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Increasing Rice Production Using Different Lime Sources on an Acid Sulphate Soil in Merbok, Malaysia

Elisa Azura Azman, Shamshuddin Jusop*, Che Fauziah Ishak and Roslan Ismail

Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

ABSTRACT

Acidity is released in high amounts when pyrite-bearing sediments in the coastal plains of Malaysia are drained for development, either agriculture or otherwise. The soils formed from these materials are called acid sulphate soils, which are characterized by low pH and high exchangeable Al that adversely affect plant growth. A study was conducted with the objective of increasing rice yields on these soils under rain-fed condition in Merbok, Kedah, Malaysia, using various lime sources. The acid sulphate soil was treated with ground magnesium limestone (GML), hydrated lime and liquid lime at specified rates. Paddy variety MR 219 was tested in a field experiment as this variety is the most common variety grown in Malaysia. Prior to treatments, the pH of water sample in the rice field was 3.7, while Al concentration was 878 µM. Thus, rice plants grown under these conditions would suffer from H^+ and Al^{3+} stress without amelioration, thus retard and/or minimize rice growth and yield. In the first season (1st season) rice plants were affected by drought during the vegetative period, while in the subsequent season (2nd season), they were infested with rice blast fungus (*Magnaporthe grisea*). In spite of that, however, the rice yield was 3.5 t ha^{-1} based on the application of 4 t GML ha^{-1}, which was almost equivalent to the average national yield of 3.8 t ha^{-1}. As a result, it was noted that the ameliorative effects of lime application in the 1st season had continued to the 2nd season. Liming at 4 t GML ha^{-1} incurs high cost to the farmers. However, the yield obtained is worth the effort and cost.

Keywords: Acid sulphate soil, aluminium, ground magnesium limestone, pyrite, rice, rice blast

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E-mail addresses:
elisa1814@gmail.com (Elisa Azura Azman),
shamshud@upm.edu.my (Shamshuddin Jusop),
cfauziah@upm.edu.my (Che Fauziah Ishak),
roslanismail@upm.edu.my (Roslan Ismail)
* Corresponding author

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INTRODUCTION

Global demand for rice is increasing by the years. This means that the world needs to produce more rice than it does now, and this is part of the agenda in food security that has been addressed in the World Food Summit 1996. However, in many areas with high population density, highly productive rice land has been lost to housing and industrial development and/or to growing of vegetables and other cash crops. Plus, the possibility of increasing area for rice cultivation is almost nil, and this is mainly because arable land has been exhausted in most Asian countries. Arable lands are marked by good and fertile land for agriculture production.

Rice is a staple food for Malaysians. Therefore, the government of Malaysia realizes that it needs to increase self-sufficiency level (SSL) in rice production from 73% to 86%. In order to increase SSL, there are three possible alternatives: 1) expanding the rice cultivation area, 2) increasing the yield per unit area, and/or 3) combination of alternatives 1 and 2. At present condition, with scarcity of good and fertile lands, minimal expansion in rice area can be expected, coupled with slow increase in rice yield. In reality, growth in rice production is in contrast to demand. For that reason, farmers need to increase their rice production on land that is previously idle and less fertile such as the acid sulphate soils in Malaysia. These soils have low pH and high Al content which can be detrimental for crop production. Expanding rice-growing areas in such a challenging area must be done with great care. Rice cultivation must be sustainable with minimal environmental impact on the ecosystem.

Acid sulphate soils are widespread in Malaysia, occurring almost exclusively along its coastal plains (Shamshuddin & Auxtero, 1991; Shamshuddin *et al*., 1995; Muhrizal *et al*., 2006; Enio *et al*., 2011). These soils are dominated by pyrite (FeS_2) and marked with high acidity (soil pH< 3.5). These soils are produced when the pyrite-laden soils in the coastal plains are opened up for crop production and/or development. This scenario leads to release of high amounts of Al into the soil environment (Shamshuddin *et al*., 2004b) and affects crop growth. As an example, it affects oil palm growth (Auxtero & Shamshuddin, 1991) and cocoa production (Shamshuddin *et al*., 2004a), but kills plants and aquatic life in the surrounding areas. Despite the abovementioned limitations, about 3000 ha of land in Merbok, Kedah, have been cultivated with rice since 1964 (Ting *et al*., 1993), but the yield is far below the national average of 3.8 t ha^{-1}.

Among the major agronomic problems common to acid sulphate soils are toxicity due to the presence of Al, decrease of P availability, nutrient deficiencies, and Fe (II) toxicity (Dent, 1986; Elisa *et al*., 2011). Thus, under normal circumstances, acid sulphate soils are not suitable for crop production, unless some amelioration practices are made. Among the practices are liming with ground magnesium limestone (GML), submergence, leaching, applying manganese dioxide (Park & Kim, 1970), phosphate application and applying basalt.

From all of the above practices, liming is the common approach to raise pH. By increasing soil pH to more than 5, soluble Al often precipitates in soil as gibbsite ($Al(OH)_3$), thereby reduces Al toxicity in soil. Besides increasing soil pH, GML can supply large quantity of Ca and Mg for crop uptake, which is essential nutrient for good rice growth. Furthermore, Ting *et al*. (1993) stated that rice yield increased from < 2 to 4.5 t ha^{-1} seasons after annual GML application of 2 t ha^{-1}.

Besides liming material, organic fertilizers can also be applied to acid sulphate soils. Under flooded condition, these organic fertilizers supply NPK and alleviate Al toxicity in the acid sulphate soils (Muhrizal *et al*., 2003). Meanwhile, in another study under flooded, reduced and re-flooded conditions, organic materials (acting as organic fertilizers) in combination of Fe (III) oxides does not increase soil pH above 5 (Muhrizal *et al*., 2006). This means that, to some extent, the Al is still present in the solution at toxic level.

On the other hand, Suswanto *et al*. (2007) found that under field trial condition, application of GML+organic fertilizer can produce rice yield up to 7.5 t ha^{-1} (Suswanto *et al*., 2007). Therefore, with applications of lime, basalt, organic fertilizer and/or their combinations at appropriate rates, acid sulphate soils are able to be ameliorated (Suswanto *et al*., 2007; Shazana *et al*., 2011). The current study was conducted to determine the effects applying lime from various sources for rice production on an acid sulphate soil under rain-fed condition in Merbok, Kedah, Malaysia.

MATERIALS AND METHODS

Background of the Study Area

This study was conducted in Merbok, Kedah, and the soil is an acid sulphate soil (Merbok series). At the study site, approximately 3000 ha are being utilized for rice cultivation for more than 40 years using fertilizers and pesticides subsidized by the Malaysian government. This area has been experiencing low rice yield with an average production of less than 2 t ha^{-1} $season^{-1}$. Besides that, this area is often exposed to severe infection of *Magnaporthe grisea* fungal disease, more commonly known as rice blast, which further reduces yield. To make matters worse, the farmers rely solely on rain water (rain-fed condition) as there is no irrigation system in this area. Formerly, these areas were occupied by high tidal mangrove flats and were converted to paddy fields in 1964. The mean rainfall recorded at these areas is 2155 mm $year^{-1}$, with pronounced dry period in December-March annually. During these dry periods, temperature reaches 50°C thus evapo-transpiration rate exceeds precipitation as described by Ting *et al*. (1993).

Soil and Site Description

Field trials were conducted in Merbok, Kedah, Malaysia (5.7185 N, 100.3812 E) (Fig.1). The experimental plots were established on an acid sulphate soil classified as Merbok Series (Paramananthan, 1987) which is Typic Sulfaquents (Soil Survey Staff, 2010). This area has been cultivated with paddy for more than 40 years by farmers using fertilizers and pesticides subsidized by the Malaysian government. This area has been experiencing low rice yield, with an average production of < 2 t ha^{-1} $season^{-1}$. It is often exposed to severe infection of rice blast which further reduces yield. At the onset of the current experiment (March 2010), soils were sampled at 15 cm interval to the depth of 75 cm at selected locations in the experimental plots in order to determine their original chemical properties (Table 1). The texture is clay loam with 31.25% sand, 39.36% silt and 29.18% clay. The topsoil (0–15 cm depth) contains 2.78% total carbon, 0.19% total N, 2.28 mg kg^{-1} available P, 0.31 $cmol_c$ kg^{-1} exchangeable K and 6.19 $cmol_c$ kg^{-1} exchangeable Al. Soil pH is 3.4.

Experimental Design, Treatments and Field Management

In this study, Randomized Completely Block Design (RCBD) was used with five treatments replicated five times. The plot size was 5.0 m x 5.0 m and the plots were separated from one another by sealed ridge (sealed using plastic film; the depth was 15 cm under the soil surface) to prevent water movement among the plots.

The soils were treated with GML, hydrated lime or liquid lime at the rate shown in Table 2. GML and hydrated lime were applied only once during the 1st season (dry season), a month prior to sowing. These liming materials were evenly distributed and incorporated within the topsoil. For liquid lime treatment, 20 L ha^{-1} was mixed with water at ratio of 1:5 and sprayed onto the soil surface a day before sowing.

TABLE 1
Initial chemical characteristics of the soil at various depths prior to sowing

Depth (cm)	pH water (1:2.5)	EC (dS m^{-1})	Exchangeable cations ($cmol_c$ kg^{-1})					Fe (mg kg^{-1})	CEC ($cmol_c$ kg^{-1})	Total N (%)	Total carbon (%)	Available P (mg kg^{-1})
			K	Ca	Mg	Na	Al					
0-15	3.40	0.78	0.25	2.37	2.56	0.12	6.19	525.00	10.36	0.19	2.78	2.28
15-30	2.36	1.08	0.21	2.42	2.80	0.29	7.82	284.70	10.71	0.10	1.82	1.53
30-45	2.90	1.73	0.91	2.57	2.99	0.44	8.53	316.40	11.93	0.10	1.89	1.44
45-60	2.93	2.17	0.22	2.53	3.65	0.69	8.63	307.50	13.21	0.10	2.30	1.58
60-75	2.81	4.06	0.23	2.85	4.63	1.44	10.02	560.55	17.64	0.12	3.54	2.11

Rice (*Oryza sativa*) variety MR 219 with 90% germination rate was used. This is the rice variety that is commonly planted by the farmers throughout Peninsular Malaysia. Seeds were sown during April 2010 and October 2010 for the first and second season, respectively, at a seeding rate of 150 kg ha^{-1}. The seeds were soaked with hormone-based chemical (Zappa™) for 24 hours. The seeds were rinsed with tap water and left in the dark place for 24 hours before sowing in the field.

Fertilizers were applied in the experimental plots based on standard fertilizer rate (120 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}) using urea, NPK Blue (12:12:17+TE) and NPK Green (15:15:15+TE) as the sources of the nutrients. Growth enhancers, namely Vita-grow™ and Robust™, were applied 15, 45

TABLE 2
Treatments in the field

Symbol	Treatments
T1	Control (without lime)
T2	4 t ha^{-1} ground magnesium limestone (GML)
T3	2 t ha^{-1} hydrated lime
T4	20 L ha^{-1} of liquid lime (only apply for the 1st season)
T5	20 L ha^{-1} of liquid lime (apply for 1st and 2nd season)

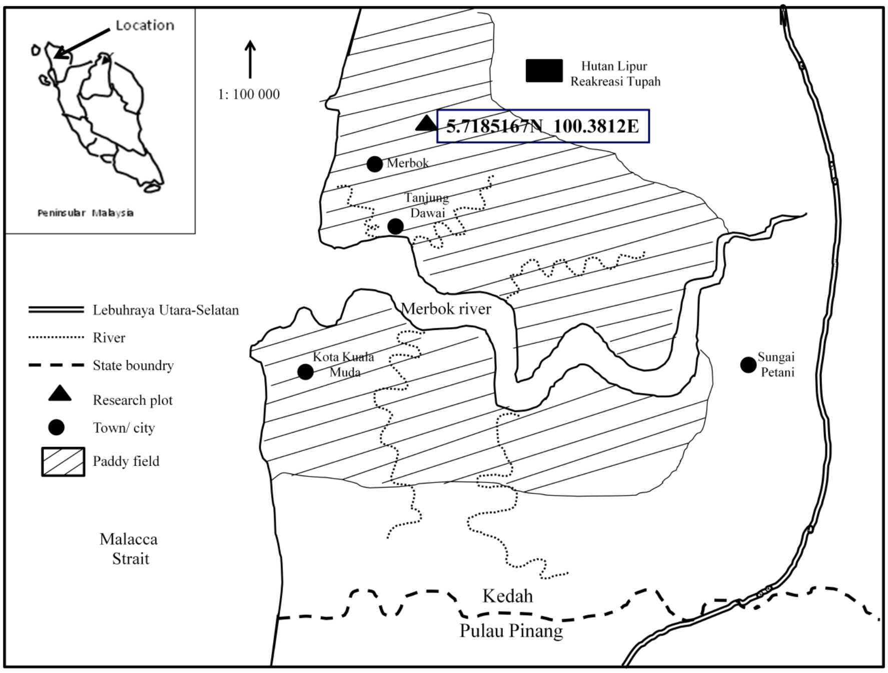

Fig.1: Map indicating Merbok in Kedah, where the field trial was carried out

and 60 days after seeding (DAS) at the rate of 75 mL and 100 mL, respectively. Both growth enhancers were mixed with 20 L of water for 1 ha of paddy field to boost the growth.

During the first season (April-August, 2010), there was an extended dry period during the vegetative and reproductive phases. Therefore, water needed to be pumped from the nearest drainage canal (acidic water) to ensure that the rice seeds were germinated. On the other hand, there was no water limitation during the second season (September 2010-January 2011) due to intermittent heavy rainfall throughout the season. The crop of rice was harvested in August 2010 and January 2011 for the first and second seasons, respectively.

Soil Sampling and Chemical Analysis

Soil sampling was carried out three times: (i) before rice planting of the first season (April 2010); (ii) after the first harvest (August 2010); and (iii) after second harvest (February 2011). Only topsoil (0-15 cm) was sampled and three samples were taken from each experimental plot using a soil auger. After air-drying, the soil samples were ground and passed through a 10-mesh sieve (2 mm). The following soil analyses were carried out: (i) Soil pH was determined in water at soil to solution ratio of 1:2.5; (ii) cation exchange capacity (CEC) was determined by 1 M NH_4OAc at pH 7 (Chapman, 1965); (iii) exchangeable Ca, Mg and K in the NH_4OAc extract were determined by Perkin Elmer Analyst 400 atomic absorption spectrometry (AAS); (iv) 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 a filter paper (Whatman No. 42) before determining the Al by AAS; and (v) extractable Fe was determined using double acid method. Fe was extracted using 0.05 M HCl in 0.0125 M H_2SO_4. Five g of air-dried soil was mixed with 25 mL extracting solution, shaken for 15 minutes and centrifuged at 180 rpm. The supernatant was then filtered through filter paper (Whatman no 42) and the Fe was determined using AAS. The analysis methods are detailed in Carter *et al*. (1993).

Harvesting and Yield Component Measurements

The crops were harvested on 29th August, 2010 and 13th February, 2011 for the first and second seasons, respectively. During harvest, a quadrate of 25 cm x 25 cm size was used for sampling the plant parts. The quadrate was thrown 4 times randomly in each of the experimental plot. The samples were taken to the laboratory for yield components analysis.

The following yield components analysis were determined: (i) panicle number was determined by counting all the panicles from each quadrate sampling and 20 panicles were selected randomly from each experimental plot for further yield component analysis; (ii) panicle length was measured using a ruler; (iii) determination of spikelet per panicle was done by threshing the grains from the samples and unfilled grains were separated from filled grains using the seed separator; (iv) percentage of filled spikelet was calculated using a formula (filled spikelet per panicle/total spikelet per panicle) x 100; and (v) 1000 grain weight. Grain yield was determined from all plants from a 25 m^2 site (except border plants) in each experimental plot.

Plant Tissue Analyses

The upper part of the plants was oven-dried at 65ºC for three days. The samples were ground using a stainless steel grinder and passed through a 1-mm 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 filtered through Whatman filter paper No. 42 and made up to 100 mL volume with distilled water. The concentrations of calcium (Ca), magnesium (Mg), aluminum (Al) and iron (Fe) were measured using Perkin-Elmer AAnalyst 400 AAS. Nitrogen (N) and potassium (K) were measured using Lachat QuickChem® FIA+ 8000 Series auto analyzer (AA).

Analysis of Water from the Field Plots

Water was collected from each of the experimental plots. The samples were taken every week for the first 5 weeks, followed by every 2 weeks until harvest. For the first season, the sampling started at 14 DAS due to dry conditions on the field at 7 DAS, while for the second season, the sampling was stopped at 77 DAS when the paddy field dried up. After filtering the samples, pH was determined using Sartorius pH meter PB-11. Al and Fe concentrations were determined using Perkin-Elmer AAnalyst 400 AAS.

Statistical Analysis

Data from the experiment were analyzed statistically using analysis of variance (ANOVA), and least significant difference (LSD) test was employed to determine the mean differences between the treatments. The statistical package used was SAS v9.1 software.

RESULTS AND DISCUSSION

Changes in soil properties

The soil under investigation is low in pH and high in exchangeable Al (Table 1). Soil pH throughout the soil profile is < 3.50. This low pH is consistent with the presence of jarosite in the sub-soil, which qualifies it to be classified as an acid sulphate soil (*Typic Sulfaquents*). Exchangeable Al in the soil is very high throughout the soil depth. The topsoil (0-15 cm depth) is the zone where the development of rice root occurs. The pH values and exchangeable Al of the topsoil are 3.4 and 6.19 $cmol_c$ kg^{-1}, respectively (Table 1). The concentration of Al exceeds the critical level for rice production of 1-2 mg kg^{-1}, as suggested by Dobermann and Fairhust (2000). The pH and the concentration of Al in the water at the soil pit is 3.70 and 878 µM, respectively. The concentration of Al is far above the critical toxic level of 74 µM for rice growth as suggested by Dent (1986). The favourable pH for optimal rice (MR 219) root growth is 6 (Elisa *et al*., 2011).

However, to raise the pH up to this level is costly and many ordinary farmers may not be able to afford it. Aluminium toxicity can occur in soil when pH < 3.5 (van Breemen & Pons, 1978). A study conducted in Japan showed that the growth of Al-tolerant rice variety began to be inhibited when the Al^{3+} ion concentration exceeded 900 µM (Cate & Sukhai, 1964). This value is close to aluminium concentration in this study at 878 µM; thus, rice growth in this study area can be inhibited by Al. Moreover, the rice variety used in the current study is not Al-tolerant.

First Season

The first season started in August 29, 2010. The result showed that treating the soil with 4 t GML ha^{-1} was able to increase rice production by 29.17% from 2.50 t ha^{-1} (control) to 3.53 t ha^{-1}, and this value was slightly higher than average rice yield using farmer's practice of less than 2 t ha^{-1} $season^{-1}$ (Table 3). However, this yield was not significantly different from the control. Meanwhile, application of 4 t GML ha^{-1} produced the highest value in terms of panicle number m^{-2} , spikelet number per panicle, 1000 grain weight and panicle length, with values of 914, 132, 25.30 g and 24.65 cm, respectively, among the other treatments. However, there was no significant difference among the treatments for panicle number m^{-2}. There were significant differences observed for the percentage of filled spikelet. The means that treating with 2 t ha^{-1} of hydrated lime was significantly higher compared to treating with 20 L ha^{-1} of liquid lime, with values of 73.13% and 61.27%, respectively. Based on LSD, there were significant differences observed for the 1000 grain weight and panicle length.

In this study, it was observed that relative rice yield was affected by the soil pH and exchangeable Ca (Fig.2). It means that as the soil pH and exchangeable Ca increase, the relative rice yield also increases. The

TABLE 3
Mean rice grain yield and its components for the first and second seasons

Seasons	Treatments	Actual yield (t ha^{-1})	Panicle number m^{-2}	Spikelet num/ panicle	Filled spikelet (%)	1000 grain weight (g)	Panicle length (cm)
S1	T1	2.50^{ab}	794^{a}	120^{ab}	68.02^{bc}	23.00^{b}	23.03^{ab}
	T2	3.53^{a}	914^{a}	132^{a}	71.23^{ab}	25.30^{a}	24.65^{a}
	T3	3.24^{a}	866^{a}	118^{ab}	73.13^{a}	24.70^{a}	24.14^{a}
	T4	1.79^{b}	763^{a}	101^{b}	64.27^{cd}	22.80^{b}	21.65^{b}
	T5	1.57^{b}	831^{a}	103^{b}	61.27^{d}	22.36^{b}	22.05^{b}
S2	T1	2.10^{a}	610^{a}	144^{a}	71.45^{a}	24.89^{a}	24.56^{a}
	T2	1.90^{a}	679^{a}	153^{a}	71.56^{a}	23.10^{a}	23.80^{a}
	T3	1.88^{a}	675^{a}	150^{a}	68.51^{a}	24.89^{a}	24.68^{a}
	T4	1.84^{a}	607^{a}	134^{a}	70.57^{a}	25.12^{a}	24.43^{a}
	T5	1.60^{a}	657^{a}	132^{a}	68.61^{a}	24.90^{a}	24.43^{a}

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

relative rice yield is positively correlated with soil pH (Fig.2a) and exchangeable Ca (Fig.2b) and the corresponding relationship is given by equation Y= 91.10x – 238.36 (R^2=0.70) and Y= 49.86x + 30.30 (R^2=0.49), respectively. The pH value corresponding to 90% relative yield is 3.60. The critical exchangeable Ca is 1.197 $cmol_c kg^{-1}$, which is comparable to that found by Dobermann and Fairhust (2000). High Ca, to some extent, is able to reduce Al toxicity (Alva *et al*., 1986).

The yield for the first season can be increased with proper field management. Besides high soil acidity and Al toxicity, farmers in this area are facing another problem, which is drought. Bouman and Tuoang (2001) wrote that lowland rice is extremely sensitive to water shortage and drought problem when soil water contents drop below saturation and this will reduce leaf area expansion, closure of stomata, leaf rolling, deeper root growth, enhanced leaf senescence, reduced plant height, delayed flowering and reduced number of tillers, panicle, spikelet and grain weight. In the current study, the paddy field was dry when the seeds were sown during the

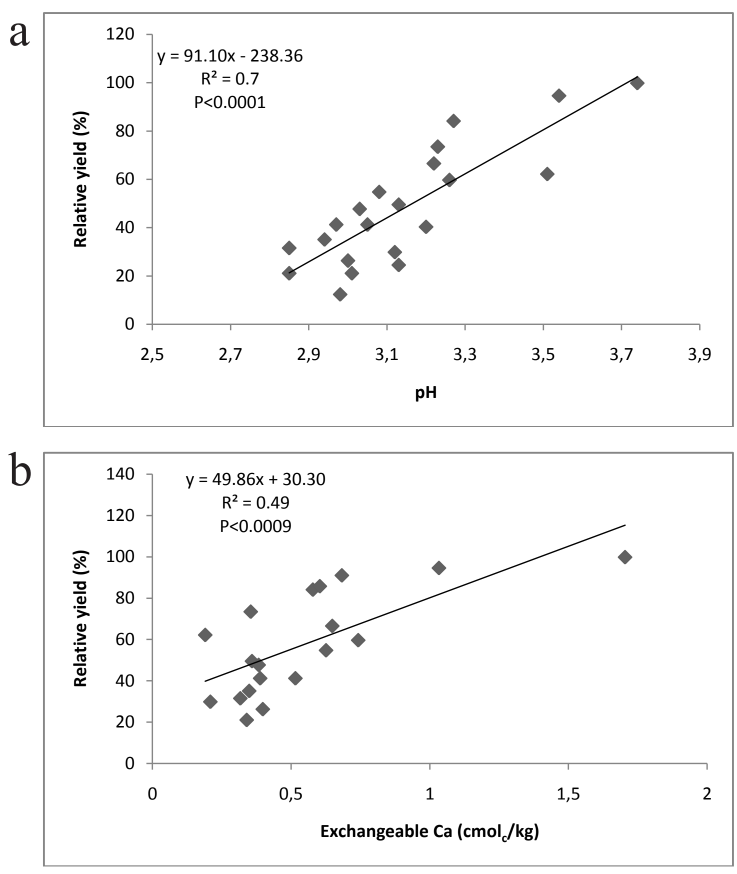

Fig.2: Relationship between: (a) relative yield and pH and (b) relative yield and exchangeable Ca for the first season

first season. There was no proper water management practice in the area where the farming communities depend solely on rain water that falls erratically throughout the growing season; hence, it was insufficient. As a result, the broadcasted seeds did not germinate well and the seedlings suffered because their roots were unable to tap the underground water. Therefore, acid water was pumped in from the nearest drainage canal to germinate the seeds. This had affected the subsequent growth of rice seedlings and hence the eventual rice yield.

The acid water contains Al concentration at 878 µM with pH of 3.70. This Al concentration is far above the critical toxic level of 74 µM for rice growth, as suggested by Dent (1986). Furthermore, Zhu *et al.* (2009) mentioned that rice is expected to suffer from H^+ stress if grown on a soil with low pH. Growing rice in an area with low pH and high Al concentration would inhibit the elongation of plant roots (Horst *et al.*, 2009). There will be disruption of root cap forming processes, decline in cell division and deposition of lignin (Susan *et al.*, 2007). In the end, root length is inhibited. As a result, nutrient uptake is curtailed and multiple nutrient deficiencies occur (Godbold *et al.*, 1988; Tan & Keltjens, 1995; Ridolfi & Garrec, 2000), and this has been proven by this study which showed that the concentration of Ca in the root was <0.01% (Table 4) due to the presence of high Al. Elongation of root length is well associated with root surface area. Root surface area of rice seedling needs to be increased for better absorption of nutrients and this can be done by raising solution pH by using lime. At 42 days after sowing, the water level in the plot was about 30 cm due to heavy rainfall. Thus, the ripening period was delayed to 125 DAS. This had affected the time for harvesting and pest started to attack the rice, resulting in a lower yield than had otherwise been expected.

Rice is known to tolerate some levels of acidity. Table 5 shows the effects of lime

TABLE 4
Mean nutrients concentrations of the above ground parts and root at 75 day after seeding

Seasons	Treatments	Upper part (%)						Root (%)					
		N	K	Ca	Mg	Al	Fe	N	K	Ca	Mg	Al	Fe
S1	T1	2.62^{ab}	2.78^{ab}	0.14^{ab}	0.27^{b}	0.03^{b}	0.16^{a}	1.86^{a}	1.19^{a}	6.8x10$^{-4\ b}$	0.09^{ab}	1.74^{a}	4.38^{a}
	T2	2.33^{b}	2.58^{bc}	0.13^{ab}	0.33^{a}	0.06^{a}	0.15^{a}	1.56^{a}	1.02^{a}	1.9x10$^{-3\ a}$	0.10^{a}	1.77^{a}	4.71^{a}
	T3	2.36^{b}	2.43^{c}	0.14^{a}	0.28^{ab}	0.04^{ab}	0.16^{a}	1.76^{a}	1.24^{a}	7.8x10$^{-4\ b}$	0.09^{ab}	2.25^{a}	4.65^{a}
	T4	2.85^{a}	2.93^{a}	0.11^{ab}	0.27^{b}	0.04^{ab}	0.16^{a}	1.87^{a}	1.26^{a}	6.4x10$^{-4\ b}$	0.07^{b}	1.92^{a}	4.55^{a}
	T5	2.69^{ab}	2.77^{ab}	0.11^{ab}	0.26^{b}	0.04^{ab}	0.19^{a}	1.74^{a}	1.05^{a}	3.0x10$^{-4\ b}$	0.07^{b}	1.75^{a}	5.27^{a}
S2	T1	2.40^{ab}	2.28^{ab}	0.12^{a}	0.27^{a}	0.03^{a}	0.05^{a}	1.26^{a}	0.64^{ab}	1.8x10$^{-3\ b}$	0.06^{a}	1.56^{a}	3.48^{a}
	T2	2.84^{a}	2.54^{a}	0.12^{a}	0.26^{a}	0.04^{a}	0.05^{a}	1.27^{a}	0.55^{b}	4.0x10$^{-3\ a}$	0.06^{a}	1.40^{a}	3.03^{a}
	T3	2.45^{ab}	2.47^{a}	0.12^{a}	0.28^{a}	0.04^{a}	0.05^{a}	1.15^{a}	0.65^{ab}	2.8x10$^{-3\ ab}$	0.06^{a}	1.82^{a}	2.76^{a}
	T4	2.19^{ab}	2.07^{ab}	0.11^{a}	0.26^{a}	0.04^{a}	0.06^{a}	1.26^{a}	0.72^{ab}	2.0x10$^{-3\ b}$	0.05^{a}	1.73^{a}	3.10^{a}
	T5	2.39^{ab}	2.28^{ab}	0.11^{a}	0.26^{a}	0.04^{a}	0.05^{a}	1.08^{a}	0.82^{a}	3.0x10$^{-3\ ab}$	0.06^{a}	1.96^{a}	3.09^{a}

on the soil properties in the Merbok trial. It is seen that pH is still below 5 after the first harvest. According to Ponnamperuma *et al*. (1973), only at pH below 4, rice was adversely affected. Soil pH for treatment with 2 t ha^{1-} of hydrated lime was the highest with 3.36 and it is higher than treatment with 20 L ha^{-1} of liquid lime and the control. Brady (1974) mentioned that hydrated lime reacted with the soil much more rapidly than its carbonate form. However, dolomitic limestone is often preferred because it supplies significant quantity of Mg. Besides that, GML can stay reasonably longer in the soil compared with hydrated lime. Nonetheless, exchangeable Al did not show any significant difference among the treatments.

Fig.3 shows the pH, Al and Fe concentrations of water from the field with time for the first season. The water was sampled every week for the first 5 weeks, followed by every 2 weeks until harvest. However, the sampling of water was started in the second week after sowing due to dry condition (Fig.4a). Therefore, water was pumped in from the nearest drainage canal to irrigate the experimental plots (Fig.4b). It is common knowledge that GML increases soil pH. Liming is a standard agronomic practice to increase pH of acid sulphate soils and this phenomenon is clearly shown in Fig.3a. However, the application rates of liming materials are dependent on localities; hence, field experiment such as conducted in this study are often necessary to justify the most suitable and feasible application rate.

Soil pH started to increase immediately after the field plots were flooded. It reached maximal value after 4 weeks. The increase was also due to reduction process that had taken place. Fig.3b shows the Al concentration was lower with the applications of 4 t GML ha^{-1} and 2 t hydrated lime ha^{-1} compared to the control. It seemed that the pH was still low and Al concentration was still high in the water in the research plots and these explained why rice yield was not

TABLE 4
Mean nutrients concentrations of the above ground parts and root at 75 day after seeding

Seasons	Treatments	Upper part (%)						Root (%)					
		N	K	Ca	Mg	Al	Fe	N	K	Ca	Mg	Al	Fe
S1	T1	2.62^{ab}	2.78^{ab}	0.14^{ab}	0.27^{b}	0.03^{b}	0.16^{a}	1.86^{a}	1.19^{a}	$6.8 \text{x} 10^{-4\ b}$	0.09^{ab}	1.74^{a}	4.38^{a}
	T2	2.33^{b}	2.58^{bc}	0.13^{ab}	0.33^{a}	0.06^{a}	0.15^{a}	1.56^{a}	1.02^{a}	$1.9 \text{x} 10^{-3\ a}$	0.10^{a}	1.77^{a}	4.71^{a}
	T3	2.36^{b}	2.43^{c}	0.14^{a}	0.28^{ab}	0.04^{ab}	0.16^{a}	1.76^{a}	1.24^{a}	$7.8 \text{x} 10^{-4\ b}$	0.09^{ab}	2.25^{a}	4.65^{a}
	T4	2.85^{a}	2.93^{a}	0.11^{ab}	0.27^{b}	0.04^{ab}	0.16^{a}	1.87^{a}	1.26^{a}	$6.4 \text{x} 10^{-4\ b}$	0.07^{b}	1.92^{a}	4.55^{a}
	T5	2.69^{ab}	2.77^{ab}	0.11^{ab}	0.26^{b}	0.04^{ab}	0.19^{a}	1.74^{a}	1.05^{a}	$3.0 \text{x} 10^{-4\ b}$	0.07^{b}	1.75^{a}	5.27^{a}
S2	T1	2.40^{ab}	2.28^{ab}	0.12^{a}	0.27^{a}	0.03^{a}	0.05^{a}	1.26^{a}	0.64^{ab}	$1.8 \text{x} 10^{-3\ b}$	0.06^{a}	1.56^{a}	3.48^{a}
	T2	2.84^{a}	2.54^{a}	0.12^{a}	0.26^{a}	0.04^{a}	0.05^{a}	1.27^{a}	0.55^{b}	$4.0 \text{x} 10^{-3\ a}$	0.06^{a}	1.40^{a}	3.03^{a}
	T3	2.45^{ab}	2.47^{a}	0.12^{a}	0.28^{a}	0.04^{a}	0.05^{a}	1.15^{a}	0.65^{ab}	$2.8 \text{x} 10^{-3\ ab}$	0.06^{a}	1.82^{a}	2.76^{a}
	T4	2.19^{ab}	2.07^{ab}	0.11^{a}	0.26^{a}	0.04^{a}	0.06^{a}	1.26^{a}	0.72^{ab}	$2.0 \text{x} 10^{-3\ b}$	0.05^{a}	1.73^{a}	3.10^{a}
	T5	2.39^{ab}	2.28^{ab}	0.11^{a}	0.26^{a}	0.04^{a}	0.05^{a}	1.08^{a}	0.82^{a}	$3.0 \text{x} 10^{-3\ ab}$	0.06^{a}	1.96^{a}	3.09^{a}

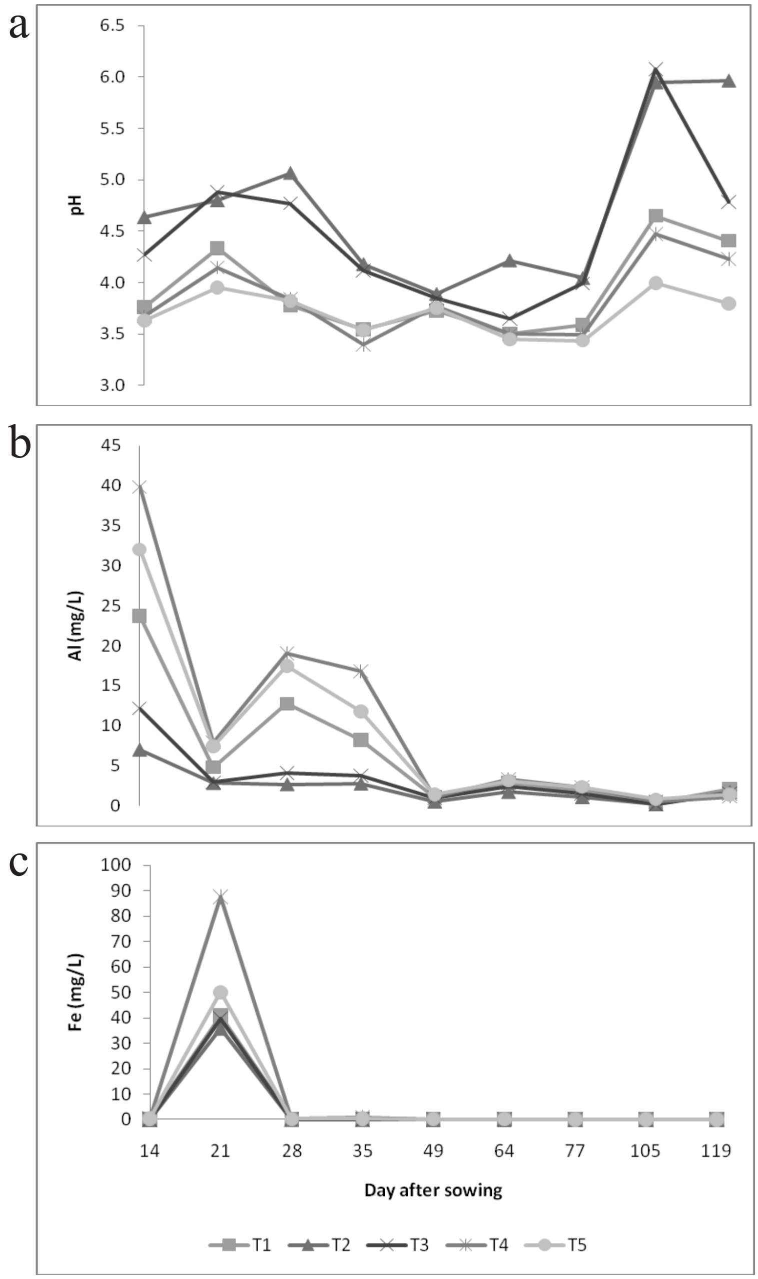

Fig.3: Changes in water pH (a) Al (b) and Fe (c) in the first season with time

up to expectation, below the national average of 3.8 t ha^{-1}. The highest concentration of Fe was found at 21 DAS (Fig.3c). Fig.5 shows the relationship between water pH and Al (a) and pH and Fe (b) for the first season, which are presented by equation Y= -5.88x + 32.36 (R^2=0.40) and Y= -0.08x + 0.44 (R^2=0.35), respectively. As Al and Fe in the water increased, the pH decreased. When Al and Fe increased above their pKa, the metal precipitated to form their inert hydroxides.

Second Season

The non-significant yield difference between treatments can be attributed to the adverse effect of rice blast during the flowering stage (Table 3). The area received high amount of rainfall during that time (October, 2010-December, 2010) period and farmers faced difficulties to drain out the excess water, as shown in Fig.6. This situation had resulted in high humidity which attracted diseases and as such the rice yield for the second season was erratic (Fig.7).

a

b

Fig.4: Dry condition during the first week after sowing (a) and water was pumped in from drainage canal (b) (for the first season)

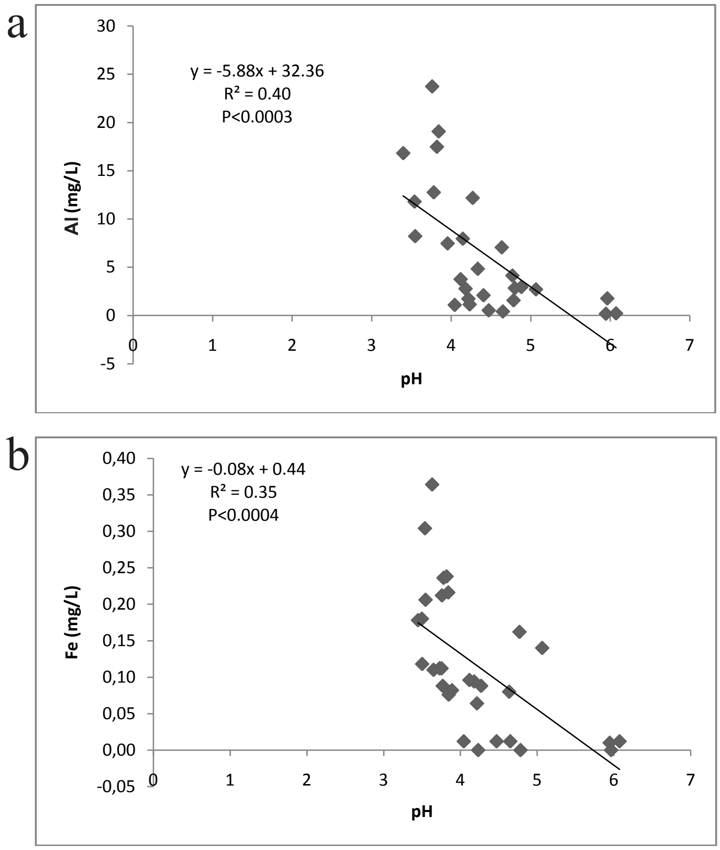

Fig.5: Relationship between water pH and Al concentration (a) and water pH and Fe concentration during the first season

Fig.6: The field condition during the second season with excess water

Rice blast is caused by an ascomycete fungus (*Magnaporthe grisea*). It spreads through spores and reproduces on its own. Thus, this disease spreads quickly in the infested paddy field. *M.grisea*, in some instance, has been named as *Magnaporthe oryzae*, *Pyricularia grisea* and *Pyricularia oryzae*. All these names are acceptable because scientists have yet to agree on a single name as it has different symptoms at different localities. Besides that, members of the *M. grisea* complex can also infect other cereal crops such as wheat, rye and pearl millet causing blast disease (Scardaci, 2003). Rice blast fungus causes economically significant crop losses annually in at least 85 countries worldwide. It is estimated to destroy enough rice to feed more than 60 million people (Scardaci, 2003; Crop Protection Compendium, 2011).

a

b

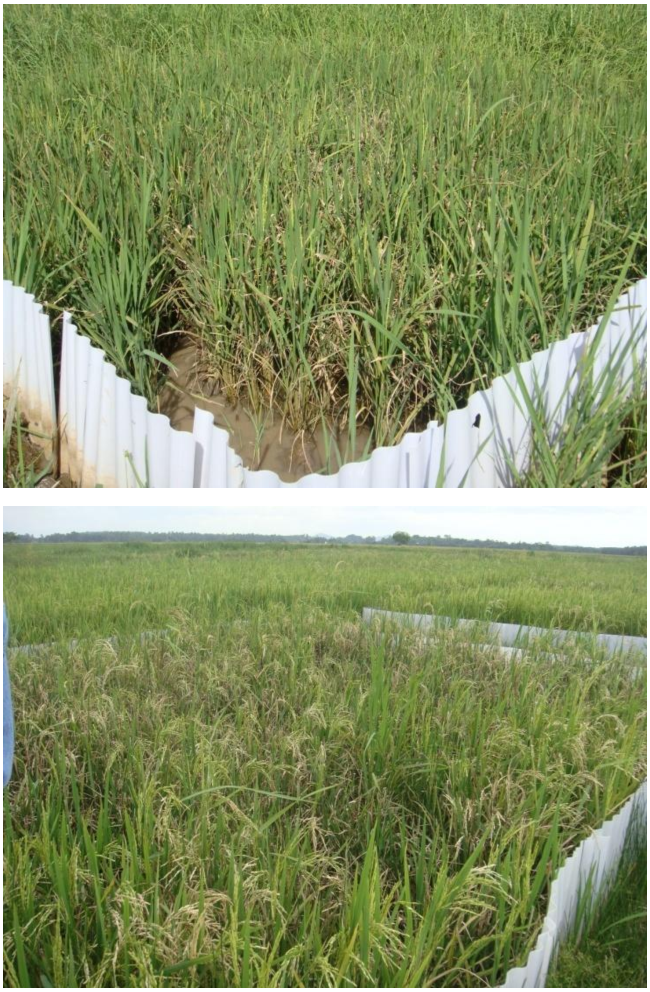

Fig.7: The condition of rice after being attacked by rice blast at 75 DAS (a) and 90 DAS (b) (the second season)

In the paddy field of the current trial, this disease started to attack the rice at 75 DAS. According to Yashida and Parao (1976), Ou (1985) and Scardaci (2003), rice blast is well known to cause severe yield losses in rice production systems. This scenario was noted to occur when cloud cover is high leading to low solar radiation. With low solar radiation, humidity often increases significantly and so does the rice blast infection. The infection rate of rice blast in paddy field tend to increase directly with increase in humidity as found by Dobermann and Fairhust (2000). Besides that, based on a study in multi-locations (Korea, Japan and China), Luo *et al*. (1998) found that changes of temperature between +3^{o}C in the ambient air show significant rice yield losses directly due to severe rice blast.

It is postulated that, the rice yield would have been higher than national average of 3.8 t/ha/season of rice yield if the paddy fields had not been attacked by the disease. In order to eliminate the disease, it is necessary to apply fungicide (a type of pesticide). However, usage of high amount of fungicide posses risk of environmental pollution and affects the farmers health as found in Vietnam (Hakan Berg, 2001), hence controlled usage of fungicide has to be practiced by the farmers. According to the farmers from the area, rice blast infested their paddy field every year with different degrees of severity. Therefore, a practical alternative is to use rice variety that is tolerant to the disease, which requires investment in terms of money and infrastructures.

Table 5 shows that the soil pH was still below 5 after the second harvest even after the application of 4 t GML ha^{-1}. Therefore, it was noted that the applied treatments did not alleviate the soil pH to the desired level of pH 6, and hence, not sufficient enough for good rice growth. Besides that, there was no significant difference for the concentrations of Al and Fe between the treatments (Table 5). It was noted that Al tended to decrease and Fe tended to increase over season. Al and Fe often precipitated as Al and/or Fe oxides and/or hydroxides in the soil. Al does not show prominent coloration in solution compared to Fe. In this trial, Fe was often observed as *'rust water'* within the nearby water-canal. This water is visually found to represent the iron reddish colour seeping from soil to the soil solution. Hence, oxidation-reduction processes that took place in a high acidity soils such as an acid sulphate soil also influence the Fe toxicity of the soil. This phenomenon has been described by Shamshuddin (2006) and Tan (2008).

Fig.8 shows the changes in water pH, Al and Fe concentration with time in the second season. The sampling was stopped at 77 DAS as the paddy field started to dry up. Application of GML and hydrated lime did not increase the pH and decrease the Al and Fe concentration as compared to the control. Likewise, liquid lime had no effect on pH. Fig.9 shows that Al concentration decreased with increasing pH and the equation is given by Y= -0.25x + 1.97 (R^2=0.53). This means that the pH needs to be increased in order to eliminate Al from damaging rice in the field.

Phosphorus Deficiency

Phosphorus (P) is mostly available for plant uptake when the soil pH is between 6.0 to 6.5, and decreases outside this pH range. In the study area (Merbok), the pH levels were less than 3.5, which are categorized as low soil pH (a.k.a high acidity). Besides that, these soils have high content of iron (Fe), as shown in Table 1.

When the soil is flooded, ferric (Fe) phosphate is converted to ferrous phosphate, which is more soluble in water, through a process called reduction process. The rate at which this process occurs, governs the amount of available P in the soil. On low pH soils, such as the Merbok soil, this reaction occurs quickly compared to alkaline soils. Thus, when the soil is flooded, the amount of P in solution increases available P for plant uptake. While P deficiency may seem to be present in Merbok soil soon after flooding; sufficient P may be released later in the season to produce better rice yields. When the soil is drained and the soil dries, P may again form compounds that are less soluble than prior to flooding.

It is stated by Dobermann and Fairhurst, (2000) that rice needs between 7 to 20 mg kg^{-1} of P for good rice growth. In this study, it was found that the available P at harvest was less than 3 mg kg^{-1} and there was no significant difference among the treatments. However, rice growth was not significantly affected by the low available P (Table 1), but reduction in the rice yield in the second season was prominent due to rice blast. Therefore, it was likely that P was immobilized by Al and Fe present in the

TABLE 5
pH, CEC, exchangeable bases (K, Ca, Mg, Al) and Fe of the soil

Sampling	Treatments	pH	CEC ($cmol_c\ kg^{-1}$)	Exchangeable bases ($cmol_c\ kg^{-1}$)				Fe ($mg\ kg^{-1}$)
				K	Ca	Mg	Al	
1st (Before rice planting during first season on April 2010)	T1	3.14^a	11.73^a	0.13^a	0.15^a	2.69^a	10.96^a	222.48^a
	T2	3.18^a	13.96^a	0.37^a	0.58^a	3.16^a	10.56^a	215.15^a
	T3	3.22^a	14.10^a	0.18^a	0.63^a	3.24^a	11.27^a	214.91^a
	T4	3.10^a	12.20^a	0.15^a	0.39^a	2.87^a	11.01^a	196.95^a
	T5	3.05^a	15.07^a	0.16^a	0.35^a	3.12^a	12.03^a	176.31^a
2nd (After first harvest on August 2010)	T1	3.17^{bc}	15.57^{ab}	0.13^b	0.51^{abc}	2.81^b	7.27^a	333.32^a
	T2	3.25^{ab}	19.07^a	0.15^{ab}	0.70^{ab}	3.39^a	8.35^a	309.52^a
	T3	3.36^a	14.03^b	0.18^a	0.77^a	2.94^b	7.29^a	281.97^a
	T4	3.03^c	14.41^b	0.15^b	0.37^{bc}	2.96^b	8.68^a	264.45^a
	T5	3.00^c	15.29^{ab}	0.16^{ab}	0.33^c	3.07^b	8.73^a	198.52^a
3rd (After second harvest on February 2011)	T1	3.12^b	13.90^{ab}	0.11^a	0.60^b	3.01^b	6.74^a	358.36^a
	T2	3.33^a	15.31^a	0.13^a	0.98^a	3.99^a	6.43^a	371.96^a
	T3	3.13^b	13.30^b	0.13^a	0.95^a	3.27^b	6.14^a	365.93^a
	T4	3.07^b	13.66^{ab}	0.11^a	0.49^b	3.15^b	6.87^a	335.18^a
	T5	3.09^b	14.29^{ab}	0.11^a	0.45^b	3.07^b	6.84^a	316.50^a

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

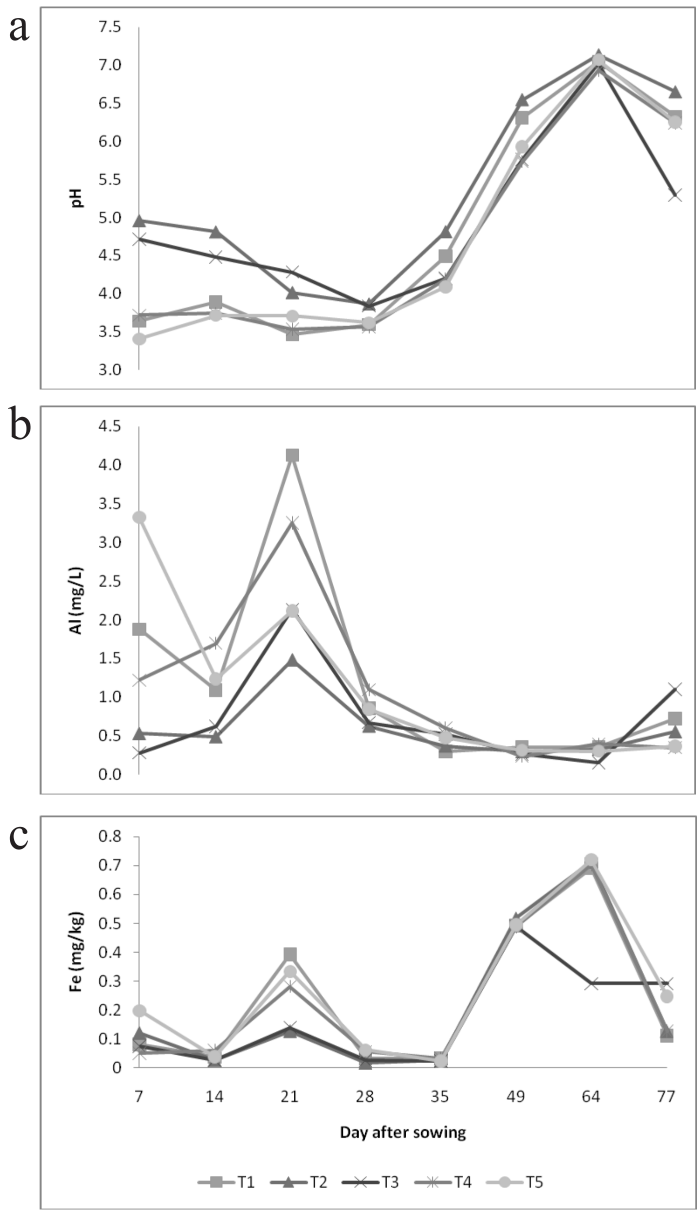

Fig.8: Changes in water pH (a), Al (b) and Fe (c) in the second season with time

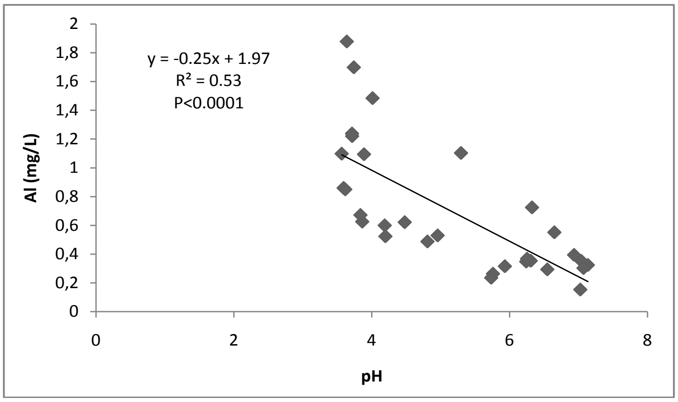

Fig.9: Relationship between water pH and Al concentration during the second season

soil via the formation of insoluble $AlPO_4$ or $FePO_4$ after the soil is drained and dries during harvest.

GENERAL DISCUSSION

Agronomic Practices

Several management and cultural practices can be used to improve the area and to increase rice production. The options include improving water management to irrigate and drain excess water, use of Al-tolerant rice variety and enhance soil fertility. In Merbok, the area used for rice cultivation is about 3000 ha. There is a potential to increase rice yield above the national average of 3.80 t ha^{-1} if an effective system of irrigation and drainage is put in place. Formerly, the area was occupied by high tidal mangrove flats and was converted to paddy field in 1964. The annual rainfall is 2155 mm with a pronounced dry period in December-March with evapo-transpiration rate exceeding rainfall (Ting *et al*., 1993). Another option is that Merbok River, which is approximately 2 km from the study area, can be utilized as a water source to irrigate the paddy field (Fig.5). Otherwise, the paddy field should get water from the nearby Muda Agricultural Development Authority (MADA) which has established irrigation and drainage system covering 96,000 ha to enable double cropping of rice.

Temperature and water source are the two major constraints in rice production, inclusive in Merbok (Kedah). Temperature at the study area varied highly from 32 to 50^{o}C and water source was scarce. High temperature may lead to heat stress mechanism in crop. This mechanism involves rolling in leaf to reduce moisture loss, thus reducing their yield (Ohta & Kimura, 2007). Meanwhile, scarcity of water adds to the lack of medium for nutrient mobilization and uptake. Therefore, one possible solution is to continuously pond the water during primary (March to June) and secondary (August to November) rainy season in Merbok (Kedah). This method is also suggested by Ikehashi (2007) as a good practice to improve water scarcity in rice field area. The pond water can be later used to provide the best growth condition for rice root development during growth stage thus increasing possibility of high rice yield. After planting, flooding would also help suppress weed growth, improves the efficiency of nitrogen (Cassman *et al*., 1998) and in some environments, helps to protect the crop from high fluctuations in temperature. Meanwhile, Yang *et al*. (2004) found that continuous water logging prior to root development decrease root development and its activity. Fertilizer uptake by crop may also be affected. Plus, Kirk and Bouldin (1991) reported suppressive effects on rice root systems that reduce the yield under continuous flooding practice. Therefore, continuous flooding of rice paddy field is best avoided. These scenarios suggest that field capacity water is much preferred during vegetative stage for rice seed to imbibe the water and germinate well.

Many rice varieties are available in the market (i.e., MR 219, MR 220, MR 253 and etc.); however, MR 219 is often used by the farmers in Merbok (Kedah) and also used in this study. MR 219 has some tolerance to Al toxicity although it also shows low resistance to rice blast. Besides that, high amount of Al was detected in the water. This scenario creates another problem for rice production in the area. As such, another option is to breed Al-tolerant cultivars. Recently, Malaysia has released MR 256 variety, which is known to be acid-tolerant. Planting Al-tolerant cultivar would accumulate less Al in their foliage and subsequently the uptake of Ca and P is efficient even in the presence of high Al concentration in the water of the paddy field.

Planting time can be delayed after application of lime and flooding until the pH increases due to reduction of Fe (III) to Fe (II). The same reason is given for the satisfactory growth of oil palm seedlings grown on acid sulphate soils under flooded conditions (Auxtero & Shamshuddin, 1991). The application of 4 t GML ha^{-1} on an acid sulphate soils before rice planting only managed to raise the pH to about 4.5 (Shamshuddin, 2006). Liming at higher rate than this can become uneconomical for the farmers as shown in Table 6. The soluble Al and Fe will decline, while the exchangeable Ca and Mg will increase after liming. In addition, a study had reported that the toxic effect of Al can be reduced by the presence of Ca and Mg (Bohn *et al*., 1979). Likewise, Sanchez (1976) found that Al toxicity can be reduced somewhat by the presence of extra calcium and magnesium.

Adding GML would increase the soil pH with the addition of Ca and Mg into the soil. GML will ameliorate acid soil according to the following reactions:

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

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

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

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).

Farmers in Merbok are provided with subsidized fertilizers, pesticides and seeds by the Malaysian government for every planting season. Besides that, better link between farmers-government-extension officers-industry players are needed. Drum seeders in Bangladesh and India is a technology that saves labour and increases rice yield. This technology is known to be farmer-friendly, easy to use and practical to be applied in the field. Such improvement in rice cultivation in Malaysia can help the farmers to save time and reduce cost of production. The drum seeder consists of a series of perforated drums supported between two wheels and the seeds are placed in the drums and the device is hand-pulled by one farmer, allowing seeds to fall in rows into the puddled rice field (Kumar *et al.*, 2009) compared to the scattered pattern of rice from broadcasting method. Through this practice, at least 10% increases in rice yield (Kumar & Ladha, 2011) were observed compared to the current production system.

Fertilizers should be applied according to the requirement of rice plants and it should be based on the recommended rate and have to be applied at the right time. This practice would help decrease pest infestation so that less pesticide is used and this helps reduce water pollution. Furthermore, it would help farmers reduce their production cost, while increasing the rice yield. Agronomists should help educate and guide the farmers in the management practices.

Cost Analysis

In order to increase the farmers' income and reduce production cost, a cost analysis is presented (Table 6). Table 6 shows that the application of 4 t GML ha^{-1} is the most expensive among the others, valued at USD 382 and resulted in the highest rice yield (3.50 t ha^{-1}) for the first season. Favourable water pH for rice growth is 6 and to raise the pH of acid sulphate soils to the desired level, it requires more than 4 t GML ha^{-1}, which is too costly. According to the record, rice yield in Merbok can be increased from <2 to 4.5 t ha^{-1} after annual liming at 2 t GML ha^{-1}

TABLE 6
Cost of different types of liming materials with labour

Rate	4 t ha^{-1} GML	2 t ha^{-1} hydrated lime	20 L ha^{-1} liquid lime (only 1st season)	20 L ha^{-1} liquid lime (1st and 2nd season)
Price	USD 50 t^{-1} = USD 200	USD 140 t^{-1} = USD 279	USD 97/20L = USD 97	USD 97/20L = USD 194
Labor	USD 46 =USD 182	USD 45 t^{-1} =USD 90	USD 16 ha^{-1} =USD 16	USD 16 ha^{-1} = USD 32
Total	USD 382 USD 3,820*	USD 369 USD 3,690*	USD 113 USD 1,130*	USD 226 USD 2,260*

*Average paddy land size is 10 ha^{-1} $farmer^{-1}$

(Ting *et al*., 1993). However, application of lime annually incurs labour cost and time consuming. Thus, a simple economics dictate here, as cost increase, profit margin decrease. Rice yield in Merbok (± 2 t ha^{-1} $season^{-1}$) is already lower than national level of 3.8 t ha^{-1}, hence farmers profit is quite low. With increase in production cost, most farmers may be reluctant to continue growing paddy. Currently, farmers in Merbok are using 2 t ha^{-1} of hydrated lime for every two season for rice production. And, with combination of direct drum-seeding method in Merbok, rice yield is expected likely to increase significantly.

CONCLUSION

Using ground magnesium limestone (GML) and hydrated lime at appropriate rate, rice cultivated on acid sulphate soils can yield comparable to that of the granary areas of Malaysia. This study showed that rice yield can be as high as 3.50 t ha^{-1} $season^{-1}$ even though it was subjected to drought and disease infestation. This yield was achieved by applying 4 t GML ha^{-1} although it cost USD 382 to the farmers. One ton of rice sold at the market price of USD 318. At this rate of lime application, the ameliorative effect can last for 2 seasons. In order to improve rice yield in Merbok, it is suggested that canal-water management and direct drum-seeding are applied through knowledge transfer from researchers to the rice farming community. Hence, it is believed that acid sulphate soils can be used productively for rice production so that self-sufficiency level (SSL) in Malaysia can be increased significantly, at least by 10-20% ha^{-1} $season^{-1}$.

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