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PATTERNS OF NUTRIENT AVAILABILITY AND EXCHANGEABLE ALUMINUM AFFECTED BY COMPOST AND DOLOMITE IN RED ACID SOILS IN LAMPUNG, INDONESIA

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ABSTRACT: Planting in red acid soils, widely distributed in Indonesia, is generally related to limited crop productivity due to their initially low nutrient-supplying potential and soil erosion. Dolomite is commonly used to raise the soil pH in acid soils in Indonesia, where it has been beneficial as a fertilizer comprising calcium (Ca) and magnesium (Mg). Compost is also commonly used to improve the chemical and physical properties of these soils. To prepare a piece of land to be cultivated as a pineapple plantation, dolomite and compost are applied to improve the soil properties and to decrease the aluminum toxicity. A greenhouse-scale experiment was conducted in this study to determine the patterns of changes in the soil nutrients due to dolomite and compost applications during the land preparation which generally takes 12 weeks. The experiment was done with soil incubation in a polybag, and the aim was to learn the effects of the dolomite and compost applications on increasing the soil pH, the availability of nutrients, and the decrease in exchangeable aluminum (Al) in the soil. The results showed that the applications of dolomite and compost could significantly increase the soil pH. The patterns of changes in the soil nutrients, such as Ca and Mg, showed strongly positive correlations with changes in the soil pH, but a good relationship was not seen for K and Na. The exchangeable Al in the soil showed a good quadratic correlation with the soil pH and decreased as the soil pH increased due to the applications of dolomite and compost.

Keywords: Compost, Dolomite, Macronutrient, Soil pH, Exchangeable aluminum

1. INTRODUCTION

Red soils classified by the USDA are distributed in tropical and subtropical zones around the world and occupy 6.4×10^9 ha or 45% of the world's land area [1]. The total area of red soils in Indonesia is 51 million ha or 27% of the land area [2]. These soils are divided into four major groups according to the Indonesian soil classification: Red Yellow Mediterranean soil, Latosol, Red Yellow Podzolic soil, and Lateritic soil. Podzolic soil, found on acidic volcanic tuff in Lampung, Indonesia, can be classified into Oxic Dystropepts, Sumbritropepts, Tropohumults, and Paleodults [3]. They are marginal soils that have many problems. Their characteristics are their low pH and low organic matter [2, 4], poor nutrients [4, 5], high aluminum (Al) content and low base saturation [2], and low cation exchange capacity and sensitivity to erosion [3, 5]. Such problems in red soils have commonly been improved by the application of compost / organic matter, dolomite, *etc*.

Compost is derived from organic matter that has been decomposed and is relatively stable due to aerobic microbial degradation [6]. Compost is very important for improving soil fertility and for helping to increase plant productivity [7]. It is rich in nutrients and organic matter [8]. Many factors are affected by the provision of compost in the soil, including the enhancement of nutrient levels, as it contains N, P, K, Ca, Mg, and S. Compost is rich in alkaline cations, and thus, also has a liming effect that can increase the soil pH [9] .

Dolomite is limestone which is commonly applied to increase the soil pH [10]. It is used not only for liming, but also as fertilizer due to the Ca and Mg elements contained in it which are needed to improve soil fertility and increase plant productivity [11]. An increase in pH due to dolomite application also increases the availability of nutrients and can reduce the aluminum in the soil. This is a positive influence because it can reduce the effects of Al toxicity which can interfere with plant growth [12]. The applications of compost and dolomite will affect the patterns of the essential nutrient availability in marginal soils.

PT Great Giant Pineapple (hereafter PT GGP) is a pineapple plantation located in Lampung, Southern Sumatra whose soil types include red-yellow podzolics [13, 14, 15]. These soils have a low base saturation value (<35%), very high acidity (pH<4.5), low cation exchange capacity, and high Al saturation. The nutrient content is generally low because nutrient leaching is very intensive. On the other hand, the organic matter content is low because the decomposition process runs fast and causes partial erosion. The low soil pH and low availability of potassium (K), magnesium (Mg), and calcium (Ca) are the greatest constraints in most acid upland soils [16].

To overcome these soil constraint problems, the soil is improved by liming and the application of organic matter. Dolomite is commonly used for liming, because it can also raise the Ca, Mg, and base saturation in addition to increasing the soil pH. Compost can be used to increase the organic matter in the soil. Compost is the product of the decomposition process of organic matter that has been sanitized; it is very useful for improving the soil properties [15].

On pineapple plantations, the soil fertility is usually monitored before soil tillage, especially the soil pH and nutrient availability. It is very important to determine the amount of lime to be applied. Land preparation for pineapple plants takes approximately three months or 12 weeks depending on the readiness of the land. Compost is also applied during land preparation to improve the physical, chemical, and biological properties of the soil. After the land preparation, soil amendment, and seedling preparation, the soil is resampled to determine the nutrient content.

As background information, it is very important to determine the correct doses of dolomite and compost application for controlling the soil pH that can increase the availability of nutrients and can reduce the aluminum toxicity in the soil. The aim of this study is to evaluate the effects of dolomite and compost applications on the increase in soil pH, the availability of nutrients, and the decrease in exchangeable aluminum in the soil as well as the relationship between the soil pH and the Ca, Mg, K, Na, and Al contents.

2. MATERIALS AND METHODS

2.1 Materials

This experiment was conducted at the Research and Development Department, PT GGP, Lampung, Indonesia (about 46 meters above sea level with coordinates of 4°49’27’’S and 105°13’55’’E), over three months, from February to May 2016. The soil was classified as sandy clay with a soil texture of 52.4 wt.% sand, 2.6 wt.% silt, and 45.0 wt.% clay. The nutrient contents in the soil and the pH are shown in Table 1. The compost was obtained through a composting process, lasting about one month, from cow dung, bromelain waste, and chopped bamboo at a compost plant at PT GGP. The nutrient content of the compost is also given in Table 1. Dolomite is used as liming material, containing 32.0 wt.% CaO and 18.0 wt.% MgO, with a particle size distribution of 57 wt.% passing through a 60-mesh sieve.

Table 1 Characteristics of initial soil and compost

Properties	Initial soil	Criteria	Compost	Criteria
pH	4.26	Extremely acid*	7.29	Neutral*
Total C (wt%)	1.32	Low**	20.4	Very high**
Total N (wt%)	0.15	Low**	1.73	Very high**
C/N ratio	8.8		11.8	
P (g kg^{-1})	0.02	Good***	2.59	Very high***
K (g kg^{-1})	0.08	Medium***	18	Very high***
Ca (g kg^{-1})	0.08	Medium***	20.8	Very high***
Mg (g kg^{-1})	0.03	Low***	5.45	Very high***

* USDA [17], **Pusat Penelitian Tanah [18], ***Kelly in Pineapple Pest and Disorders [19]

Table 2 Detailed treatments and abbreviations

		Compost (t/ha)		
		0	50	100
Dolomite (t/ha)	0	C0D0	C50D0	C100D0
	1	C0D1	C50D1	C100D1
	2	C0D2	C50D2	C100D2
	3	C0D3	C50D3	C100D3
	4	C0D4	C50D4	C100D4
	5	C0D5	C50D5	C100D5

2.2 Experimental Design

The experiment was conducted using a completely randomized factorial design with two factors and three replications. The first factor was the compost dose with three treatments: no compost (C0), 50 t ha^{-1} compost (C50), and 100 t ha^{-1} compost (C100). The second factor was the dolomite dose with six treatments: no dolomite (D0), 1 t ha^{-1} dolomite (D1), 2 t ha^{-1} dolomite (D2), 3 t ha^{-1} dolomite (D3), 4 t ha^{-1} dolomite (D4), and 5 t ha^{-1} dolomite (D5). The total number of combinations of factors was 18. Details on the treatments and their abbreviations are presented in Table 2.

2.3 Methods

In a polybag, 15 kg of soil was collected as one sample, and then the compost and dolomite were added for soil improvement according to the following treatments. Based on the soil conditions whereby the bulk density of the soil was 1.2 g cm^{-3}

and the root depth was 20 cm, the weight of the soil amendment was determined. Thus, for the dolomite treatments, dose 1 t/ha was equivalent to 6.25 grams per polybag, and doses 2, 3, 4, and 5 t/ha were equivalent to 12.5 grams, 18.75 grams, 25 grams, and 31.75 grams per polybag, respectively. The compost dose of 50 t/ha was equivalent to 312.5 grams per polybag and the dose of 100 t/ha was equivalent to 625 grams per polybag. The soil was mixed with dolomite and compost in the polybag until it became homogenous; then it was kept under field capacity conditions.

2.4 Soil Sampling and Analysis

Soil sampling and analysis were firstly conducted before the treatment, and then 12 weeks after the treatment to learn of the changes in the soil chemical properties. In this experiment using polybags, a 100-gram soil sample was taken from every polybag (54 polybags). Soil sampling was carried out by firstly stirring/ mixing the soil until it became homogenous. Then, the 100 grams of soil was air dried for 3-7 days depending on the soil moisture content. After that, the soil was put through a 2-mm sieve. The soil that passed through the sieve was analyzed in the laboratory. Observations of the soil properties consisted of: (1) The pH H_20 was determined with the pH Meter-Mettler Toledo and (2) K, Ca, and Mg were determined by extraction with ammonium acetic pH 7 and reading with Atomic Absorption Spectrofotometry (AAS)-GBC. The Al was determined by the volumetric method.

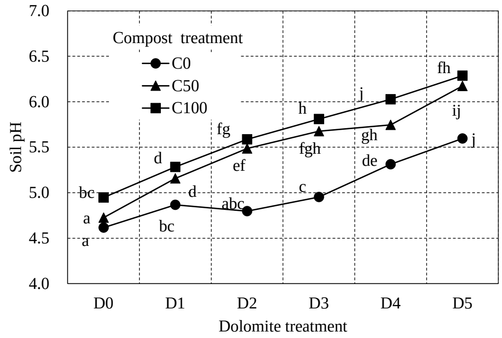
2.5 Statistical Analysis

Each parameter from every treatment consisted of three samples for data analysis. The collected data were statistically tested with Analysis of Variance (Anova) for soil pH. A linear regression analysis was employed to determine the relationship between the soil pH and the available Ca, Mg, K, Na, and Al, respectively, in the soil. To identify the significance of each compost and dolomite application on the soil pH, Ca, Mg, K, Na, and Al, a multiple regression analysis was carried out.

3. RESULTS AND DISCUSSION

3.1 Effects of Soil Amendment on Soil pH

Dolomite is ground limestone and the most common liming material [20]. It is seen in Figure 1 that increasing the dolomite dose can significantly increase the soil pH 12 weeks after the dolomite application. The control (D0) with no application



Note: Mean followed by the same letter is not significantly different at α=0.05

Fig. 1 Effects of dolomite and compost application on soil pH 12 weeks after treatment

of dolomite has the lowest soil pH, while the dolomite dose of 5 t ha^{-1} (D5) shows the highest pH among all treatments at the same level of compost dose. Therefore, the soil pH has a clear tendency to increase with increasing dolomite dose applications.

Compost applications also increase the soil pH because the pH value of compost is higher (pH 7.29) than that of the initial soil (pH 4.26), as seen in Table 1. The soil pH when applying the compost dose of 100 t ha^{-1} (C100) is the highest, while the soil pH under the no compost application (C0) is the lowest at the same level of dolomite dose. It was also stated in a previous research [9] that applications of compost, based on cow manure and wheat straw at doses of 20 ton ha^{-1} and 30 ton ha^{-1}, respectively, increase the soil pH.

Furthermore, the simultaneous application of compost and dolomite can increase the soil pH. Figure 1 shows that the highest soil pH was achieved with the treatment of the compost dose of 100 t ha^{-1} and the dolomite dose of 5 t ha^{-1}, and that the combination of the two treatments produced the highest soil pH and was significantly different from the other treatments. The effects of the interaction of compost and dolomite are presented in the table at the bottom of Figure 1. The soil pH increases significantly from 4.62 (a) to 5.60 (fh) by applying up to 5 tons ha^{-1} of dolomite without compost amendments, while the soil pH increases from 4.62 (a) to 4.95 (bc) by applying 50 ton ha^{-1} of compost without dolomite. In other words, it was proven that the effect of dolomite is more dominant than that of compost in increasing the soil pH.

When dolomite ($CaMg(CO_3)_2$ is put into the soil, it will reduce the H^+ by the following simple reactions [21]:

1. $CaMg(CO_3)_2 + 2H^+ \Leftrightarrow Mg^{2+} + CaCO_3 + CO_2 + H_2O$

2. $CaCO_3 + CO_2 + H_2O \Leftrightarrow Ca^{2+} + HCO_3^{-} 3OH^{-}$
3. $Al^{3+} + 3\ OH^{-} \Leftrightarrow Al(OH)_3$ (settles)

The chemical reaction of dolomite in soil can cause the release of Mg, Ca, and OH^-.

Bayer *et al.* [22] stated that decomposed organic material will produce OH^- ions which can neutralize the H^+ ion activity. Thus, applying compost to soil can increase the soil pH. The application of 5 ton ha^{-1} of dolomite can increase the pH by 1.09 points [15]. Moreover, the application of 50 ton ha of compost can increase the pH by 0.9 points [23]. The combined application of 15 ton ha of compost and 0.7 ton ha of dolomite can increase the pH by 0.77 points [24].

3.2 Effect of Soil pH on Nutrient Availability

Figure 2 shows the correlations between the soil pH and the availability of nutrients 12 weeks after the treatments of dolomite and compost.

Calcium (Ca) and (Mg) magnesium are base cations that decline with the increase in acidity. If the soil pH increases, the base cations also increase [25].

The contents of Ca and Mg in the soil correlate well with the soil pH. Figure 2 shows a good agreement between the soil pH and the available Ca with R^2:0.702 12 weeks after the treatment. This means that the increase in the soil pH is affected by the applications of compost and dolomite, which can increase the Ca availability. It was stated by Adugna [6] that the soil pH affects the nutrient availability in the soil. The application of compost has a liming effect that can enrich the Mg, Ca, and K cations resulting from the mineralization of the organic material.

The available Mg content in the soil also increases significantly with the increase in the soil pH 12 weeks after the treatment. Figure 2 shows a good correlation between the soil pH and the available Mg with R^2:0.941. This means that the soil pH is increased by the application of compost and dolomite, which can also increase the Mg availability. This is in line with the statement by Valarini et al. [9], namely, that increasing the pH level due to the addition of compost to the soil will also increase the exchangeable bases.

The available K and Na in the soil do not correlate well with the increase in the soil pH. Figure 2 shows a low correlation between the soil pH and the available K and Na with R^2:0.208 and 0.0064, respectively, 12 weeks after the treatment. The increasing soil pH is affected by the applications of compost and dolomite, which do not increase the available K and Na.

The above results led to the soil pH being strongly affected by the application of dolomite, which consisted of calcium and magnesium compounds, but did not include K or Na. This is the reason why the availability of Ca and Mg was affected by the pH in soil, but not the K or Na.

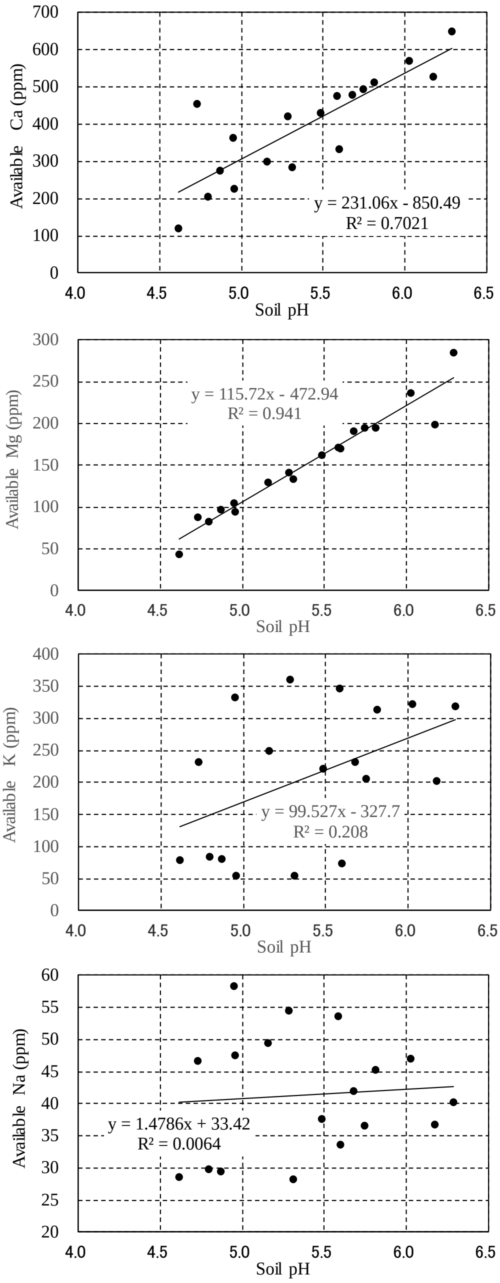


Fig. 2 Effect of soil pH on nutrient availability 12 weeks after treatment

3.3 Pattern of Exchangeable Aluminum Affected by Soil pH

Aluminum (Al) is the third most abundant element in the Earth's crust after oxygen and silicon, and is universally present in soil. Al is harmless because it is stably retained by soil minerals in neutral soil, but it dilutes into Al^{3+} ions in acidic soil (pH 5.5 or less). Even in trace

Table 3 Results of multiple regression analysis

objective	coefficient			p-value			r	r^2
	intersept	compost	dolomite	intersept	compost	dolomite		
pH	4.49	0.00633	0.236	1.75E-19	1.43E-06	4.52E-09	0.965	0.931
Ca	171	2.58	38.2	8.58E-05	3.81E-06	0.000542	0.906	0.822
Mg	43.3	0.850	26.1	0.000485	1.49E-06	6.29E-08	0.955	0.912
Na	36.8	0.170	-1.58	3.19E-09	0.000167	0.0725	0.809	0.655
K	93.1	2.61	-5.92	1.51E-08	3.96E-14	0.0219	0.990	0.980
Al	0.753	-0.00401	-0.123	8.15E-07	0.00188	0.000229	0.845	0.713

r:multiple correlation coefficient

amounts, it rapidly inhibits plant root elongation.

The aluminum (Al) in the soil has a good correlation with the soil pH. The exchangeable Al in the soil decreases significantly and correlates well with the increase in the soil pH. Figure 3 shows that the correlation between the soil pH and the exchangeable Al is very fitting to the quadratic curve with R^2:0.883. This means that the increasing soil pH is affected by the applications of compost and dolomite, which can decrease the aluminum availability to a soil pH of 5.5. Dolomite, as lime, can reduce the Al and metal element [26]. Increasing the soil pH can decrease the Al [27]. Prasetyo and Suriadikarta [16] also stated that there was a good relationship between the increase in pH due to liming and the Al content in the soil.

3.4 Effect of Compost and Dolomite Application on Nutrient Availability

A multiple regression analysis was carried out to evaluate the effect of compost and dolomite applications on the soil chemical properties.

As for the regression analysis, the chemical properties of the soil (pH, Ca, Mg, Na, K, and Al) were used as the response variables, and the applications of compost and dolomite were used as the explanatory variables. Table 3 presents the results of the multiple regression analysis. The results indicate that:

The soil pH is closely related to both the compost (p-value: $1.43*10^{-06}<0.01$) and the dolomite (p-value: $4.52*10^{-09}<0.01$) applications, which means that dolomite has a greater effect on the soil pH than compost.

The soil pH can be predicted with high accuracy (R^2=0.931, significant F-value=$1.98*10^{-9}$) by the multiple regression equation as follows:

$$\text{Soil pH} = 4.49+0.00633\times\text{compost (t/ha)}+0.236\times\text{dolomite (t/ha)} \quad \cdots\cdots (1)$$

Here, the value of the intercept (4.49) is considered as the soil pH of the initial condition before the applications of compost and dolomite.

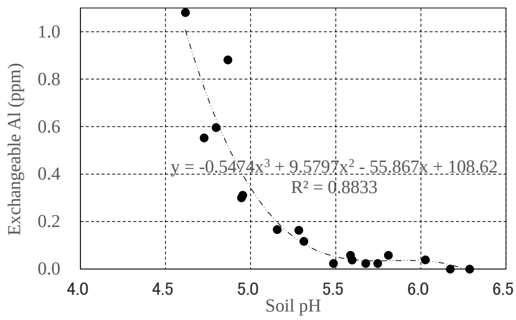


Fig.3 Effect of soil pH on exchangeable aluminum (Al) 12 weeks after treatment

The available Mg is also closely related to both the compost (p-value: $1.49*10^{-06}<0.01$) and the dolomite (p-value: $6.29*10^{-08}<0.01$) applications, which means that the dolomite application increases the Mg more than the compost application.

The available Ca is more strongly influenced by the compost (p-value: $3.81*10^{-06}<0.01$) than by the dolomite (p-value: $0.000542<0.01$) due to the fact that compost can supply a higher Ca element (20.8 g kg^{-1}) than dolomite.

The application of 5 ton ha^{-1} of dolomite can increase K by 14.7 ppm, Ca by 315.5 ppm, and Mg by 148.9 ppm [15]. Moreover, the application of 50 ton ha of compost can increase K by 80 ppm, Ca by 580 ppm, and Mg by 150 ppm [23].

On the other hand, the compost application significantly increases the available Na (p-value: $0.000167<0.01$) and K (p-value: $3.96*10^{-14}<0.01$), but the dolomite application has no significant effect on the available Na (p-value: $0.0725>0.01$) and available K (p-value: $0.0219>0.01$). These results suggest that the available Na and K can be supplied by compost applications, but are not affected by the soil pH (see Figure 2) which is increased by dolomite applications.

The exchangeable Al in the soil decreases with the increase in compost and dolomite applications due to the value of the coefficient being less than 0 (compost: -0.00401 and dolomite: -0.213), and is more significantly influenced by dolomite (p-value: 0.000229) compared to compost (p-value: 0.00188). The multiple correlation coefficient (r) has the lowest value (0.845) among all the soil chemical properties, except for Na, due to the limitation of the linear equation adopted in this analysis.

Finally, the following effects can be clarified from the results of the multiple regression analysis, as shown in Table 3. The contents of Ca and Mg cations increase by 38.2 and 26.1 ppm by each application of 1 t/ha of dolomite, respectively, but Na and K do not increase because dolomite does not contain these two cations since its chemical formula is $CaMg(CO_3)_2$. On the other hand, each application of 1 t/ha of compost can increase the contents of Ca, Mg, Na, and K cations by 2.58, 0.85, 0.17, and 2.61 ppm, respectively.

4. CONCLUSION

The application of dolomite and compost, respectively, can significantly increase the soil pH. The combination of compost and dolomite can increase the soil pH even more significantly. The pattern of nutrient changes in the soil, such as Ca and Mg, showed a good linear correlation with the changes in the soil pH, but K and Na did not show a good relationship. The exchangeable aluminum in the soil showed a good quadratic correlation with the soil pH for red acid soils.

Furthermore, the available Ca, Na, and K were more significantly affected by the application of compost than by that of dolomite. Contrarily, the available Mg and Al were more significantly affected by the application of dolomite than compost. It can be concluded from this experiment that the best combination of compost and dolomite applications for improving the soil pH, base cations, and decreasing Al toxicity is a 100 t/ha dose of compost and a 5 t/ha dose of dolomite. This is due to the fact that the soil pH (6.303), Ca (620 ppm), Mg (258.8 ppm), Na (45.90 ppm), K (324.5 ppm), and Al (0 ppm) can be attained by this combination of compost and dolomite based on the results of a multiple regression analysis (see Table 3), all of which are appropriate values for pineapple plants, as shown in Table 1.

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