ISSN: 1394-7990
Malaysian Journal of Soil Science Vol.11 : 1-16 (2007)
Malaysian Society of Soil Science

Effects of Lime and Fertiliser Application in Combination with Water Management on Rice (*Oryza sativa*) Cultivated on an Acid Sulfate Soil

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ABSTRACT

Acid sulfate soils are widespread along the coastal plains of the Malay Peninsula, with some being cultivated with rice. Following farmers' practice, rice yields are very low due to low pH and prevailing adverse conditions such as Al and/or Fe toxicity. A study was conducted in a glasshouse to determine the effect of lime and fertiliser application in combination with water management on rice cultivated on an acid sulfate soil, using MR 219 rice variety as the test crop. The soil used was Typic Sulfosaprists. The results showed that soil pH increased from 4.27 to 4.93 by applying 4 t GML/ha, thereby reducing Al and/or Fe toxicity. In this treatment, exchangeable Ca increased from 1.28 to 3.13 $cmol_c$/kg soil, which is above the rice Ca requirement. The increase in exchangeable Ca also reduced Al toxicity. Fertiliser or fertiliser in combination with lime affected rice production significantly. Rice yield was negatively correlated with acid-extractable Fe. Additionally, rice yield increased with increasing pH and Ca. The best yield of 14.15 t/ha was obtained for treatment with 4 t/ha lime together with 120 kg N/ha + 16 kg P/ha + 120 kg K/ha. This shows that liming together with prudent fertiliser management improves rice production on an acid sulfate soil.

Keywords: Rice, ground magnesium limestone, acid sulfate soil, aluminum, iron

INTRODUCTION

The Kemasin-Semerak Integrated Agriculture Development Project, comprising a total area of 68,350 ha, was incorporated in 1982. The project area is located in the Kelantan Plain, in the east coast state of Peninsular Malaysia. The plain is characterised by the presence of a mixture of riverine and marine alluvial soils, formed as a result of the rise and fall in sea level in the Quaternary (Djia 1973). Peaty materials are sometimes overlain by mixed clayey-sandy sediments and occasionally contain pyrite which is scattered over the plains, especially along the coastline. This eventually caused the development of acid sulfate soil conditions which are harmful to crop cultivation (like rice) on these soils.

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Normally, acid sulfate soils are not suitable for crop production, unless they are adequately ameliorated. Among the agronomic problems common to acid sulfate soils are toxicity due to the presence of Al, decrease in P availability, nutrient deficiency, Fe(II) toxicity and plant stress due to the presence of a sulfuric horizon (Dent 1986).

The activities of Al^{3+} in the soil solution are controlled by $Al(OH)_3$ (gibbsite) at high pH. Thus, raising the pH would render the Al inactive, as gibbsite is inert. Al in soil solution at 1-2 mg/kg can be toxic to plants (Dobermann and Fairhurst 2000). Soluble Al accumulates in the root tissues, preventing cell division and elongation (Rorison 1973). Rice roots rapidly absorb Al, causing a reduction in root length (Gupta and Toole 1986), and inhibited root growth reduces nutrient uptake.

Fe(II) may be released in toxic amounts by a reduction in Fe(III) in flooded soil conditions. In an incubation experiment in Vietnam, Tran and Vo (2004) found soluble Fe exceeding 1000 ppm. But flooding can increase solution pH with a concomitant lowering of soluble Fe (Tran and Vo 2004). According to Moore and Patrick (1993), Fe(II) activities are seldom at equilibrium with iron solid phases in acid sulfate soils. Ponnamperuma *et al.* (1973) reported values of 5000 mg/kg Fe(II) within two weeks of flooding acid sulfate soils. Iron uptake by rice is correlated with Fe^{2+} activities (Moore and Patrick 1993). Concentrations above 500 mg/kg Fe(II) are considered toxic to rice plants growing on acid sulfate soils (Nhung and Ponnamperuma 1966).

According to Rutger (1981), rice plant requires pH of 5.0-7.5 to grow optimally, although it can tolerate a pH of 4.3-8.7 (Duke 1973). Coronel (1980) found no adverse effect of pH of 3.5-5.0 on rice root growth in a nutrient culture study in the Philippines.

Liming is a normal agronomic practice to manage acid sulfate soils for crop production. In Malaysia, some areas of acid sulfate soils have been reclaimed for rice cultivation using lime. In the acid sulfate soils of the Muda Agricultural Development Authority (MADA) granary areas in Kedah-Perlis coastal plains (northwest coast of Peninsular Malaysia), for instance, rice yield improved significantly after applying 2.5 tonnes of ground magnesium limestone (GML) per ha (Arulando and Kam 1982). In another area called the Merbok Scheme (in the Kedah-Perlis coastal plains), rice yield increased from 1.4 t/ha (in 1974) to 4.5 t/ha (in 1990) after yearly application of 2 t GML/ha (Ting *et al.* 1993). These success stories are frequently reported.

Acid sulfate soils can also be ameliorated, to some extent, by correct water management practices. The acid soil infertility can somewhat be alleviated by flooding as flooding re-introduces an anaerobic condition. In the presence of easily-decomposable organic matter, Fe(III) would be reduced, resulting in the elimination of soil acidity. Maintaining a high water table level can control the rate of pyrite oxidation and thus curtail acid production. Irrigation and leaching can help remove acid water from the area under rice cultivation.

The objective of this study was to determine the effects of lime and fertiliser application in combination with water management on rice cultivated on an acid sulfate soil. It is hoped that the study will provide a base to recommend rice cultivation on acid sulfate soils of Malaysia.

MATERIALS AND METHODS

The Soils

The soils (topsoil) for this study were taken from a rice field trial conducted at the Jelawat Rusa Irrigation Scheme in the Kemasin-Semerak IADP, Kelantan, Malaysia (06^o 00N, 102^o 23E). The soils in the experimental plots belong to the Nipis-Bakri Associations (organic soils containing sulfidic materials within 100 cm depth), which is classified as Typic Sulfosaprists. The topsoil contains 25.6 % organic carbon, while the CEC of the soil in this zone is about 20 $cmol_c$/kg soil. The peaty materials have been somewhat degraded as a result of a long history of rice cultivation. In the soil profile, the sulfuric layer occurs below a depth of 45 cm. Selected chemical properties of the soils are given in Table 1. Soil pH and exchangeable Al at 45-60 cm depth are 3.1 and 13.54 $cmol_c$/kg soil, respectively. These characteristics are typical of an acid sulfate soil.

The Rice Variety Tested

The rice (Oryza sativa) variety used in the trial was MR 219. This is the most common rice variety planted by Malaysian rice growers. This is a rice variety specially bred for the conditions prevailing in Malaysia, but not necessarily for acid sulfate soils.

Experimental

A glasshouse experiment was designed (split-split plot design) to determine the potential yield of rice cultivated on an acid sulfate soil under various treatments. It was conducted under a controlled environment at the Glasshouse Unit, Faculty of Agriculture, Universiti Putra Malaysia. Rice plants were planted in 27-cm diametre pots; with each pot containing 6 kg of air-dried soil. In this study, three

TABLE 1
Selected chemical properties of the Nipis-Bakri Associations

Depth	pH	Exchangeable cations ($cmol_c$/kg)			
cm	water	Al	Ca	Mg	K
0 -15	4.4	2.72	0.46	0.18	2.20
15 - 30	3.8	5.94	0.23	0.12	0.41
30 - 45	3.5	8.82	0.16	0.39	1.32
45 - 60	3.1	13.54	0.27	0.65	0.99
60 - 75	2.5	26.73	0.25	0.68	0.75

factors were evaluated: (i) lime application; (ii) fertiliser application; and (iii) water management.

The experiment was conducted over 120 days. At harvest, the yield in each pot was recorded, dried out so as to contain 14 % moisture content and weighed. Statistical analysis was carried out using SAS, version 8. Water samples were taken at planting (30 days after liming) and 30 days after planting for determination of pH, Ca and Mg.

Lime treatment: Lime material used in this study was ground magnesium limestone (GML). The rates were control (no GML), GML at optimum rate and GML at the top of soil requirement (lime requirement). The predicted optimum liming rate was 4 t GML/ha, while the lime requirement to increase the soil pH to 5 for the soil was 13.8 t GML/ha. Lime was applied 30 days before planting.

Fertiliser treatment: In determining the amounts of N, P and K to apply, the simplest way is to use crop nutrient uptake, target yield and initial yield (without fertiliser). The gap between target yield and initial yield should come from fertilisers. According to IRRI (2002), the nutrient uptake per tonne grain yield is approximately (i) N – 15-20 kg; (ii) P – 2-3 kg; and (iii) K – 15-20 kg (if the straw remains in the field, the amount is 3-5 kg/ha).

For the acid sulfate soil under study, the average rice yield is about 2 t/ha, using typical farmers' practice. This is far below the national average. To achieve the optimal target yield of 10 t/ha, the additional yield (provided that soil infertility is ameliorated) should be contributed by fertilisers. From the calculations shown in Table 2, the amounts of N, P and K are 120-160, 16-24 and 120-160 kg/ha, respectively. Producing 8 tonnes of additional grain requires 8 times more nutrient uptake of 15-20 kg N, 2-3 kg P and 15-20 kg K. These rates were calculated based on the assumption that all the rice straw is removed from the field. In the case where the straw remains in the field, the calculation is not the same, especially for K.

The fertiliser treatments were (i) F0 - no fertilizer; (ii) F1- medium rate of fertiliser to achieve 5 t rice/ha (45- 60 N/ha; 6-9 kg P/ha; 45-60); and (iii) F2-

TABLE 2
Estimation of fertiliser requirement based on the gap between target and initial yield and crop nutrient uptake

Target		5 t/ha	10 t/ha
Initial (t/ha)		2	2
Gap (t/ha)		3	8
Element	Nutrient uptake (kg/ha)	Fertiliser rate (kg/ha)	
N	15-20	45-60	120-160
P	2-3	6-9	16-24
K	15-20	45-60	120-160

maximum rate of fertiliser to achieve 10 t rice/ha (120-160 kg N/ha;16-24 kg P/ ha; 120-160 kg K/ha).

The fertilisers were applied at the critical time during the growth period, which included supplying sufficient N before maximum tillering at 20-35 day after seedling (DAS), providing enough nutrients during panicle initiation (50-55 DAS) and during grain filling (> 60 DAS). A growth enhancer (Vitagrow), which supplies micronutrients was applied during the growing period. The details of fertiliser application are given in Table 3.

Water management: In a continuously submerged rice field, the main limiting factor of yield is reduction in topsoil. In acid sulfate soil conditions, soil acidity can be somewhat reduced when the field is flooded, but Fe(II) toxicity usually arises. Reduction of topsoil can be prevented, to a certain extent, by surface water management. When surface water is regularly drained from the field and the topsoil is allowed to dry for a few days, it can be oxidised. However, the oxidation process would result in production of protons, leading to lowering of pH and an increase in Al ions in the water. This experiment was so designed to determine the effects of surface water management on the growth of rice. The treatments for this study were as follows: (i) W0- continuously submerged condition (control); and (ii) W1- drying period once (50 DAS) for about 5-12 days.

TABLE 3
List of component and rate of fertiliser and schedule of application based on critical times during plant growth

DAS*	Fertiliser application	Rate/pot		
0	Seedlings	23 seeds		
	(400 seeds/m^2)			
20	Subsidised fertiliser	F1	0.46	g
	(180 kg/ha)	F2	1.19	g
25	Vitagrow	0.5 mL Vitagrow mixed with		
	(Foliar fertiliser)	100 mL water for all treatments		
35	Subsidised fertiliser	F1	0.20	g
	(80 kg/ha)	F2	0.53	g
35	Urea	F1	0.23	g
	(100 kg/ha)	F2	0.57	g
45	Vitagrow	0.5 mL Vitagrow mixed with		
	(Foliar fertiliser)	100 mL water for all treatments		
50	NPK Blue (12:12:17:TE)	F1	0.32	g
	(150 kg/ha)	F2	0.86	g
60	NPK Green (15:15:15:TE)	F1	0.32	g
	(100 kg/ha)	F2	0.86	g
65	Vitagrow	0.5 mL Vitagrow mixed with		
	(Foliar fertiliser)	100 mL water for all treatments		

* Day after seeding

TABLE 4
Summary of treatments on glasshouse experiment

Treatment	Symbol	Description
Water Management	W0	Continuous submerged (control)
	W1	Once dry period on 50 DAS, 5-12 days.
Lime	L0	No lime (control)
	L1	GML at optimum (predicted) rate (4 t/ha)
	L2	GML at top soil requirement (13.8 t/ha)
Fertiliser	F0	No fertiliser (control)
	F1	Medium rate fertiliser (to achieve 5 t/ha of yield)
	F2	Maximum rate fertiliser (to achieve 10 t/ha of yield)

Soil Analysis
Soil pH (1:2.5) was determined in water. The cation exchange capacity (CEC) was determined using NH_4OAc solution, buffered at pH 7. Exchangeable Ca, Mg, and K in the NH_4OAc extract were determined by atomic absorption spectrometry (AAS). Exchangeable Al was extracted by 1 M KCl and determined by AAS. The organic carbon was determined by the Walkley-Black method (Nelson and Sommers 1996).

Iron in the soils was determined by double acid method (henceforth referred to as acid-extractable Fe). It was extracted using 0.05 M HCl in 0.0125 M H_2SO_4. A five-gram sample of the soil was mixed with 25 mL of the extracting solution and shaken for 15 minutes. The solution was then filtered through Whatman filter paper number 42 before determining the Fe by atomic absorption spectrometry, Model Perkin Elmer 5100.

RESULTS

The Initial Soil Chemical Properties
Data in Table 1 show the soil chemical characteristics by depth. The topsoil pH was low; the value was even lower at depths below 50 cm. At depths of 45-60 cm, the pH value was lower than 3.5. This low pH in combination with the presence of jarositic mottles in the soil at that depth qualifies the soil to be classified as an acid sulfate soil. The low pH was due to the presence of high amounts of exchangeable Al, especially at depths below 45 cm, the sulfuric layer.

The initial topsoil exchangeable Ca was 0.46 $cmol_c$/kg soil, which is lower than the required level for rice growth of 2 $cmol_c$/kg soil (Palhares 2000). The initial exchangeable Mg in the soil was only 0.18, but Mg requirement for rice is

TABLE 5
The change in pH, exchangeable Ca, exchangeable Mg and Fe with liming

Treatment	pH	Exchangeable Cations ($cmol_c$/kg)		
		Ca	Mg	Fe
L0	4.27[c]	1.28[c]	0.50[c]	0.29[a]
L1	4.93[b]	3.13[b]	1.02[b]	0.24[b]
L2	5.83[a]	6.28[a]	1.28[a]	0.11[c]
$LSD_{0.05}$	0.12	0.27	0.24	0.03

Means with the same letter are not significantly different ($p<0.05$)by LSD

1 $cmol_c$/kg soil (Dobermann and Fairhurst 2000). Exchangeable Al was high especially at increasing depths. This means there could be high concentrations of Al in the soil solution. According to these researchers, Al concentration of 1-2 mg/kg in the soil solution would cause toxicity to the growing rice plants. Potassium seemed to be moderately high and thus would be sufficient for rice growth in this soil.

Changes in Soil Chemical Properties

It can be seen that the GML had ameliorated the soil by increasing the soil pH (Table 5). Soil pH increased from 4.27 to 4.93 by applying 4 t GML/ha (L1). When the pH was near 5, the toxic effect of Al toxicity would be minimal. At this pH, Al starts to precipitate, forming inert gibbsite. The pH further increased to 5.83 when the liming rate was increased to that of the soil lime requirement (L2). At this pH, the Al and Fe are not expected to reduce rice yield.

Exchangeable Ca had increased significantly with GML application (Table 5). So did exchangeable Mg. The exchangeable Ca had increased from 1.28 to 3.13 $cmol_c$/kg soil by applying 4 t GML/ha. This has passed the critical limit of 2 $cmol_c$/kg soil (Palhares 2000). At this GML rate, the exchangeable Mg has passed the critical limit of 1 $cmol_c$/kg soil (Dent 1986). The increase on Ca content in the GML treated soils had somewhat alleviated Al toxicity (Alva *et al.* 1986).

The Effect of Treatments

The analysis of variance showed that ($p<0.01$) the combination of liming and fertiliser application ($p<0.01$) had affected the yield of rice (MR219) significantly. LSD grouping was applied to determine the effects of lime and fertiliser application. The yield results given in *Figure* 1 show that lime and fertilisers play a major role in affecting rice yield. It also shows that fertiliser in combination with lime improves rice yield significantly.

Effects of fertiliser application: Fertiliser application had significantly increased rice yield even without liming (*Fig.* 1). This means that in an acid sulfate soil condition, rice yield can be increased simply by heavy fertiliser applica-

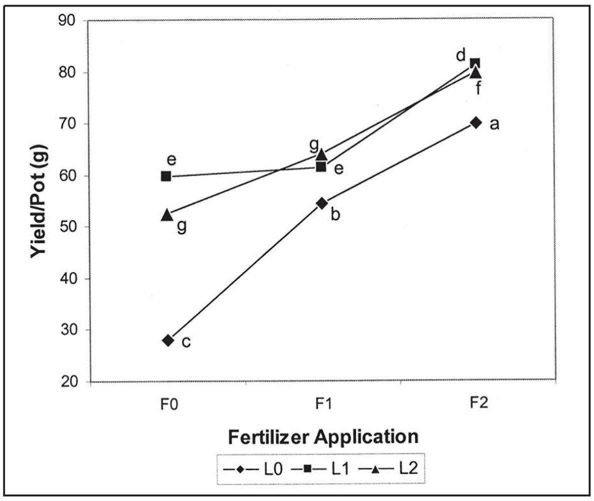
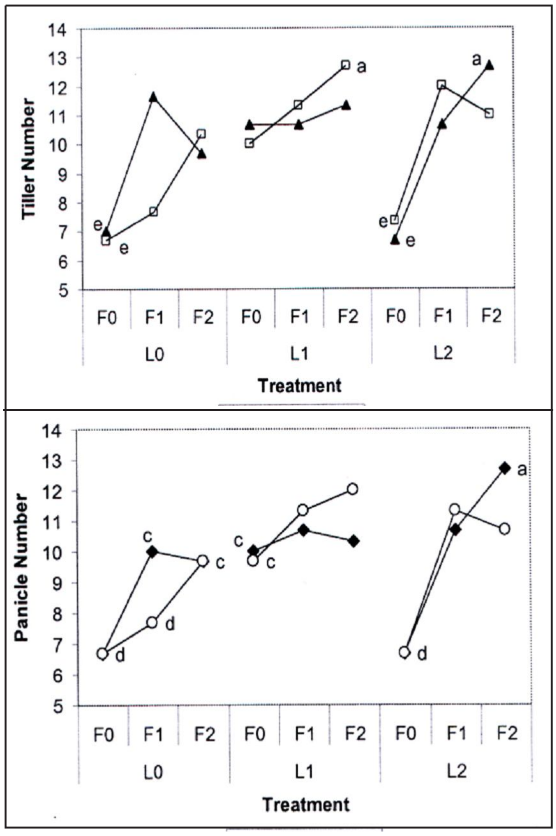


Fig. 1: Effect of lime in combination with fertilizer on yield



(a)

(a)

Fig. 2: Effects of water treatment in combination with lime and fertiliser on: (a) tiller number (LSD=0.44) and (b) panicle number (LSD=0.40). Means with the same letter are not significantly different (p=0.05)

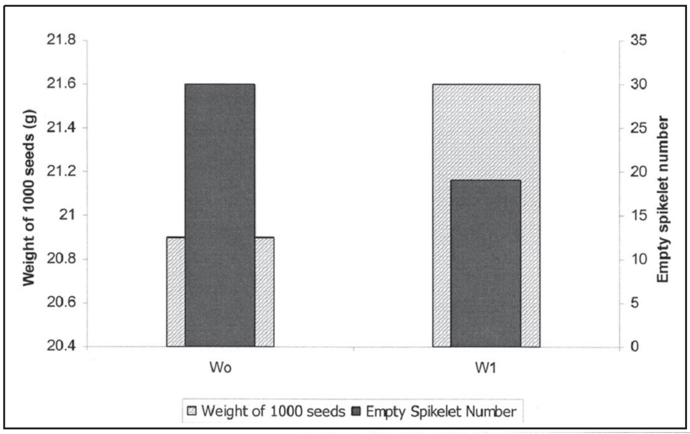
tion. The presence of phosphate resulting from fertiliser application can, to a certain extent, reduce Fe in the solution by forming insoluble $FePO_4$ (Shamshuddin *et al.* 2004).

Effects of lime application: Using GML (L1 and L2), the rice yield can be increased to the level achieved under intensive fertilisation. It shows that GML and fertiliser applied at medium rates are complementary in increasing rice yield. Taking cost into consideration, the application of GML is more beneficial than fertiliser alone. If this is done, the farmer saves cost by using less fertiliser. In this experiment, the highest yield was achieved in the treatment using GML and maximum fertiliser application (L1F2 and L2F2 with value of 14.15 and13.91 t/ha, respectively). By application of GML (L1 and L2), the number of empty spikelets decreased significantly resulting in significant grain improvement.

Effects of water management: In this study, GML and fertiliser application in combination with water management improved rice growth significantly, shown by improvement in tiller number, panicle number, panicle length, spikelet number and grain weight (*Fig.* 2).

Tiller and panicle number improved significantly (a,b,c $p< 0.01$ and $p< 0.05$) by water management in combination with GML and fertiliser application (*Fig.* 2). The highest tiller number was found in the water management treat-

(a)



(b)

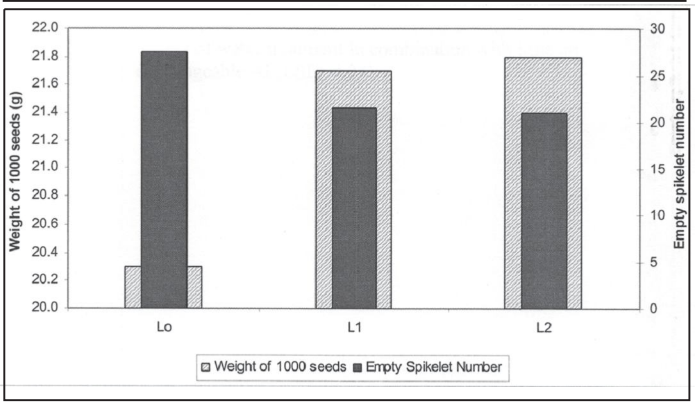


Fig. 3: Effect of water management (a) and lime (b) on the weight of 1000 seeds and empty spikelet number (LSD=0.40)

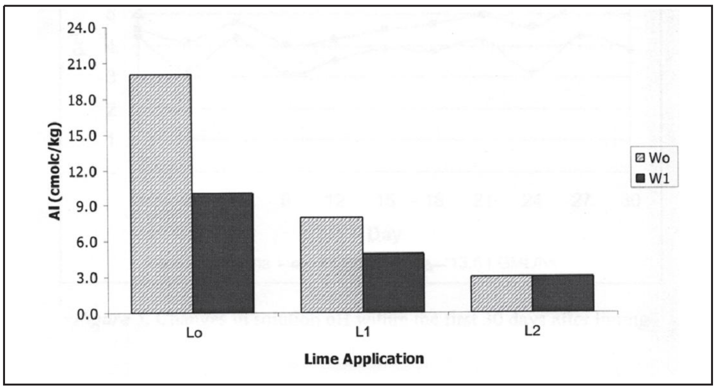


Fig. 4: Effect of water treatment in combination with lime on exchangeable Al (LSD=4.24).

TABLE 6
Correlation (r) between yield and soil parameters

Dependent	pH	Exch. Ca	Exch. Mg	Exch. Al	Fe
pH	ns	0.93**	0.63**	-0.64**	-0.81**
Yield	0.27*	0.29*	ns	ns	-0.30*

ns: not significant (p=0.05)

ment and GML with maximum rate of fertiliser treatment (W1L1F2, W0L2F2), while the lowest was the treatment without fertiliser (F0). Panicle number was found to be significantly higher than the control for the maximum rate of GML and fertiliser application (W0L2F2). *Fig.* 2 shows that an increase in treatment rate could improve the number of tillers and panicles, leading to an increase in rice yield.

Grain weight and empty spikelet numbers were affected by individual factor of water management (a, $p< 0.01$ and $p< 0.05$) and GML treatment (b, $p< 0.01$ and $p< 0.05$). Drying the soils produced significantly lower empty spikelet numbers compared to the control treatment. This is in agreement with the study of Hanhart *et al.* (1997) who concluded that during several weeks of continuously submergence of field in acid sulfate soils, vegetative growth of rice plants would be retarded and reproductive development would be disturbed, resulting in a high percentage of empty grains. So a dry period and GML application could increase rice yield by reducing empty spikelets. *Fig. 3* shows the effects of water management and GML on grain weight and empty spikelet numbers.

Water management in combination with GML application decreased Al toxicity. *Fig. 4* shows that GML application at the lime requirement level eliminated exchangeable Al from the soil to less than 3 $cmol_c$/kg soil; the effect being more clearly shown for the treatment under one time dry period. Lower exchangeable Al in a soil is usually associated with a higher pH. This would translate into better crop growth, resulting in increased rice yield.

DISCUSSION

Ca and Mg Deficiency

The presence of large amounts of Ca in soils is good in itself. It is by nature that Ca is, to a certain extent, able to reduce the toxic effect of high Al concentration (Alva *et al.* 1986; Shamshuddin *et al.* 1991). This occurred in L1 and L2. The amelioration of Al toxicity, should there be any, would be shown by an increase in rice yield. The presence of extra Mg could also contribute to alleviation of Al toxicity as had been shown by Shamshuddin *et al*. (1991) for maize grown on an acid upland soil.

Soil pH was linearly significantly correlated with exchangeable Ca and Mg, with r values of 0.93 and 0.63, respectively (Table 6). The presence of these metals would increase pH via their hydrolysis.

Aluminum Toxicity

Low pH is usually associated with high exchangeable Al, which is clearly shown by the data given in Table 1. The lowest pH coincides with the highest exchangeable Al. There was a linear negative correlation between pH and exchangeable Al, with r value of -0.64 (Table 6). As seen in Table 1, the initial exchangeable Al was extremely high in some soil samples, reaching a value of 26.73 $cmol_c$/kg soil in the subsoil (60-75 cm depth). The lowest value was 2.27 $cmol_c$kg soil, which was in the topsoil.

In the water of the experimental plots, Al would probably be in excess of the critical value for rice production of 1-2 mg/kg; this was based on the data available from an unpublished study of the area (pers.comm., officer in-charge). This Al in the solution can be reduced to an acceptable level by applying GML at an appropriate rate. Our study believes that GML application at 4 t/ha would eliminate solution Al to the minimal level, making the soil suitable for rice cultivation.

Iron Toxicity

Acid-extractable Fe in the soils was slightly above the critical level, with a value of 0.29 $cmol_c$/kg soil in the no lime treatment plot (Table 5). Critical Fe concentration is known to vary from 0.05 to 5.37 $cmol_c$/kg soil (Dobermann and Fairhurst 2000), implying that Fe may not be the only source of soil infertility. It is seen that even at the GML rate of 4 t/ha, the acid-extractable Fe concentration is still above the critical value for rice growth.

Relationship between Rice Yield and Soil Parameters

Iron in the acid sulfate soil is indeed toxic to rice plant as shown by data presented in Table 6. The rice yield was significantly correlated with acid-extractable Fe, with r value of -0.30 ($p < 0.05$). This means that as the acid-extractable Fe increased, the rice yield decreased. High amounts of acid-extractable Fe mean that there would also be high amounts of Fe in the soil solution. According to

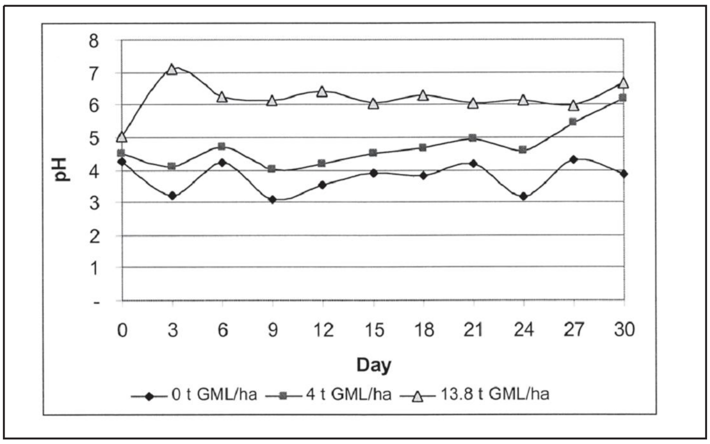
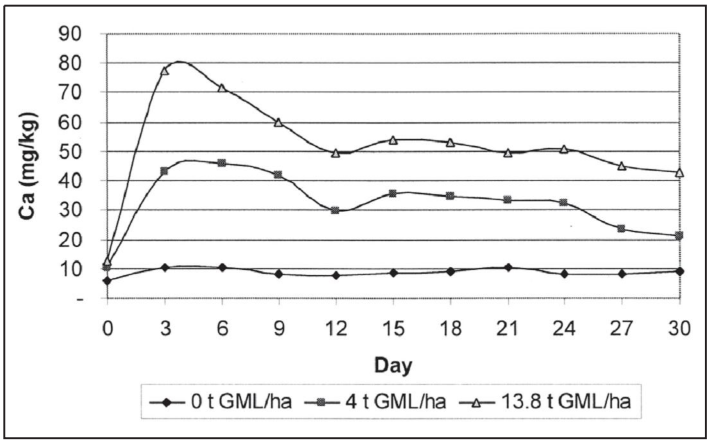


Fig. 5: Changes in solution pH within the first 30 days after liming

(a)



(b)

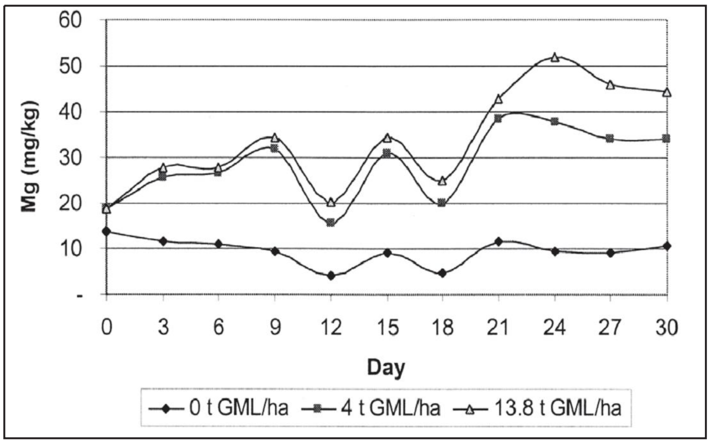
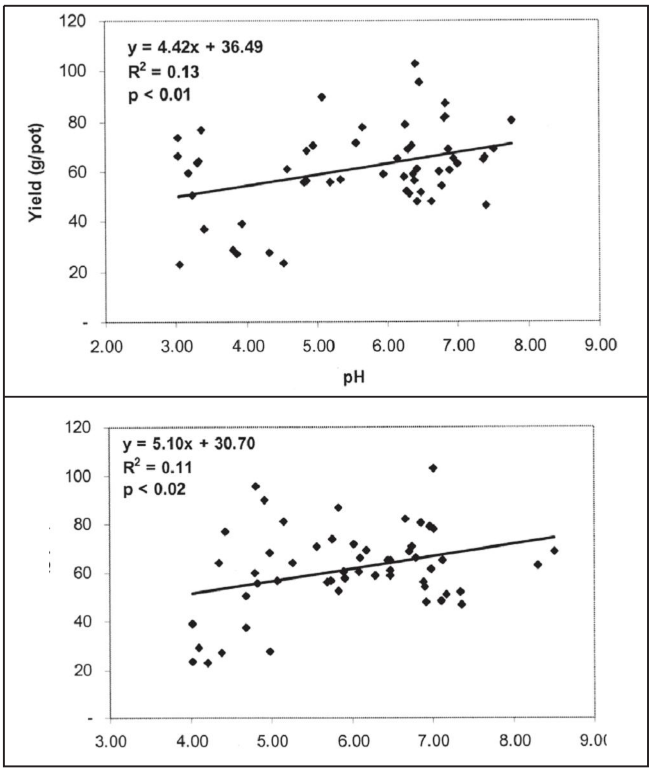


Fig. 6: Changes in solution Ca (a) and solution Mg (b) Within the first 30 days after liming



(a)

(b)

Fig. 7: Relationship between rice yield and solution pH at planting (a) and 30 days after planting (b)

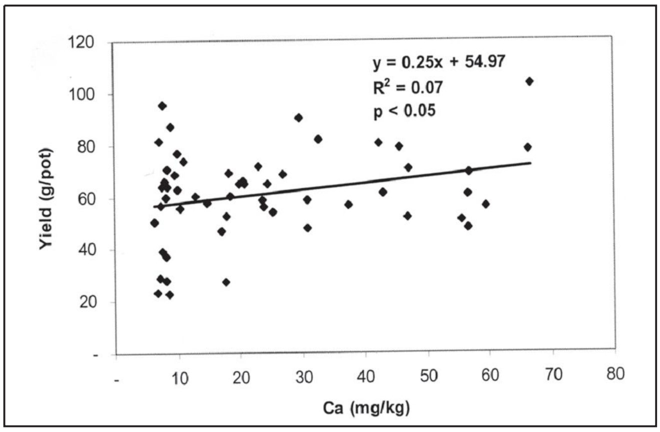


Fig. 8: Relationship between rice yield and solution Ca at planting

Ponnamperuma *et al.* (1973), toxic amounts of Fe(II) would be present in the water after 2 weeks of flooding. This Fe(II) can, to a certain extent, be eliminated by liming. It is possible that by liming at a GML rate of 4 t/ha, the Fe(II) would have been mostly eliminated from the solution. This can be shown by better rice growth for this treatment. Relative rice yield (RRY) was correlated with pH, acid-extractable Fe and exchangeable Ca and Al. It is seen that in all cases the correlation were poor, with R^2 values of 0.08 or less.

Relationship Between Rice Yield and Solution Parameters

Reasonably high solution pH is essential for rice growth. At pH below 5, there would be high Al in the solution; the level could be toxic to the rice plant. In this experiment, solution pH of the control treatment was 3-4 (*Fig.* 5). When 4 t GML/ha was applied, pH slowly increased. It reached the level of 6 at 30 days after lime application. The rice plant was transplanted 30 days after liming. The lime rate of 4 t GML/ha is the recommended rate for rice cultivation on acid sulfate soils in Malaysia.

Solution Ca (*Fig.* 6a) and solution Mg (*Fig.* 6b) increased when the GML was dissolved. In the control treatment, solution Ca was low and it did not change with time, within 30 days after liming (*Fig.* 6a). When GML was applied, solution Ca increased with time up to 3 days. It then started to decrease. It was plausible that some of the solution Ca entered the soil and became part of the exchangeable Ca, thus no longer existing as free ions in the water. In the exchange complex, Ca is usually the most abundant element, followed by Mg. Solution Mg was higher than solution Ca at 30 days after liming (*Fig.* 6b). Less Mg was needed to satisfy the exchange complex of the soil, thus most of the Mg from the dissolution of the GML remained in the solution. Note that more Ca than Mg is present in the GML.

Rice yield was plotted against pH at planting (*Fig.* 7a) and at 30 days after planting (*Fig.* 7b). This figure shows that rice yield increased linearly with increasing pH. It means that as the solution pH increased, Al in the solution was precipitated. Thus, the amount of solution Al which caused toxicity to rice plant decreased.

The increase in soluble Ca improved the rice growth. This is shown by an increase in yield with increasing solution Ca (*Fig.* 8). It means specifically that in acid soils it is a good agronomic practice to lime the soil for rice cultivation. Under a normal acid sulfate soil situation, there is insufficient amounts of Ca in this soil for rice production.

CONCLUSION

Under normal unmanaged circumstances, acid sulfate soils in Malaysia are not suitable for rice cultivation. However, application of 4 t GML/ha could ameliorate the soils. Liming acid sulfate soils at this rate has the potential to raise exchangeable Ca to above rice requirements, and soil pH would be increased to about 5, thereby eliminating most of the Al and/or Fe toxicity. There should also be sufficient amounts of plant nutrients in the soil. Liming in combination with appropriate fertiliser application would make acid sulfate soils suitable for rice cultivation.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial and technical support provided by Universiti Putra Malaysia and the Ministry of Science, Technology and Innovation, Malaysia.

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