



Effects of adding organic materials to an acid sulfate soil on the growth of cocoa (*Theobroma cacao* L.) seedlings

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Abstract

Acid sulfate soils having a pH of less than 3.5 are widespread in Malaysia. Some of these soils are planted to cocoa, but the yield is reported to be low due to soil infertility related to Al toxicity. Cocoa growth is sensitive to the presence of Al in the soil. To a certain extent, Al toxicity in soils can be reduced by organic matter application and to a greater extent in iron-poor acid sulfate soil. A study was conducted to determine the efficacy of various types of organic materials easily available in the country to ameliorate acid sulfate soil infertility for growing cocoa seedlings. The treatments were control (nil), lime (3 t/ha), peat (10% w/w), peat plus green manure (10% w/w), peat plus rice straw (10% w/w), peat plus chicken dung (10% w/w) and peat plus POMS (Palm oil mill sludge) (10% w/w). The growth of cocoa seedlings was affected significantly by the presence of Al in the cocoa tissues. As the amount of Al in the leaves increased, the relative top dry weight of cocoa seedlings decreased. Likewise, the relative plant height was negatively correlated with Al in the leaves. Peat as well as peat in combination with green manure, rice straw, chicken dung or palm oil mill sludge was able to reduce Al toxicity in acid sulfate soil; the highest top dry weight of cocoa seedlings were obtained in the peat plus green manure treatment. The best cocoa seedlings root growth was found for the peat treatment alone. The relative top dry weight of cocoa seedlings was negatively correlated with Al^{3+} as well as $\text{Al}^{3+} + \text{Al}(\text{OH})^{2+} + \text{Al}(\text{OH})_2^+$ activity in the soil solution. The critical values for Al^{3+} and the combination of $\text{Al}^{3+} + \text{Al}(\text{OH})^{2+} + \text{Al}(\text{OH})_2^+$ activity in the soil solution were 10 μM and 15 μM , respectively.

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1. Introduction

In areas along the coastal plains inundated with seawater but protected by mangrove, pyrite (FeS_2) seems to be formed in the affected sediments in large quantities over the years. Such areas are extensive in the tropics such as Thailand, Vietnam,

Indonesia and Malaysia (Kawalec, 1973; Dent, 1986). Under its natural condition, this pyrite is stable and environment-friendly. Recent population explosion leads to allotment of the land for development, either for agriculture or otherwise. Developing this land would expose pyrite to the atmosphere, resulting in the release of acidity and toxic metals that pollute soils and affect aquatic life in the vicinity. These acid soils with oxidized pyrite are collectively termed as acid sulfate soils.

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In Peninsular Malaysia, the soils are distributed widely in the coastal plains of the west coast. The land area covered by these soils is large, running into a few hundred thousands of hectares (Vimala et al., 1992). Together with peat soils, they make up a large tract of land earmarked for development. A few areas are planted to cocoa with mixed success. In these acid sulfate soils, Al activity in the soil solution is very high (Shamshuddin and Auxtero, 1991; Shamshuddin et al., 1995). This becomes a serious limitation for crop production on these soils. For an oil palm seedling, which is Al-tolerant, its growth is retarded when Al^{3+} activity exceeds 100 μM (Auxtero and Shamshuddin, 1991). We believe that the critical value for Al-sensitive crop like cocoa could be much lower than that of oil palm. It is a fact that Al present in acid soils, particularly acid sulfate soils, affects the quality of cocoa bean, fetching lower prices at the marketplace in Europe.

Some of the acid sulfate soils in the west coast of Peninsular Malaysia are already planted to cocoa (e.g. Arcadia Estate, in the state of Perak), but the yield is reported to be less than 1 t/ha of cocoa bean (Chew et al., 1984). This low yield is due in part to soil infertility related to acidity and the presence of a large amount of Al, either on the exchange complex or in the soil solution. Liming acid soil reduces Al^{3+} activity (Shamshuddin et al., 1991) by precipitating the Al as gibbsite ($\text{Al}(\text{OH})_3$), but for acid sulfate soils the amount of lime required to neutralize the acidity in the soils is too much and therefore impractical (Dent, 1986). For example, for 1% oxidized sulfur, approximately 30 tonnes of CaCO_3 per hectare (depth up to 10 cm and bulk density of 10^3 kg m^{-3}) is required to neutralize the activity (van Breemen, 1993). The increase in soil pH as a result of liming would improve the soil environment for crop growth (Curtin and Smillie, 1995).

In the presence of organic matter, the toxicity of Al in soils is considerably reduced. This is thought to be due to the detoxifying effect of organic acids via the formation of Al-organic complexes (Hue et al., 1986; Ahmad and Tan, 1986; Bessho and Bell, 1992). Addition of fresh organic materials inactivates soluble Al by adsorbing it on their surfaces (Hoyt and Turner, 1975).

The elimination of soluble Al from the soil system can also be by production of hydroxyl ions resulting from ligand exchange reactions (Hue and Amien, 1989). It is, therefore, worthwhile to look at the various natural or byproduct organic materials, available in the vicinity of acid sulfate soils, as soil amendments. Also, the usage of iron-poor acid sulfate soil (with <1% total Fe in the solum) can be an added advantage. Although not much work has been done on this type of acid sulfate soil, it is anticipated that it will be more responsive to pH change due to the addition of organic materials compared to the normal, that is the iron-rich acid sulfate soil.

Peat is abundant in Malaysia, and so are chicken dung and palm oil mill sludge (POMS). Rice straw and green manure (*Calopogonium* spp.) are also easily available. In earlier studies, POMS (Shamshuddin et al., 1987, 1998) and chicken dung (Hue, 1992) were found to be good ameliorants for growing crop on an acid Ultisol. These various forms of organic materials can, therefore, be put to good use to ameliorate acid sulfate soils in Malaysia for crop production. A study was conducted to determine the efficacy of organic materials to ameliorate acid sulfate soil infertility for growing cocoa seedlings. A long-term application of this organic matter is not expected to be damaging to the acid sulfate soil environment.

2. Materials and methods

2.1. The soil

The acid sulfate soil used in this study was the Linau soil, classified as Typic Sulfaquepts, from Kuala Linggi, Melaka, Malaysia. The site of soil sampling was planted to cocoa for a number of years; it was subjected to liming for growing cocoa (Denamany and Ting, 1991). Unlike the 'standard or normal' acid sulfate soil, Linau is an iron-poor acid sulfate soil. The normal acid sulfate soils of Malaysia have total Fe content of >1% in the soil solum. Little is known of the chemical processes of Malaysian iron-poor acid sulfate soils. Low Fe concentration implies lower pH buffering capacity of the soil, and therefore greater pH increase is expected compared to the well-buffered soil sys-

tem. Also, low total Fe content implies low S content (Table 1). It has been suggested that sulfur content will determine the behavior of acid sulfate soil following drainage. It has been reported that materials with sulfur content of <0.7% did not develop severe acidity following drainage (Dent, 1980). The soil samples were taken from every horizon, placed in plastic bags and immediately sent to the laboratory at the Universiti Putra Malaysia and kept in a cold room before being used for analysis. The soil for the experiment with cocoa seedlings was specially selected from the sulfuric horizon (Bw₁), identified by pH<3.5; jarosite (KFe₃(SO₄)₂(OH)₆) mottles, if they were there, could not be identified by the naked eye. In an acid sulfate soil environment, this horizon is the most acid part of the soil profile. Under normal conditions, acid-intolerant plant root would not penetrate it, more so for cocoa, which is very sensitive to acidity and/or Al toxicity.

2.2. Experimental

Two kilograms of soil samples were placed in plastic bags and were subsequently incubated for 10 weeks. The treatments were control (nil), lime (3 t/ha), peat (10% w/w), peat plus green manure (10% w/w), peat plus rice straw (10% w/w), peat plus chicken dung (10% w/w) and peat plus POMS (10% w/w). These treatments were henceforth referred to as C, L, P+GM, P+RS, P+CD and P+PM, respectively. Peat to organic material ratio was 2:1, having the approximate C to N ratio ranging from 12 to 40. Deionized water was added into the soil to maintain moisture content at 90% moisture level. The plastic bags were tapered at the end so as to prevent the loss of moisture during the incubation period.

Cocoa seeds were germinated in sand. After 2 weeks, seedlings of the same height were selected and transferred to plastic pots containing the 10-week-old incubated soils. The pots were arranged in a completely randomized design (CRD), with the treatments replicated four times. Basal fertilizer having a grade of 18:18:18 was added to the soils at the rate of 5 g/pot. The cocoa seedlings were watered daily with deionized water to keep the soils at 90% moisture level. After 18 weeks, the

cocoa seedlings were harvested; at this time, the height of the seedlings as well as the top dry weight and root dry weight was recorded (samples dried at 60 °C for 48 h).

2.3. Soil and tissue analyses

2.3.1. Soil analysis

Fresh soil pH (determined immediately after the soil was sampled) and air-dried soil pH were determined in water at soil to solution ratio of 1:1, while total C, N and S were determined by a CHNS analyzer. The CEC of the soil was determined by the NH₄OAc method at pH 7 and exchangeable Ca, Mg, K, Na, Al and Fe were extracted using NH₄Cl (Ross, 1995). Briefly, 2 g of air-/oven-dried samples were put in 50 ml centrifuge tubes and added 20 ml 1 M NH₄Cl. After intermittent shaking for 2 h, the tubes were centrifuged at 2500 rev./min for 15 min. The supernatant were transferred and filtered with no. 42 Whatman filter paper into plastic vials. The exchangeable Ca, Mg, K, Na, Al and Fe in the extract were determined by atomic absorption spectrophotometry (AAS). Available P was determined by the method of Bray and Kurtz (1945). Total Fe and P were determined using an aqua-regia method (HCl:HNO₃=3:1) (Ure, 1995a,b). Pyrite was determined by the method of Begheijn et al. (1978), while total potential acidity (TPA) and total actual acidity (TAA) were determined by the method of Konsten et al. (1988) that had been modified by Dent and Bowman (1996).

2.3.2. Soil solution

Soil solutions at harvest were extracted using a rhizon soil moisture sampler (Eijelkemp, Holland). The moisture samplers, with porous tip, were mounted onto the soils at 90% moisture level for 48 h. Extraction of the soil solution from the samplers was carried out using a 10-ml syringe. Soil solution pH and EC were immediately recorded. The Al and basic cations (Ca, Mg, K, Na) in the soil solutions were subsequently determined using AAS. Sulfate was measured turbidimetrically using a spectrophotometer at 600-nm wavelength. Nitrate was determined using the salicylic acid-thiosulfate method of Bremner and Mulavaney

Table 1
Chemical characteristics of the Linau soil

Soil series	Horizon	pH fresh	pH H ₂ O	EC (mS/cm)	C-org (%)	Total N (%)	Total P (mg/kg)	Total Fe (%)	Total S (%)	SO ₄ -S (mmol/l)	FeS ₂ (%)	
Linau												
	Ap	–	3.08	320	4.37	0.11	69.23	0.38	0.72	0.65	0.00	
	Bw ₁	3.46	3.07	380	3.44	0.11	81.32	0.40	0.64	0.65	0.00	
	Bw ₂	3.15	3.05	542	4.67	0.13	63.71	0.53	0.79	1.47	0.00	
	BCg	3.00	2.95	1128	6.25	0.15	70.62	0.87	1.10	4.12	0.62	
	Cg	3.91	2.31	3280	6.23	0.16	78.00	0.25	2.58	16.81	2.08	
		Exchangeable						CEC	TPA	TAA	Available	
		Ca (cmol _c /kg)	Mg (cmol _c /kg)	K (cmol _c /kg)	Na (cmol _c /kg)	Al (cmol _c /kg)	Fe (cmol _c /kg)	(cmol _c /kg)	(cmol _c /kg)	(cmol _c /kg)	P (mg/kg)	
Linau												
	Ap	0.81	0.36	0.22	1.43	4.29	0.24	11.40	15.64	16.28	45.39	
	Bw ₁	0.64	0.31	0.24	1.24	5.55	0.19	14.45	24.02	19.78	12.57	
	Bw ₂	0.17	0.14	0.14	1.22	5.75	0.12	21.39	37.97	31.5	7.19	
	BCg	0.94	1.24	0.27	2.92	12.50	0.71	21.87	53.35	32.9	6.98	
	Cg	0.80	1.42	0.48	1.99	11.56	5.38	31.34	65.38	23.04	7.47	

(1982). Chloride was measured colorimetrically using a spectrophotometer at 460-nm wavelength, using the mercury (II) thiocyanate method (Adriano and Doner, 1982). The activities of the metals and ligands in the soil solutions were estimated using GEOCHEM-PC version 2.0 (Parker et al., 1990).

2.3.3. Tissue analysis

The leaves were separated and ground using a stainless steel grinder with 1-mm sieve. The leaf samples were then digested by wet-ashing, using $\text{H}_2\text{SO}_4\text{--H}_2\text{O}_2$ for determination of Al and basic cations; the metals were then determined by AAS.

2.3.4. Data analysis

Analysis of variance (ANOVA) for a single factor was performed using a statistical program in Microsoft Excel. Least significant difference (Lsd) was used to compare the means of the treatments.

3. Results and discussion

3.1. The chemical properties of the soil

Table 1 shows relevant chemical properties of the soil samples used in this study. The fresh pH throughout the soil profile, except the Cg-horizon, is <3.5 . It is seen that in the sulfuric horizon (Bw₁-horizon), where the samples for the experiment were taken, the soils are very acid (pH 3.46). The pH became even lower after the soils were air-dried, presumably due to the oxidation of some pyrite still present in the soil (pH 3.07); the highest drop in soil pH after air-drying was in the Cg-horizon where 2.08% pyrite is present. This is consistent with the high amount of $\text{SO}_4\text{--S}$ in this horizon with a value of 16.81 mmol/l. Sulfate is produced when pyrite undergoes oxidation on exposure to the atmosphere. The oxidation of pyrite in acid sulfate soils produces high amounts of acidity, as long as known and understood by all the soil scientists working with these soils (Dent, 1986).

This iron-poor acid sulfate soil contains moderate amounts of organic carbon. A large majority of acid sulfate soils in Malaysia contains much

less organic carbon than reported in this study. The Fe content is low except in the Cg-horizon with a value of 5.38 cmol/kg soil (Table 1). The exchangeable Al in the soil is very high, especially in the BCg- and Cg-horizons. The amounts of exchangeable Al in these horizons were 12.50 cmol_c/kg and 11.56 cmol_c/kg soil, respectively (Table 1). These values are very high, typical of acid sulfate soil in the tropics. As such, the total potential acidity (TPA) and total actual acidity (TAA) in these two horizons are very high. In the sulfuric horizon, the exchangeable Al and the acidity are lower, but still considered to be above the values for normal non-acid sulfate soils in the upland areas of Malaysia (Tessens and Shamshuddin, 1983). Hence, the Linau soil as sampled for this study is suitable for testing the growth performance of cocoa seedlings under adverse environmental conditions, i.e. in the presence of toxic amounts of Al. The results from this study would provide information on the response of cocoa seedling to elimination of Al by organic matter. The findings would certainly be useful for successful management of acid sulfate soils for sustainable cocoa production on acid sulfate soils.

3.2. The chemical composition of the organic materials

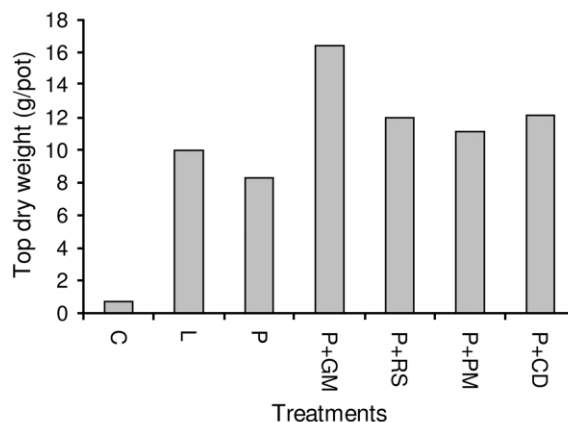
The green manure used in this study contains a high amount of K, with a value of 4.06% (Table 2). Potassium is a basic metal that presumably has a potential of increasing soil pH when K-containing material (like green manure) is added to soil at a suitable rate. This, to a certain extent, would alleviate soil acidity. Peat and green manure used in this study contain high amounts of carbon with a value exceeding 40% (Table 2). Nitrogen is low in the peat, but lignin is high having a value of 35.41%. The highest C to N ratio was recorded for the peat, followed by rice straw; the values are 50.31 and 35.52, respectively.

Total Al in the peat and chicken dung are 1.21% and 4.84% respectively, but their presence in water-soluble form is low. This means that organic materials, as shown by the peat and chicken dung in this study, are able to fix Al, possibly rendering it unavailable to plant growth. As such, peat is a

potential source of organic material that can be used to ameliorate Al toxicity in acid sulfate soils. Peat in Malaysia contains substantial amounts of humic and fulvic acids (Shanty, 1995), which can detoxify Al by forming Al-organic complexes as shown by many previous studies (Hue et al., 1986; Ahmad and Tan, 1986).

3.3. The effects of organic materials on the growth parameters

Amelioration of acid soils, acid sulfate soil included, by liming or incorporating organic matter is an accepted agronomic practice in the tropics. Alleviation of the soil infertility by addition of organic matter may be partly due to increase of cation and anion holding capacity or through the neutralization of soil acidity, improved physical conditions and added source of nutrients. In this study, it is seen that the top dry weight of cocoa seedlings increased significantly when the soil acidity was alleviated by lime treatment, as shown in Fig. 1. This is consistent with the result of a cocoa field trial by Ng and Chan (1977). Studies in the past indicated that lime treatment at an



lsd (5%)= 1.08; lsd (1%)=1.50

Fig. 1. The effects of organic material treatment on the top dry weight of the cocoa seedlings (lsd (5%)=1.08; lsd (1%)=1.50).

appropriate rate would eliminate Al^{3+} activity in the soil solution in the Typic Paleudult (Shamsuddin et al., 1991) and Typic Sulfaquept (Shamsuddin and Auxtero, 1991); the latter soil is

Table 2
Chemical composition of organic materials used in this study

Soil parameters	Peat	Rice straw	Chicken dung	Green manure	POMS
Carbon (%)	46.29	36.94	8.58	41.11	17.59
Nitrogen (%)	0.92	1.04	2.28	3.59	2.69
Lignin (%)	35.41	6.85	2.99	7.13	21.54
Polyphenols (%)	0.36	3.95	9.28	0.36	1.02
C/N	50.31	35.52	3.77	11.47	6.54
Total ions (%):					
Ca	0.17	0.31	1.45	0.56	0.72
Mg	0.27	0.47	2.69	1.00	1.40
K	0.52	1.06	3.49	4.06	0.77
Al	1.21	0.12	4.84	0.03	0.66
Exchangeable ions (%):					
Ca	0.14	0.16	0.28	0.18	0.59
Mg	0.01	0.10	0.35	0.15	0.23
K	0.02	0.58	1.17	1.05	0.32
Al	0.32	0.01	0.15	0.01	0.01
Water-soluble ions (%):					
Ca	0.03	0.08	0.15	0.14	0.29
Mg	0.00	0.01	0.22	0.13	0.15
K	0.00	0.54	1.08	0.94	0.26
Al	0.01	0.00	0.03	0.01	0.01

comparable in terms of chemical properties to the soil under investigation. Removal of Al via precipitation to gibbsite, (Friesen et al., 1980) when the soil solution pH increases to a value above 5, would considerably improve the growth of Al-sensitive plants, such as cocoa seedling. Soil pH would increase to an acceptable value provided that appropriate amount of lime is applied; the rate is definitely high for the Linau soil (Denamany and Ting, 1991).

Almost a comparable result to that of the lime treatment was obtained for the peat treatment (Fig. 1). As mentioned earlier, peat in Malaysia contains important amounts of humic and fulvic acids (Shanty, 1995). These organic acids are able to detoxify Al in the soil solutions to a certain extent (Hue et al., 1986; Ahmad and Tan, 1986), thus making the soil environment conducive for the growth of cocoa seedlings. In the presence of peat, cocoa seedlings would be able to grow with less interference from Al toxicity, as most of the Al originally present in the soil would have been rendered unavailable to the cocoa seedlings by the formation of insoluble Al–organic complexes.

When the peat was applied in combination with other organic materials, there was a synergistic improvement of the top dry weight of the cocoa seedlings, the highest being for the P+GM treatment with a value of approximately 16 g/pot (Fig. 1). The green manure apparently has a high mitigating effect on the soil acidity. This finding is similar to that of Hue and Amien (1989) and Bessho and Bell (1992). The result showed that the P+GM treatment gave the highest soil pH, with a value of 4.35 (Table 3). According to the study of Hoyt and Turner (1975), freshly added organic material inactivated soluble Al by adsorbing it on their surfaces. The highest soil pH coincided with the lowest Al concentration in the soil solution in the P+GM treatment. This means that when the solution pH increased from 3.65 to 4.35 (Table 3), some of the Al in the soil solution precipitated as insoluble gibbsite (Friesen et al., 1980), rendering it unavailable to the cocoa seedlings. The increase in solution pH in this treatment is thought to be due partly to production of some ammonium ions during mineralization of the green manure. The increase in soil pH could also be due

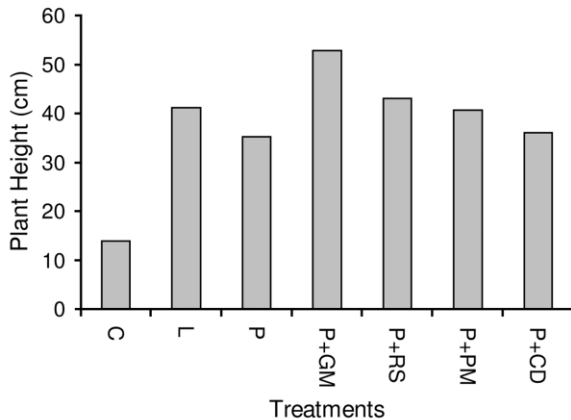
Table 3

The effects of peat and peat in combination with green manure, rice straw, palm oil mill effluent and chicken dung on soil solution pH and metal concentration

Treatment	Solution pH	Metal conc. (mM)			
		Al	Ca	Mg	K
C	3.65	2.26	3.08	2.58	2.64
L	4.00	0.45	17.05	3.77	7.09
P	3.33	1.82	4.40	3.89	3.38
P+GM	4.35	0.33	9.99	4.32	4.48
P+RS	3.58	0.68	5.32	5.07	3.69
P+PM	3.65	1.88	23.10	10.05	11.67
P+CD	3.67	0.43	27.02	10.03	12.50
Lsd _{0.05}	0.21	0.24	1.22	0.48	0.16

to the release of OH⁻ resulting from ligand exchange that had taken place between organic anions and hydroxyls during incubation period (Hue and Amien, 1989; Hue, 1992). These together with the fixation of Al by the organic acids from the peat would have reduced Al toxicity considerably, leading to a good growth of the cocoa seedlings. However, the solution pH of the peat alone treatment was slightly lower than that of the control. This is expected as peat itself contains organic acids that can lower soil solution pH slightly. However, it is seen that in the peat treatment, the soil solution Al was also lower than that of the control. The lower soil solution Al in the peat treatment compared to that of the control is not consistent with lower soil solution pH. This phenomenon can be partially explained by chelation of Al by the organic acids in the peat, forming an Al-organic complex that is non-toxic to plant roots. In the combined peat and chicken dung treatment, the soil solution Al was found to be much lower than that of the control although the cocoa seedlings grew better. This was presumably due to the high Al-fixing ability of the chicken dung. As data in Table 2 show, total Al in the chicken dung is very high, with a value of 4.84%, but only 0.03% is water-soluble.

The study showed that pH increase arising from liming or due to green manure treatment improved top dry weight of the cocoa seedlings, and that peat to a certain extent detoxified Al toxicity. It is therefore probable that if peat is applied in com-



lsd (5%)=5.29

Fig. 2. The effects of organic material treatment on the height of cocoa seedlings (lsd (5%)=5.29).

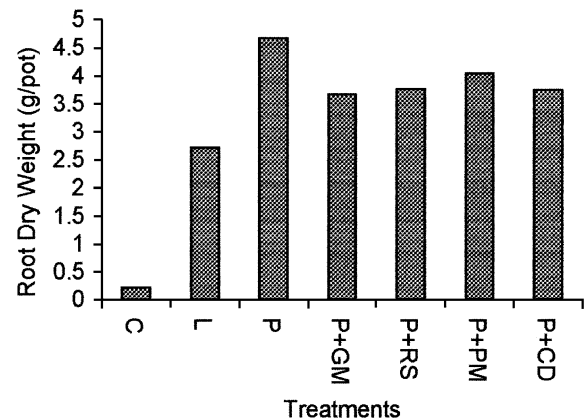
combination with liming, the result would be even better compared to either lime or peat treatment alone. In this combination, the synergistic effect of pH increase and elimination of Al toxicity would have a maximal potential for amelioration of acid sulfate soils for crop production. Although not tested in this study, this combination would be worth trying in future.

Chicken dung is known to be able to correct soil acidity for plant growth and enhanced Ca uptake in a tropical forage legume (Hue, 1992). However, in this study it is seen that the presence of high amounts of Ca in the soil solutions of the P+CD and P+PM did not seem to help promote better growth in the cocoa seedlings. The presence of high amounts of Mg in the soil solution did not help either. The samples with much less solution of Ca and Mg seemed to give similar plant growth performance to those with high amounts of these macronutrients. In acid sulfate soils, Ca and Mg contents are normally adequate for crop growth (Shamshuddin and Auxtero, 1991; Auxtero and Shamshuddin, 1991); the growth of crops like oil palm and cocoa are not likely to be limited by these macronutrients.

The effects of the treatments on the height of the cocoa seedlings (Fig. 2) followed the trend of the effects of treatments on the top dry weight of

the cocoa seedlings (Fig. 1). The highest cocoa seedlings height, with a value of approximately 50 cm, was reported for the P+GM treatment. The reasons for the positive effect of peat and/or peat in combination with other organic materials used in this study on cocoa seedlings height are presumably the same as mentioned earlier for the top dry weight.

In the case of the responses of the root of the cocoa seedlings to the treatment, peat only treatment gave the highest root dry weight (Fig. 3). Treating the acid sulfate soil with peat only produced root dry weight of approximately 4.5 g/pot. This was followed by P+PM treatment, with a value of approximately 3.8 g/pot. It is seen that there was no significant difference in the root dry weight of the cocoa seedlings between the various combination of the peat and organic material treatments, but their values were less than peat only treatment at the 5% significant level. However, peat or peat in combination with the various types of organic materials produced better root system compared to the lime treatment. This indicates that the positive effect of reduction of Al toxicity via complexation with organic material is more than that of liming. Rice straw, chicken dung and palm oil mill sludge in combination with peat treatment



lsd (5%)=0.58

Fig. 3. The effects of organic material treatment on the root dry weight of cocoa seedlings (lsd (5%)=0.58).

Table 4

The correlation coefficient (*r*) between Al and Ca in the leaves of cocoa seedlings and their corresponding contents in the soil and soil solution

	Al	Ca
Exchangeable	0.66**	0.88***
Activity	0.87***	0.93***

** , ***Significant at 0.01 and 0.001 probability levels, respectively.

did not change soil solution pH significantly compared to that of the control.

3.4. The uptake of Al

It is reasonable to assume that the more Al in the soil solution, the more is the uptake of Al by the cocoa seedlings. The more Al is taken up, the smaller would be the cocoa seedlings as a result of Al toxicity. The growth of cocoa seedlings would be stunted by the presence of excess amounts of Al. This is clearly shown by the results of this study as presented in Table 4; there was a positive linear relationship between the Al in the leaves of the cocoa seedlings and its corresponding content in the soil or soil solution. This is consistent with the negative exponential relationship between relative top dry weight of the cocoa seedlings and Al in the leaves (Fig. 4). The relative top dry weight of the cocoa seedlings was nega-

tively correlated with the Al in the leaves ($r=0.89$; $P<0.01$). The Al in the leaves of the cocoa seedlings corresponding to 90% relative top dry weight was approximately 80 mg/kg. This means that in the situation where cocoa seedlings are growing on acid sulfate soil with high amounts of soil solution Al, the cocoa seedlings take up high amounts of Al so that its presence in the leaves might exceed 80 mg/kg, and as such the cocoa seedlings growth would be stunted. The cocoa seedlings will not survive for long if the Al toxicity is not alleviated.

The relative plant height was also negatively correlated with Al in the leaves ($r=0.85$; $P<0.01$). The Al in the leaves of the cocoa seedlings corresponding to 90% relative plant height was also approximately 80 mg/kg (Fig. 5). Data in Figs. 4 and 5 suggest that the critical Al concentration in the cocoa seedlings leaves is approximately 80 mg/kg. Hence, the amounts of lime or organic matter to be applied on acid sulfate soils for the purpose of ameliorating them for cocoa production should be on the basis of reducing Al in the leaves to approximately 80 mg/kg or less. In this study, it is seen that only the P+GM treatment was able to reduce the Al concentration in the leaves of cocoa seedlings to 80 mg/kg or 0.008% (Table 5). The Al in the leaves of the cocoa seedlings for the P+CD treatment was 90 mg/kg (0.009%); the corresponding values for the

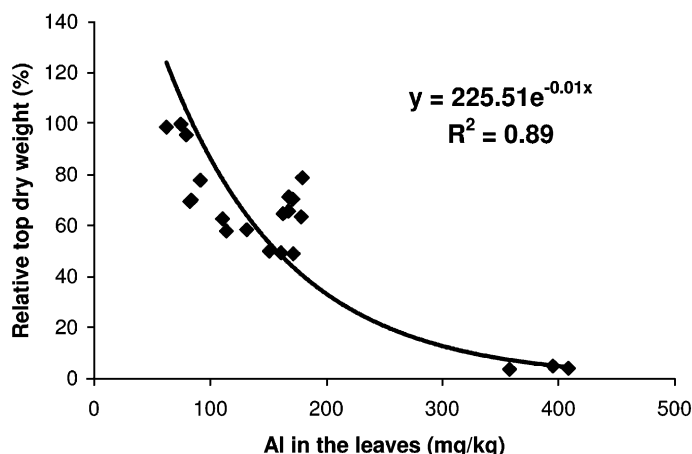


Fig. 4. The relationship between relative top dry weight and Al in the leaves of cocoa seedlings.

others were > 100 mg/kg. For this reason, the top dry weight of the cocoa seedlings for the two treatments was higher than those of the other treatments.

The Ca and Mg concentrations in the cocoa leaves under experimental conditions grown on a coastal non-acid sulfate soil were 0.558% and 0.584%, respectively (Ng and Chan, 1977). When these values were compared to those obtained in the current study (Table 5), it was observed that cocoa seedlings grown on the Linau soil took up less of these macronutrients. It is possible that some Al still present in the acid sulfate soil was affecting the uptake of Ca and Mg by the cocoa seedlings. However, the Ca in the leave of the cocoa seedlings was positively correlated with the exchangeable Ca ($r=0.88$; $P=0.001$) and Ca^{2+} activity ($r=0.93$; $P=0.01$) (Table 4).

In the case of K concentration in the leaves, the value obtained by the current study is comparable to that of Ng and Chan (1977). The highest K uptake was seen for the P+GM treatment (Table 4), consistent with the highest top dry weight of the cocoa seedlings. In acid sulfate soils, application of K fertilizer is not as critical as removal of acidity and/or Al. Data in Table 1 show that exchangeable K in the soil is >0.2 cmol_c/kg soil throughout the profile, except the Bw₂-horizon; these values, which are higher than the weathered

Table 5

The concentration of Al, Ca, Mg and K in the leaves of cocoa seedlings

Treatment	Metal concentration (%)			
	Al	Ca	Mg	K
C	0.036	0.427	0.520	1.384
L	0.012	0.604	0.419	1.527
P	0.015	0.305	0.402	1.725
P+GM	0.008	0.454	0.399	1.766
P+SR	0.016	0.380	0.322	1.686
P+PM	0.018	0.563	0.412	1.712
P+CD	0.009	0.638	0.496	1.667
Lsd _{0.05}	0.103	0.047	0.056	0.069

soils of the upland areas (Tessens and Shamshuddin, 1983), are considered adequate for cocoa growth.

3.5. Relationship between relative top dry weight and Al in the soil solution

In acid sulfate soils, Al^{3+} activity is very high (Shamshuddin and Auxtero, 1991; Shamshuddin et al., 1995). This high Al^{3+} activity in the soil solution of acid sulfate soils affected the growth of oil palm seedlings significantly (Auxtero and Shamshuddin, 1991). Cocoa is an Al-sensitive crop (Chew et al., 1984). Hence, its growth is much

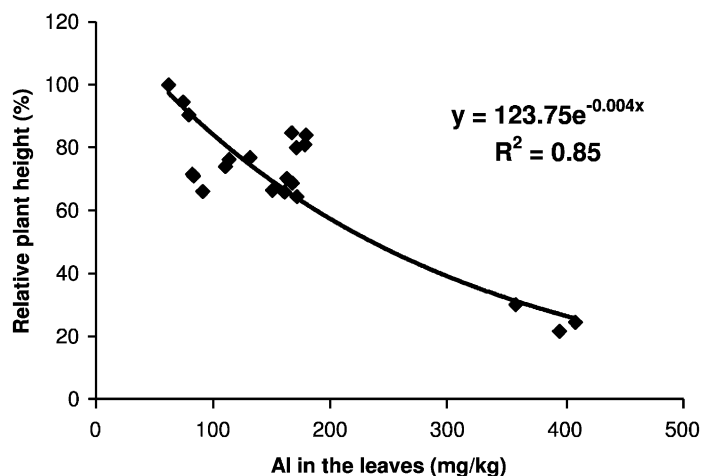


Fig. 5. The relationship between relative plant height and Al in the cocoa seedlings leaves.

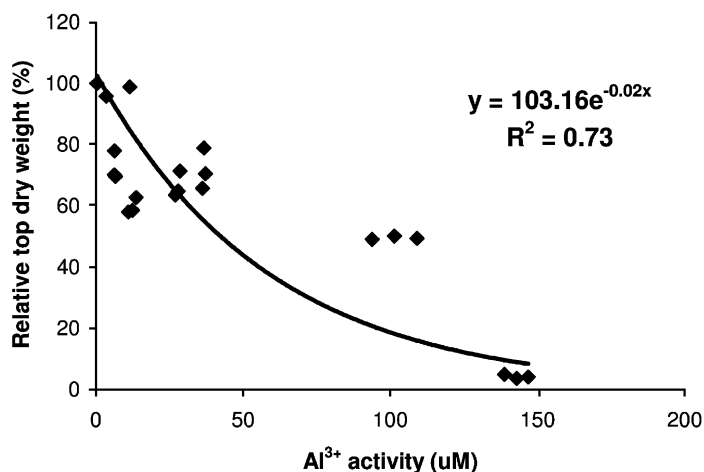


Fig. 6. The relationship between the RTDW and Al activity.

more affected by the presence of Al compared to that of oil palm. Fig. 6 clearly demonstrates the sensitivity of cocoa seedlings to Al toxicity. The relative top dry weight (RTDW) of the cocoa seedlings was negatively correlated with Al^{3+} activity, shown by an exponential relationship with $r=0.73$; $P<0.01$. It was observed that the Al^{3+} activity corresponding to 90% RTDW was $10 \mu\text{M}$. This value can be considered as the critical Al^{3+} activity for cocoa growth. This is slightly higher than that of mung bean (Bessho and Bell, 1992), but much lower than the value reported for oil palm seedlings obtained by Auxtero and Shamshuddin (1991) with a value of $100 \mu\text{M}$. This result shows that cocoa is approximately 10 times more sensitive to Al toxicity than oil palm. For this reason, oil palm is able to grow well on acid sulfate with moderate soil management, for example managing the water table level and adding adequate fertilizers. But, much more management input is required for cocoa, for example liming is necessary for growing cocoa on acid sulfate soils (Denamany and Ting, 1991). Liming to alleviate Al toxicity in acid sulfate soils is costly and therefore is considered an untenable option. This study suggests that lime in combination with a suitable organic material would probably be an excellent management approach to ameliorate acid sulfate soils for cocoa production.

The result of this study showed also that the relative top dry weight of the cocoa seedlings was negatively correlated with $\text{Al}^{3+} + \text{Al}(\text{OH})_2^+ + \text{Al}(\text{OH})_2^+$ activity ($r=0.76$; $P<0.01$) (Fig. 7). The critical $\text{Al}^{3+} + \text{Al}(\text{OH})_2^+ + \text{Al}(\text{OH})_2^+$ activity for the growth of cocoa seedlings based on the top dry weight was $15 \mu\text{M}$. This again shows that cocoa seedlings are sensitive to the various species of Al in the soil solution of acid sulfate soils.

This experiment clearly indicates that for the acid sulfate soils to be suitable for growing cocoa, the soils have to be low in soil solution Al. The obvious choice would be application of lime as dolomitic limestone, available from the market in Malaysia as ground magnesium limestone (GML). However, the TPA and TAA are very high in acid sulfate soil (Table 1), making liming an unviable agronomic practice for this soil. So, our attention should now turn to other options, such as application of organic materials, which are environment friendly and available in large quantities in Malaysia. This study clearly indicates that peat and peat in combination with POMS applications give comparable results to that of lime treatment (Figs. 1–3). These former treatments did not change the solution pH significantly, but soil solution Al had been reduced to such an extent that its toxic effect on cocoa seedlings growth had been considerably reduced. In this situation, the soil environment is

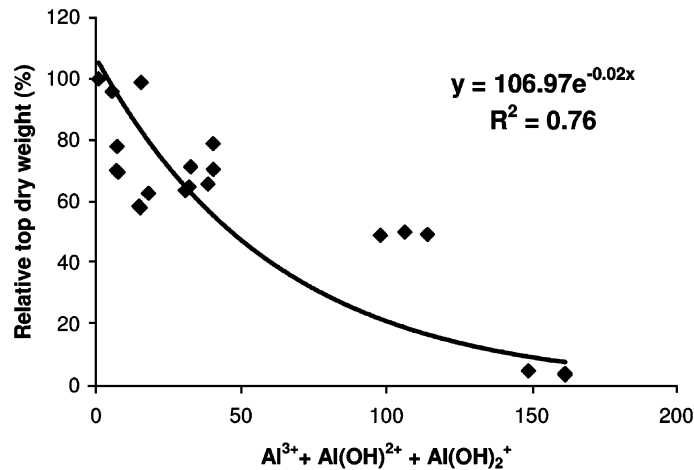


Fig. 7. The relationship between the RTDW and $\text{Al}^{3+} + \text{Al}(\text{OH})^{2+} + \text{Al}(\text{OH})_2^+$.

more conducive for growth compared to that without organic matter treatment.

4. Conclusion

It can be concluded that the growth of cocoa seedlings on acid sulfate soil is affected by Al toxicity. With the help of organic matter, especially peat, the Al toxicity can be reduced to a certain extent. The critical Al^{3+} activity for the growth of cocoa seedlings is $10 \mu\text{M}$. It seems that a viable option would be application of peat plus palm oil mill sludge on acid sulfate soils as these organic materials are abundant, environment-friendly and cheaply available in Malaysia. It would also be worthwhile to look at the potential of peat in combination with lime for ameliorating acid sulfate soils for cocoa production.

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