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IMPROVING FERTILITY OF ACID SULFATE SOIL USING VARIOUS LIME SOURCES FOR RICE GROWN IN MALAYSIA

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ABSTRACT

The main problems of acid sulfate soils are high acidity and Al and/or Fe toxicity to the soil. This problem causes rice root inhibition, hence retard plant nutrient uptake for its growth. Improving these conditions is important; hence, liming seems to be a common practice to ameliorate this soil, especially for rice cultivation. A study was conducted to evaluate the effects of applying ground magnesium limestone (GML), hydrated lime and liquid lime on the growth of rice under glasshouse conditions. MR 219 rice variety was used in this experiment. It was found that the application of 4 t ha^{-1} of GML had produced the highest rice yield of 8.2 t ha^{-1} under glasshouse condition. The result showed that as panicle length increase, spikelet per panicle also increases. Relative rice yield is negatively correlated with the soil pH, and this indicates that as soil acidity increase (observed with pH between 2 to 3), the rice yield decreases and vice versa. At harvest, due to liming practices, the soil pH exceeded 6 for all the treatment. It was also observed that as soil exchangeable Ca increase, soil pH also increases. Among the treatment, soil treated with 2 t ha^{-1} of hydrated lime gave the highest exchangeable Ca in the soil of 11.86 cmol$_c$ kg^{-1} soil with Ca concentration of 0.12% in the root. It was observed that liming increases soil pH and exchangeable cations in the soil. Therefore, liming is essential to ameliorate the acid sulfate soils for rice cultivation.

KEYWORDS

Acid Sulfate Soil, Aluminium, Ground Magnesium Limestone, Liming Materials, Rice, Soil Fertility.

INTRODUCTION

Rice feeds roughly half the planets' population, and approximately three-quarters of a billion of the world's most disadvantaged people depend on the staple to survive (Zeigler, 2007). Further improvement in rice productivity is needed in order to overcome the challenges of poverty and hunger. Rice plays a vital role in contributing to food and nutritional security, income generation, poverty alleviation and socio-economic growth of people. Rice yield needs to be increased by 43% in 30 years from 2000 to meet the demands of population growth in the world (Cassman, 1999).

Most of the acid sulfate soils in Malaysia are found in the coastal plains (Shamshuddin et al., 1995; Jusop Shamshuddin & Auxtero, 1991). The area covered by these soils is estimated at 0.5 million ha. Most often, these areas are left idle, and some are cultivated with rice-producing low yield. As such, on the west coast of Peninsular Malaysia, around 3000 ha in Merbok (Kedah) is cultivated with paddy, the yield is below the national average of 3.80 t ha^{-1} $season^{-1}$ due to low pH (marked with high acidity) and a high amount of Al and/or Fe of the acid sulfate soil (Jusop Shamshuddin, 2006; Jusop Shamshuddin & Auxtero, 1991). Rice root growth is often inhibited by Al^{3+} and Fe^{2+} toxicities. The critical Al concentration for rice variety MR 219 of 15 μM has been found by (Elisa et al., 2011). The high amount of Al in the soil environment (Shamshuddin et al., 2004) affects other crops such as cocoa (Shamshuddin et al., 2004) and oil palm growth (Auxtero & Shamshuddin, 1991).

There are several methods to improve the fertility of acid sulfate soils, and liming appears to be a standard method. Liming increases the soil pH and reduces aluminum toxicity, especially in an acid sulfate soil. Besides increasing the soil pH, lime (GML) also supplies Ca and Mg which are required in large amount for plant growth. In Merbok (Kedah), application of 2 t ha^{-1} GML annually could increase the rice yield from $<$ 2 to 4.5 t ha^{-1} $season^{-1}$ (Chaang et al., 1993). Similar results have been obtained by Elisa et al. (2014) for the rice yield in Merbok (Kedah), the yield increased up to 3.50 t ha^{-1} $season^{-1}$ by applying 4 t GML ha^{-1}. Therefore, the objective of this study was to determine the effects of lime application on the chemical properties of an acid sulfate soil and the growth of rice under glasshouse condition.

MATERIALS AND METHODS

Experimental Site and Preparation of media

A pot experiment was conducted at Field 10, Universiti Putra Malaysia (02°N 59.476' 101°E 42.867', 51 m altitude) under rain shelter. The paddy soil (acid sulfate soil) named Merbok Series, classified as *Typic Sulfaquept*, was obtained from Kampung Singkir Darat, Merbok, Kedah. The topsoil (0-15 cm) was then crushed and sieved before filling the pots. The pot dimension was 0.07 m^2 filled with 15 kg of mixed soil (uniformly mixed). The pots received various liming materials were watered at field capacity and left for 7 days to ensure that the moisture was well distributed. Before the application of treatments, soil samples were randomly collected from 10 pots (1 sample/pot) to determine the initial soil properties. These samples were air-dried, sieved (Endecotts® 2.0 mm sieve) and analyzed for soil texture, pH, EC, CEC, total C, available P, total N, exchangeable cations (K, Ca, Mg, Al) and extractable Fe. The results are given in Table 1.

TABLE 1. Selected chemical characteristics of the soil used in the experiment

Soil parameters	Value
Texture	clay loam
pH	4.67
CEC ($cmol_c\ kg^{-1}$)	10.3
Total C (%)	2.25
Avaialble P ($mg\ kg^{-1}$)	29.4
N (%)	0.23
Exchangeable K ($cmol_c\ kg^{-1}$)	0.13
Exchangeable Ca ($cmol_c\ kg^{-1}$)	6.68
Exchangeable Mg ($cmol_c\ kg^{-1}$)	3.03
Exchangeable Al ($cmol_c\ kg^{-1}$)	0.27
Extractable Fe ($mg\ kg^{-1}$)	388.5

Experimental design and treatments

The experiment consisted of 4 treatments, arranged in Complete Randomized Design (CRD), with 5 replications. The treatments were: (1) T1, no application of lime; (2) T2, 4 t ha^{-1} of ground magnesium limestone (GML); (3) T3, 2 t ha^{-1} of hydrated lime; (4) T4, 20 L ha^{-1} of liquid lime. Rice variety MR219, developed by the Malaysian Agricultural Research and Development Institute (MARDI), were planted in the pots. This variety was released in 2001 and is a widely cultivated rice variety in Peninsular Malaysia (Table 2). This variety was developed for tropical conditions.

TABLE 2. Selected agronomic characteristics of rice variety MR 219

Agronomic characteristics	Value
Growth duration (days)	104-119
Culm height (cm)	25.7
Number of tillers m^{-2}	485
Grain weight (1000 grains g^{-1})	28.3
Potential yield t ha^{-1}	8-9

Rice planting

The rice seeds were soaked with hormone-based chemical (Zappa™) solution for 48 hours. The ratio of Zappa™ to water was 0.3 L: 40 L for 40 kg of rice seeds. Then, the water was drained from the seeds and left for 24 hours. The pre-germinated seeds were then transferred to the soil with 20 seeds per pot. The soil was moistened at saturation in order to ensure suitable condition for the emergence of the seedlings. Two weeks after seeding (14 DAS), seedling numbers per pot were thinned to ten. After this period, the water level was maintained at 5 cm above the soil surface throughout the growing period until two weeks before harvesting in order to allow ripening and drying of grains.

The recommendations for fertilizer cultivation in Malaysia are based on the subsidiary fertilizer package and sustainable fertilizer package where the recommended fertilizer rate is 120 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}.

Grain yield components

At physiological maturity (PM) stage, five productive tillers per pot were randomly sampled and subjected to grain yield components analysis. The yield components analysis are total yield (g pot^{-1}), one-thousand-grain weights, the number of spikelet per panicle, % of filled spikelet, percentage of productive tillers and panicle length. PM was identified when grains on the lower portion of the secondary and tertiary panicles reached the hard dough stage and began to lose their green colour (Dobermann & Fairhurst, 2000). Spikelets were stripped off from the panicles by threshing the panicles with hand and removing all rachis and branches. The number of grains per panicle was obtained by dividing the total number of grain on an average hill by the total number of panicles on the hill, as shown in the following equation:

SpNoPan = GNoH/PanNoH

Where
SpNoPan = Spikelet number per panicle.
GNoH = Total grain number on an average hill.
PanNoH = Panicle number on average hill.

The percentage of filled grains was calculated by determining the ratio of the number of fully ripened grains (filled grains) to the total number of grains on the average hill. The filled grains were separated from unfilled grains using seed separator.

% Filled Spikelets = [FSpW / (FSpW + UFSpW)] x 100

Where

FSpW = Filled spikelet weight

UFSpW = Unfilled spikelet weight

The filled grains were again dried in an oven for 48 hours to attain complete oven- dryness (about 14% in moisture content). The 1000-dried grains from each pot were accurately weighed with a 2-decimal electronic balance (AND GF-3000, Japan) to determine the weight of filled spikelet. Grain yield was taken from the whole pot and expressed in grams (g) per pot.

Soil analysis

About 500 grams of soil were sampled from each experimental pot at harvest. The soils were air-dried, sieved (Endecotts® 2.0 mm sieve) and analyzed. The analysis consists of soil texture, soil pH, cation exchange capacity (CEC), exchangeable cations (K, Ca, Mg, Al), available P, total nitrogen and carbon and extractable Fe as described in Carter & Gregorich (2008). Soil pH measurement was carried out by adding 25 mL of de-ionized water to 10 g of air-dried soil in a capped plastic vial, followed by 30 minutes shaking at 150 rpm. The pH was recorded using a pH meter (PHM 93 Radiometer) after 24 hours. The method to determine exchangeable basic cations (Ca^{2+}, Mg^{2+} and K^{+}) and CEC was done simultaneously. Exchangeable basic cations were extracted using 1 M NH_4OAc (ammonium acetate) method. Briefly, exchangeable basic cations were determined by saturating 10 g air-dried soil samples with 100 mL of NH_4OAc at pH 7. The supernatants were made up to volume with NH_4OAc. The exchangeable bases (Ca, Mg and K) were determined using atomic absorption spectrophotometer (Perkin Elmer 5980 AAS spectrophotometer). Excess NH_4OAc was removed with 95% of ethanol, and the total amounts of NH_4^+ retained in the soil were extracted with 0.05 M K_2SO_4. NH_4^+ was determined by the AutoAnalyzer (AA). Determination of exchangeable Al was done using 5 g of air-dried soil extracted with 50 mL of 1 M KCl. The mixture was shaken for 30 minutes and filtered using filter paper (Whatman No. 42) before determining the Al by AAS. Fe was extracted using the double acid method that is 0.05 N HCl in 0.025 N H_2SO_4 as extracting agent. Thus, for Fe extraction, 5 g of air-dried soil was mixed with 25 mL of extracting agent and shaken for 15 minutes at 180 rpm. The supernatant was then filtered using filter paper (Whatman No. 42), and the Fe was determined using AAS. Total carbon and nitrogen were determined using CNS analyzer. Available P was determined by the method of Bray & Kurtz (1945).

Plant analysis

The upper part and roots of the rice plants were separately oven-dried at 65 ºC for three days. The samples were ground using a stainless-steel grinder and passed through a 1 mm sieve (Endecotts® sieve). The samples (0.25 g) were digested by using 1:1 ratio H_2SO_4-H_2O_2 on a block digester at 350 ºC. The digested solutions were made up to a volume of 100 mL with distilled water and filtered through Whatman filter paper No. 42. The concentration of calcium (Ca), magnesium

(Mg), aluminium (Al) and iron (Fe) was measured using AAS. The nitrogen (N), phosphorus (P) and potassium (K) in the plant tissue were measured using the auto-analyzer (AA).

Water analysis

Water in the pots was sampled at 14, 21, 35, 49 and 63 DAS. The water samples were filtered using filter paper Whatman No.42 for determinations of pH, aluminium (Al) and iron (Fe) content. The pH was measured using pH meter (PHM 93 Radiometer), while Al and Fe concentrations were determined using AAS.

Statistical analysis

Data from the experiment were analyzed statistically using Analysis of Variance (ANOVA) and Least Significant Difference (LSD) test to determine the significance of the differences between treatments. Correlation analysis (r) between measured characteristics was performed by using Pearson's correlation coefficients (CORR procedure of SAS). The statistical package used was SAS statistical software package (Version 9.1).

RESULTS AND DISCUSSION

Initial chemical properties of the soil

The pH and exchangeable Al of the topsoil was 4.67 and 0.27 $cmol_c\ kg^{-1}$ (89.91 µM), respectively (Table 1). The pH and the Al concentration of the water collected from the soil pit were 3.70 and 878 µM, respectively. Hence, the observed Al concentration is far above the critical toxic level of 74 µM for rice growth, as stated by Dent (1986). Elisa Azura et al. (2011) found that the favourable pH is 6 and the critical Al concentration is 15 µM for optimal root growth of rice (variety MR 219). Hence, the growth of rice root would be inhibited with the presence of high Al concentration in water. Cate & Sukhai (1964) found that some acid-tolerant rice seedlings start to show Al toxicity at 925 µM. These indicate that the selection of rice variety to be planted in the field plays a vital role in the rice tolerant mechanism towards Al toxicity (Elisa et al., 2011) and subsequently, their yield.

Rice yield component

Table 3 shows the results of rice yield components. No significant differences were observed for 1000 grain weight, percentage of filled spikelet and percentage of productive tillers among the treatments. Meanwhile, there were significant differences observed for total rice yield, number of spikelet per panicle and panicle length between treatments.

Rice yield was increased by 11% with the application of 4 t ha^{-1} of GML. Soil treated with GML was significantly different compared to control (no lime). Means comparison show that application of 4 t ha^{-1} of GML gave the highest number of spikelet per panicle with the value of 134 and it is significantly different from treatment with 20 L ha^{-1} of liquid lime.

TABLE 3. Effect of various liming sources on the rice yield components

Treatments	Yield (g pot^{-1})	[1]Yield (t ha^{-1})	1000 grain weight (g)	number of spikelet/ panicle	% filled spikelet	% of productive tillers	Panicle length (cm)
Control (no lime)	50.81^{b}	7.25^{b}	24.25^{a}	129^{ab}	80.89^{a}	98.46^{a}	23.65^{ab}
4 t ha^{-1} GML	57.62^{a}	8.23^{a}	24.04^{a}	134^{a}	80.51^{a}	98.72^{a}	23.27^{ab}
2 t ha^{-1} HL	56.50^{a}	8.07^{a}	23.94^{a}	124^{ab}	80.14^{a}	96.97^{a}	23.02^{b}
20 L ha^{-1} LL	55.57^{ab}	7.93^{ab}	24.08^{a}	119^{b}	80.32^{a}	97.01^{a}	23.77^{a}

Note: Means followed by the same letter within a column are not significantly different (LSD's test, P > 0.05).
[1]Conversion of yield from g pot^{-1} to t ha^{-1}

The spikelet per panicle was positively correlated with panicle length (Figure 1), and the relationship is given by the equation of $y = 17.78x - 290.15$ (R=0.89). Besides, it was found that the relative rice yield was negatively correlated with soil pH (Figure 2), and the relationship is given by the equation $y = -23.87x+241.66$ (R=0.75). The soil pH equivalent to 90% relative yield is 6.3, which is similar to Elisa et al. (2011).

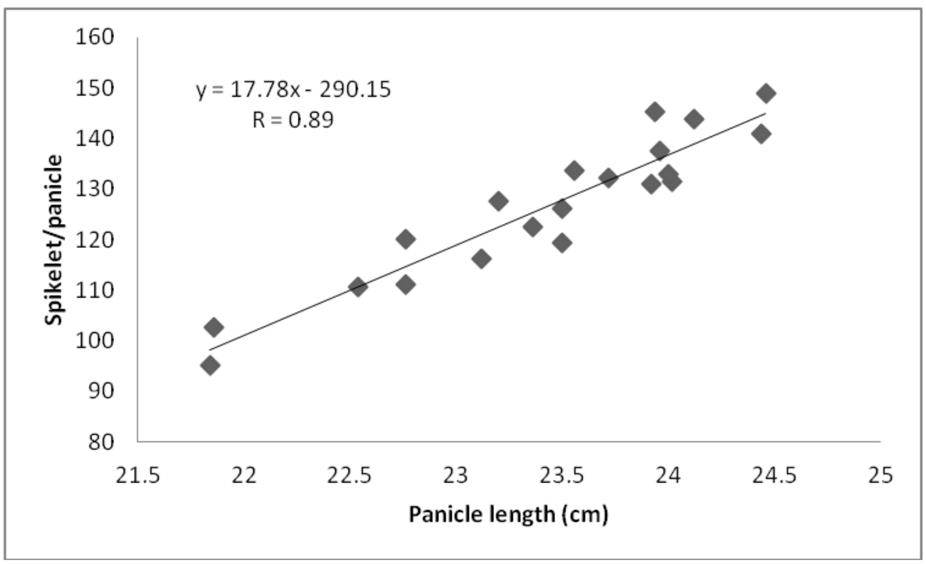

FIGURE 1. Linear correlation between panicle length and number of spikelets per panicle of paddy. Solid line indicates a significant positive linear relationship at P ≥ 0.05.

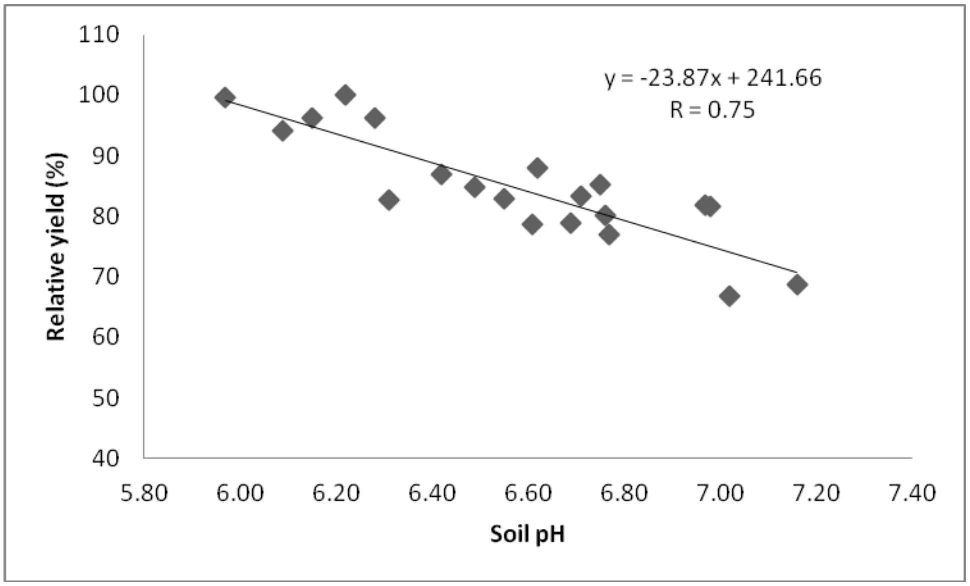

FIGURE 2. Linear correlation between soil pH and relative yield of paddy. Solid line indicates a significant negative linear relationship at P ≥ 0.05.

Effect of liming on selected chemical soil properties after harvest

Table 4 shows the effect of various lime sources on the selected soil chemical properties at harvest. There was no significant difference was observed between soil pH treated with 2 t ha^{-1} of hydrated lime and 4 t ha^{-1} of GML. The soil pH for soil received with 2 t ha^{-1} hydrated lime and 4 t ha^{-1} of GML increased from 4.3 (initial soil pH) to 6.96 and 6.73 (at harvest soil pH), respectively. The untreated soil (control) showed an increase in soil pH from 4.30 to 6.34 due to proton consumption during the reduction of Fe (III) to Fe (II). This study shows that soil pH increased to a value above 5, and when this happens, Al exists in the form of Al-hydroxides. Thus, Al toxicity to the growing crop was minimized or nil. It was found that the exchangeable Al was decreased to less than 1 cmol$_c$ kg^{-1} soil for entire treatments, a condition suitable for rice growth. Higher pH in the soil is reflected by lower Al concentration.

TABLE 4. Soil pH, exchangeable cations (K, Ca, Mg, Al) extractable Fe and available P at harvest

Treatments	pH water (1:2.5)	Exchangeable cations				Extractable	Available
		K	Ca	Mg	Al	Fe	P
		(cmol$_c$ kg^{-1})					(mg kg^{-1})
Control (no lime)	6.34^{c}	0.05^{a}	8.03^{b}	2.24^{a}	0.06^{a}	1.92^{a}	27.14^{a}
4 t ha^{-1} GML	6.73^{ab}	0.05^{a}	10.56^{ab}	2.47^{a}	0.05^{a}	1.64^{a}	29.47^{a}
2 t ha^{-1} HL	6.96^{a}	0.05^{a}	11.86^{a}	2.37^{a}	0.05^{a}	1.69^{a}	29.14^{a}
20 L ha^{-1} LL	6.55^{bc}	0.06^{a}	8.99^{ab}	2.82^{a}	0.06^{a}	1.64^{a}	30.06^{a}

Note: Means followed by the same letter within a column are not significantly different (LSD's test, P > 0.05).

In response to the lime application, exchangeable Ca was increased significantly. Means comparison show that the untreated soil had the lowest exchangeable Ca with a value of 8.03 $cmol_c\ kg^{-1}$. The exchangeable Ca had increased from 6.68 (initial) to 11.86 $cmol_c\ kg^{-1}$ for soil treated with 2 t ha^{-1} hydrated lime. This value has passed the critical limit of 2 $cmol_c\ kg^{-1}$ soil (Palhares de Melo et al., 2001). According to Jusop Shamshuddin et al. (1991), high Ca content to a certain extent, was able to reduce Al toxicity. Besides, the presence of Mg was able to reduce the toxic effect of Al (Sanchez, 2019). A positive relationship was observed between soil pH and exchangeable Ca. This is shown by the equation $y = 9.61\times - 53.69$ with $R=0.72$ (Figure 3).

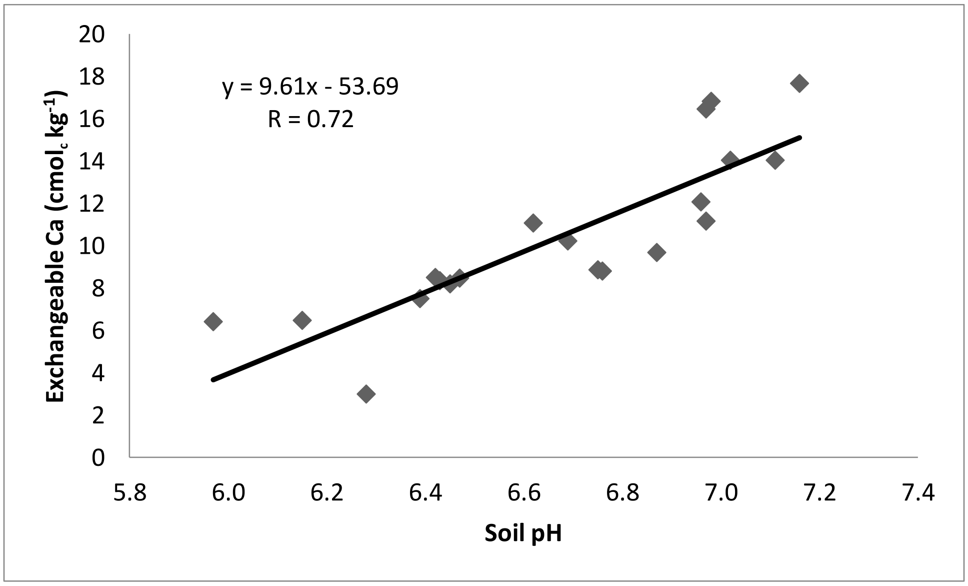

FIGURE 3. Linear correlation between soil pH and exchangeable Ca. Solid line indicates a significant positive linear relationship at $P \geq 0.05$.

From this study, it was found that adding GML to an acid sulfate soil was not able to increase the exchangeable Mg significantly, contradictory to that of (Jusop Shamshuddin et al., (1991), who found that Mg released from the GML dissolution, contribute to the alleviation of Al toxicity. In this study, the amount of exchangeable Mg was more than 2 $cmol_c\ kg^{-1}$, and these values are well above the sufficiency level of exchangeable Mg of 1 $cmol_c\ kg^{-1}$ for rice growth (Dobermann & Fairhurst, 2000).

Application of 4 t ha^{-1} of GML on acid sulfate soils manages to increase the soil pH to about 4.50 (Jusop Shamshuddin, 2006; Shazana et al., 2013). GML ameliorates the soil according to the following reactions:

$$(Ca, Mg)(CO_3)_2 \rightarrow Ca^{2+} + Mg^{2+} + CO_3^{2-} \quad \text{(equation 1)}$$

$$CO_3^{2-} + H_2O \rightarrow HCO_3^{-} + OH^{-} \quad \text{(equation 2)}$$

$$Al^{3+} + 3OH^{-} \rightarrow Al(OH)_3 \quad \text{(equation 3)}$$

The GML dissolves readily on applying it into the acidic soil, releasing Ca and Mg (equation 1), and these macronutrients could be taken up by the growing rice plants. Subsequently, the hydrolysis of CO_3^{2-} (equation 2) would produce hydroxyls that neutralize Al by forming inert Al-hydroxides (equation 3). There are several advantages to using GML. Sanchez (2019) reported that the toxic effect of Al could be reduced with the presence of Ca and Mg. Figure 4 shows the relationship between Ca content in the root and exchangeable Ca in the soil. The line was shifted to the right due to the application of 4 t ha^{-1} of GML. This implies that the application of GML to the soil would supply extra Ca for rice uptake. The increased availability of exchangeable Ca in the soil, the more is the Ca uptake by rice root for rice growth.

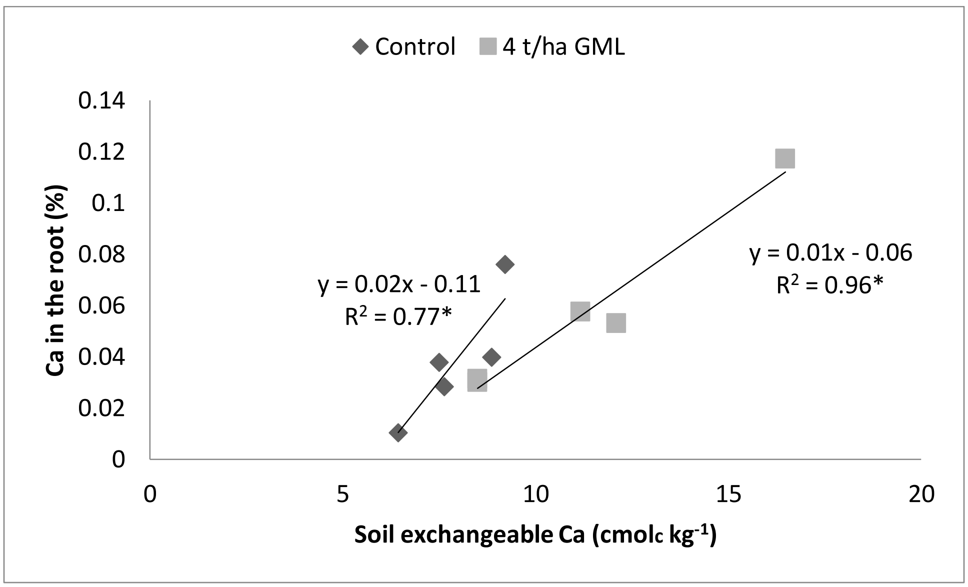

FIGURE 4. Linear correlations between soil exchangeable Ca and percentage of Ca in the root for a) control and 4 t/ha GML. Solid line indicates a significant positive linear relationship at $P \geq 0.05$.

Rice needs 7-20 mg kg^{-1} of P for its good growth (Dobermann & Fairhurst, 2000). It was found that the available P at harvest was sufficient and above the value of 20 mg kg^{-1}, and there was no significant difference among the treatments (Table 5).

The high amount of Fe would cause Fe^{2+} toxicity to rice plant. The most common Fe toxicity symptom is necrosis of the leaves, and other symptoms are dark green foliage, stunted growth and root growth as well as leaf bronzing (Dobermann & Fairhurst, 2000). In this study, acid-extractable Fe was high, which were in the range of the critical level of 0.05-5.37 $cmol_c$ kg^{-1} soil (Dobermann & Fairhurst, 2000). Fe concentration in the root was positively correlated with the Fe in the soil (Figure 5). It means that as the Fe in the soil increased, more Fe was taken up by the roots.

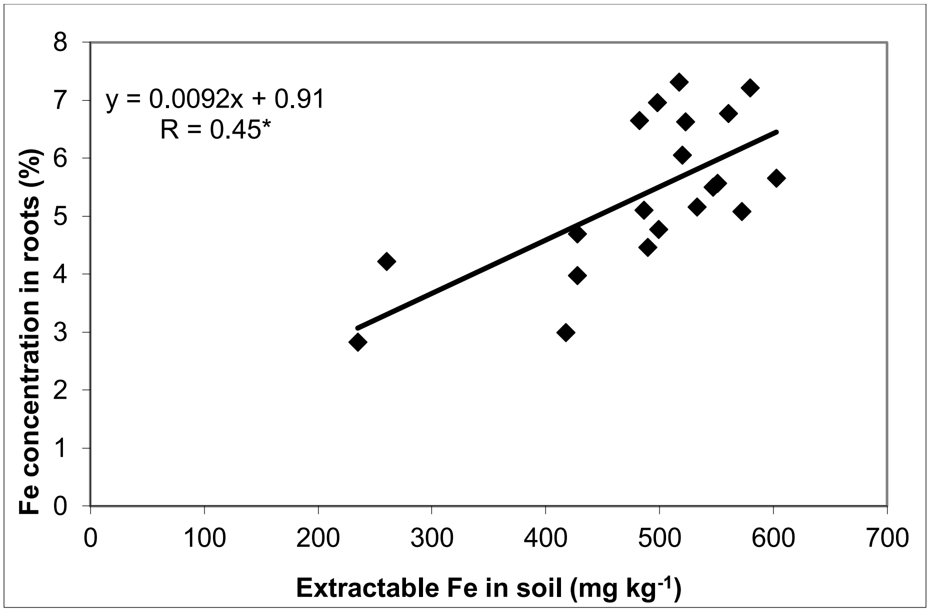

FIGURE 5. Linear correlation between extractable Fe in the soil and percentage of Fe in the roots. Solid line indicates a significant positive linear relationship at P ≥ 0.05.

Mineral composition of the rice plant

Table 5 shows the concentration of nutrients in the upper part and the roots of the rice plant at harvest. There is no significant difference observed for N, P, K, Ca, Mg, Fe and Al between the treatments for the upper parts of the rice plant. However, the nutrient concentration of Ca in the rice roots shows a significant difference for the soil treated with 2 t ha^{-1} of hydrated lime from the control. This result is consistent with exchangeable Ca of the soil treated with 2 t ha^{-1} of hydrated lime. Liming had increased the uptake of Ca.

TABLE 5. Nutrient concentration in the upper part (a) and root (b) of rice plant at harvest

a

Treatments	N	P	K	Ca	Mg	Fe	Al
	----------------------------------Upper part(%)----------------------------------						
Control (no lime)	0.52^a	0.02^a	1.40^a	0.72^a	0.14^a	0.04^a	0.10^a
4 t ha^{-1} GML	0.55^a	0.03^a	1.24^a	0.77^a	0.14^a	0.05^a	0.09^a
2 t ha^{-1} HL	0.47^a	0.03^a	1.48^a	0.75^a	0.12^a	0.04^a	0.13^a
20 L ha^{-1} LL	0.48^a	0.03^a	1.26^a	0.74^a	0.11^a	0.03^a	0.10^a

b

Treatments	N	P	K	Ca	Mg	Fe	Al
	-----------------------------------Root (%)-----------------------------------						
Control (no lime)	0.63[a]	0.05[a]	0.15[a]	0.05[b]	0.11[a]	4.62[a]	1.31[a]
4 t ha^{-1} GML	0.67[a]	0.05[a]	0.12[a]	0.09[ab]	0.11[a]	5.29[a]	1.25[a]
2 t ha^{-1} HL	0.69[a]	0.05[a]	0.16[a]	0.12[a]	0.13[a]	4.54[a]	1.06[a]
20 L ha^{-1} LL	0.67[a]	0.05[a]	0.14[a]	0.07[ab]	0.12[a]	4.70[a]	1.41[a]

***Note**:* Means followed by the same letter within a column are not significantly different (LSD's test, $P > 0.05$).

Changes of pH, Al and Fe in water

Figure 6 shows the pH, Al and Fe concentration of water in the pots. It is known that application of GML would increase the pH. Figure 6a has shown that the pH of the water for soil treated with GML and hydrated lime is higher compared to liquid lime and untreated soil. Thirty days after sowing, the pH of the water had increased to pH 8. the pH of the water in the pot treated with hydrated lime had increased from 7.12 at 14 DAS to 8.27 at 21 DAS. The maximum pH achieved was 8.44 at 49 DAS due to application of 2 t ha^{-1} of hydrated lime. The pH of the water decreased shortly after 21 DAS for all treatments except for soil treated with 2 t ha^{-1} of hydrated lime. A decrease followed the increase in pH in Al concentration (Figure 6b). Likewise, the concentration of Fe decreased, and the pH increased (Figure 6c).

After two weeks, the Al concentration in the water was 0.4 mg L^{-1}. After that, the pH of the water decreased with a concomitant increase in Al and Fe concentrations due to changes in the acidity of the soil related to the precipitation and reduction of Al and Fe, respectively. These precipitation-reduction processes in the water-system may increase the H^+ ion availability in the soil solution system. This ion increases the soil pH; therefore, it is plausible that the presence of such ions in the soil has elevated the pH level as observed in Figure 6. It is also plausible that, at 35 DAS onward, the Al and Fe reaches equilibrium in the water-system; hence the pH becomes more stable and not much change were observed hereafter.

Meanwhile, for the untreated soil, it was found that Al concentration changed from 0.13 mg L^{-1} at 14 DAS to 1.4 mg L^{-1} at 21 DAS. A similar trend occurred for Fe concentration; it increased from 0.141 mg L^{-1} at 14 DAS to 0.784 mg L^{-1} at 21 DAS. There was a decrease of Fe concentration with the increase in pH of the water at 35 DAS. When pH was raised to about 7, Fe concentration of the water was reduced to < 0.5 mg L^{-1} and this level is considered favourable for rice growth. This shows that soil treated with 2 t ha^{-1} of hydrated lime and 4 t ha^{-1} of GML was able to increase pH of the water and concomitantly reduced the Al and Fe concentrations in the water to the level required for good growth of rice. Figure 7 and 8 show the relationship between pH and Al and pH and Fe concentration of the water, respectively. The relationship is presented by the equation $Y= -3.51\ln(x) + 7.63$ (R=0.68) and $Y= -1.35\ln(x) + 2.96$ (R=0.51), respectively. It means that as the Al or Fe in the water decreased, the pH decreased.

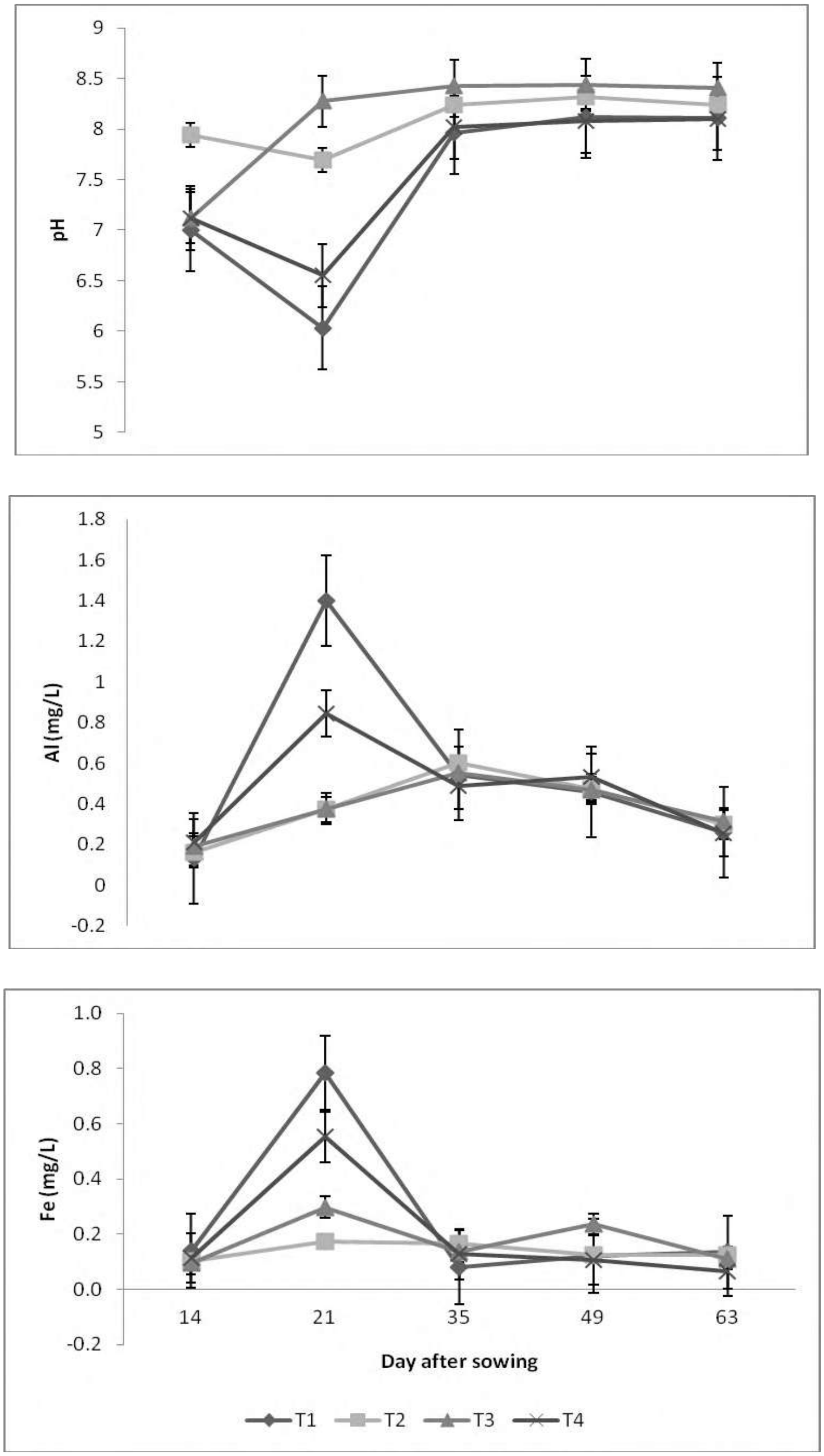

FIGURE 6. Changes in water pH (a), Al (b) and Fe (c) with time

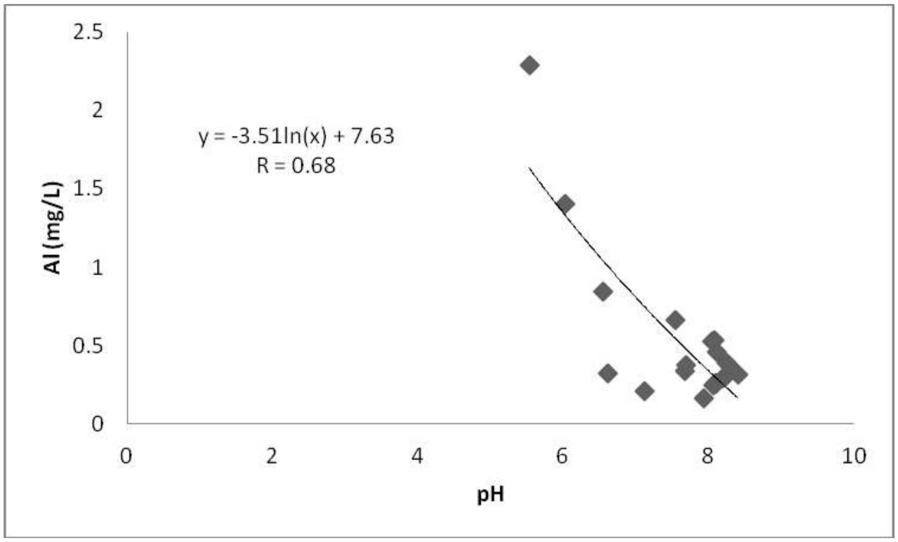

FIGURE 7. Relationship between pH and Al in the water

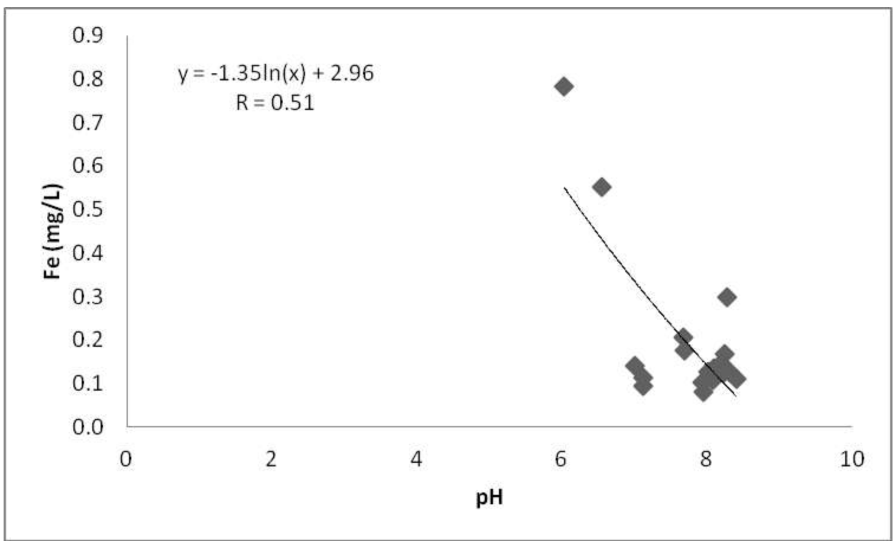

FIGURE 8. Relationship between pH and Fe in the water

CONCLUSION

From this study, the application of 4 t ha-1 GML is the preferable liming material. Soil treated with GML was alleviated soil acidity by increase the soil pH and produced the rice yield significantly.

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