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Research Article

Exchangeable Al, peanut growth, and nodulation on Ultisol Bogor as affected by ameliorant proportion of lime and organic matter

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Abstract

Ultisols are characterized as acid soils with high exchangeable Al as the primary constraint for plant growth. This study aimed to investigate the effect of the proportion of lime and organic matter in decreasing exchangeable Al on Ultisol Bogor and continued to observe the impact on the growth and nodulation of peanuts. The pot experiment used a completely randomized design with a single treatment of the addition of ameliorant consisting of 12 levels of the treatment of lime (calcite and dolomite), organic matter (dry cow dung and rice straw compost), and their combinations with three replications. The first step was applying the ameliorant and incubating for eight weeks, then continuing the cultivation of peanuts. Results showed that during incubation, the decrease in exchangeable Al levels varied between treatments, along with an increase in soil pH and available P. The treatments of calcite 100% (T1) and dolomite 100% (T2) showed the highest increase in soil pH and available P and the highest decrease in exchangeable Al. The result of plant growth showed that the highest plant dry weight, N-uptake, and P-uptake were obtained by the treatment of dolomite 25% + rice straw compost 25% + dry cow dung 25% + NPK 25% (T10), whereas the highest number and total weight of nodules were obtained by the rice straw compost 50% + dry cow dung 50% (T7) and dolomite 25% + rice straw compost 75% (T8).

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Introduction

Peanut is one of the important agricultural products in Indonesia due to its high nutritional content. The nutritional content of peanuts includes 25-30% protein, 40-50% fat, 12% carbohydrate, and vitamin B1 (Silitonga et al., 2018). Although peanut productivity in Indonesia showed a slight increase from 1.29 t ha^{-1} to 1.34 t ha^{-1} in the period of 2018-2022, however, at the same period, annual peanut production decreased from 457,026 tons to 379,928 tons, which was impacted by the decrease in the harvest areas from 353,768 to 283,498 ha (Directorate General for Food Crop, 2023). Some factors that may cause the decline in peanut production include pest and disease attacks, land degradation, and a decrease in peanut area due to land conversion. The persistent deficit in peanut stocks every year has resulted in the dependence on imported peanuts.

Indonesia is a wet tropical climate region with high annual rainfall. The varied geography with high rainfall throughout the year causes acid-reacting soils, one of which is Ultisol which covers 36.3 million ha or 19.29% of the total land area in Indonesia (Center for Research and Development of Agricultural Land Resources, 2021). Lal (2017) described the characteristics of Ultisol as follows: 1) Advanced soil weathering, 2) Land surface has been stable for a long time, 3) Long-term wetting and drying periods, 4) The soil is relatively infertile and has limited ability to replenish nutrients through inherent mechanisms. Ultisols are mineral soils characterized by argillic or kandic endopedons with high clay content compared to the upper horizon and low base saturation (<35%) (Soil Survey Staff, 2016). High rainfall causes weathering and leaching that leaches alkali and organic matter and reduces their content (Enita et al., 2022), leaving sesquioxide that causes a low pH (<5.0), and the high Al concentration can be toxic to plants (Pulunggono et al., 2022). Xiang et al. (2021) reported that the peanut yield in the dryland of Ultisols in southern China was only 60% of that in northern China, which is known to be dominated by alkaline calcareous soils.

The presence of aluminum in the soil in the form of aluminosilicates is not toxic, but in the conditions of acidic pH (<5.0), the solubilization of Al to a limited extent would cause the release of phytotoxic forms, mainly as monomeric Al^{3+}, and also formulates the monomeric species such as $AlOH^{2+}$, $Al(OH)_2^{+}$, $Al(OH)_3$, and $Al(OH)_4^{-}$, but Al^{3+} is the most toxic among all the species (Singh et al., 2017). In soil, Al^{3+}, $AlOH^{2+}$, and $Al(OH)^{2+}$ are exchangeable cations that effectively compete with the base cations for exchange sites on clay minerals and soil organic matter (Essington, 2015). Zhang et al. (2019) explained that Al toxicity limits crop yield by inhibiting root growth and affecting water and nutrient uptake. A common strategy to overcome Al toxicity is liming by applying calcite ($CaCO_3$), dolomite (($CaMg(CO_3)_2$), or quicklime (CaO) to neutralize exchangeable Al (Jiang-Ming, 2022), but excessive liming resulted in micronutrient deficiencies and decreasing available P and plant yields (Olego et al., 2021). Sutriadi and Setyorini (2012) reported a decrease in soil phosphate levels when dolomite plus was applied at a dose of 3,200 kg ha^{-1}, and thus, other neutralizing agents are required to handle the exchangeable Al constraints in Ultisols.

The other ameliorant for aluminum detoxification is the use of organic fertilizer, such as tree leaves and plant or grass straw, which are widely used as green fertilizer, or pig, cattle, rabbit, or goat feces, which are used as animal manure (Skwira et al., 2012), or compost (Enita et al., 2022). The application of crop straw decayed products of peanut, canola, rice, and pea significantly increased soil pH and pH buffering capacity (acidification resistance) of a sandy Ultisol, and also slowed down soil acidification and reduced the concentration of soil soluble Al and exchangeable Al during simulated soil acidification (Pan et al., 2021). Research by Zheng et al. (2016) reported that using organic matter in the form of biogas slurry plus chemical fertilizers with appropriate proportions on Ultisols increased yields and peanut biomass compared to results without the addition of organic matter and chemical fertilizers or only chemical fertilizers. The utilization of lime and organic matter in combination treatment was reported by Malik et al. (2018), who applied biochar on dry soil basis at 2% and 4% and applied CaO based on exchangeable acid percentage (H^{+} + Al^{3+}) at 50% and 100% on Ultisol Zhejiang, China, and the highest effect in neutralizing exchangeable Al was obtained by 6 treatments, but for the highest effect for plant growth was resulted by 4% straw biochar (C2) + 100% CaO.

Although there have been many research reports related to the use of lime and/or organic materials for exchangeable Al neutralization in Ultisols, information on the effect of the proportion of the combination of the two materials using various types of lime and organic materials is still limited. This study aimed to examine the effect of the proportion of lime and organic matter in neutralizing exchangeable Al on Ultisol Bogor and supporting peanut growth. The dosage of lime materials (calcite and dolomite) in this study was determined based on the value of 1x (100%) of exchangeable Al level, whereas the dosage of organic matter (rice straw compost and dry cow dung) was designed at the same rate with the dosage of lime, in order to examine the differences of the effects of those materials in decreasing Al^{3+} and supporting plant growth using the same dosage.

Materials and Methods

The pot experiment was carried out at the greenhouse of the Faculty of Agriculture, Sebelas Maret University, Surakarta. The research was conducted in two experimental stages, namely, stage I to test the effect of a variety of combination of lime and organic matter after two months of soil incubation in March-May 2021 toward the chemical characteristics of Ultisol, and stage II to observe and analyze the effect of soil incubated from stage I on the growth of peanuts until the maximum vegetative phase in May-July 2021.

Ultisol soil samples were taken from Setu Village, Jasinga District, Bogor Regency at coordinates 6º27'44.4" South Latitude and 106º28'31.6" East Longitude, located in a rubber secondary forest. The chemical properties of Ultisol soil are presented in Table 1. Other research materials consisted of calcite lime (Ca: 95%, Merck), dolomite (Ca: 30%; Mg 18%, Merkaindo), urea, SP-36, KCl, rice straw compost, dry cow dung, legin, and peanut seed. Rice straw compost was prepared by the research team according to Cahyani et al. (2002) method with a modification without chemical fertilizer. Dry cow dung was obtained from the farmer in Nayan Village, Kebakkramat District, Karanganyar, legin (Legume Inoculant) was obtained from the UGM Microbiology Laboratory, and peanut seeds of local variety obtained from the farmer in Rejosari Village, Gondangrejo District, Karanganyar. The chemical properties of rice straw and dry cow dung compost are presented in Table 2. The pot experiment used a completely randomized design single treatment of exchangeable Al neutralizing ameliorants (proportion of lime and organic matter) consisting of 12 levels with 3 replications. Ultisol soil was air dried and sieved with a 2 mm sieve and put in pots with ± 12 cm in diameter and 11 cm in height with a soil weight of 1 kg pot^{-1}. Preliminary soil analysis showed an exchangeable Al level of 20 cmol (+) kg^{-1}. The determination of 100% lime dosage is based on the calculation of 1x initial soil exchangeable Al (20 cmol(+) kg^{-1}) that was equal to 20 t ha^{-1} of lime material. The determination of the dose of organic matter was designated to the same as the dosage of lime, which mean that a dose of 100% organic matter was equal to 20 t ha^{-1} of organic matter.

Table 1. Soil properties of Ultisol Bogor.

No	Soil properties	Method	Value	Status
1	Moisture content (%)	Gravimetry	18.36	-
2	Total N (%)	Kjedahl	0.2	Low*
3	Available P (ppm)	Bray I	0.74	Very Low*
4	Exchangeable K (cmol(+) kg^{-1})	SSA	0.51	Medium*
5	Exchangeable Ca (cmol(+) kg^{-1})	NH_4OAc 1M pH 7	3.96	Low*
6	Exchangeable Mg (cmol(+) kg^{-1})	NH_4OAc 1M pH 7	1.07	Medium*
7	Exchangeable Na (cmol(+) kg^{-1})	NH_4OAc 1M pH 7	0.7	Medium*
8	Organic C (%)	Walkley-Black	1.29	Low*
9	C/N	-	6.45	Low*
10	CEC (cmol(+) kg^{-1})	NH_4OAc 1M pH 7	27.92	High*
11	BS (%)	NH_4OAc 1M pH 7	23	Low*
12	pH-H_2O	Electrophotometry	4.15	Acidic*
13	pH-KCl	Electrophotometry	3.61	Very Acidic*
14	Exchangeable H^+ (cmol(+) kg^{-1})	KCl extract	1.45	-
15	Exchangeable Al (cmol(+) kg^{-1})	KCl extract	20	High*
16	Bulk Density (g dm^{-3})	Paraffin wax	1.44	-

*The status and value of the soil properties referred to the Indonesia Soil Research Institute (2009).

Table 2. Organic matter properties.

No	Organic matter properties	Method	Value	
			Dry Cow Dung	Rice Straw Compost
1	Moisture content (%)	Gravimetry	14.12	10.74
2	Total N (%)	Kjedahl	0.25	0.28
3	P_2O_5 (%)	HNO_3 and $HClO_4$ Extraction	0.58	0.60
4	K_2O (%)	HNO_3 and $HClO_4$ Extraction	0.45	0.31
5	pH-H_2O	Electrophotometry	7.25	7.03
6	Organic C (%)	Walkley-Black	10.78	16.67
7	C/N	-	16.46	19.33

The ameliorant treatment of the proportion of lime and organic matter was designed as follows: control (T0); 100% calcite (T1); 100% dolomite (T2); 100% rice straw compost (T3); 100% dried cow dung (T4); 50% dolomite + 50% rice straw compost (T5); 50% dolomite + 50% dried cow dung (T6); 50% rice straw compost + 50% dried cow dung (T7); 25% dolomite + 75% rice straw compost (T8); 25% dolomite + 75% dry cow dung (T9); 25% dolomite + 25% rice straw compost + 25% dry cow dung + 25% NPK (T10); and 33.3% rice straw compost + 33.3% dry cow dung + 33.3% NPK (T11).

The first stage of the research was the application of ameliorants according to the treatment proportion and incubation for two months. Soil moisture during incubation was maintained at 70% field capacity (Yuan and Xu, 2011). During soil incubation, the analysis of pH (H_2O) using the electrophotometric method with a pH meter (Kicińska et al., 2022) was conducted weekly, whereas the analysis of exchangeable Al using 1N KCl extract method (Antonangelo et al., 2022) and soil available P using Bray I method (Afrida et al., 2022) were conducted every two weeks. After the soil incubation, the second stage of the research was peanut planting. Each pot was planted with five peanut seeds. Seven days after planting (DAP), thinning was conducted by leaving only one plant per pot. Plants were harvested at the age of 35 DAP. Observations, measurements, and analyses at harvest included plant height, plant fresh and dry weight, number of nodules, nodule weight, inner nodule color, the concentrations of N in plant shoot (Kjedahl method, Tang et al., 2022), the concentration of P and K in plant shoot (HNO_3 and $HClO_4$ extraction methods), and nutrients uptake of N, P, and K (by multiplying the nutrient concentration in plant shoot with the respective plant dry weight for each treatment) (Indonesia Soil Research Institute, 2009).

All data were analyzed statistically, including ANOVA using the F test with a 95% confidence level, followed by Duncan's Multiple Range Test (DMRT) to determine the differences of significant effect among the treatments and Pearson Correlation to determine the correlation among observed variables. Statistical analysis used the application of IBM SPSS 25 on Windows 10.

Results and Discussion

Effect of treatment of proportion of lime and organic materials during 2 months incubation

Ultisol soil with an initial soil pH (H_2O) of 4.15, which was treated with the proportion of lime and organic matter, showed a variety in the increase of pH during incubation for eight weeks. The changes in soil pH during soil incubation are shown in Figure 1. During the incubation period (Figure 1), the 100% calcite treatment (T1) showed the fastest and highest increase in soil pH among all the treatments, reaching pH 7.2 at week 2, then retaining at the range 6.99-7.36 and finally at the level of 7.2 at week 8. The 100% dolomite treatment (T2) showed the second fastest and highest increase in soil pH, reaching pH 7.13 at week 3, followed by slight fluctuation in the range 6.63-6.91 and ending at pH 6.75 at week 8. The faster and higher pH increase in the 100% calcite treatment is because calcite has a higher solubility compared to dolomite (Li et al. 2019). Calcite only contains $CaCO_3$, unlike dolomite, which is composed of 2 components, namely $CaCO_3$ and $MgCO_3$. The solubility of the $CaCO_3$ component in dolomite is faster than that of the $MgCO_3$ component, resulting in slower solubility than calcite (Olego et al., 2021). Holland et al. (2019) reported that application of ground lime of $CaCO_3$ on acidic soils (pH around 4.4) with four different doses of control (no liming), low doses (1-5 t ha^{-1}), medium doses (1.5-10 t ha^{-1}) and high doses (2.5-15 t ha^{-1}) for 6 times (in 1962 twice, 1978, 1981, 1982, and 1986) at two locations of Rothamsted and Woburn were observed periodically from 1965 to 1995. The results showed that the increases in soil pH occurred immediately following lime application, and the soil pH decreased when no lime was applied and when the effect of lime ended. Furthermore, they reported that the high dose of lime treatments indicated the largest increase in pH with pH values between 7 and 8 and showed the least change after liming, whereas the low and medium doses of lime treatments yielded pH values varied between pH 5 and 7, and for the control treatments showed the greatest decline in pH with values mostly less than 5. The rapid increase in pH value by liming treatment is caused by CO_3^{2-} ions binding H^+ ions in the soil solution (Tan, 2011), causing H^+ levels to decrease and OH^- to increase. In the present study, at the end of the incubation period (week 8), the soil pH on the treatments of 50% dolomite + 50% dried cow dung (T6), 25% dolomite + 75% dried cow dung (T9), and 25% dolomite + 25% rice straw compost + 25% dried cow dung + 25% NPK (T10) increased to the range of 5.95 to 6.06, whereas on the treatments of 100% rice straw compost (T3) and 100% dried cow dung (T4), the soil pH was still slightly acidic at pH 4.9 to 5.2.

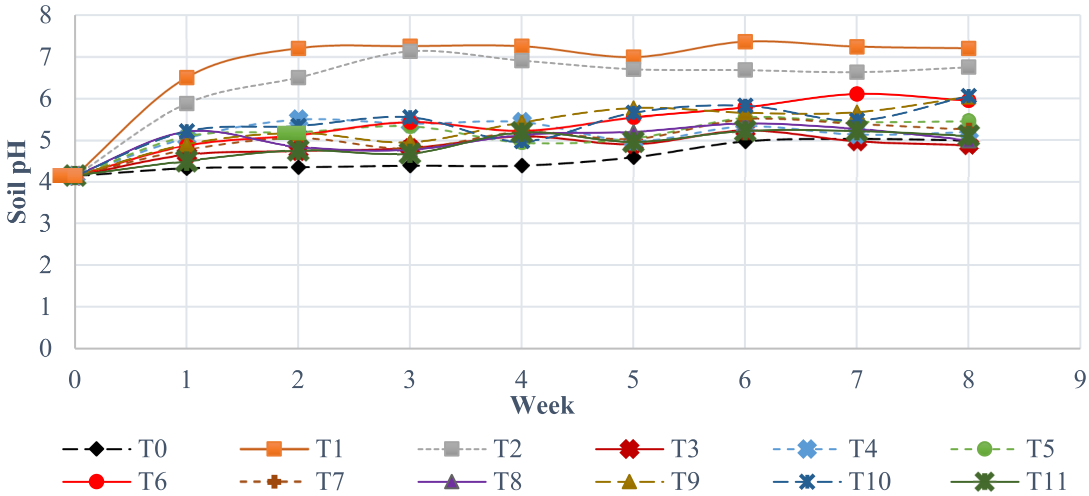

Figure 1. Changes in pH value during 8 weeks of incubation from the effect of ameliorant treatment.

Similar results were reported by Lin et al. (2018), who found that the soil pH value increased from 4.8 to 5.58 in the NPK + pig manure treatment and to 6.59 in the NPK + $CaCO_3$ treatment. The present results of the slow increase in pH values in the treatments T3, T4, T6, T9, and T10 were due to the presence of organic matter that produces H^+ from functional groups such as carboxyl during the decomposition process (Farni et al., 2022) as well as from various functional groups that have two charges simultaneously (He et al., 2019). Jiang et al. (2016) reported that the increase of organic matter content in the soil leads to the increase of pH buffering capacity in the soil and causes the slow effect of liming.

The fluctuation of exchangeable Al levels over eight weeks is shown in Figure 2, starting with an initial soil exchangeable Al level of 20 cmol(+) kg^{-1}. The 100% calcite treatment (T1) at week 1 of incubation resulted in a very low exchangeable Al value of 0.2 cmol(+) kg^{-1}, followed by 100% dolomite (T2) with an exchangeable Al value of 5.0 cmol(+) kg^{-1}. These two treatments of T1 and T2 showed significantly higher and faster effects in reducing the exchangeable Al compared to the other treatments. Research from Cunha et al. (2018) showed that the use of dolomite of 14 t ha^{-1} was able to reduce exchangeable Al from 13.2 cmol(+) kg^{-1} to 3.1 cmol(+) kg^{-1} after 98 days of incubation. Getaneh and Kidanemariam (2021) explained that the use of liming materials results in higher effectiveness for managing or correcting soil acidity compared to organic matter such as compost, manure, and undecomposed plant residues, since during the decomposition of organic matter in part have also an acidifying effect on soil.

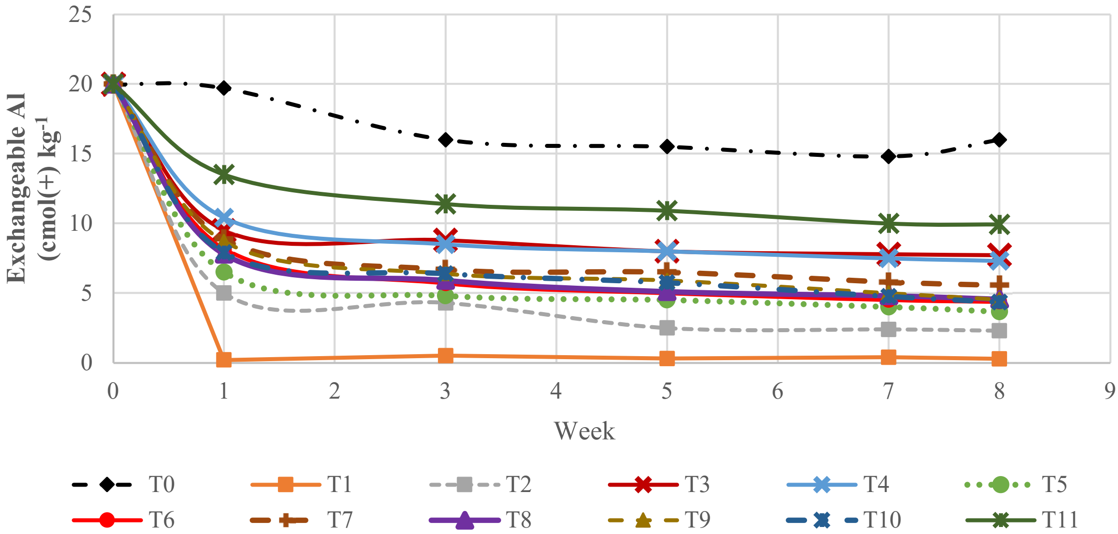

Figure 2. Changes in exchangeable Al values during 8 weeks of incubation from the effect of ameliorant treatment.

Wang et al. (2014) reported that a higher rate of peanut biochar application at 20 g kg^{-1} in their study had no significant effect on soil pH compared to the low-rate application of 10 g/kg, but gave a significant reduction of exchangeable acidity and Al saturation. They explained that exchangeable acidity in soil could counteract the alkalinity produced by the decarboxylation of organic anions; therefore, there is no significant effect of biochar application on soil pH at a high rate compared to a lower rate. However, organic matter can still bind exchangeable Al into Al-organic compounds, resulting in the decrease of exchangeable Al level (Mockeviciene et al., 2021).

Soil available P levels are strongly influenced by many factors, such as soil pH, which determine P removal/release mechanisms or P retention mechanisms, including anion exchange, precipitation of Ca phosphates, ligand exchange (adsorption) to Al and Fe oxides/hydroxides and edges of alumino-silicate minerals, precipitation of Al and Fe phosphates (Penn and Camberato, 2019). As shown in Figure 3, soil available P in the 100% calcite (T1) and 100% dolomite (T2) treatments increased sharply from 0.75 ppm to 12.24 ppm (T1) and 11.43 ppm (T2) at week 5 and then increased slowly to 14.99 ppm (T1) and 14.57 ppm (T2) at week 8. In the 100% rice straw compost (T3) and 100% dried cow dung (T4) treatments, soil available P increased slowly from 0.75 ppm to 7.34 ppm (T3) and 7.67 ppm (T4) at week 5, then continuously increased slowly to 9.8 ppm (T3) and 9.18 ppm (T4) at week 8. Nduwumuremyi et al. (2013) explained that soil available P increases due to the ability of lime to increase soil pH and reduce exchangeable Al, which means phosphorus bound to Al and Fe can be released and enter the soil solution. ANOVA results (Table 3) showed that the treatments in the present study had a very significant effect ($p<0.01$) on soil pH, exchangeable Al, and soil available P at week 8. The 100% calcite treatment (T1) showed the highest pH value of 7.12, while the 100% dolomite treatment (T2) showed an insignificant difference in pH value compared to T1, which was 6.64. The treatment of 100% rice straw compost (T3) showed a pH value of 4.91, which was significantly lower than 100% dry cow dung (T4), which was 5.25, whereas the control treatment indicated pH of 4.60. It is important to note that rice straw compost used in the present study was made in the period July - September 2020 (77 days), and then kept in the storehouse for 6 months until the day of application. This fact might result in the lower effect of the application of 100% rice straw compost (T3) in the present study compared to the same application of rice straw compost with the same dosage of 20 t ha^{-1} on Ultisol that was reported by (Pane et al., 2014) which resulted in the higher increase pH to 5.32 compared to the control with pH 4.63. These findings indicated that the application of 100% calcite or 100% dolomite yielded an increase in pH by 44-55% compared to the control, while the application of 100% rice straw compost and 100% dried cow dung resulted in an increase in pH by 7-14% compared to the control.

In the combination treatment of lime and organic materials (T5-T11), the pH value was obtained in the range of 4.95-5.51 with the treatment of 50% dolomite + 50% dry cow dung (T6) and 25% dolomite + 25% rice straw compost + 25% dry cow dung + 25% NPK (T10) having the highest pH value of 5.51. These results showed that the combination treatment of lime and organic matter (T5-T11) increased pH by 8-20% compared to the control. As for exchangeable Al, the treatments of 100% calcite (T1) and 100% dolomite (T2) had the lowest values of 0.24 cmol(+) kg^{-1} and 2.30 cmol(+) kg^{-1}, which were not significantly different between the two treatments. The 100% rice straw compost treatment (T3) showed the level of exchangeable Al at 7.72 cmol(+) kg^{-1}, which was significantly higher than the 100% dry cow dung treatment (T4), which at the level of 7.30 cmol(+) kg^{-1}. These results indicated that the effect of lime in the reduction of exchangeable Al was significantly much higher than that of organic matter, with a reduction of 86-99% by the 100% calcite and 100% dolomite treatments compared to the control, while in the 100% rice straw compost and 100% dry cow dung treatments affected in the reduce of 52-54% level of exchangeable Al compared to the control. In the combined treatment of lime and organic materials (T5-T11), the exchangeable Al levels ranged from 3.66 to 9.92 cmol(+) kg^{-1}. Among them, the treatment of 50% dolomite + 50% rice straw compost (T5) indicated the lowest exchangeable Al levels.

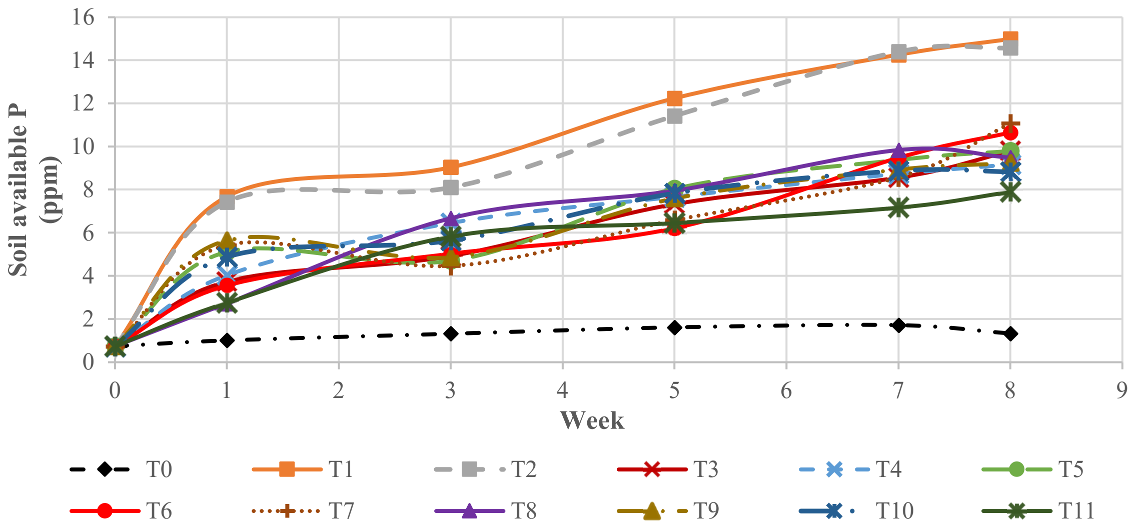

Figure 3. Changes in soil available P values during 8 weeks of incubation from the effect of ameliorant treatment.

The combination treatment of lime and organic materials (T5-T11) reduced the exchangeable Al content by 65-73% compared to the control. At the end of the incubation, the highest increase of available P was obtained in the treatments of 100% calcite (T1) and 100% dolomite (T2) at the levels of 14.99 ppm and 14.57 ppm, which showed no significant difference between both treatments. In the treatment of 100% rice straw compost (T3), the available P content was 9.80 ppm, which showed no significant difference from 100% dry cow dung treatment (T4), which is 9.17 ppm. These results indicated that the effect of lime in increasing soil available P was higher than organic matter, in which the increases in the treatments of 100% calcite and 100% dolomite were at the range of 987-1,027% compared to the control, while in the treatments of 100% composted rice straw and 100% dry cow dung were at 585-631% compared to control. In the combination treatment of lime and organic matter (T5-T11), the soil available P content ranged from 7.89 to 11.07 ppm, in which the treatment of 50% dolomite + 50% dry cow dung (T7) yielded the highest soil available P content. The combination treatment of T5-T11 showed increases in soil available P at the range of 489-726% compared to the control. The application of lime, organic matter, and their combination significantly affected soil pH. The results of the present study showed that soil pH had a highly significant negative correlation with exchangeable Al ($r = -0.681$; $p<0.01$), but had a highly significant positive correlation with soil available P ($r = 0.757$; $p<0.01$). This fact indicated that the increase in pH caused by applying lime, organic matter, and the combination of both materials significantly reduced the exchangeable Al, and was followed by the increase of soil available P. This was confirmed by the correlation between exchangeable Al and soil available P, showing a highly significant negative correlation (r = 0.756; p<0.01).

Table 3. Soil chemical properties after eight weeks of incubation from the effect of ameliorant treatment.

Treatment	Soil pH	Exchangeable Al (cmol(+) kg^{-1})	Soil Available P (ppm)
T0	4.60^{e}	16.00^{f}	1.33^{c}
T1	7.12^{a}	0.24^{a}	14.99^{a}
T2	6.64^{a}	2.30^{a}	14.57^{a}
T3	4.91^{de}	7.72^{de}	9.80^{b}
T4	5.25^{bcd}	7.30^{d}	9.17^{b}
T5	5.26^{bcd}	3.66^{bc}	9.79^{b}
T6	5.51^{b}	4.38^{bc}	10.65^{b}
T7	5.12^{cde}	5.56^{c}	11.07^{b}
T8	5.10^{de}	4.56^{c}	9.48^{b}
T9	5.44^{bc}	4.54^{c}	9.22^{b}
T10	5.51^{b}	4.36^{bc}	8.82^{b}
T11	4.95^{de}	9.92^{e}	7.89^{b}
Sig.	0**	0**	0**

Notes: Mean values within the column followed by the same letter are not significantly different at p<0.05 according to Duncan's Multiple Range Test. Significant level: ** = p<0.01.

Ayodele and Shittu (2014) reported that the application of CaO lime at 2.5 t ha^{-1} was able to reduce exchangeable Al from 24.3 cmol(+) kg^{-1} to 0.54 cmol(+) kg^{-1} (97% reduction) and affected the increase of soil available P from 4.9 mg kg^{-1} to 8.7 mg kg^{-1} (77% increase). Furthermore, the results of Ayodele and Shittu (2014) showed that the application of a compost mixture of sawdust and cow dung at 10 t ha^{-1} was able to reduce exchangeable Al from 24.3 cmol(+) kg^{-1} to 1.62 cmol(+) kg^{-1} (93% reduction), and had an impact on increasing soil available P from 4.9 mg kg^{-1} to 323.4 mg kg^{-1} (6,500% increase) after 1 week of incubation followed by 2 maize growing seasons (2 x 42 days). The results of the present study, which used a higher dose of calcite and dolomite lime (20 t ha^{-1}), resulted in an equivalent level of exchangeable Al reduction (86-99%) but yielded a lower level of soil available P (987-1,027%) compared to the results of Ayodele and Shittu (2014). Meanwhile, compared to the use of mixed compost of sawdust and cow dung in the Ayodele and Shittu (2014) study, the use of rice straw compost and dry cow dung in this study resulted in lower levels of exchangeable Al reduction (52-54%) and lower soil available P increase (585-631%). The results of increasing pH, reducing exchangeable Al, and increasing soil available P in the lime treatment in this study could be explained by the fact that lime application in acid soil can increase soil pH by increasing OH^- ion by basic cation, causing the release of phosphate ion bound by Al and Fe ion into the soil solution (Negese et al., 2022). On the other side, the mechanisms mediated by organic matter could be described as the decomposition of organic matter producing a variety of organic acids, such as citrate, oxalate, and others, that are capable of adsorbing soluble Al and induce the formation of organo-Al complexes that are difficult to release into the soil solution and may interfere with the production of soluble Al (Li et al., 2022). Furthermore, soil available P can also be enhanced by directly adding organic matter and enhancing soil organic P mineralization through liming (Buni, 2014; Neswati et al., 2022).

Effect of treatment on peanut growth

Statistical analysis of ANOVA (Table 4) showed that the treatments in the present study significantly affected plant height (p<0.5), plant dry weight (p<0.05), nodule number (p<0.01), nodule weight (p<0.01), plant tissue P content (p<0. 01), plant tissue K content (p<0.05), plant N uptake (p<0.05), plant P uptake (p<0.01) and plant K uptake (p<0.05), but had no significant effect on plant fresh weight (p>0.05) and plant tissue N content (p>0.05). Plant height in the 100% calcite treatment (T1) was 26.90 cm, which was significantly lower than 100% dolomite (T2), which was measured at 31.80 cm. In the treatments of 100% rice straw compost (T3) and 100% dried cow dung (T4), the heights were 32.23 cm and 31.26 cm, showing no significant difference between the two treatments. In the combination of lime and organic matter (T5-T11), the plant height was between 25.63 and 36.4 cm, of which the combination of 50% dolomite + 50% rice straw compost (T5) had the highest plant height (36.4 cm).

As for the variable plant dry weight, the treatments of 100% calcite (T1) and 100% dolomite (T2) yielded plant dry weights of 5.10 g and 5.73 g, respectively. The treatment of 100% calcite (T1) was significantly lower than 100% dolomite (T2). On the other hand, plant dry weight in the application of 100% rice straw compost (T3) was 8.76 g, which was significantly higher than that in the application of 100% dried cow dung (T4) with 7.65 g. According to the results obtained, the effect of lime on plant dry weight was lower than that of organic matter, in which the treatment of 100% calcite (T1) and 100% dolomite (T2) increased the level of plant dry weight only 16-30% compared to the control in, while in the treatment of 100% rice straw compost (T3) and 100% dry cow dung (T4) increased by 74-99% compared to the control. In the combination treatments of lime and organic matter (T5-T11), the plant dry weights ranged from 6.55 to 10.02 g, among which the combination of 25% dolomite + 25% rice straw compost + 25% dried cow dung + 25% NPK (T10) had the highest plant dry weight. Thus, the combination of lime and organic matter treatment gave an increase of 49-128% in plant dry weight compared to the control.

Table 4. Peanut growth and nodulation as affected by ameliorant treatment.

Treatment	Plant Height and Weight			Nodule			Plant Tissue Level (%)			Plant Nutrient Uptake (mg plant^{-1})		
	H (cm)	PFW (g)	PDW (g)	Number	Weight (g)	Color	N	P	K	N	P	K
T0	24.30^{d}	5.85	4.40^{d}	2.33^{e}	0.02^{e}	W	0.19	0.29^{f}	0.19^{c}	1.03^{d}	1.34^{d}	0.84^{b}
T1	26.90^{bcd}	7.49	5.10^{cd}	4.00^{de}	0.04^{de}	W	0.20	0.33^{ef}	0.29^{abc}	1.37^{cd}	1.88^{cd}	1.97^{ab}
T2	31.80^{abc}	8.39	5.73^{bcd}	3.00^{e}	0.03^{de}	W	0.21	0.30^{f}	0.28^{abc}	1.50^{bcd}	2.20^{bcd}	1.87^{ab}
T3	32.23^{abc}	11.10	8.76^{ab}	5.33^{de}	0.06^{cde}	R	0.29	0.37^{cdef}	0.40^{ab}	1.68^{bcd}	2.94^{bc}	2.64^{a}
T4	31.26^{abc}	9.00	7.65^{abcd}	7.66^{cd}	0.14^{b}	R	0.29	0.37^{cdef}	0.26^{bc}	1.98^{abcd}	2.26^{bcd}	3.46^{a}
T5	36.40^{a}	9.46	7.70^{abcd}	4.33^{de}	0.06^{cde}	R	0.22	0.35^{f}	0.26^{abc}	1.54^{bcd}	3.01^{bc}	2.00^{ab}
T6	33.06^{ab}	10.75	7.21^{abcd}	6.00^{de}	0.11^{bcd}	R	0.22	0.36^{f}	0.24^{bc}	1.68^{bcd}	2.94^{bc}	2.59^{a}
T7	30.60^{abcd}	10.32	6.55^{abcd}	14.33^{a}	0.25^{a}	R	0.27	0.45^{abc}	0.42^{ab}	1.75^{bcd}	2.94^{bc}	2.74^{a}
T8	32.16^{abc}	11.02	7.99^{abc}	11.33^{ab}	0.24^{a}	R	0.28	0.51^{a}	0.43^{ab}	2.20^{abc}	3.63^{ab}	2.01^{a}
T9	29.40^{bcd}	13.45	8.26^{abc}	5.67^{de}	0.13^{bc}	R	0.33	0.46^{ab}	0.39^{ab}	2.58^{ab}	3.61^{ab}	3.48^{a}
T10	28.83^{bcd}	11.37	10.02^{a}	9.67^{bc}	0.16^{b}	R	0.30	0.45a^{bc}	0.45^{a}	3.03^{a}	4.57^{a}	3.48^{a}
T11	25.63^{cd}	11.29	8.80^{ab}	4.33^{de}	0.05^{de}	R	0.30	0.42^{bcd}	0.39^{ab}	2.64^{ab}	3.73^{ab}	3.14^{a}
Sig.	0,012*	0,109^{ns}	0,03*	0**	0**	-	0,256^{ns}	0**	0,03*	0,014*	0,003**	0,049*

Remarks: Mean values within the column followed by the same letter(s) are not significantly different at p<0.05, according to Duncan's Multiple Range Test. Significant level: ns = not significant; * = p<0.05; ** = p<0.01. T = treatment H = plant height; PFW = plant fresh weight; PDW = plant dry weight; N = nitrogen; P = phosphorus; K = potassium.

Applying a combination of lime and organic matter provides more nutrients than lime or organic matter alone, giving better plant height and dry weight results. Similar results were reported by Van Chuong et al. 2019), who showed that applying 5tha^{-1} of coconut fiber + 5 t ha^{-1} of lime resulted in a peanut yield of 7.59 t ha$^{-1,}$ which was significantly higher compared to the control treatment, which only yielded 4.63 t ha^{-1}. Similarly, Van Chuong et al. 2019) reported that by applying the same dose of (5 t ha^{-1}), the treatment of organic matter of coconut fiber produced higher peanut pod than the treatment of lime, while the combination of those two treatments produced the highest yield (7.59 t ha^{-1}). Mutamminah et al. (2022) explained that lime and organic matter complement each other in providing nutrients such as N, P, K, Ca, and Mg, which are required by plants for optimal growth; thus the combination of lime and organic matter proportionally gave the highest yield.

As for the variable N uptake, the treatments of 100% calcite (T1) and 100% dolomite (T2) indicated N uptake at 1.37 mg plant^{-1} and 1.50 mg plant^{-1}. In the treatments of 100% calcite (T1), N uptake was significantly lower than that of 100% dolomite (T2). Meanwhile, in the treatments of 100% rice straw compost (T3) indicated the N uptake levels at 1.68 mg plant$^{-1,}$ which was significantly lower than the treatments of 100% dried cow dung (T4), which was at 1.98 mg plant^{-1}. Based on these results, the treatments of 100% lime resulted in lower plant N uptake than the treatments of 100% organic matter, in which the increases of N uptake in the treatments of 100% calcite (T1) and 100% dolomite (T2) were only 33-46% compared to control, whereas the increases in the treatments of 100% rice straw compost (T3) and 100% dried cow dung (T4) were 63-92% compared to control. In the combination treatment of lime and organic materials (T5-T11), the plant N uptake levels ranged from 1.54-3.03 mg plant^{-1}, among which the combination of 25% dolomite + 25% rice straw compost + 25% dried cow dung + 25% NPK (T10) gave the highest level of 3.03 mg plant^{-1}. These results showed that the combination treatment of lime and organic matter yielded an increase of plant N uptake by 50-194% compared to the control. This result was similar to the study reported by Sari et al. (Sari et al., 2019), that using cow bio urine up to 3,500 L ha^{-1} increased peanut N uptake by up to 100% compared to the control. High N uptake was caused by the mineralization of organic N from organic matter used during soil incubation (Wang et al., 2011), which allows N nutrients to be used by plants.

As shown in Table 4, the treatment of 100% calcite (T1) indicated a significantly higher plant tissue P content than the treatment of 100% dolomite (T2), in which T1 showed at the level of 0.33%, while T2 was at the level of 0.30. Plant tissue P content in the treatment of 100% rice straw compost (T3) and 100% dried cow dung (T4) showed the same level at 0.37% and 0.37%. Based on these results, the treatments 100% lime materials indicated lower plant tissue P levels than the treatments of 100% organic matter, in which the increased plant tissue P content in the treatments of 100% calcite (T1) and 100% dolomite (T2) was 3-14% compared to control, while in treatments of 100% rice straw compost (T3) and 100% dried cow dung (T4) was 28% compared to control. In the combination of lime and organic materials (T5-T11), the plant tissue P content ranged from 0.35 to 0.51%. Among these treatments, the highest value was obtained by the treatment of 25% dolomite + 75% rice straw compost (T8) with 0.51%. From these results, the effect of combination treatments of lime and organic matter treatment increased plant tissue P levels by 50-194% over control.

Regarding the P uptake variable, the treatments of 100% calcite (T1) and 100% dolomite (T2) had P uptake levels at 1.88 mg plant^{-1} and 2.20 mg plant^{-1} indicating that T2 was significantly higher than T1. Meanwhile, P uptake in the treatments of 100% rice straw compost (T3) and 100% dry cow dung (T4) treatments was 2.94 mg plant^{-1} and 2.26 mg plant^{-1}, indicating that T3 was significantly higher than T4. Based on these results, the increases of P uptake affected by lime treatment were lower than those by organic matter treatments, as revealed that the increases by T1 and T2 were 40-64% compared to control, while the increases by T3 and T4 were 69-119% compared to control. The combined treatment of lime and organic matter (T5-T11) showed P uptake ranging from 2.94 to 4.57 mg plant$^{-1,}$ which indicated that the effect of the combination of lime and organic matter yielded the increases of P uptake by 119-241% higher than the control. Among these treatments, the highest P uptake was obtained by the treatment of 25% dolomite + 25% rice straw compost + 25% dry cow dung + 25% NPK (T10) with 4.57 mg plant^{-1}. The results were similar to those reported by Crusciol et al. (2019), who reported that adding lime at 2.7 t ha^{-1} resulted in a peanut plant tissue P content of 6.8 g kg^{-1} compared to the control of 4.1 g kg^{-1}. The results reported by Crusciol et al. (2019) showed that a lower dose of liming (lime 2.7 t ha^{-1} + gypsum 2.1 t ha^{-1}) yielded plant tissue P levels of 0.68%, which was higher than the results of this study in which the treatment of calcite 20 t ha^{-1} yielded plant tissue level 0.33%, and dolomite 20 t ha^{-1} yielded at level 0.30%. Gu et al. (2023) reported that applying green manure could increase the plant tissue P content up to 0.175%. High plant tissue P content can be supported by increasing the amount of available P in the soil by releasing phosphate ns from the fixation of Al and Fe in the acidic soil and mineralizing organic P (Dasog and Patil, 2007).

As for the variable plant tissue K content, the treatments of 100% calcite (T1) and 100% dolomite (T2) had plant tissue K content of 0.29% and 0.28%, respectively, indicating no significant difference between the two treatments. Plant tissue K content in the treatments of 100% rice straw compost (T3) and

100% dry cow dung (T4) were 0.40% and 0.26%, respectively, indicating that T3 was significantly higher than T4. The present results showed that the increases of plant tissue K content by lime treatments were lower than by organic matter treatments, as it was indicated that the increases by T1 and T2 were 47-53% higher than the control, whereas the increases by T3 and T4 were 36-111%. In the combined treatment of lime and organic materials (T5-T11), the K content of plant tissues was obtained in the range of 0.24-0.45%. Among these treatments, the highest content was obtained by the combination of 25% dolomite + 25% rice straw compost + 25% dried cow dung + 25% NPK (T10) with 0.45%. These results showed that the combined treatment of lime and organic matter increased plant tissue K levels by 26-137% compared to the control. As for the K uptake variable, the treatments 100% calcite (T1) and 100% dolomite (T2) gave plant K uptake at 1.97 mg plant^{-1} and 1.82 mg plant^{-1}, respectively, in which there was no significant difference between both treatments. The K uptake levels in the treatments of 100% rice straw compost (T3) and 100% dried cow dung (T4) were obtained at 2.64 mg plant^{-1} and 3.46 mg plant^{-1}, respectively, in which there was no significant difference between the two treatments.

Based on these two results, the increases of plant K uptake by the 100% lime treatments were lower than by the 100% organic matter treatments, as indicated that the increases of K uptake of T1 and T2 were 123-135% compared to the control, while the increases by T3 and T4 were 214-312% compared to the control. In the combination treatments of lime and organic matter (T5-T11), the K uptake levels ranged from 2-3.48 mg plant-1, among which the highest level was obtained by the treatment of 25% dolomite + 75% dry cow dung (T9) and the treatment of 25% dolomite + 25% rice straw compost + 25% dry cow dung + 25% NPK (T10) with 3.48 mg plant^{-1}. From these results, the combination treatments of lime and organic matter increased plant K uptake by 138-314% compared to the control. These results align with the research of Singh et al. (2013), that the application of 500 kg ha^{-1} lime + 10 t ha^{-1} manure + 50% NPK recommendation increased K uptake to the level 278.28 kg ha^{-1} or 60.82% higher than the control (173.03 kg ha^{-1}).

The application of organic matter that mostly consisted of complex organic substances resulted in the releasing or mineralization of plant nutrients such as N, P, and K. Adriano et al. (2012) explained that organic matter is degraded to release nutrients such as K into the soil to be used for plants. Research conducted by Otieno et al. (2018) showed the application of a combination of 10 t ha^{-1} cow manure + 5 t ha^{-1} lime + NPK (20 kg ha^{-1} Urea; 30 kg ha^{-1} TSP; 60 kg ha^{-1} KCl) on acidic soil in Eshirali, Kenya resulted in the higher soybean nutrient levels of 5.75% N; 0.51% P; and 2.75% K, compared to the control which had values of 1.81% N; 0.15% P; and 1.31% K. Otieno et al. (2018) reported that the highest increase plant tissue P content among the treatments was 240% compared to the control, this level showed as the highest increase compared to the increase of plant tissue N and K content. Meanwhile, the highest increase of plant tissue P in the present study was 76%, thus being lower than that reported by Otieno et al. (2018).

Nodules on peanut roots are formed by infection of the roots by rhizobium bacteria. The infecting bacteria then symbiotically colonize the peanut and fix free nitrogen from the air. In the treatments of 100% calcite (T1) and 100% dolomite (T2), the number of nodules obtained was 4 and 3, with 100% calcite (T1) significantly greater than 100% dolomite (T2). On the other hand, treatment with 100% rice straw compost (T3) and 100% dry cow dung (T 4) resulted in 5.33 and 7.66 nodes, respectively, indicating that 100% rice-straw composting (T3) was significantly smaller than 100% dry cow dung (T4). From these results, lime treatment gave a lower number of nodules than organic matter, which was 29-72% compared to control in 100% calcite (T1) and 100% dolomite (T2) treatment, while 100% rice straw compost (T3) and 100% dry cow dung (T4) were 129-229% compared to control. Among the combination treatments of lime and organic materials (T5-T11), the highest number of nodules were shown by the treatment of 50% rice straw compost + 50% dry cow dung (T7) with 14.33 nodules dolomite 25% + rice straw compost 75% (T8) with 11.33 nodules. Based on these results, in the combination treatments of lime and organic matter (T5-T11), the number of nodules increased by 86-515% compared to the control.

In the variable of nodule weight, the treatments of 100% calcite (T1) and 100% dolomite (T2) yielded 0.04 g and 0.03 g, respectively, showing no significant difference between both treatments. The treatments of 100% rice straw compost (T3) and 100% dry cow dung (T4) yielded nodule weights of 0.06 g and 0.14 g, respectively. From these results, lime treatment gave lower nodule weight than organic matter, which showed the increase of nodule weight at 50-100% in 100% calcite (T1) and 100% dolomite (T2) treatment compared to control, while the increase of nodule weight was at 200-600% by the treatments of 100% rice straw compost (T3) and 100% dry cow dung (T4) compared to control. In the combination treatments of lime and organic matter (T5-T11), the weight of nodules was between 0.05 to 0.25 g, with the highest level obtained by the treatments of 50% rice straw compost + 50% dry cow dung (T7), which no significant difference with 25% dolomite + 75% rice straw compost (T8). The increase in nodule weight among the combination treatment of lime and organic matter (T5-T11) was 150 to 1,150% compared to the control. The results in this study are in line with those reported by Yao et al. (2019) that compared to the treatment of lime and biochar separately, the combination of lime 1.5 g kg^{-1} and biochar 10 g kg^{-1} on acidic soil (Orthic Acrisol, pH H_2O = 5.5;

exchangeable Al = 4.17 cmol(+) kg^{-1}) yielded the highest nodulation in rice bean (*Phaseolus calcaltus*) plants, with the number of nodules 122.5 nodules pot^{-1} and nodule weight 4.48 g pot^{-1}.

The effectiveness of the nodules can be seen from the color of the inside of the nodules. Nodules with red color inside were found to be dominant in the treatments T3 to T11. The red color in the inside of the nodule associated with leghemoglobin indicated the effectiveness of rhizobium in fixing nitrogen (Hensley et al., 2021). In the treatments of T0, T1, T2, it was found that the inside nodules were white in color. The white color inside of the nodule was used as an indicator to show the ineffectiveness of rhizobium in fixing free nitrogen (Dupont et al., 2012).

Based on the results of Pearson correlation, the variables of plant tissue P content and plant P uptake showed a significant negative correlation with exchangeable Al ($r = -0.335$; $p<0.05$ and $r = -0.221$; $p<0.05$), which indicated that decreasing exchangeable Al according to the treatments, was followed by the increase in plant tissue P content and P uptake. It is important to note that the highest P uptake was obtained by the treatment of T10, which clearly explains that the highest decrease of exchangeable Al (obtained by T1 and T2) was not followed by the highest increase in P uptake. Thus, it proved that the treatment of T10 facilitated a decrease of exchangeable Al and, at the same time, contributed to the supply P nutrient. Similar results were reported by Ayodele and Shittu (2014) and Rabileh et al. (2015), that the combination treatments of lime and organic matter resulted in a significant decrease of exchangeable Al and also the highest maize P uptake on Ultisol. Variables of plant tissue K content and plant K uptake showed a negative and significant correlation with exchangeable Al ($r = -0.411$; $p<0.01$ and $r = -0.306$; $p<0.05$), which indicated that as exchangeable Al decreased in the soil, there was an increase in soil tissue K content and plant K uptake. Rabileh et al. (2015) reported that the highest maize K uptake was obtained in the combination treatment of 20 t ha^{-1} biochar and 2 t ha^{-1} dolomite, along with decreasing exchangeable Al.

Thus, the treatment of T10 yielded the highest plant growth, based on the measurement of variables of plant dry weight and nutrient uptake (N, P, K). This result confirmed that the variable of plant height was not always a key indicator to determine plant growth status since, in some cases, the highest plant height was not always followed by the highest plant fresh and dry weight and/or the highest plant nutrition status.

Conclusion

Applying 100% calcite and 100% dolomite gave the highest results in reducing exchangeable Al and increasing soil pH and available P. However, applying these treatments did not produce better growth and nodules of peanut plants compared to the combination treatment with organic matter. The highest peanut plant growth was obtained in the treatment of 25% dolomite + 25% rice straw compost + 25% dry cow dung + 25% NPK (T10), while the highest nodulation was obtained from the treatment of 50% rice straw compost + 50% dry cow dung (T7) and 25% dolomite + 75% rice straw compost (T8).

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