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Effects of Applying Ground Basalt with or without Organic Fertilizer on the Fertility of an Acid Sulfate Soil and Growth of Rice

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ABSTRACT

Rice yield grown on acid sulfate soils is very low because of Al^{3+} and/or Fe^{2+} toxicity. A study was conducted to determine the effects of applying ground basalt with or without organic fertilizer on the growth of rice. Results showed clear benefits of ground basalt as an amendment for acid sulfate soil infertility. The ameliorative effects were comparable with that of applying 4 t ground magnesium limestone (GML) ha^{-1}; however, basalt had an additional advantage over GML as it contained K and P besides Ca and Mg. But as basalt needs time to disintegrate and dissolve completely in the acid sulfate soil under submerged conditions, the best option is to apply ground basalt in combination with organic fertilizers a few months ahead of transplanting rice in the field. The organic fertilizers would then be able to partly reduce Al and/or Fe in the soil via the chelation process.

Keywords: Acid sulfate soil, aluminum toxicity, basalt, iron toxicity, organic fertilizer, rice production

INTRODUCTION

The paddy fields in the Kelantan Plains, Peninsular Malaysia, are chemically degraded due to acidity released by the oxidation of pyrite (FeS_2) when the area is drained. Oxidation of pyrite also results in the formation of straw-yellow jarosite, [$KFe_3(SO_4)_2(OH)_6$], present as mottles in the soil profiles (Shamshuddin *et al.* 2004). Pyrite was formed when the Plains, were inundated with seawater some 6,000 years ago when the sea level was 3-5 m above the present level (Roslan *et al.* 2010; Enio *et al*. 2011). Pyrite-bearing soils are collectively called acid sulfate soils (Shamshuddin 2006). Some of the paddy fields are located in acid sulfate soils, which are not only low in pH (< 3.5), but also contain high amounts of Al and/or Fe (Shamshuddin 2006). It is known that the critical pH and Al

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concentration in water for rice growth is 6 and 15 µM, respectively (Elisa *et al*. 2011), a clear indication that rice plants are sensitive to H^+ and Al^{3+} stress.

The rice plant shows symptoms of Fe^{2+} toxicity during its reproductive stage causing roots to die (Hanhart and Duong 1993). However, the rice plant has a special mechanism to reduce the effects of Fe^{2+} toxicity. According to Moormann and van Breemen (1978), the rice plant can do so by pumping O_2 downwards via its root, creating an oxidized area around it where $Fe(OH)_3$ is precipitated, preventing further uptake of toxic Fe^{2+}.

Most of the rice fields on acid sulfate soils in the Kemasin-Semerak, Integrated Agricultural Development Area (IADP), Kelantan, produce rice yields below the national average of 3.8 t ha^{-1}; this has led to some farms being abandoned by the farming community (Shamshuddin 2006). Studies conducted earlier using GML as soil amendments have shown promising results (Suswanto *et al.* 2007). The increase in rice yield resulting from the treatment is probably due to pH increase and/or the increasing availability of macronutrients such as Ca and Mg originating from the dissolving limestone. Calcium, to a certain extent, alleviates Al^{3+} toxicity (Alva *et al*. 1986). The critical exchangeable Ca in soil for rice growth is 2 cmolc kg^{-1} soil (Doberman and Fairhurst 2000). Hence, it is justified that the infertility of acid sulfate soils is ameliorated by using appropriate amendments that increase soil pH and supply Ca to the growing rice plants in the field.

Ground basalt is an alternative to GML for increasing soil pH and consequently eliminating Al in soil solution (Anda *et al.* 2009). It not only increases soil pH, but also supplies Ca, Mg, K and P to the growing crops in the field (Shazana *et al.* 2013). Shamshuddin and Kapok (2010) have shown that ground basalt releases these nutrients into soils under glasshouse conditions. In the upland soils of Malaysia with pH of 4-5, basalt takes time to disintegrate and dissolve completely (Anda *et al.* 2009). But under acid sulfate soil conditions (pH< 3.5), basalt is expected to dissolve much faster (Shazana *et al.* 2013). Fe is abundant in the water of the paddy fields in the Kelantan Plains as indicated by the red coloration of the water before rice sowing (Shamshuddin 2006). As a result of proton consumption, the pH of the water will be increased, and consequently Al will be precipitated as inert Al-hydroxides. This reduction process can be accelerated by adding organic matter (Muhrizal *et al.* 2006). Low pH soils, especially acid sulfate soils, contain low total microorganisms. The addition of organic fertilizers to the rice crop stimulates the microbes into the soil. Microbes contained in the fertilizers increase plant growth either by supplying essential nutrient elements or increased availability of nutrient elements to the plant roots (Panhwar *et al.* 2013). This study was conducted to determine the effects of applying ground basalt with or without organic fertilizers on the chemical properties of an acid sulfate soil and the growth of rice in pots under flooded conditions.

MATERIALS AND METHODS

Location and Soil Sampling

Soil samples were taken from paddy fields within the Kemasin-Semerak Integrated Agricultural Development Area (IADP), Kelantan, and the soil was taxonomically classified as Typic Sulfaquepts (Soil Survey Staff 2010). Samples for soil characterization were taken at 0-15, 15-30, 30-45 and 45-60 cm depths using an auger. Soils for the pot experiment were taken from the surface horizon (0-15 cm depth).

Experimental

Moist soils taken from the field were mixed with the amendments and placed in 1 m×1 m pots. The experiment was conducted using randomized complete block design (RCBD) with 4 replications. The treatments were: T1 = control; T2 = 4 t GML ha^{-1}; T3 = 4 t ground basalt ha^{-1}; T4 = 0.25 t organic fertilizer ha^{-1}; and T5 = 4 t ground basalt ha^{-1} + 0.25 t organic fertilizer ha^{-1}. The organic fertilizer used was JITU™, a rice husk-based commercial compost currently available in the marketplace.

The rice variety (*Oryza sativa* L.) used was MR 219. All treatments received standard fertilizer rates, recommended for rice production in Malaysia: 90- 120 kg N, 12-18 kg P, and 90- 120 kg K ha^{-1}, using urea and ammonium sulfate, single super phosphate and muriate of potash, respectively, as the nutrient sources. Vita-grow™ and Robust™ were sprayed as micronutrient foliar fertilizers on 15, 40 and 60 days after transplanting. Vita-grow™ enhance the growth of rice plants in the pots.

The experiment was conducted over 120 days using transplanting technique with a planting density of 15 cm × 25 cm (20 points in each tank; one point containing approximately 3 rice plants). The soils were kept moist with the amendments added and mixed at three weeks before transplanting was carried out. Water in the pots was sampled at regular interval in order to determine pH, Al, Fe and other chemical properties. At harvest, soils for chemical analyses were sampled and yield component measurements were recorded. Roots were sampled for examination under scanning electron microscope.

Mineralogical Analysis

Clay was separated from the rest of the soil by mechanical analysis and this clay fraction was used for the identification of minerals by X-ray diffraction analysis. The samples for the XRD analysis were treated with Mg, Mg-glycol, K and K heated at 550^{o}C. They were then X-rayed using a diffractometer, Philips PW 3040/60 X'Pert PRO (Philip Analytical B.V., AA Almelo, The Netherlands).

Analysis of Water Samples

Water collected from the pots containing soils under treatments was immediately analyzed for chemical properties after centrifugation so as to remove the particulates floating in the water. pH of the water was determined, followed by the determination of the concentration of cations (Ca, Mg, K, Al and Fe) in the solutions using atomic absorption spectrophotometer (AAS).

Analysis of Soil Samples
Soil pH was determined in water at a soil-to-solution ratio of 1:2.5 using a pH meter. Basic cations were extracted using 1 M NH_4OA_c, buffered at pH 7. The cations (Ca, Mg, K, Na) in the NH_4OA_c solution were determined by AAS. Exchangeable Al was extracted by 1 M KCl and the Al in the extract was determined by AAS. Extractable Fe (double acid method) was also determined by AAS. Total carbon was determined by the Carbon Analyzer Leco CR-412 (Leo Corporation, St. Joseph, MI). Available P was determined by the method of Bray and Kurt (1945) with the extracted P determined by an auto analyzer (AA).

Analysis of Tissue
Leaf samples were collected using quadrate 25 cm × 25 cm with 5 tillers being selected for plant tissue analysis. The samples were separated into 'above ground plant parts' (leaves stems) and 'below ground plant parts' (roots). The fresh samples were cleaned and dried in an oven set at 70° C until dry. The samples were ground and digested following Benton (2001). The cations in the solutions (Ca, Mg, K, Al and Fe) were determined by AAS, while N and P were determined by AA.

Grain Yield and Yield Component Parameters
At harvest, all plant parts were harvested and grain yields were measured. Plant growth parame-ters were measured using the same 25 cm ×25 cm quadrate. In this exercise, twenty tillers were selected randomly to count the number of panicles with at least one filled grain per hectare, number of filled grain per panicle and 1000-grain weight.

Electron Microscopic Study
The roots of the rice plants for electron microscopic investigation were freeze-dried. The roots for this study were especially selected from the control treatment, treated with ground basalt and observed under scanning electron microscope (JEOL JSM-7600F, Field Emission Scanning Microscope, Japan). The elemental composition (Al, Fe, Si, K, Mg, etc.) was determined by energy dispersive X-ray (EDX) attached to the microscope.

Statistical Analysis
Statistical analysis for means comparison was carried out by Tukey's test using SAS version 9.2 (SAS Institute, Inc., Cary, N.C., USA).

RESULTS AND DISCUSSION

Chemical Properties of the Untreated Soil

The soil under field conditions was very acidic as evidenced by the presence of jarosite in the topsoil. Pyrite was certainly present in this soil as it is the precursor of jarosite. Exchangeable Al in the topsoil was 5.36$cmol_c kg^{-1}$, increasing in value with depth, indicating the higher acidity in the subsoil. Basic cations were low, but available P was within the sufficient range for rice growth. This is a true acid sulfate soil which under normal circumstances would not be suitable for rice production (Table 1).

TABLE 1
Chemical properties of the untreated soil taken from the field

Depth (cm)	pH H_2O	Total C (%)	Exchangeable cations ($cmol_c kg^{-1}$)					Ext. Fe	Avail. P ($mg\ kg^{-1}$)
			Ca	Mg	K	Na	Al		
0 - 15cm	3.44	1.45	0.30	0.25	0.21	0.28	5.36	0.91	24.4
15 - 30cm	3.43	1.44	0.20	0.23	0.14	0.17	6.98	0.57	20.7
30 - 45cm	3.44	0.66	0.22	0.24	0.14	0.25	8.67	0.37	22.8
45 - 60cm	3.47	0.46	0.17	0.24	0.12	0.54	8.96	0.28	22.6

Mineralogy of the Clay Fraction

The mineral that controls the chemical properties of the soil is pyrite and its product of oxidation, jarosite. The presence of jarosite in the topsoil was observed during the field work. However, pyrite only occurred in the subsoil below the water table. Other minerals present in the soil (clay fraction) were identified by X-ray diffraction analysis *(Figure 1)*. The most common minerals were mica (10 and 4.98 Å), kaolinite (7.1 and 3.57 Å) and quartz (4.25 and 3.3Å). A small amount of gibbsite was detected in the XRD diffractogram, indicated by the weak reflection at 4.83Å. Part of the mica had been weathered to form smectite, its presence being indicated by the diffractogram of Mg-glycolated sample (15.60Å). The presence of the above minerals was the main factor controlling the change in the chemical properties of the soil as affected by the treatments. Similar findings were reported by Auxtero (199), Enio *et al*. (2011) and Shazana *et al.* (2011).

Changes in Solution pH and Al Concentration with Time

Water pH and Al were monitored till the pots dried up just before rice harvest. Changes in pH with time are shown in *Figure 2a*, while changes in Al are shown in *Figure 2b*. The pH of water increased to a value higher than 6 at day 6, for all treatments due to consumption of proton during the reduction process. Subsequently, pH decreased to about 4 except in the case of the lime treatment.

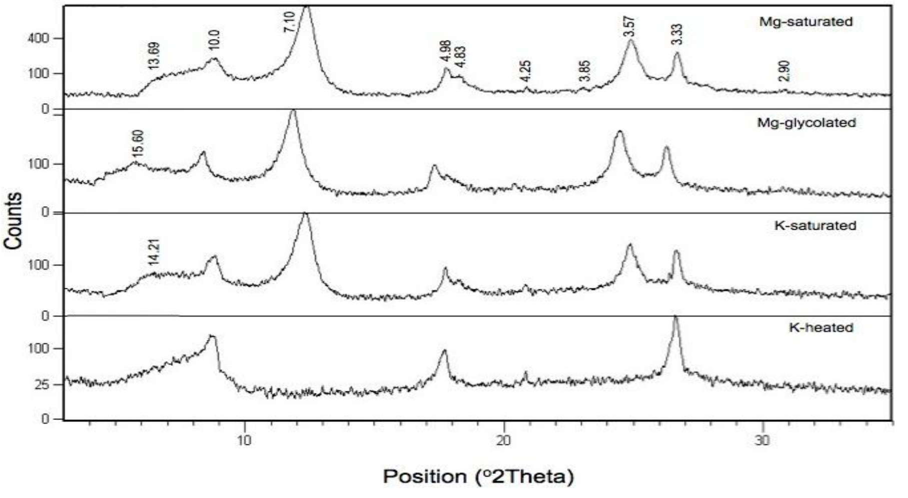

Figure 1: XRD diffractograms of the clay fraction of the soil treated with Mg, Mg-glycol, K and K-heated at 550°

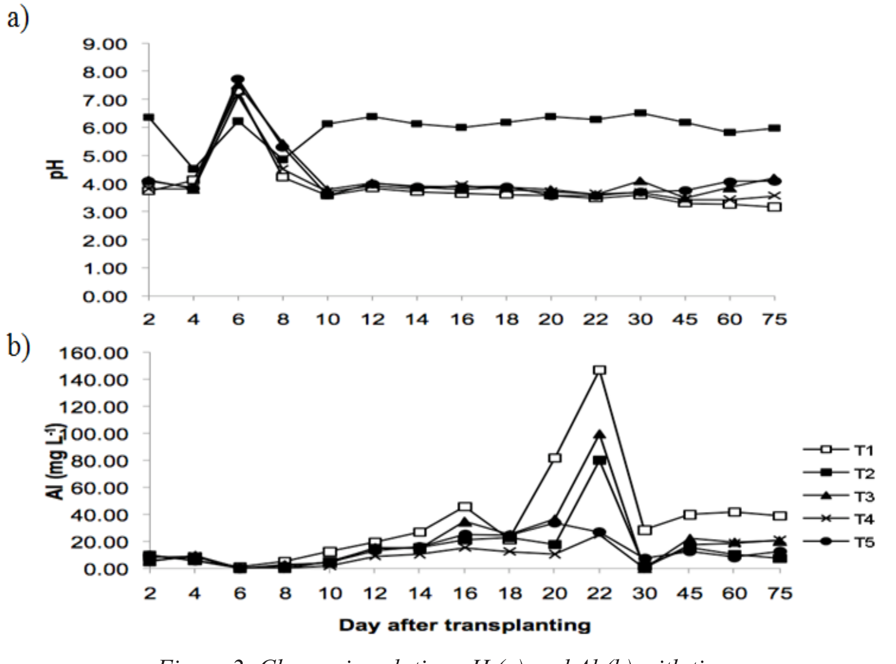

Figure 2: Change in solution pH (a) and Al (b) with time

Al concentration in the water did not change much during the first 10 days. For reasons unknown, Al concentration increased significantly in T1, T2 and T3. The changes in pH and Al concentration as observed in this study would have profound effects on the growth of rice.

Rice variety MR 219 was able to grow well in water at a pH of about 6 (Elisa *et al*. 2011). This means that rice grown on acid sulfate soils with pH < 3.5 would produce uneconomic yields. This finding is consistent with the results of other studies conducted elsewhere in Malaysia (Suswanto *et al*. 2007). The current study showed that Al in the soils can be significantly reduced by applying 4 t basalt ha^{-1}, which resulted in an acceptable rice yield. Moreover, if the same soil was used for the second cycle of rice cultivation, the pH could have been higher as clearly shown by the study of Shazana *et al*. (2013). At pH 5, Al in soil solution will start to precipitate as inert Al-hydroxides. This reaction occurs when GML or basalt is applied onto the acid sulfate soil causing the lime to immediately disintegrate and subsequently dissolve to release hydroxyls.

Effect of Treatment on Chemical Properties of Soil at Harvest

Chemical properties of the soils at harvest are shown in Table 2. According to HSD, all the chemical properties of the soil showed significant difference between treatments. Soil pH was below 3.5 except for the soil treated with 4 t GML ha^{-1}. This means that the soil was still acidic although it was treated with ground basalt over a period of more than 120 days. The low soil pH is consistent with the high exchangeable Al and Fe. Exchangeable Al in the control treatment was 4.18 cmolc kg^{-1} soil, which was far too high for rice growth. As GML takes a shorter time to react completely with the soil compared to ground basalt, exchangeable Ca and Mg in the lime treatment showed high values during the time of harvest. This was not the case for the basalt treatment where the values were not significantly different from the control treatment.

TABLE 2
Chemical properties of the soil at harvest

Treatments	pH H_2O	Exchangeable cations $cmol_c\ kg^{-1}$				Avail. P $mg\ kg^{-1}$	Fe
		Ca	Mg	K	Al		
T1	3.42 b	0.15 b	0.82 b	0.15 a	4.18 a	16.28 a	252.09 ab
T2	4.37 a	3.10 a	4.30 a	0.08 b	0.69 b	13.60 a	274.33 a
T3	3.34 b	0.27 b	1.71 bc	0.09 ab	3.19 a	14.28 a	227.01 ab
T4	3.18 b	0.11 b	0.38 c	0.09 ab	4.01 a	16.55 a	103.50 b
T5	3.49 b	0.37 b	1.97 b	0.07 b	2.92 a	15.73 a	125.38 ab
HSD	<0.001	<0.001	<0.001	0.02	<0.01	0.27	0.02

Notes: Means followed by the same letter within a column are not significantly different (HSD P<0.05). Where T1= Control, T2= GML 4 t ha^{-1}, T3= ground basalt 4 t ha^{-1}; T4 = 0.25 organic fertiliser t ha^{-1}; and T5 = ground basalt 4 t ha^{-1} + 0.25 organic fertiliser t ha^{-1}.

There was a significant increase in exchangeable Ca in the soil treated with 4 t basalt ha^{-1}. Ca, to certain extent, could detoxify Al (Alva *et al.* 1986), resulting in better rice growth as reflected in the higher rice yield. The highest exchangeable Ca was more than 3.5 $cmol_c$ kg^{-1} soil. Doberman and Fairhurst (2000) found that the critical exchangeable Ca level for rice production was 2 $cmol_c$ kg^{-1}. Thus, applying ground basalt at 4 t ha^{-1} succeeded in increasing exchangeable Ca level above the critical value for rice growth.

Effects of Treatment on the Growth of Rice

The effect of basalt application on the growth of rice was significant (Table 3). In the control treatment, rice grew poorly. On the other hand, basalt treatment resulted in better growth compared to that of the control. Table 3 shows the results of rice yield and its components. Sig-nificant differences were noted for yield and rice components among the treatments. Application of ground basalt improved soil fertility somewhat, giving a yield of 441.43 g pot^{-1} (4.41 t ha^{-1}), which is considered good for infertile soils like the acid sulfate soil used in this study, while for the control treatment, it was very low, 47.69 g pot^{-1} (<1 t ha^{-1}). The highest yield [472.82 g pot^{-1} (4.7 t ha^{-1})] was obtained by treating the soil with basalt in combination with organic fertilizers. Treating the soil with organic fertilizers alone did not help as the yield was still very low. The pattern for the spikelet number per panicle was similar to that of the grain yield. According to HSD, all treatments showed an increase in panicle number. The mean comparison of treatments showed that basalt with organic fertilizers gave the highest percentage of filled spikelets at more than 90%. Similar findings were reported by Panhwar *et al.* (2014) where the application of basalt with a combination of organic sources (biofertilizers) on the acid sulfate soil improved rice yield and growth.

TABLE 3
Data on rice yield components

Treatments	Grain yield (g pot^{-1})	Yield Component			
		Panicle number (10^4 ha^{-1})	Spikelet number ($panicle^{-1}$)	Filled spikelet (%)	1000 grain weight (g)
T1	47.69 b	252 b	58.25 b	74.58 b	20.10 c
T2	421.31 a	760 a	116.75 a	94.87 a	20.40 a
T3	441.43 a	784 a	99.75 a	93.26 a	23.68 a
T4	109.97 b	704 a	65.00 b	80.99 ab	20.33 bc
T5	472.82 a	796 a	109.75 a	93.53 a	23.55 ab
$HSD_{0.05}$	<0.01	<0.01	<0.01	<0.01	<0.01

Notes: Means followed by the same letter within a column are not significantly different (HSD P<0.05). Where T1= Control, T2= GML 4 t ha^{-1}, T3= ground basalt 4 t ha^{-1}; T4 = 0.25 organic fertiliser t ha^{-1}; and T5 = ground basalt 4 t ha^{-1} + 0.25 organic fertiliser t ha^{-1}.

Effects of pH, Exchangeable Al and Exchangeable Ca on Rice Yield
Rice variety MR 219 grows well in water with a pH of about 6. Hence, at a lower pH, rice yield islow, clearly shown in *Figure 3a*. The relative rice yield was positively correlated with soil pH and the relationship is given by the equation, y= 32.65x – 63.85 (r = 0.22). This means that rice grown on acid sulfate soils with pH < 3.5 would produce uneconomic yields. It is known that excess Al in a soil is toxic to the rice plant. As exchangeable Al in the soil increased, relative rice yield linearly decreased *(Figure 3b)*. To reduce Al completely in the soil, pH has to be raised to a value above 5 (the pK_a of Al is 5). The current study showed that Al in the soils can be significantly reduced by applying 4 t basalt ha^{-1}, which resulted in an acceptable rice yield (Table 3).

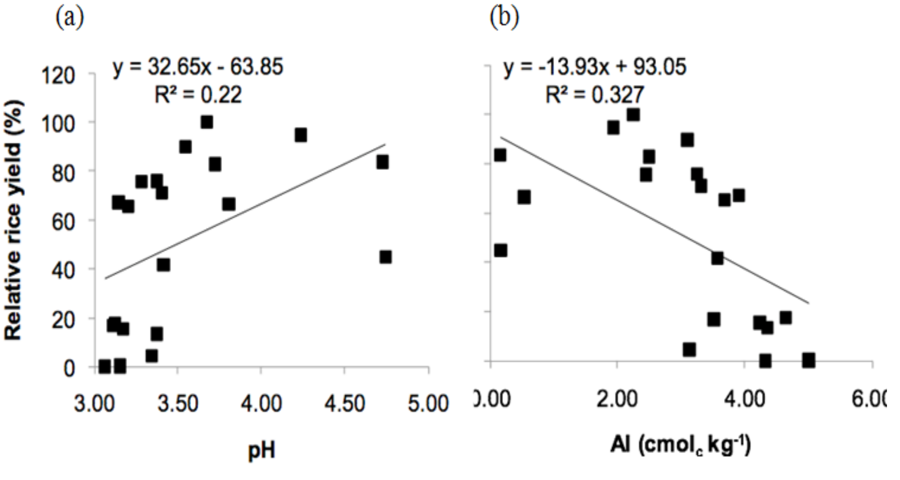

Figure 3: Relationship between relative rice yield and (a) pH and (b) exchangeable Al in the soil at harvest

Table 4 gives the elemental composition in the upper part of the rice plant and the root at harvest time. No significant difference was observed for N, P, K, Ca, Mg, Al and Si. However, there was a significant difference in Fe concentration. The Fe concentration in the upper part decreased from 0.07 to 0.05% due to an application of 4 t GML ha^{-1}. Mean comparison showed that soils treated with basalt had a lower concentration of Fe in the rice plants.

As basalt contains Ca, application of basalt increased Ca in the soil. There was a significant increase in exchangeable Ca in the soil treated with 4 t basalt ha^{-1}. Ca, to certain extent, could detoxify Al, resulting in better rice growth as shown by the higher rice yield *(Figure 4a)*. The best rice yield was reported for treatment with 4 t basalt ha^{-1} in combination with 0.25 t organic fertilizers ha^{-1}. This is because organic fertilizers are partly responsible for the reduction in Al^{3+} toxicity via the chelation process. Furthermore, organic matter such as organic fertilizers used in the current study hasten the reduction of Fe resulting in a more

TABLE 4
Concentration of nutrients in the plant above ground and roots

Treatments	Metal concentration in the upper parts (%)							
	Al	Fe	Ca	Mg	N	P	K	Si
T1	0.03 a	0.07 a	0.09 a	0.52 a	1.83 a	0.17 a	2.04 a	0.17 a
T2	0.03 a	0.05 b	0.15 a	0.57 a	2.63 a	0.18 a	1.90 a	0.28 a
T3	0.02 a	0.03 ab	0.14 a	0.75 a	2.12 a	0.18 a	1.29 a	0.34 a
T4	0.03 a	0.05 ab	0.13 a	0.59 a	2.54 a	0.20 a	1.87 a	0.49 a
T5	0.04 a	0.05 ab	0.14 a	0.60 a	2.66 a	0.17 a	1.58 a	0.40 a
$HSD_{0.05}$	0.55	0.08	0.33	0.61	0.47	0.8	0.59	0.1
Treatments	Metal concentration in the root (%)							
	Al	Fe	Ca	Mg	N	P	K	
T1	0.55 b	1.33 a	0.0007 a	0.03 a	1.53 a	0.11 a	0.28 a	
T2	0.63 ab	1.21 a	0.0006 a	0.05 a	1.43 a	0.15 a	0.20 a	
T3	0.46 b	0.93 a	0.0009 a	0.04 a	1.27 a	0.10 a	0.19 a	
T4	0.90 a	1.53 a	0.0006 a	0.03 a	1.43 a	0.16 a	0.27 a	
T5	0.60 ab	1.28 a	0.0006 a	0.04 a	1.35 a	0.12 a	0.14 a	
$HSD_{0.05}$	0.01	0.48	0.42	0.83	0.12	0.45	0.20	

Notes: Means followed by the same letter within a column are not significantly different (HSD P<0.05). Where T1= Control, T2= GML 4 t ha^{-1}, T3= ground basalt 4 t ha^{-1}; T4 = 0.25 organic fertiliser t ha^{-1}; and T5 = ground basalt 4 t ha^{-1} + 0.25 organic fertiliser t ha^{-1}.

rapid increase in pH (Muhrizal *et al*. 2006). Basalt itself increases the pH of water resulting in precipitation of some Al as inert Al-hydroxides, rendering it unavailable for uptake by rice plant (Anda *et al.* 2009).

Effect of Organic Fertilizer on Yield

The organic fertilizer with basalt proved better results with because of increased water pH that precipitated Al for rice plant uptake (Anda *et al.* 2010).The critical exchangeable Al for rice growth of 0.5 $cmol_c$ kg^{-1} was obtained *(Figure 4)*. A sonly 0.25 t ha^{-1} of as organic fertilizer had been applied, no significant differences were observed among the treatments. But beneficial effects observed were plant growth enhancement and induced soil microbial activity. Ultimately, itenhanced plant growth and reduced the toxicity of Fe and Al in the acidic soil. Similar findings were reported by Raja Namasivayamand Bharani (2012) who stated that organic fertilizers contain several beneficial bacteria, fungi and actinomycetes. In general, these soils have a low microorganisms population and the type of microbes found differs significantly according to the vegetation and nutrients available. It is known that a high number of microbes is found in the plant rhizosphere which enhances crop growth by supplying phytohormones (Naher *et al*. 2009).

A study was conducted using acid sulfate soils of the Kelantan Plains, Malaysia, to prove the occurrence of the bacteria. Different types of

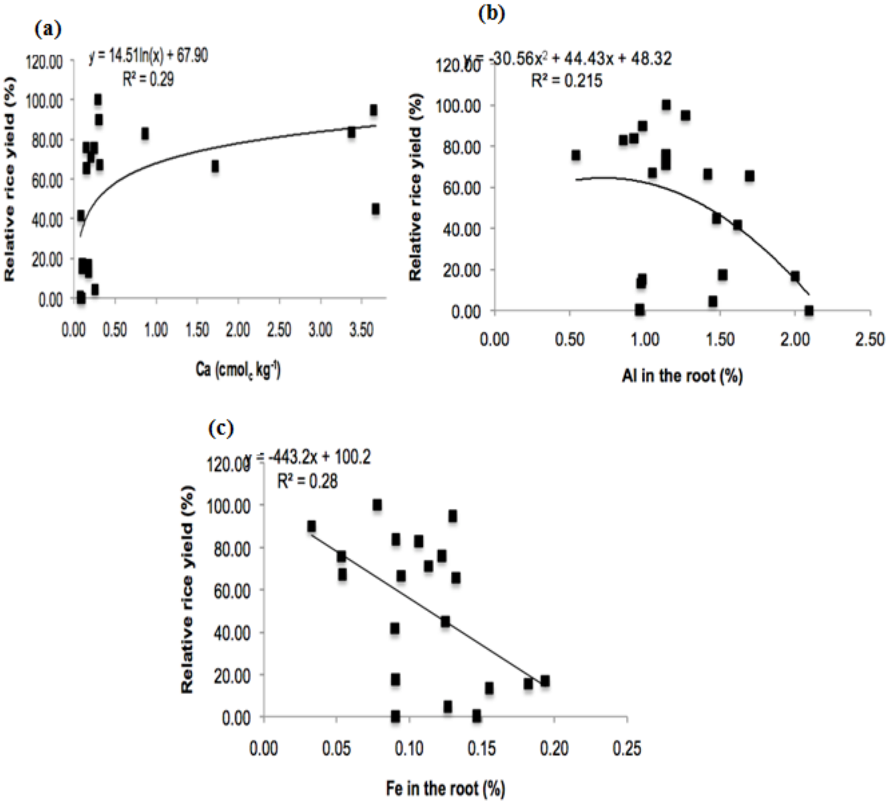

Figure 4: Relationship between relative rice yield with (a) exchangeable Ca (b) Al in the root (c) Fe in the root

microorganisms (bacteria, fungi and actinomycetes) were found in these soils but comparatively, the population of these microorganisms was lower than in the normal soils (Shamshuddin *et al.* 2014). Organic fertilizers like JITU™ have microorganisms and the application of such fertilizers on these soils may improve nutrient availability and lessen Al toxicity. Phosphate-solubilising bacteria produce large amounts of organic acids (Panhwar *et al*. 2012) that result in P binding by chelation and this could serve as a possible mechanism for reducing Al toxicity of plant roots (Ma and Furukawa 2003).

Relationship between Relative Rice Yields with Al concentration

Rice plants take in Al through the roots if a sufficient amount is present in the solution. Its presence in the roots may have damaged the cells that significantly affect rice growth, as reflected by poor yields. As the Al in the roots increased, rice yield decreased *(Figure 4c)*. This clearly shows that Al^{3+} affects rice production, and therefore needs to be eliminated from the soil at all costs in order to achieve agricultural sustainability. *Figure 4c* shows the relationship between the linear decrease in relative yield and increasing Fe in the root. This is shown by the equation y= -443.2x +100.2 (R^2 = 0.28). In the control treatment, much of the Fe was taken up by the roots, but Fe was not detected in the roots of the basalt-treated rice plants.

When rice plant roots are coated with Fe oxides, the capacity of roots to absorb nutrients from the soil is reduced, causing stunted growth (Doberman and Fairhurst 2000). According to Panhwar *et al.* (2014), the addition of microbes improves root growth and volume by reducing Al toxicity and improving dry weight of the inoculated plants, an indication of the potential of microbes in biofertilizer formulations for rice cultivation on acid sulfate soils

SEM Investigation of the Roots

Rice roots were studied under SEM to investigate their structure and to determine Al, Fe, Si and other elements *(Figure 5)*. In this investigation, roots from the control and those from basalt treatment were compared. A SEM micrograph of the roots of the control treatment is given in *Figure 5a*. The Al concentration in the roots at spectrum 1 was 1.06%. Treating the soil with basalt at 4 t ha^{-1} reduced the Al concentration to 0.86% (*Figure 5b*, spectrum 3). Essentially, this means that less Al had been taken up by the rice as a result of basalt treatment as less Al was available in the solution because of an increase in pH.

In the control treatment, much Fe was taken up by the roots, but Fe was not detected in the roots of basalt treated plants. As the pH increased due to basalt application, pH of the water too increased, resulting in the precipitation of Fe as Fe-hydroxides. Rice roots can only take in Fe in soluble form, not as $Fe(OH_3)$. Therefore, in order to reduce the effects of Fe^{2+} toxicity under field conditions, the pH of water needs to be raised as soon as the paddy field is flooded for rice

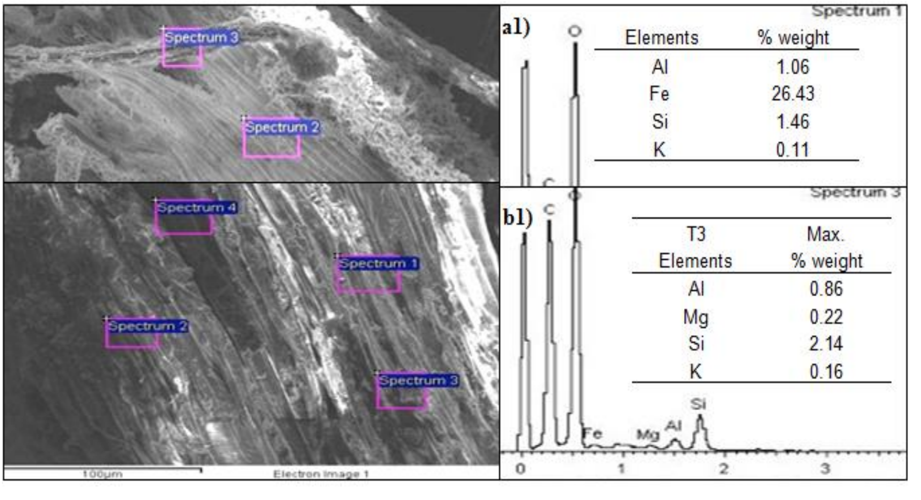

Figure 5: SEM micrographs of the root with a1 which is an X-ray spectrum 1 for electron image a (control); b1 which is an X-ray spectrum 3 for electron image b (basalt treatment)

cultivation. This can be done by liming or applying basalt at the appropriate rate and time; about 4 t ha^{-1} is probably sufficient for this purpose. Adding organic fertilizers into a flooded acid sulfate soil intensifies the reduction process and increases microbial activity, resulting in the release of Fe^{2+}, which is toxic to rice plants (Muhrizal *et al.* 2003; Tran and Vo 2004). It is also proven that microbes have the potential to produce large amounts of organic acids which result in P binding chelation which may be a possible mechanism for reducing Al toxicity of roots (Sudhakar *et al*. 2000). However, this is compensated by a pH increase that consequently precipitates Fe as inert Fe-hydroxides. In the presence of high quality organic matter in the soil, an immediate reduction could take place reducing Fe^{3+} to Fe^{2+} (Muhrizal *et al.* 2003).

CONCLUSION

This study has clearly shown the efficacy of ground basalt as an amendment for alleviating the infertility of chemically degraded acid sulfate soils. The low pH and high aluminum of acid sulfate soils can be effectively ameliorated by the application of 4 t ground basalt ha^{-1}. This is comparable to applying 4 t GML ha^{-1}, which is the standard lime requirement of acid sulfate soils in Malaysia. However, basalt has an additional advantage over GML because besides containing plant nutrients such as P and K, it also contains Si. The only problem with basalt is that it takes time to disintegrate and dissolve completely in soil under submerged conditions. In this regard, organic matter application may enhance microbial activity for the dissolution of basalt and enhance plant growth. It is, therefore, a good option for long-term sustainability of yields. The best option is to apply basalt in combination with organic fertilizers, way ahead of transplanting rice in the field.

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REFERENCES

Alva, A.K., C.J. Asher and D.G. Edwards. 1986. The role of calcium in alleviating aluminum toxicity. *Australian Journal of Soil Research*. 37:375-383.

Anda, M., J. Shamshuddin, C.I. Fauziah and S.R. Syed Omar. 2009. Dissolution of ground basalt on an Oxisol and its effect on chemical properties and cocoa growth. *Soil Science*. 174:264-271.

Anda, M., J. Shamshuddin, C.I. Fauziah and S.R. Syed Omar. 2010. Increasing the organic matter content of an Oxisol using rice husk compost: changes in the composition and its chemistry. *Soil Science Society of America Journal.* 74: 1167-1180.

Auxtero, E.A. and J. Shamshuddin. 1991. Growth of oil palm (*Elaeisguineensis*) seedlings on acid sulfate soils as affected by water regime and aluminum. *Plant and Soil*. 137: 243-257.

Benton, Jr. J. 2001. *Laboratory Guide for Conducting Soil Tests and Plant Analysis*. New York, USA:CRC Press LLC.

Bray, R.H. and L.T. Kurt. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science*. 59: 39-45.

Doberman, A. and T. Fairhurst. 2000. *Rice: Nutrient Disorders and Nutrient Management*. Los Banos, The Philippines: International Rice Research Institute (IRRI).

Elisa Azura, A., J. Shamshuddin and C.I. Fauziah. 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(3): 324-331.

Enio Kang, M.S., J. Shamshuddin, C.I Fauziah and M.H.A. Husni. 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.

Hanhart, K. and V.N. Duong. 1993. Water management on rice fields at Hoa An, Mekong Delta, Vietnam. In: *Selected Papers of the Ho Chi Minh City Symposium on Acid Sulfate Soils*, ed. D.L. Dent and M.E.F. van Mensvoort (pp. 161-175). Wageningen, The Netherlands: ILRI.

Ma, J.F., and J. Furukawa. 2003. Recent progress in the research of external Al detoxification in higher plants, a mini review. *Journal of Inorganic Biochemistry*. 97: 46-51.

Moormann, F.R. and N. van Breemen. 1978. *Rice: Soil, Water & Land*. Los Banos, The Philippines: International Rice Research Institute(IRRI).

Muhrizal, S., J. Shamshuddin, C.I. Fauziah and M.H.A. Husni. 2003. Alleviation of aluminum toxicity using organic materials. Communications in Soil Science and Plant Analysis. 34: 2999-3017.

Muhrizal, S., J. Shamshuddin, C.I. Fauziah and M.H.A. Husni. 2006. Changes in iron-poor acid sulfate soil upon submergence. *Geoderma*. 131: 110-122.

Naher, U.A., O. Radziah, Z.H. Shamsuddin, M.S. Halimi and I. Mohd Razi. 2009. Isolation of diazotrophs from different soils of Tanjong Karang rice growing area in Malaysia. *International Journal of Agriculure and Biology*. 11(5):547–552

Panhwar, Q.A., J. Shamshuddin, U.A. Naher, O. Radziah, and I. Mohd Razi. 2014. Biochemical and molecular characterization of potential phosphate-solubilizing bacteria in acid sulfate soils and their beneficial effects on rice production. *PLOS ONE*. 9(10): e97241. doi:10.1371/journal.pone.0097241.

Panhwar, Q.A., O. Radziah, U.A. Naher, A.R. Zaharah, M. Sariah, I. Mohd Razi and J. Shamshuddin, J. 2013. Effect of phosphate-solubilizing bacteria and oxalic acid on P uptake from different P fractions and growth improvement of aerobic rice using ^{32}P technique. *Australian Journal of Crop Science*. 7(8): 1131-1140.

Panhwar, Q.A., O. Radziah, A.R. Zaharah, M. Sariah and I. Mohd Razi. 2012. Isolation and characterization of phosphorus solubilizing bacteria from aerobic rice. *African Journal of Biotechnology.* 11(11):2711-2719.

Raja Namasivayam, S.K. and R.S.A. Bharani. 2012. Effect of compost derived from decomposed fruit wastes by effective microorganism (EM) technology on plant growth parameters of *Vignamungo. Journal of Bioremediation and Biodegradation*. 3:167. doi:10.4172/2155-6199.1000167.

Roslan, I., J. Shamshuddin, C.I. Fauziah and A.R. Anuar. 2010. Occurrence and properties of soils on sandy beach ridges in the Kelantan-Terengganu Plains, Peninsular Malaysia. *Catena.* 83: 55-63.

Shamshuddin, J., A. Elisa Azura, M.A.R.S. Shazana, C.I. Fauziah, Q.A. Panhwar and U. A. Naher. 2014. Properties and management of acid sulfate soils in Southeast Asia for sustainable cultivation of rice, oil palm and cocoa. *Advances in Agronomy.* 124: 91-142.

Shamshuddin, J.and J.R. Kapok. 2010. Effects of ground basalt on chemical properties on an Ultisol and Oxisol in Malaysia. *Pertanika Journal of Tropical Agricultural Science*. 33(1): 7-14.

Shamshuddin, J. 2006. *Acid Sulfate Soil in Malaysia.* Serdang, Malaysia:UPM Press

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

Shazana, M.R.S., J. Shamshuddin, C.I. Fauziah and S.R. Syed Omar. 2013. Alleviating the infer-tility of an acid sulphate soil by using ground basalt with or without lime and organic fertiliz-er under submerged condition. *Land Degradation and Development.* 24: 129-140.

Soil survey Staff. 2010. K*eys to Soil Taxonomy.* Washington DC, USA:United States Department of Agriculture.

Sudhakar, P., G.N. Chattopadhyay, S.K. Gangwar and J.K. Ghosh. 2000. Effect of foliar application of *Azotobacter, Azospirillum* and *Beijerinckia* on leaf yield and quality of mulberry (*Morus alba*). *Journal of Agricultural Sciences.* 134: 227–234.

Suswanto, T., J. Shamshuddin, S.R. Syed Omar, Peli Mat and C.B.S. Teh. 2007. Alleviating an acid sulfate soil cultivated to rice *(Oryza sativa)* using ground magnesium limestone and or-ganic fertilizer. *Journal of Soil and Environment*. 9(1): 1-9.

Tran, K.T. and T.G. Vo. 2004. Effect of mixed organic and inorganic fertilizers on rice yield and soil chemistry of the 8^{th} crop on heavy acid sulfate soil (HydraquenticSulfaquepts) in the Mekong Delta of Vietnam. In: *6^{th} International Symposium on Plant Soil at Low pH*. 1-5 August, 2004: Sendai: Japan.