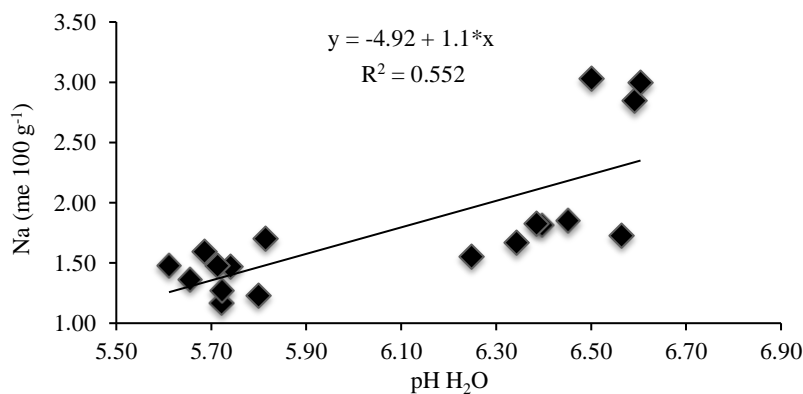
Figure 3. The relationship between the soil pH H₂O and the content of Mg in soil, (A) = Soil sample at depth of 0-30 cm; (B) = Soil sample a depth of 30-60 cm

Results of correlation and regression analysis of soil samples from a depth of 0-30 cm (Figure 4A) depicted a positive significant correlation ($p < 0.05$) between pH H₂O and soil Na content. The relationship in soil samples from a depth of 30-60 cm is presented in Figure 4B. Results of the correlation and regression test showed a positive significant correlation

($p < 0.05$) between pH (H₂O) and Na content. This indicates that the increase in soil pH (H₂O) will increase Na in the soil at a depth of 30-60 cm ($R^2 = 0.552^*$). The results of other studies also prove that the Na content of the soil is associated with high soil pH (Pistocchi et al., 2017; Uke and Haliru, 2021; Zhang et al., 2021).



A.



B.

Figure 4. The relationship between the soil pH H₂O and the content of Na in soil, (A) = Soil sample at depth of 0-30 cm; (B) = Soil sample at a depth of 30-60 cm

Application of 10 tons ha⁻¹ or 20 tons ha⁻¹ of compost combined with 2.5 tons ha⁻¹ of lime was proven to be able to increase the pH value of the soil. The increase in the pH value gave a significant effect on the availability of base cations compared to the control treatment. Paradelo et al. (2015) reported that based on the chemical reaction of lime in the soil, Ca²⁺ and Mg²⁺ from lime are found in soil solution. In addition to the lime application, the application of compost to the soil affects the chemical and physical properties of the soil. Elnasikh and Satti (2017) have explained that the application of organic fertilizers tends to reduce soil bulk density and then improve soil permeability. From the research results that have been obtained both from the chemical characteristics and the value of the SHC, the application of compost at a dose of 10 tons ha⁻¹ combined with lime at a dose of 2.5 tons ha⁻¹ is recommended, considering the effectiveness in its implementation. Although the highest value was obtained from the combination of giving 20 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime, a further test showed that giving 20 tons ha⁻¹ of compost was not significantly different from the treatment of 10 tons ha⁻¹ of compost. Application of 10 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime is considered sufficient to improve nutrient availability and SHC in coffee plantations, ATP Jatikerto, Malang.

CONCLUSIONS

The combination of compost and lime shows a significant effect on improving the chemical characteristics of the soil and the SHC of the topsoil (0-30 cm) and the subsoil (30-60 cm). A combination of 20 tons ha⁻¹ of compost and 2.5 tons ha⁻¹ of lime gives the highest values for all soil characteristics studied, both topsoil (0-30 cm) and subsoil (30-60 cm). The lime application increases soil pH and is positively correlated with other soil chemical characteristics. Soil organic matter content is positively and significantly correlated with the value of SHC.

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