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Analysis of Soil Base Cations Content after Application of Organic Fertilizer on Inceptisols at Lemon-Tree Orchard

Roby Nurdianto, Atiqah Aulia Hanuf*, M. Wasilul Lutfi, Retno Suntari, Soemarno Soemarno

Department of Soil Science, Faculty of Agriculture, Universitas Brawijaya, Malang, East Java 65145, Indonesia

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ABSTRACT
The lack of effectiveness of fertilization and the continuous use of inorganic fertilizers results in soil quality degradation. This research was conducted to analyses the effect of compost and manure on soil base saturation. This study used a simple Completely Randomized Design with 8 (eight) treatments and 4 (four) replications. The treatment consisted of P1 (topsoil); P2 (Subsoil); P3 (topsoil + compost); P4 (subsoil + compost); P5 (topsoil + cow manure); P6 (subsoil + cow manure); P7 (topsoil + goat manure); P8 (subsoil + goat manure). The results showed that the application of topsoil + compost significantly increased the exchangeable Ca content of the soil at 8 and 12 WAA (weeks after application). Application of goat manure on topsoil influenced increasing soil exchangeable Mg and exchangeable Na. The application of various organic materials increases the value of soil pH, CEC, and organic C content. The deep-placement fertilization technique effectively enhances soil quality through chemical means, particularly by augmenting base cations and the soil's cation exchange capacity. This technology is pivotal in delivering nutrients directly to plant roots, thereby mitigating fertilizer losses caused by surface runoff and volatilization.

Keywords: *Cytrus limon*; Compost; Cow manure; Goat manure; Soil chemical properties

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INTRODUCTION

Lemon *(Cytrus limon* L.) is one of the leading fruit crops in Indonesia. Lemon fruits have various benefits to improve body health because they contain lots of vitamins, especially vitamins C and A. Therefore, lemons can be used as superior fruit plants that have high economic value for farmers. Lemon fruit can be used for various preparations, such as orange juice, orange pudding to orange sauce. Besides having various benefits, lemon plants can also grow well in various climatic and soil conditions in Indonesia. These various features make oranges a very popular fruit crop and have great potential to be developed in Indonesia.

The area with the highest orange production in Indonesia is East Java. Ministry of Agriculture (2024) reports that East Java has a production of 822,260 tons of Siam oranges in 2021. Indonesia has a production of 2.4 million tons of Siam oranges in 2021. Thus, East Java produces 34.2% of Indonesia's orange production. The high production of Siam oranges in East Java in 2021 still cannot surpass the production of Siam oranges in East Java in 2019, which reached 985,455 tons. The decline in lemon production was caused by various factors, such as soil quality and low fertilizer efficiency. Although oranges can grow well in various types of soil, their fruit production is higher if planted in soil that suits their needs (Shirgure and Srivastava 2013).

Organic fertilizers have been shown to have a positive impact on soil quality. Organic fertilizer combined with chemical fertilizer had the most significant effect on improving soil nutrients (Jiang et al. 2024). Organic fertilizers do not provide more nutrients than chemical fertilizers but need to be transformed and degraded before being taken up by plants. This process can lead to changes in soil microbial communities and may limit microbial activity in the original soil. However, organic fertilizers can increase soil organic matter content, which is essential for maintaining soil structure and fertility (Jiang et al. 2024). Long-term application of organic fertilizers has been found to have a lasting impact on soil quality. Organic fertilizer incorporation practices improved soil fauna feeding activity by 35.2%–42.5% and increased crop yields (Zhou et al. 2022).

On the other hand, chemical fertilizers have been shown to enhance soil fertility directly and effectively. Nevertheless, the inorganic nitrogen in chemical fertilizers decomposes rapidly and is prone to be lost, while the nitrogen in organic fertilizers decomposes more slowly and is better retained in the soil (Richter and Roelcke 2000). Thus, in the long run, a combination of

****Corresponding Author***:
E-Mail: atiqahaulia6@gmail.com

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organic and inorganic fertilization is a beneficial strategy for fields with varying fertility levels. The combination of organic and inorganic fertilization significantly improves soil quality, particularly in low-fertility soils (Ma et al. 2023). The long-term use of chemical fertilizers along with pig manure can increase soil phosphatase activity, while the use of organic fertilizers enhances soil structure and fertility (Liu et al. 2017).

Low soil fertility is one of the causes of decreased productivity or non-optimal productivity (Toor et al. 2021). Agronomic and human activities, and factors, including soil pH, poor organic manures, and salinity, all negatively impact nutrient uptake and mobilization (Fageria et al. 2002; Ahmed et al. 2020; Usanmaz and Atti 2020). Mismanagement of fertilization has greatly impaired the citrus fruit yield and quality while enhancing fruit-dropping (Yasin Ashraf et al. 2012). Soil fertility management is based on macro and micronutrient management. Macro-mineral is required in greater amounts, such as calcium, potassium, sodium, and magnesium. Mineral nutrients required by citrus trees are in large quantities to attain adequate growth and yield, and the requirements for some of the nutrients vary with soil fertility and type.

Cation exchange capacity (CEC) is a measure of the soil's ability to hold positively charged ions. It is a very important soil property that affects the stability of soil structure, nutrient availability, soil pH, and soil reaction to fertilizers and other ameliorants (Ogeleka et al. 2017). The main ions associated with CEC in soils are exchangeable cations of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}) and are commonly referred to as basic cations.

One way to improve soil quality is by applying organic matter such as compost or manure (Gerke 2022; Zuo et al. 2023). The application of compost and manure in citrus orchards has been carried out by citrus farmers, but the application technology and amounts are still very diverse, so the results are not optimal (Canali et al. 2004; Costa et al. 2008). Placement technology of organic matter on the soil surface around citrus trees is prone to nutrient loss by leaching and runoff, so the efficiency is still low (Smith et al. 2001; Oenema et al. 2007; Smith et al. 2007; Guo and Li 2012; Liu et al. 2018).

This research is a preliminary study on the application of deep placement technology using biopore infiltration holes in lemon plants. A common problem is the low effectiveness and efficiency of fertilizer absorption by plants through conventional applications such as broadcasting, dibbling, or L-shaped placement on the topsoil. The low effectiveness and efficiency are due to the ease with which fertilizer is leached, preventing it from being optimally distributed to the subsoil. This is significant considering that citrus plants have active nutrient-absorbing roots that extend to a depth of 40 cm. Increasing the efficiency and effectiveness of fertilization can be done by using deep-placement technology. The technology is to apply fertilizer to the subsoil so that the rate of loss (leaching and volatilization) can be reduced. Many studies have proven that deep-placement technology can increase efficiency and effectiveness rather than spreading it on the surface (Agyin-Birikorang et al. 2020; Khalofah et al. 2021). Additionally, most of them only discussed nitrogen nutrients. Meanwhile, base cations have not been studied much, given the important role of these nutrients for soil and plants. Therefore, this research was conducted to analyze the effect of compost and manure on exchangeable K, Na, Ca, and Mg.

MATERIALS AND METHODS

Time and location of research

This research was conducted from July to December 2022. Sampling of topsoil (0-30 cm) and subsoil (30-60 cm) was carried out at the BSIP Jestro (Citrus and Subtropical Fruit Agricultural Instruments Standardization Agency). The soil sampling location is at latitude -7.9028 and longitude 112.5348. The incubation research was conducted in the Greenhouse of the Faculty of Agriculture, Brawijaya University, Malang. The soil moisture content used during incubation is at field capacity conditions, where the topsoil and subsoil are at 66% and 65%, respectively. Meanwhile, the incubation took place at latitude -7.9527 and longitude 112.6114. Analysis of soil samples was carried out at the Soil Chemistry Laboratory, Soil Science Department, Faculty of Agriculture, Brawijaya University.

Research methods

This study used a completely randomized design with eight treatments and four replications. The treatments consisted of P1 (topsoil), P2 (subsoil), P3 (topsoil + compost), P4 (subsoil + compost) P5 (topsoil + cow manure) P6 (subsoil + cow manure) P7 (topsoil + goat manure) P8 (subsoil + goat manure). Sampling and observations were conducted three times, at 4, 8, and 12 weeks after application (WAA). These pots were placed randomly within the greenhouse at the Faculty of Agriculture, Brawijaya University, Malang. Inceptisols soil samples, consisting of topsoil (0-30 cm) and subsoil (30-60 cm), were collected, with 10 kg of air-dry soil per pot. Organic matter, including leaf litter compost, cow manure, and goat manure, was incorporated into the soil during preparation (0 WAA). Leaf litter compost was sourced from the Compost Unit, Faculty of Agriculture, Brawijaya University, while manure was obtained from local farmers near BSIP Jestro. Both soil and organic fertilizers were sieved through a 2 mm sieve. Each organic fertilizer was applied at a rate of thirty tons per hectare, following BSIP Jestro's recommended dosage for citrus fertilization. This study marks the initial exploration of the deep placement method, which involves placing fertilizer directly into the root zone (Komolafe et al. 2019). The deep placement technology utilizes biopore infiltration holes, with depths tailored to match the root depth of the target plants. In this study, citrus plants were selected, with an optimal root depth of 40 cm. The research aims to evaluate the efficacy of fertilization in the subsoil by implementing deep placement as a novel approach in citrus orchards.

Parameters observed included: soil pH (electrometry), CEC (NH_4OAc 1N), soil organic C content (Walkley and Black), and exchangeable Ca, Mg, Na, and K (NH_4OAc 1N). Observations were made thrice, 4, 8, and 12 weeks after application (WAA). All the analysis laboratories are based on the standard operational procedure of (the Center for Standard Testing of Soil and Fertilizer Instruments 2023).

Analysis of compost, cow manure, and goat manure has nutrient content that follows the 2018 Ministry of Agriculture fertilizer quality standards. Compost has a pH (6.9), Organic C content (12.27%), Exchangeable Ca (3.16%), Exchangeable Mg (0.36%), and Exchangeable Na (0.35%). Goat manure has a pH (H_2O) of 6.9 and contains Organic C (12.39%), Exchangeable-Ca (2.55%), Exchangeable Mg (0.21%), and Nadd (1.47%). Cow manure has a pH (H_2O) of 6.9, Organic C (15.72%), Exchangeable Ca (3.71%), Exchangeable-Mg (0.03%), and exchangeable Na (0.39%). Soil analysis during the incubation period was carried out three times, namely at 4, 8, and 12 WAA (week after application).

The results of the initial topsoil analysis showed the pH value, Organic C, Exchangeable K, Exchangeable Ca, Exchangeable Mg, Exchangeable Na; soil CEC and base saturation on topsoil respectively: 5.40 (acid); 1.70% (low); 0.24 cmol kg^{-1} soil (low); 5.28 cmol kg^{-1} soil (low); 0.85 cmol kg^{-1} soil (low); 0.29 cmol kg^{-1} soil (low); 26.75 cmol kg^{-1} soil (high); and 24.89% (low). Meanwhile, initial subsoil analysis has a pH value, Organic C, Exchangeable K, Exchangeable Ca, Exchangeable Mg, Exchangeable Na; soil CEC and base saturation on subsoil respectively: 4.80 (acid); 0.64% (very low); 0.09 cmol kg^{-1} soil (low); 6.13 cmol kg-1 soil (medium); 0.32 cmol kg^{-1} soil (very low); 0.25 cmol kg^{-1} soil (low); 25.33 cmol kg^{-1} soil (high); 26.80% (low).

Statistical analysis

The data obtained were analyzed using analysis of variance (ANOVA) at a 5% level to determine the effect of treatment on the research variables. If there is a significant effect, then the LSD test at a 5% level is carried out to find out the differences between treatments and at the same time determine the best treatment. The data analysis was carried out using SPSS (Statistical Package for the Social Sciences) software.

RESULTS AND DISCUSSIONS

Soil pH, Soil Organic Carbon (SOC) and Cations Exchange Capacity (CEC)

The results of the variance analysis showed that the application of various organic materials had a significant effect on increasing soil pH, organic C, and CEC (Table 1). The soil pH value increased in all treatments from the initial soil pH value (Table 1). The rise in the pH level of the control soil was attributed to the higher pH levels of the fertilizer types, thereby leading to an increase in soil pH. The application of organic matter resulted in a higher soil pH compared to the control, although no significant differences were observed among different fertilizer types. However, treatments P3 (topsoil + compost) and P4 (subsoil + compost) showed a significant difference. This is following Weil dan Brady (2017) that the application of organic matter can increase the pH of acidic soil (neutralizes Al by forming organic Al complexes) and can increase the availability of nutrients through nutrient chelation with organic matter. The application of organic matter derived from plant compost or animal manure can increase soil pH because organic matter has a negative charge (OH^-, COO^-), which could bind metal Al^{3+} so that Al^{3+} hydraulic reactions do not occur, which produce three ions H^+, which can acidify the soil (Nariratih et al. 2013). Another study showed that the application of cow manure increased the pH higher than the application of chicken manure (Lyimo et al. 2012). The application of compost increased the pH compared to the application of inorganic fertilizers (Forge et al. 2016). The application of the urea-bio-compost combination increased soil pH compared to that without the application of bio-compost.

Preliminary analysis shows that the organic C content of the soil in the topsoil is 1.70% (low criteria), and in the subsoil, it is 0.64% (very low criteria). The results of the analysis of variance found that the application of organic matter had a significant effect on the organic C content of the soil (Table 1). The highest organic C value of the soil was in the topsoil treatment, with a value of 4.03% with an increase of 24.10% (high). This increase in soil organic C value is because soil organic C content is influenced by the contribution of organic matter that undergoes a decomposition process (Prasetyo et al. 2009). The addition of organic matter to acid soils will speed up the carbon release process so that organic C content will increase (Putra and Nuraini 2017). The application of compost can also increase the organic C content, due to the release of element C in the compost (Widodo et al. 2018). In addition, compost also contains organic compounds such as fulvic acid and humic acid, humic acid has a C content of 40-80% (Firda et al. 2016).

In Table 1, it is shown that as the Soil Organic Carbon (SOC) increases, the Cation Exchange Capacity (CEC) also increases. CEC plays a crucial role in determining its fertility and its ability to supply essential nutrients to plants. CEC measures the soil's capacity to retain and exchange cations, such as calcium, magnesium, potassium, and sodium, which are vital for plant growth. A higher CEC indicates a greater capacity for retaining these essential nutrients, thereby enhancing soil fertility. Consequently, soils with higher CEC tend to have better nutrient retention and supply, which can positively influence plant growth and productivity. Additionally, CEC indirectly affects soil pH regulation, as it influences the soil's buffering capacity against changes in pH.

The results of the variance analysis showed that the application of organic matter had a significant effect on increasing soil CEC (Table 1). Preliminary analysis shows that the CEC value of the soil in the topsoil is 26.75 cmol kg^{-1} soil, and the subsoil is 25.33 cmol kg^{-1} soil, both of which show high criterion values. Soil CEC values are affected by the decomposition process of organic matter in the soil (Rusmanta et al. 2013). The application of compost significantly increases soil CEC by 37-47% compared to inorganic fertilization (Lyimo et al. 2012). The highest CEC value was in the topsoil goat manure treatment with a value of 72.94 cmol kg^{-1} soil with an increase of 36.94%, a very high criterion. The application of goat manure has a high Organic C content (50.47%) so that it can increase the CEC value of the soil, causing nutrients to be properly available for plants (Hartati et al. 2022).

Table 1. Soil pH, organic C, and CEC value after application of organic matter

Treatment	Soil pH			Organic C (%)			CEC (cmol kg^{-1})		
P1	6.1 a	AM	0	3.25 ab	T	0	53.27 a	ST	0
P2	6.0 a	AM	0.00	2.90 a	S	0.00	54.13 a	ST	0.00
P3	6.3 b	AM	3.65	3.07 a	T	-5.56	72.75 c	ST	36.57
P4	6.4 c	AM	7.81	3.48 ab	T	19.76	66.36 b	ST	22.60
P5	6.4 c	AM	5.37	4.03 b	T	24.10	71.40 b	ST	34.04
P6	6.4 c	AM	6.61	3.38 ab	T	16.56	67.03 b	ST	23.83
P7	6.2 b	AM	2.34	3.81 b	T	17.36	72.94 c	ST	36.94
P8	6.2 b	AM	4.11	2.95 a	S	1.46	65.54 b	ST	21.08
Note	0.16 (**)	Catg	Chg (%)	0.56 (*)	Catg	Chg (%)	8.31 (**)	Catg	Chg (%)

Remarks: Criteria according to the Center for Standard Testing of Soil and Fertilizer Instruments (2023): N: Neutral, AM: Slightly acid, S: moderate, T: High, ST: Very High. Numbers in the same column followed by the same letter are not significantly different in the 5% LSD Test. WAA: Week After Application. P1: Topsoil; P2: Subsoil; P3: topsoil + compost; P4: subsoil + compost; P5: topsoil + cow manure; P6: subsoil + cow manure; P7: topsoil + goat manure; P8: subsoil + goat manure; ns: not significant; (*) significantly different; (**): Very significantly different; Catg: Category according to the Criteria; Chg: Change in value: %.

Exchangeable K content

The application of organic fertilizers had a very significant effect on the exchangeable K content of topsoil and subsoil at observations 4, 8, and 12 WAA (Table 7). The P7 treatment had the highest Exchangeable K content at 4, 8, and 12 WAA observations, respectively 2.25 cmol kg^{-1}, 2.28 cmol kg^{-1} and 3.10 cmol kg^{-1}. Some potassium in organic matter applied to the soil will be released into the soil in the form of K^+ cations. Furthermore, this K+ is adsorbed on negatively charged soil colloidal particles into exchangeable K. Some research results show that goat manure contains a certain amount of potassium, and its application to the soil can increase the available K content in the soil (Wuta and Nyamugafata 2012; Irshad et al. 2013; Uwah and Eyo 2014; Taiwo et al. 2018; Situmeang et al. 2019; Prado et al. 2022; Sharma et al. 2022).

Table 2 shows that in observations 4, 8, and 12 WAA, the exchangeable K content of the soil in all treatments increased when compared to the results of the initial analysis. This is because, during the incubation period, the water content is always maintained at field capacity so that the nutrient transformation process can take place properly. The availability of K elements in the soil is closely related to soil moisture (Sanjaya et al. 2014). The availability of water in the soil greatly influences the process of hydrolysis of mineral compounds containing K in the soil (Štyriaková et al. 2003; Manning 2010; Sharma et al. 2016; Liang et al. 2017; Xue et al. 2021).

The results showed that the application of organic matter was able to improve soil quality in terms of increasing exchangeable K levels. In the last observation (12 WAA), the P7 treatment (topsoil + goat manure) showed the highest results which were significant to the other treatments except P5 (topsoil + cow manure). This shows that the type of organic fertilizer has no significant effect. However, what is interesting is the percentage increase in exchangeable K content in the subsoil treatment showed an increase of more than 100% (P6: subsoil + cow manure and P8: subsoil + goat manure). This shows the success of research aimed at improving the quality of the subsoil.

Exchangeable Ca content

The results of the analysis of variance showed that the application of organic matter had a very significant effect on the exchangeable Ca content in the soil at 4, 8, and 12 WAA. The effect of organic matter application on soil exchangeable Ca content is presented in Table 3. Preliminary analysis shows that the exchangeable Ca content in the topsoil is 5.28 cmol kg^{-1} (low criteria) and subsoil has an exchangeable Ca content of 6.13 cmol kg^{-1} (moderate criteria). Table 3 shows that each organic matter treatment resulted in a higher exchangeable Ca content than the control. The application of organic matter has a significant effect on the exchangeable Ca content of the soil. The highest exchangeable Ca content in the 4 WAA observations was shown by the topsoil treatment with cow manure, the Exchangeable Ca content was 14.55 cmol kg^{-1} soil, an increase of 10.06% compared to the control. The application of cow manure had a significant effect on the exchangeable Ca content in the topsoil (subsoil) and was different from the treatment of cow manure in the subsoil. This follows the results of research that stated that the application of cow manure increased the soil exchangeable Ca value by 40.6% compared to the application of chemical fertilizers (Lyimo et al. 2012). In addition, the application of 5 tons ha^{-1} of cow manure increased the exchangeable Ca value of the soil compared to the application of 200 kg ha^{-1} of NPK fertilizer, from 0.4 cmol kg^{-1} of soil to 0.6 cmol kg^{-1} of soil.

Table 2. Exchangeable K content value after application of organic matter

Treatment	Content of exchangeable K at the week of observation:								
	4 WAA			8 WAA			12 WAA		
P1	1.60 c	ST	0	1.56 bc	ST	0	1.91 bc	ST	0
P2	0.77 a	T	0	0.90 a	T	0	1.05 a	ST	0
P3	1.90 cd	ST	18.41	2.00 d	ST	28.28	2.43 c	ST	27.45
P4	1.19 b	ST	54.64	1.32 b	ST	45.97	1.81 b	ST	72.99
P5	1.56 bc	ST	-2.97	1.63 c	ST	4.34	2.96 d	ST	55.24
P6	1.04 ab	ST	34.82	1.16 ab	ST	28.91	2.29 c	ST	118.21
P7	2.25 d	ST	40.61	2.28 d	ST	46.37	3.10 d	ST	62.88
P8	1.67 c	ST	118.1	1.80 cd	ST	99.62	2.00 bc	ST	90.78
Note	0.52 (*)	Catg	Chg (%)	0.46 (*)	Catg	Chg (%)	0.67 (**)	Catg	Chg (%)

Remarks: Criteria according to the Center for Standard Testing of Soil and Fertilizer Instruments (2023): T: High, ST: Very High. Numbers in the same column followed by the same letter are not significantly different in the 5% LSD Test. WAA: Week After Application. P1: Topsoil; P2: Subsoil; P3: topsoil + compost; P4: subsoil + compost; P5: topsoil + cow manure; P6: subsoil + cow manure; P7: topsoil + goat manure; P8: subsoil + goat manure; (*) significantly different; (**): Very significantly different; Catg: Category according to the Criteria; Chg: Change in value: %.

Table 3. Exchangeable Ca content value after application of organic matter

Treatment	Content of exchangeable Ca at the week of observation:								
	4 WAA			8 WAA			12 WAA		
P1	13.22 b	T	0	16.61 ab	T	0	20.82 ab	ST	0
P2	13.80 b	T	0.0	15.49 a	T	0.00	19.47 a	T	0.00
P3	13.99 b	T	5.87	23.29 c	ST	40.27	27.54 c	ST	32.26
P4	13.95 b	T	1.07	19.23 b	T	24.09	23.69 b	ST	21.68
P5	14.55 b	T	10.06	20.6 bc	ST	24.04	24.85 bc	ST	19.35
P6	10.98 a	T	-20.41	16.29 ab	T	5.15	20.73 ab	ST	6.47
P7	14.15 b	T	7.03	18.88 ab	T	13.71	22.99 ab	ST	10.43
P8	12.98 ab	T	-5.89	16.48 ab	T	6.34	20.65 ab	ST	6.06
Note	1.62 (ns)	Catg	Chg (%)	3.34 (**)	Catg	Chg (%)	3.35 (**)	Catg	Chg (%)

Remarks: Criteria according to the Center for Standard Testing of Soil and Fertilizer Instruments (2023): T: High, ST: Very High. Numbers in the same column followed by the same letter are not significantly different in the 5% LSD Test. WAA: Week After Application. P1: Topsoil; P2: Subsoil; P3: topsoil + compost; P4: subsoil + compost; P5: topsoil + cow manure; P6: subsoil + cow manure; P7: topsoil + goat manure; P8: subsoil + goat manure; ns: not significant; (*) significantly different; (**): Very significantly different; Catg: Category according to the Criteria; Chg: Change in value: %.

The highest exchangeable Ca content observed at 8 WAA was found in the topsoil compost treatment with an exchangeable Ca content of 23.29 cmol kg^{-1}, an increase of 40.27% compared to the control. The highest exchangeable Ca content observed at 12 WAA was found in the topsoil goat manure treatment with an exchangeable Ca content of 27.54 cmol kg^{-1} soil, an increase of 32.26% compared to the control. The highest Exchangeable Ca values at 8 and 12 WAA were found in the treatment of compost application in topsoil. The application of compost increases the exchangeable Ca content up to very high criteria. The application of 25 tons ha^{-1} of compost and inorganic fertilizer increased the soil exchangeable Ca value to 1.1 cmol kg^{-1} of soil compared to the single application of inorganic fertilizer of 0.6 cmol kg^{-1} of soil (Agegnehu et al. 2015). The application of compost increased the exchangeable Ca value in the soil compared to conventional fertilization, from 0.58 cmol kg^{-1} of soil to 0.75 cmol kg-1 of soil. Compost can increase soil organic matter content, N, pH, CEC, and exchangeable Ca content in the soil (Palanivell et al. 2013; Forge et al. 2016). The addition of 355 kg ha^{-1} of compost as a soil enhancer increased the exchangeable Ca value compared to the application of inorganic fertilizers, from 0.04 to 0.16 cmol kg^{-1} of soil at the 6th month of observation. The application of municipal waste compost increased soil exchangeable Ca from 1.9 cmol kg^{-1} to 3.0 cmol kg^{-1} soil in the second year after application (Hargreaves et al. 2008).

Exchangeable Mg content

The results of the analysis of variance showed that the application of organic matter had a significant effect on the exchangeable Mg content in the soil at 8 and 12 WAA (Table 4). Preliminary analysis of the soil samples showed that the exchangeable Mg content in the topsoil was 0.85 cmol kg^{-1} (low criteria), and subsoil had an exchangeable Mg content of 0.32 cmol kg^{-1} (very low criteria). Table 4 shows that each treatment produced a higher exchangeable Mg content than the control. The highest exchangeable Mg value at 4 WAA observations was found in the subsoil treatment of cow manure with an exchangeable Mg content of 2.90 cmol kg^{-1}, an increase of 153.39% compared to the control. The application of cow manure can increase the exchangeable Mg content of the soil. Several Mg present in cow manure undergo mineralization to become Mg^{2+} which is released into the soil. The application of cow manure at 25 tons ha^{-1} increased the exchangeable Mg value of the soil compared to the application of inorganic fertilizers, from 0.4 cmol kg^{-1} soil to 0.5 cmol kg^{-1} soil (Agegnehu et al. 2016). The combined application of 0.03 ton ha^{-1} of cow manure and 0.03 ton ha^{-1} of Urea could increase the exchangeable Mg value by up to 1.3 cmol kg^{-1} of soil compared to a single application of inorganic fertilizer (Ayeni and Adetunji 2010).

The highest exchangeable Mg value at 8 WAA observations was found in the P7 treatment (topsoil + goat manure) with an exchangeable Mg content of 5.54 cmol kg^{-1} soil, an increase of 226.29% compared to the control. However, no significant difference with subsoil treatment. The highest exchangeable Mg value at 12 WAA observations was found in the topsoil goat manure treatment with an exchangeable Mg content of 13.85 cmol kg^{-1}, an increase of 222.74% compared to the control. The highest value of exchangeable Mg at observations 8 and 12 WAA was found in the application of goat manure, the application of goat manure increased the exchangeable Mg content very significantly. The application of goat manure at 10 tons ha^{-1} increased the exchangeable Mg value from 0.3 cmol kg^{-1} of soil to 0.4 cmol kg^{-1} of soil (Verde et al. 2013). Application of 10 tons ha^{-1} of goat manure mud three times a year increases the availability of Mg in the soil for up to 5 years after application (Duffková et al. 2015). The research results show that the Exchangeable Mg value is always smaller than the exchangeable Ca value.

Exchangeable Na content

The results of the variance analyses showed that the application of organic matter had a significant effect on the increase in exchangeable Na in the soil at 4, 8, and 12 WAA (Table 5). Topsoil has an exchangeable Na content of 0.29 cmol kg^{-1} soil (low criteria) and subsoil has an exchangeable Na content of 0.25 cmol kg^{-1} soil (low criteria). Table 5 shows that the application of organic matter can increase the soil exchangeable Na content. At 4 WAA and 12 WAA, the exchangeable Na content in the topsoil and subsoil did not differ significantly. This proves that deep-placement fertilization techniques can increase soil Na-dd content and improve soil quality. The highest exchangeable Na values at 4, 8, and 12 WAA were found in the topsoil goat manure treatment, each of which was 1.08 cmol kg^{-1} soil, 2.44 cmol kg^{-1} soil and 2.79 cmol kg^{-1} soil, successive increases of 77.13, 22.97, 16.97%, and the criteria are very high. Application of goat manure increases soil exchangeable Na content.

Table 4. Soil Exchangeable Mg content after application of organic fertilizers

Treatment	Content of exchangeable Mg at the week of observation:								
	4 WAA			8 WAA			12 WAA		
P1	1.56	S	0	1.48 a	S	0	5.70 a	T	0
P2	1.14	S	0.00	1.98 ab	S	0.00	6.39 a	T	0.00
P3	2.18	T	39.72	1.64 a	S	102.38	10.13 b	ST	112.73
P4	1.48	S	29.41	4.78 b	T	74.31	8.83 ab	ST	80.54
P5	1.30	S	-16.26	4.54 b	T	146.48	13.04 bc	ST	142.24
P6	2.90	T	153.39	4.16 ab	T	183.03	8.17 ab	ST	215.55
P7	1.35	S	-13.61	5.54 b	T	226.29	13.85 c	ST	222.74
P8	2.04	T	78.20	4.62 b	T	219.27	8.79 ab	ST	235.85
Note	1.46 (ns)	Catg	Chg (%)	2.32 (**)	Catg	Chg (%)	3.34 (**)	Catg	Chg (%)

Remarks: Criteria according to the Center for Standard Testing of Soil and Fertilizer Instruments (2023): S: moderate, T: High, ST: Very High. Numbers in the same column followed by the same letter are not significantly different in the 5% LSD Test. WAA: Week After Application. P1: Topsoil; P2: Subsoil; P3: topsoil + compost; P4: subsoil + compost; P5: topsoil + cow manure; P6: subsoil + cow manure; P7: topsoil + goat manure; P8: subsoil + goat manure; ns: not significant; (*) significantly different; (**): Very significantly different; Catg: Category according to the Criteria; Chg: Change in value: %.

Table 5. Soil exchangeable Na content after organic fertilizer application

Treatment	Content of exchangeable Na at the week of observation:								
	4 WAA			8 WAA			12 WAA		
P1	0.61 ab	S	0	1.99 b	ST	0	2.38 b	ST	0
P2	0.48 a	S	0.00	1.75 a	ST	0.00	2.09 a	ST	0.00
P3	0.86 bc	T	41.01	2.16 c	ST	8.94	2.46 bc	ST	3.17
P4	0.70 b	S	47.17	2.06 bc	ST	17.57	2.45 bc	ST	17.29
P5	0.88 c	T	43.97	2.26 c	ST	13.93	2.65 c	ST	11.13
P6	0.89 c	T	85.75	2.15 bc	ST	23.13	2.70 c	ST	29.10
P7	1.08 d	ST	77.13	2.44 d	ST	22.97	2.79 c	ST	16.97
P8	1.00 cd	ST	108.24	2.21 c	ST	26.22	2.60 c	ST	24.14
Note	0.21 (ns)	Catg	Chg (%)	0.22 (**)	Catg	Chg (%)	0.24 (**)	Catg	Chg (%)

Remarks: Criteria according to the Center for Standard Testing of Soil and Fertilizer Instruments (2023): S: moderate, T: High, ST: Very High. Numbers in the same column followed by the same letter are not significantly different in the 5% LSD Test. WAA: Week After Application. P1: Topsoil; P2: Subsoil; P3: topsoil + compost; P4: subsoil + compost; P5: topsoil + cow manure; P6: subsoil + cow manure; P7: topsoil + goat manure; P8: subsoil + goat manure; ns: not significant; (*) significantly different; (**): Very significantly different; Catg: Category according to the Criteria; Chg: Change in value: %.

These results are consistent with the results that found that the application of goat manure can increase the soil exchangeable Na content (Hartati et al. 2022). The application of goat manure can increase the exchangeable Na content from 0.3 cmol kg^{-1} of soil to 0.8 cmol kg^{-1} of soil. The increase in soil exchangeable Na content due to the application of goat manure is because goat manure contains a certain amount of Na (Moreno-Caselles et al. 2002; Cho et al. 2017; Mbatha et al. 2021).

CONCLUSIONS AND SUGGESTIONS

The application of organic fertilizer significantly increased the base cations of the soil (exchangeable Ca, Na, K, and Mg), and increased soil CEC. The increase occurred in both soil layers (topsoil and subsoil). Statistically, topsoil had the highest yield and was significantly different from the control. Most of the increased soil characteristics from soil with very deficient conditions into the high to very high category.

However, most of the subsoil treatment showed results that were not significantly different from the topsoil treatment. Deep-placement fertilization technology is considered effective in chemically improving soil quality by increasing base cations and soil cation exchange capacity. Deep-placement fertilization technology is considered effective in chemically improving soil quality by increasing base cations and soil cation exchange capacity., thereby reducing fertilizer losses through surface runoff and volatilization.

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