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Effects of Various Liming Materials on the Growth of Rice under Rainshelter Condition

Azman, Elisa Azura[1*], Jusop, Shamshuddin[2] & Ismail, Roslan[2]

[1]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, UPM, Serdang, 43400, Selangor Darul Ehsan, MALAYSIA

[2]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, UPM, Serdang, 43400, Selangor Darul Ehsan, MALAYSIA

*Corresponding author: elisa@upm.edu.my

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Abstract: A study was conducted to evaluate the effects of liming materials on the growth of rice under rainshelter conditions and MR 219 rice variety was used in this experiment. 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. 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}. 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 decrease and vice versa. At harvest, 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, rice, soil fertility

1. Introduction

Rice feeds roughly half the planet's 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 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. Rice yield needs to be increased by 43% in 30 years from 2000 to meet the world's population growth demands (Cassman, 1999).

Most of the acid sulfate soils in Malaysia are found in the coastal plains (Enio et al. 2011; Muhrizal et al., 2006; Shamshuddin & Auxtero, 1991; Shamshuddin, Jamilah, & Ogunwale, 1995). 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. On the west coast of Peninsular Malaysia, around 3000 ha in Merbok (Kedah) is cultivated with paddy. In Merbok (Kedah), 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, 2006; 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 (Azura, Shamshuddin, & Fauziah, 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 aluminium toxicity, especially in an acid sulfate soil. Besides increasing the soil pH, lime (GML) also supply Ca and Mg, which are required for plant growth. In Merbok (Kedah), the 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). Azman et al. (2014) increased rice yield in Merbok (Kedah) up to 3.50 t ha^{-1} season^{-1} by applying 4 t GML ha^{-1}. This study aimed to determine the effects of lime application on the chemical properties of an acid sulfate soil and rice growth under rain shelter conditions.

**Corresponding author: elisa@upm.edu.my*

2. Materials and Methods

2.1 Experimental Site and Preparation of Soil-based Media

A pot experiment was conducted at Field 10, Universiti Putra Malaysia (02°N 59.476' 101°E 42.867', 51 m altitude) under a rain shelter (Figure 1). The paddy soil named Merbok Series, classified as *Typic Sulfaquept*, was obtained from Kampung Singkir Darat, Merbok, Kedah. The obtained 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 were then applied with various liming materials such as GML, hydrated, and liquid lime. The pots 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 (Table 1). These samples were air-dried, sieved (Endecotts® 2.0 mm sieve) and analyzed for soil texture, pH, EC, CEC (Chapman, 1965), total C, available P was determined by the method of Bray & Kurtz (1945), total N, exchangeable cations (K, Ca, Mg, Al) (Ross & Ketterings, 1995) and extractable Fe (Elisa et al., 2016). The results are given in Table 1.

Fig 1: Picture showing experimental pots under glasshouse condition

Table 1: Selected chemical characteristics of the soil used in the experiment

Soil parameters	Value
Texture	clay loam
pH	4.67
EC (dS/m)	0.78
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

2.2 Treatments of the experiment

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. The rice plant, variety MR219, developed by the Malaysian Agricultural Research and Development Institute (MARDI), was 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

2.3 Planting Materials and Rice Cultivation

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 seeds. Then, the water was drained from the grains and left for 24 hours. The pre-germinated seeds were then transferred to the soil with 20 seeds per pot. After broadcasting the seeds, the soil was moistened at saturation to ensure suitable conditions 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 to allow grain ripening and drying.

The routine inspection was conducted to control the weed growth, and weeds were uprooted manually by hand every week. The purpose of conducting this research under the rain shelter's wire mesh is to act as a barrier against the entry of rodents and birds.

Table 3 shows the schedule of fertilizer application which the Malaysian government recommends to the farmers as a standard practice.

Table 3: Schedule for fertilizer application

DAS	Fertilizer Application	Rate (ha)
15	Subsidized NPK + NS	140 kg + 40 kg
20	40 mL Vitagrow™ + 70 mL Robust™ mixed with 13L of water	12 pump
35	Urea	80 kg
45	40 mL Vitagrow™ + 70 mL Robust™ mixed with 13L of water	12 pump
50-55	Subsidized NPK + NPK Blue	120 kg + 120 kg
60	40 mL Vitagrow™ + 70 mL Robust™ mixed with 13L of water	12 pump
75	Urea	20 kg

Note: DAS - Day after seeding. (Source from Program Pemindahan Teknologi Insentif Pengeluaran Padi Kerajaan Persekutuan)

2.4 Grain Yield and Yield Components

At the physiological maturity (PM) stage, five active tillers per pot were randomly sampled for determination of yield and yield components such as one-thousand filled grain weights, the number of spikelets per panicle, % filled spikelets, percentage of productive tillers and panicle length. Dobermann & Fairhurst (2000) recommended that 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. In this study, with rice variety MR 219, PM was attained at 110 DAS.

All the plant samples were cut at the soil surface. The soil and dust particles that adhered to the plant parts were carefully rinsed off with de-ionized water (Millipore® DI water system). The samples were placed in labelled paper bags and oven-dried at 70°C for 48 hours in the laboratory. After drying, the panicles were heated at 70°C for 48 hours, and their length was measured. After that, the filled and unfilled spikelets were stripped off the panicles, and this was attained by threshing the panicles by hand and removing all rachis and branches. Thus, the number of grains per panicle was obtained by dividing the total number of grains on an average hill by the total number of panicles on the hill, as shown in the following equation:

$$SpNoPan = \frac{GNoH}{PanNoH} \quad (1)$$

Where:

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

The % of filled grains was calculated by determining the ratio 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 a seed separator.

$$\%\ Filled\ Spikelets = [\frac{FSpW}{(FSpW + UFSpW)}] \times 100 \quad (2)$$

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 spikelets. Grain yield was taken from the whole pot and expressed in grams (g) per pot.

2.5 Soil and Plant and Water Analysis

About 500 grams of soil was sampled from each experimental pot at harvest. These samples were air-dried, sieved (Endecotts® 2.0 mm sieve) and analyzed for pH, cation exchange capacity (CEC), exchangeable cations (K, Ca, Mg, Al) and extractable Fe as described in Carter & Gregorich (2007). Soil pH was measured by adding 25 mL of de-ionized water to 10 g of air-dried soil in a capped plastic vial, followed by 30 minutes of shaking at 150 rpm and was recorded using a pH meter (PHM 93 Radiometer) after 24 hours. Exchangeable basic cations were extracted using the 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 Ca, Mg and K were determined using atomic absorption spectrophotometer (Perkin Elmer 5980 AAS spectrophotometer). Excess NH_4OAc was removed with 95% 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). The exchangeable Al was determined 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 of 0.05 N (0.05 M) HCl in 0.025 N (0.0125 M) H_2SO_4 as extracting agent. Thus, 5 g of air-dried soil was mixed with 25 mL of extracting agent for Fe extraction and shaken for 15 minutes at 180 rpm. The supernatant was filtered using filter paper (Whatman No. 42), and the Fe was determined using AAS.

The upper part and roots of the plants were separately oven-dried at 65ºC 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 then digested by wet ashing using 1:1 ratio H_2SO_4-H_2O_2 on a block digester at 350ºC. 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 in the pots was sampled at 14, 21, 35, 49 and 63 DAS. The water samples were filtered for determinations of pH, aluminium (Al) and iron (Fe). The pH was measured using a pH meter (PHM 93 Radiometer), while Al and Fe concentrations were determined using AAS.

2.6 Statistical Analysis

Data from the experiment were analyzed statistically using the Analysis of Variance (ANOVA) and Least Significant Difference (LSD) test to determine the significance of the differences between treatments. The statistical package used was SAS statistical software package (Version 9.1).

3. Results and Discussion

3.1 Initial Chemical Properties of the Soil

The pH and exchangeable Al of the studied topsoil were 4.67 and 0.27 $cmol_c$ kg^{-1} (89.91 µM), respectively (Table 1). Meanwhile, the subsoil's pH was very low (pH < 3.5), and the exchangeable Al was high. The acid sulfate areas of Merbok (Kedah) are believed to have been limed by the farmer's prior collection for this glasshouse study

On the other hand, 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 (Dent, 1986). 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, rice root growth 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 selecting rice varieties to be planted in the field plays a vital role in the rice tolerant mechanism toward Al toxicity (Azura et al., 2011) and their yield. Therefore, selecting the appropriate rice variety for rice cultivation in an acid sulfate soil is important.

3.2 Effect of Treatments on Rice Yield and its Component

Table 4 shows the results of rice yield and its yield components. Based on the LSD test, no significant differences were observed for 1000 grain weight, percentage of filled spikelet and percentage of productive tillers among the treatments. Meanwhile, significant differences were observed in total rice yield, the number of spikelets per panicle and panicle length between treatments.

Total rice yield was increased by 11%, and the yield could be as high as 8.23 t ha^{-1} with an application of 4 t ha^{-1} of GML. This value was based on the conversion of yield from each pot which is stated as g pot^{-1} (Table 4). Based on LSD, total rice yield was significantly increased compared to the control by application of 4 t ha^{-1} of GML or 2 t ha^{-1} of hydrated lime. Means comparison shows that application of 4 t ha^{-1} of GML gave the highest number of spikelets per panicle with the value of 134. It is significantly different for treatment with 20 L ha^{-1} of liquid lime.

This study observed that spikelet per panicle was related to the panicle length (Figure 2). It means that as the panicle length increased, the spikelet per panicle increased. The spikelet per panicle is positively correlated with panicle length, and the relationship is given by the equation Y= 17.78x – 290.15 (R=0.89). Besides that, it was found that relative rice yield was significantly related to the soil pH (Figure 3). The relative rice yield is negatively correlated with soil pH, 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 almost similar to that found by Azura et al. (2011).

Table 4: Rice yield and its 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)
T1	50.81^{b}	7.25^{b}	24.25^{a}	129^{ab}	80.89^{a}	98.46^{a}	23.65^{ab}
T2	57.62^{a}	8.23^{a}	24.04^{a}	134^{a}	80.51^{a}	98.72^{a}	23.27^{ab}
T3	56.50^{a}	8.07^{a}	23.94^{a}	124^{ab}	80.14^{a}	96.97^{a}	23.02^{b}
T4	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}

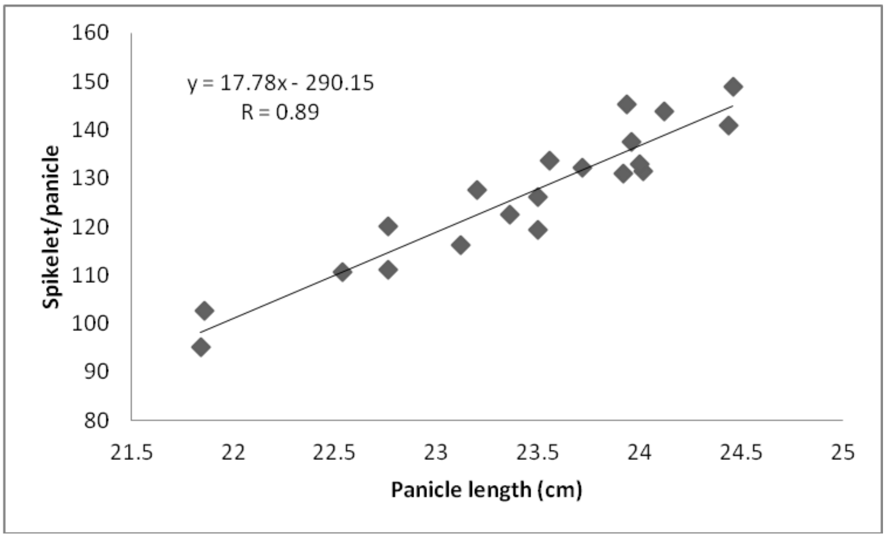


Fig 2: Relationship between panicle length and number of spikelets per panicle

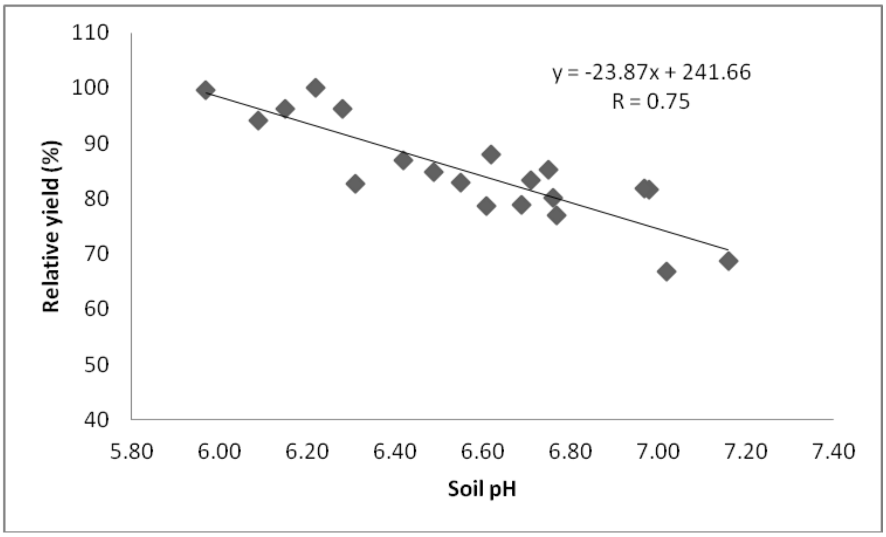


Fig 3: Relationship between soil pH and relative yield

3.3 Effect of Liming on Soil pH

The soil pH was high at harvest, with significant differences between the treatments as seen in the LSD test (Table 5). The means comparison shows that soil treated with 2 t ha-1 of hydrated lime gave the highest pH, while the untreated soil showed the lowest pH with 6.96 and 6.34, respectively. The pH for soil treated with 2 t ha^{-1} hydrated lime changed from 4.3 (initial soil pH) to 6.96 (at harvest soil pH). The untreated soil showed an increase in pH from 4.30 to 6.34 due to proton consumption during reducing 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, a condition suitable for rice growth. Higher pH in the soil is reflected by lower Al concentration. The difference in pH between the treated soils is probably due to the differences in the reaction of liming materials used.

Table 5: pH, exchangeable cations (K, Ca, Mg, Al), total N, extractable Fe, available P and total C at harvest

Treatments	pH water (1:2.5)	Exchangeable cations ($cmol_c$ kg^{-1})				N (%)	Fe	Available P	Total C (%)
		K	Ca	Mg	Al		(mg kg^{-1})		
T1	6.34^{c}	0.05^{a}	8.03^{b}	2.24^{a}	0.06^{a}	0.18^{a}	539.71^{a}	27.14^{a}	1.86^{a}
T2	6.73^{ab}	0.05^{a}	10.56^{ab}	2.47^{a}	0.05^{a}	0.19^{a}	457.93^{a}	29.47^{a}	1.97^{a}
T3	6.96^{a}	0.05^{a}	11.86^{a}	2.37^{a}	0.05^{a}	0.19^{a}	472.57^{a}	29.14^{a}	1.93^{a}
T4	6.55^{bc}	0.06^{a}	8.99^{ab}	2.82^{a}	0.06^{a}	0.19^{a}	460.30^{a}	30.06^{a}	1.92^{a}
LSD value	5.99	1.56	1.95	0.76	0.08	0.16	1.21	1.48	0.73

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

3.4 Effect of Liming on Exchangeable Ca and Mg

In response to the lime application, exchangeable Ca was increased significantly. Means comparison shows that the untreated soil had the lowest exchangeable Ca with a value of 8.03 $cmol_c$ kg^{-1}. Adding liming material increased the exchangeable Ca of the soil, as shown in Table 5. The exchangeable Ca had increased from 6.68 to 11.86 $cmol_c$ kg^{-1} soil with the application of 2 t hydrated lime ha^{-1}. This value has passed the critical limit of 2 $cmol_c$ kg^{-1} soil (Palhares & Peres, 2000). According to Alva, Asher, & Edwards (1986) and Shamshuddin, Fauziah, & Sharifuddin (1991), high Ca content, to a certain extent, was able to reduce Al toxicity. In addition, the presence of Mg reduced the toxic effect of Al (Sanchez, 2019; Bohn, Myer, & O'Connor, 2002). It is seen that soil pH increased as the exchangeable Ca increased. This is shown by the equation $Y = 0.68\ln(x) + 5.13$ with $R=0.67$ (Figure 4).

This study found that adding GML to an acid sulfate soil was not able to increase the exchangeable Mg significantly. This result contradicts that of (Shamshuddin et al., 1991), who found that Mg released from the GML dissolution contributes 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).

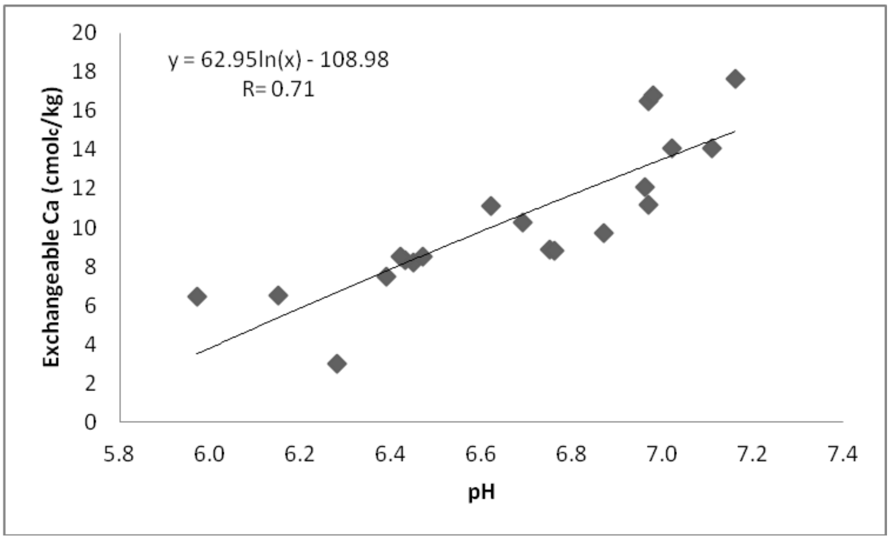


Fig 4: Relationship between exchangeable Ca and soil pH at harvest

3.5 Phosphorus Deficiency

Rice needs 7-20 mg kg^{-1} of P for good growth (Dobermann & Fairhurst, 2000). In this study, it was found that the available P at harvest was less than 5 mg kg^{-1}, and there was no significant difference among the treatments (Table 5). However, the rice growth was not significantly affected by the low available P. It was likely that Al and Fe present immobilized P in the soil via the formation of insoluble $AlPO_4$ or $FePO_4$.

3.6 Iron Toxicity

The high amount of Fe would cause Fe^{2+} toxicity to the rice plant. The most common Fe toxicity symptom is necrosis of the leaves; other symptoms are dark green foliage, stunted growth and root growth, and leaf bronzing. In this study, acid-extractable Fe was high, slightly above the critical level of 0.05-5.37 $cmol_c$ kg^{-1} soil (Dobermann & Fairhurst, 2000). Fe concentration in the root positively correlates 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. The relationship between Fe in the root and Fe in the soil is given by the equation Y= 3.51ln(x) - 16.26 (R=0.43).

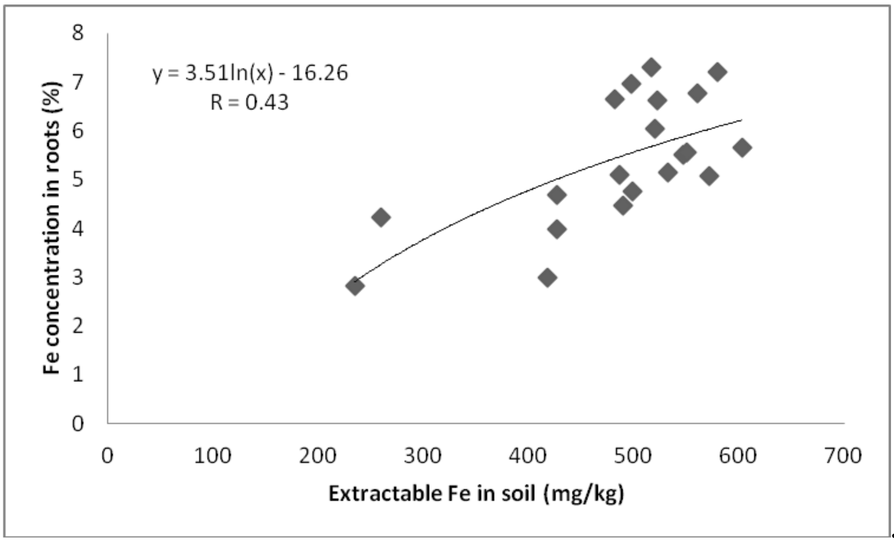


Fig 5: Relationship between extractable Fe in soil and Fe concentration in the roots

3.7 Mineral Composition of the Rice Plant

Table 6 shows the concentration of nutrients in the upper part and the roots of the rice plant at harvest. Means comparison shows that treatment with 2 t ha^{-1} of hydrated lime is significantly different from that of the control. This result is consistent with the exchangeable Ca of the soil treated with 2 t ha^{-1} of hydrated lime. Liming had increased the uptake of Ca.

Table 6: The concentration of nutrients in the upper part (a) and root (b) of rice plant at harvest

a Treatments	N	P	K	Ca	Mg	Fe	Al
	Upper part(%)						
T1	0.52^a	0.02^a	1.40^a	0.72^a	0.14^a	0.04^a	0.10^a
T2	0.55^a	0.03^a	1.24^a	0.77^a	0.14^a	0.05^a	0.09^a
T3	0.47^a	0.03^a	1.48^a	0.75^a	0.12^a	0.04^a	0.13^a
T4	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 (%)						
T1	0.63^a	0.05^a	0.15^a	0.05^b	0.11^a	4.62^a	1.31^a
T2	0.67^a	0.05^a	0.12^a	0.09^{ab}	0.11^a	5.29^a	1.25^a
T3	0.69^a	0.05^a	0.16^a	0.12^a	0.13^a	4.54^a	1.06^a
T4	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)

3.8 GML as a Liming Material

Hydrated lime reacts more rapidly with soil than carbonate forms (Brady, 1974). However, the application of dolomitic limestone is preferred because it sustains longer in the soil. Applying 4 t ha^{-1} of GML on acid sulfate soils increases the soil pH to about 4.50 (Muhrizal et al., 2006; Shazana et al. 2014, 2013). Applying GML at a higher rate is uneconomical and not sustainable in the long run. GML ameliorates the soil according to the following reactions:

$$(Ca, Mg)(CO_3)_2 \rightarrow Ca^{2+} + Mg^{2+} + CO_3^{2-} \quad (3)$$
$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^- \quad (4)$$
$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3 \quad (5)$$

The GML dissolves readily on applying it to the acidic soil, releasing Ca and Mg (3), and these macronutrients could be taken up by the growing rice plants. Subsequently, CO_3^{2-} (4) hydrolysis would produce hydroxyls that neutralize Al by forming inert Al-hydroxides (5). There are several advantages to using GML. Sanchez (2019) and Bohn et al. (2002) reported that the toxic effect of Al could be reduced with the presence of Ca and Mg. GML's ameliorative effects can last longer than that of hydrated lime. Figure 6 shows the relationship between Ca content in the root and exchangeable Ca. The line was shifted to the right due to applying 4 t ha^{-1} of GML, which 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 the Ca uptake by rice roots for rice growth.

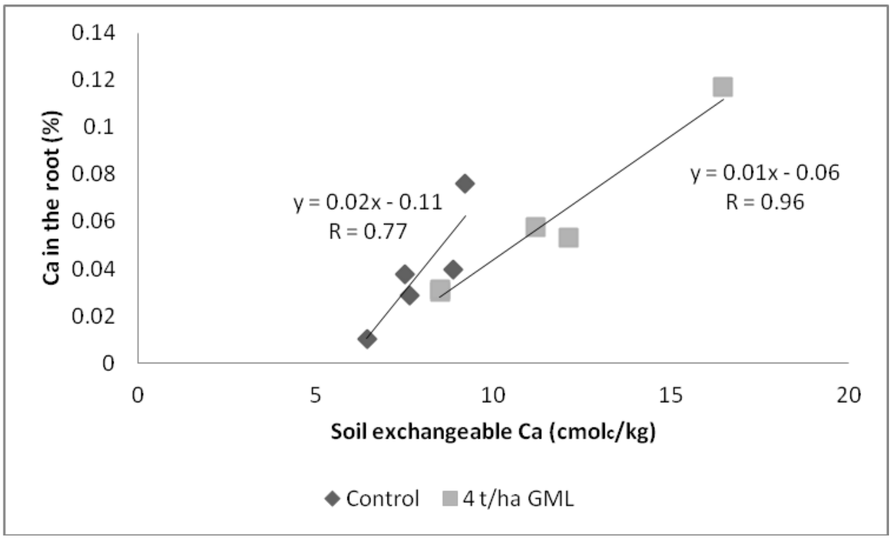


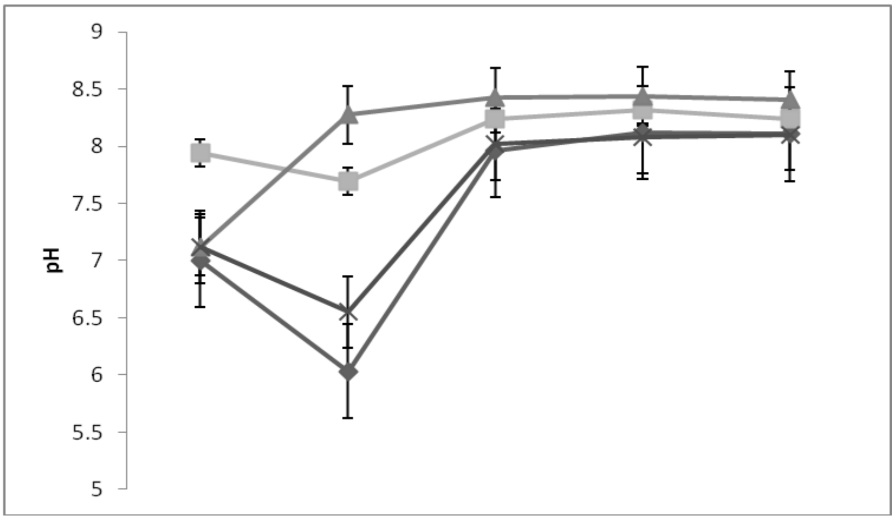
Fig 6: Relationship between exchangeable Ca and Ca concentration in the root

3.9 Changes in pH, Al and Fe in Water

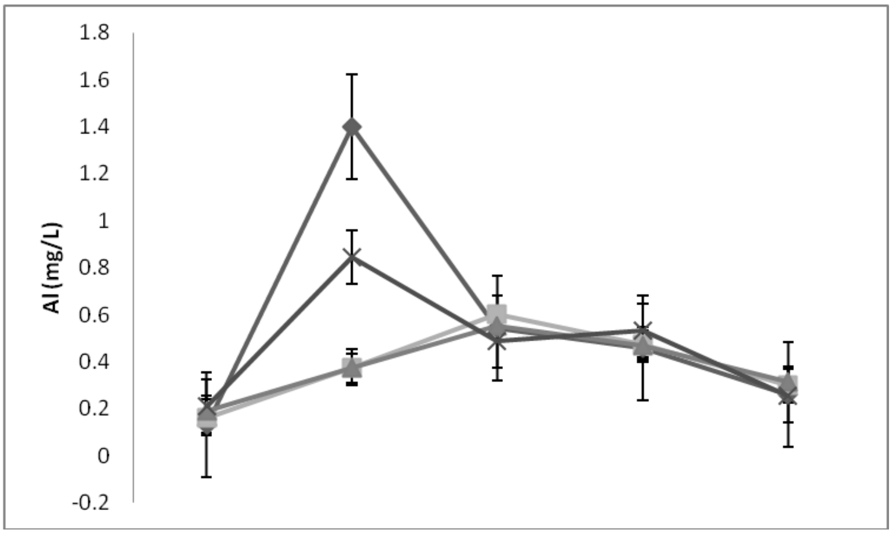
Figure 7 shows the pots' pH, Al and Fe concentration of water. It is known that the application of GML would increase the pH. Figure 7a shows that the pH of the water for soil treated with GML and hydrated lime is higher than that of liquid lime and untreated soil. Thirty days after sowing, the water's pH had increased to 8. As mentioned earlier, hydrated lime reacted more rapidly with soil than GML. In this experiment, it was observed that 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 applying 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. The increase in pH was followed by a decrease in Al concentration (Figure 7b). Likewise, the concentration of Fe decreased, and the pH increased (Figure 7c).

After 2 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, likely due to changes in the soil's acidity 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 7. It is also plausible that, at 35 DAS onward, the Al and Fe reach equilibrium in the water system; hence the pH becomes more stable and not much change was observed hereafter.

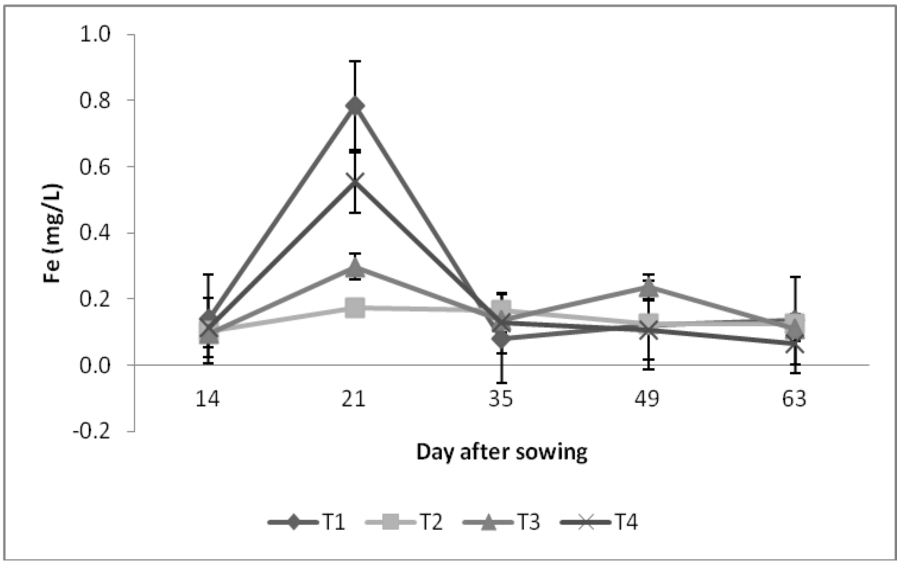
Meanwhile, for the untreated soil, it was found that Al concentration changed from 0.13 mg L-1 at 14 DAS to 1.4 mg L^{-1} at 21 DAS. A similar trend occurred for Fe concentration; it increased from 0.141 mg L^{-1} at 14 DAS to 0.784 mg L^{-1} at 21 DAS. There was a decrease in Fe concentration with the 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}, which is considered favourable for rice growth which shows that soil treated with 2 t ha^{-1} of hydrated lime and 4 t ha^{-1} of GML increased the water's pH and concomitantly reduced the Al and Fe concentrations in the water to the level required for good growth of rice. Figures 8 and 9 show the relationship between pH and Al and pH and Fe concentration of the water, respectively. The relationship are 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. As the Al or Fe in the water decreased, the pH decreased.



(a)



(b)



(c)

Fig 7: Changes in water pH (a), Al (b) and Fe (c) with time

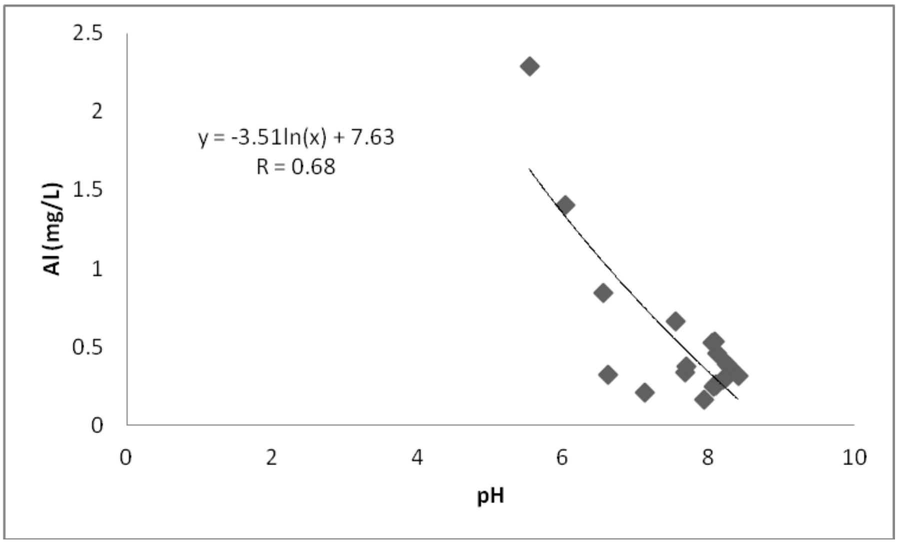


Fig 8: Relationship between pH and Al in the water

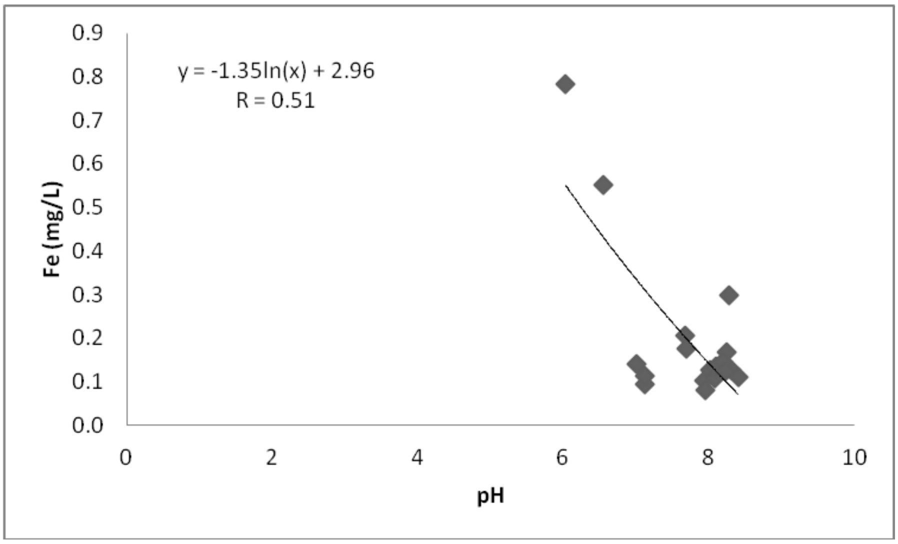


Fig 9: Relationship between pH and Fe in the water

4. Conclusion

This experiment found that the application of 2 t ha^{-1} of hydrated lime is the most suitable ameliorant compared to others. Calcium concentration can be increased significantly by the lime application, and calcium, by itself, is able to reduce Al toxicity. However, the application of 4 t ha^{-1} of GML is preferred due to its long-lasting ameliorative effects. Based on the liming practises, it was observed that the water's pH increased, which eliminated Al and Fe toxicity.

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References

Alva, A. K., Asher, C. J., & Edwards, D. G. (1986). The role of calcium in alleviating aluminium toxicity. *Australian journal of agricultural research*, *37*(4), 375-382. https://doi.org/10.1071/AR9860375.

Auxtero, E. A., & Shamshuddin, J. (1991). Growth of oil palm (Elaeis guineensis) seedlings on acid sulfate soils as affected by water regime and aluminium. *Plant and soil*, *137*(2), 243-257. https//doi.org/10.1007/BF00011203.

Azman, E. A., Jusop, S., Ishak, C. F., & Ismail, R. (2014). Increasing Rice Production Using Different Lime Sources on an Acid Sulphate Soil in Merbok, Malaysia. *Pertanika Journal of Tropical Agricultural Science*, *37*(2).

Azura, A. E., Shamshuddin, J., & Fauziah, C. I. (2011). Root elongation, root surface area and organic acid by rice seedling under Al 3+ and/or H+ stress. *American Journal of Agricultural and Biological Sciences*, *6*(93), 324-331. https//doi.org/10.3844/ajabssp.2011.324.331.

Bohn, H. L., Myer, R. A., & O'Connor, G. A. (2002). *Soil chemistry*. John Wiley & Sons.

Brady, N. C. (1974). TIle nature and properties of soils. 8th cd. *Macmillan Publication Co., Inc*.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, *59*(1), 39-46.

Carter, M. R., & Gregorich, E. G. (2007). *Soil sampling and methods of analysis*. CRC press.

Cassman, K. G. (1999). Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proceedings of the National Academy of Sciences*, *96*(11), 5952-5959. https://doi.org/10.1073/pnas.96.11.5952.

Cate Jr, R. B., & Sukhai, A. P. (1964). A study of aluminum in rice soils. *Soil Science*, *98*(2), 85-93.

Chaang, T. C., Saari, R. B., Diemont, H., & Yusoff, A. B. (1993). The development of an acid sulphate area in former mangroves in Merbok, Kedah, Malaysia. In *Selected Papers of the Ho Chi Minh City Symposium on Acid Sulphate Soils* (p. 95).

Chapman, H. D. (1965). Cation‐exchange capacity. *Methods of soil analysis: Part 2 Chemical and microbiological properties*, *9*, 891-901. https://doi.org/10.2134/agronmonogr9.2.c6.

Dent, D. L. (1986). *Acid sulphate soils: a baseline for research and development* (No. 39). ILRI. Wageningen, The Netherlands.

Dobermann, A., & Fairhurst, T. H. (2000). Nutrient disorders and nutrient management. *Potash and Phosphate Institute, Potash and Phosphate Institute of Canada and International Rice Research Institute, Singapore*, *191*.

Elisa, A. A., Ninomiya, S., Shamshuddin, J., & Roslan, I. (2016). Alleviating aluminum toxicity in an acid sulfate soil from Peninsular Malaysia by calcium silicate application. *Solid Earth*, *7*(2), 367-374. https://doi.org/10.5194/se-7-367-2016.

Enio, M. S. K., Shamshuddin, J., Fauziah, C. I., & Husni, M. H. A. (2011). Pyritization of the coastal sediments in the Kelantan Plains in the Malay Peninsula during the Holocene. *American Journal of Agricultural and Biological Sciences*, *6*(3), 393-402. http//doi.org/10.3844/ajabssp.2011.393.402.

Jusop, S. (2006). *Acid sulfate soils in Malaysia*. Penerbit Universiti Putra Malaysia.

Muhrizal, S., Shamshuddin, J., Fauziah, I., & Husni, M. A. H. (2006). Changes in iron-poor acid sulfate soil upon submergence. *Geoderma*, *131*(1-2), 110-122. https://doi.org/10.1016/j.geoderma.2005.03.006.

Palhares, R. M., & Peres, P. L. (2000). Robust filtering with guaranteed energy-to-peak performance—an LMI approach. *Automatica*, *36*(6), 851-858. https://doi.org/10.1016/S0005-1098(99)00211-3.

Ross, D. S., & Ketterings, Q. (1995). Recommended methods for determining soil cation exchange capacity. *Recommended soil testing procedures for the northeastern United States*, *493*(101), 62.

Sanchez, P. A. (2019). *Properties and Management of Soils in the Tropics*. Cambridge University Press.

Shamshuddin, J., & Auxtero, E. A. (1991). Soil solution compositions and mineralogy of some active acid sulfate soils in Malaysia as affected by laboratory incubation with lime. *Soil Science*, *152*(5), 365-376. https//doi.org/ doi: 10.1097/00010694-199111000-00008.

Shamshuddin, J., Fauziah, I. C., & Sharifuddin, H. A. H. (1991). Effects of limestone and gypsum application to a Malaysian Ultisol on soil solution composition and yields of maize and groundnut. *Plant and Soil*, *134*(1), 45-52. https//doi.org/10.1007/BF00010716.

Shamshuddin, J., Jamilah, I., & Ogunwale, J. A. (1995). Formation of hydroxy‐sulfates from pyrite in coastal acid sulfate soil environments in Malaysia. *Communications in soil science and plant analysis*, *26*(17-18), 2769-2782. https//doi.org/10.1080/00103629509369486.

Shamshuddin, J., Muhrizal, S., Fauziah, I., & Husni, M. H. A. (2004). Effects of adding organic materials to an acid sulfate soil on the growth of cocoa (Theobroma cacao L.) seedlings. *Science of the total environment*, *323*(1-3), 33-45. https://doi.org/10.1016/j.scitotenv.2003.10.003.

Shamshuddin, J., Muhrizal, S., Fauziah, I., & Van Ranst, E. (2004). A laboratory study of pyrite oxidation in acid sulfate soils. *Communications in Soil Science and Plant Analysis*, *35*(1-2), 117-129. https://doi.org/10.1081/CSS-120027638.

Shazana, M. A. R., Shamshuddin, J., Fauziah, C. I., Panhwar, Q. A., & Naher, U. A. (2014). Effects of applying ground basalt with or without organic fertilizer on the fertility of an acid sulfate soil and growth of rice. *Malaysian Journal of Soil Science*, *18*, 87-102.

Shazana, M. A. R. S., Shamshuddin, J., Fauziah, C. I., & Syed Omar, S. R. (2013). Alleviating the infertility of an acid sulphate soil by using ground basalt with or without lime and organic fertilizer under submerged conditions. *Land Degradation & Development*, *24*(2), 129-140. https://doi.org/10.1002/ldr.1111.

Zeigler, R. S. (2007). Rice and the millennium development goals: the International Rice Research Institute's strategic plan 2007–2015. *Paddy and Water Environment*, *5*(2), 67-71. https://doi.org/10.1007/s10333-007-0067-9.