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Ameliorating Effects of Palm Oil Mill Effluent on the Chemical Properties of Soils and Maize Growth in Pots

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ABSTRAK

Tanah terluluhawa di Malaysia kebanyakkannya berasid, mengandungi tinggi ketepuan Al dan rendah kandungan Ca dan/atau Mg. Satu kajian larutlesap dengan menggunakan kolum PVC dan kajian berpasu telah dijalankan untuk mengurangkan ketidaksuburan tanah asid ini dengan penggunaan efluen kilang kelapa sawit (EKKS). Keputusan daripada kajian larutlesap menunjukkan pH, C organik, dan Mg bertukarganti tanah atas bertambah dengan bertambahnya kadar penggunaan EKKS. Jagung tumbuh secara terbantut di atas tanah asid tanpa sebarang pembaikan. Berat bandingan tumbuhan atas bertambah dengan bererti dengan bertambahnya pH (H_2O) dan Mg bertukarganti. Di sebaliknya, berat bandingan tumbuhan atas berkurangan secara linear apabila Al bertukarganti dan ketepuan Al bertambah. Dengan rawatan EKKS pH (H_2O) manakala Mg bertukarganti kritikal pula ialah 0.5 cmol/kg tanah.

ABSTRACT

Highly weathered Malaysian soils are mostly acidic having high Al saturation and low Ca and/or Mg contents. A leaching experiment in PVC columns and a pot trial were carried out to alleviate these acid soil infertilities by application of palm oil mill effluent (POME). The results of the leaching study showed that the topsoil pH, organic C and exchangeable Mg increased with increasing rate of POME application. Maize grew poorly on acidic Malaysian soils without any amendment. Relative plant top weight increased significantly as the pH (H_2O) and exchangeable Mg increased. On the other hand, the relative plant top weight decreased linearly as the exchangeable Al and Al saturation increased. With POME treatment, the critical pH (H_2O) for maize growth was 4.2 - 4.5, whereas the critical exchangeable Mg was 0.5 cmol/kg soil.

INTRODUCTION

Highly weathered soils, classified as Ultisols and Oxisols, occupy an area of about 72% of Peninsular Malaysia. These acid soils, containing variable-charge minerals, are mainly used for rubber, cocoa and oil palm cultivation. In addition to high acidity, the soils have low cation-exchange capacity (CEC) and high soil solution Al concentration, and are usually deficient in Ca and/or Mg (Tessens and Shamshuddin, 1983). These soils have occasionally been used for intercropping with maize and groundnut during immature period of rubber and oil palm replanting, but yields were reported to be low due to poor soil fertility, including Al toxicity and subsoil Ca and/or Mg deficiencies (Shamshuddin *et al.*, 1991)

Acid soil infertility usually requires limestone application in the plough layer, but Ca from the limestone usually remains in the zone of incorporation (Paven *et al.*, 1984). Depending on the type of crops planted, the recommended rate of ground magnesium limestone (GML) application for acid Malaysian soils is usually about 2 t/ha (Shamshuddin *et al.*, 1991). Shamshuddin *et al.* (1992a; 1992b) using pot experiments showed that Al toxicity in these soils could be overcome to a certain extent by palm oil mill effluent (POME) application. This finding was supported by a field trial experiment conducted on a similar soil (Shamshuddin and Sharifuddin, 1993). Raw POME containing substantial amounts of N, P, K, Mg and Ca (Hishamuddin *et al.*, 1985) has been found to increase soil pH and reduce exchangeable Al when incorporated into the soil (Shamshuddin *et al.*, 1987), and furthermore it causes minimal pollution to underground water (Zin *et al.*, 1983).

Malaysia produces large quantities of POME annually (Chan *et al.*, 1983); for every tonne of crude palm oil produced, about 2.5–3 tonnes of POME are discharged by the palm oil processing mills. The current rate of crude palm oil production of over 7 million tonnes means that more than 21 million tonnes of POME are generated annually as processing waste water.

The objectives of this study were to determine the effects of land application of POME on the chemical properties of a Ultisol and an Oxisol in Malaysia, and to determine the response of growth of maize to the changes in the soil properties.

MATERIALS AND METHODS

Palm Oil Mill Effluent

Treated POME used in this study was obtained from an anaerobic ponding treatment system of a palm oil mill in Selangor. The POME was moist (moisture content about 50%) and had an organic C of 23%. The pH (H_2O) was 6.6 and the N, P, SO_4, Ca and Mg content was 1.9, 0.5, 0.6, 1.8 and 0.3%, respectively.

Soils

Two soil series were selected for the study. The first soil was the Kuala Brang series, belonging to the loamy, mixed family of Typic Hapludult. The other soil was the Munchong series, belonging to the clayey, kaolinitic family of Typic Hapludox. Both soils are derived from shale, and are commonly used for cultivation of rubber, oil palm and annual crops. The Kuala Brang soil contains kaolinite and mica with some smectite in the clay fraction, while the other soil contains similar minerals but without smectite.

Experimental Design

Leaching experiment in PVC columns The two soils were sampled in the field at depth intervals of 15 cm to a depth of 90 cm. They were air-dried and ground to pass through a 2 mm sieve. The soils were placed into PVC leaching columns and carefully repacked according to their depths.

The experiment consisted of five treatments, arranged in a completely randomized design, with three replications. The five treatments were 0, 10, 20 and 40 t POME/ha, and GML applied at 2 t GML/ha as a standard. The POME and GML were appropriately incorporated into topsoil (0-15 cm depth). The soils were watered twice weekly at a rate equivalent to 2100 mm/year. The soils were sampled at the end of 160 days.

Pot Experiment Air-dried surface soil (0–15 cm, < 2 mm) from each of the Kuala Brang and Munchong series was mixed with POME. The application rate was 0, 10, 20 and 40 t POME/ha. An additional treatment was 2t GML/ha. The response of maize (*Zea mays*, variety Thai Super Sweet) to the ameliorants was assessed in a glasshouse trial, using a complete randomised experimental design, with three replications. Pots were filled with 5 kg air-dried soil and allowed to equilibrate with the ameliorants and basic fertilizers (180 kg N/ha as urea, 150 kg P_2O_5/ha as triple superphosphate and 75 kg K_2O/ha as muriate of potash) for 30 days prior to the seeding of maize. The plants were watered daily with 500 ml H_2O and grown for 40 days, after which they were harvested. The water was not allowed to drain out of the pot. Plant top weight and plant height were determined at the time of harvest. The plant tops were then dried in an oven at 65°°C and the dry weight recorded.

Soil Analysis

Soil pH in water (w/v 1:1) and $CaCl_2$ (1:1) was determined after 1 h of intermittent shaking and an overnight stand. Basic exchangeable cations were extracted by 1 M NH_4OAc buffered at pH 7; Ca and Mg were determined by atomic absorption spectrophotometry, while K and Na were determined by flame photometry. Aluminium was extracted by 1 M KCl and determined colorimetrically (Barnhisel and Bertsch, 1982). Free iron oxide was determined by the method of Mehra and Jackson (1960), while organic C was estimated by the Walkeley-Black method (Nelson and Sommers, 1982). Soil texture was determined by the pipette method of Day (1965) and the mineralogy of the clay fraction was determined by X-ray diffraction.

RESULTS AND DISCUSSION

Changes in the Soil Chemical Properties with Depth

The Kuala Brang soil was very acid, having pH (H_2O) of <4.5 and exchangeable Al of >13 $cmol_c$/kg soil throughout the profile (Table 1). Basic exchangeable bases in the soil were very low. On the other hand, the pH (H_2O) of the Munchong soil was slightly higher than that of the Kuala Brang soil (Table 2). The exchangeable Al in the Munchong soil ranged from 1.9 to 2.4 $cmol_c$/kg soil. The results were consistent with the findings of Tessens and Shamshuddin (1983) who reported that the pH was lower and the exchangeable Al was higher in the Ultisol (Kuala Brang) compared to the Oxisol (Munchong).

In the leaching experiment, it was observed that the topsoil pH (H_2O) increased significantly with increasing rate of POME application (Table 3), which is consistent with the high pH of the POME itself. However, the topsoil pH (H_2O) of both soils was higher for the GML than the POME treatments. The organic C, exchangeable Ca and exchangeable Mg increased significantly with the POME treatments, which is because the POME contained significant amounts of organic matter, Ca and Mg. The percentage of reduction in the exchangeable Al in the Kuala Brang soil arising from POME application was small. However, treating the Munchong soil with 40 t POME/ha reduced the topsoil exchangeable Al from 2.43 to 1.72 $cmol_c$/kg soil.

The increase in the pH (H_2O), organic C and exchangeable Ca only occurred in the topsoil where the POME or GML was originally incorporated (Table 4). The soils below the zone of incorporation appeared to be unaffected by the treatment. This is evident in the pH (H_2O) in the 15-30 cm zone in the Munchong soil, which seems to be hardly changed. The phenomenon of Ca accumulation in the zone of lime incorporation was previously reported by

TABLE 1

The chemical properties of Kuala Brang soil series with depth

Depth (cm)	pH		Exchangeable cations ($cmol_c$/kg)					O.C (%)	Fe_2O_3 (%)
	H_2O	$CaCl_2$	K	Na	Ca	Mg	Al		
0–15	4.1	3.4	0.2	tr	0.4	0.1	13.1	2.1	1.7
15–30	4.3	3.5	0.1	tr	0.1	tr	13.7	1.2	1.7
30–45	4.3	3.5	0.1	tr	0.1	tr	12.5	0.9	1.5
45–60	4.3	3.5	0.1	tr	0.1	tr	14.3	0.6	1.7
60–75	4.4	3.6	tr	tr	0.1	tr	14.8	0.3	1.7
75–90	4.4	3.6	tr	tr	0.1	tr	14.2	0.3	2.0

TABLE 2

The chemical properties of Munchong soil series with depth

Depth (cm)	pH		Exchangeable cations ($cmol_c$/kg)					O.C (%)	Fe_2O_3 (%)
	H_2O	$CaCl_2$	K	Na	Ca	Mg	Al		
0–15	4.4	3.7	0.1	tr	0.7	0.1	2.4	2.1	5.8
15–30	4.5	3.8	0.1	tr	0.3	0.1	2.3	1.5	6.1
30–45	4.8	3.9	0.1	tr	0.4	0.1	2.2	1.3	6.1
45–60	4.9	4.0	0.1	tr	0.4	0.1	2.1	1.0	5.8
60–75	4.8	3.9	0.1	tr	0.3	tr	1.9	1.2	6.0
75–90	5.0	4.1	0.1	tr	0.3	tr	1.8	0.9	6.0

TABLE 3
Changes in the soil pH, organic C and exchangeable Ca, Mg and Al in the topsoil (0-15 cm) as affected by POME application on two soil series

Soil	Rate (t/ha)	pH (H_2O)	Organic C (%)	Exchangeable cations ($cmol_c/kg$)		
				Ca	Mg	Al
Kuala Brang	0 t POME	3.75e	1.52e	0.12e	0.02d	13.40a
	10 t POME	4.08d	1.86c	0.28d	0.10c	11.80b
	20 t POME	4.14c	1.96b	0.39c	0.13b	11.00c
	40 t POME	4.41b	2.12a	0.43b	0.16a	9.70d
	2 t GML	4.68a	1.63d	1.49a	0.11c	9.40e
Munchong	0 t POME	4.33c	1.66d	0.09e	0.02d	2.43a
	10 t POME	4.32c	2.03b	0.37d	0.09c	2.19b
	20 t POME	4.25c	2.07b	0.50c	0.14b	1.87c
	40 t POME	4.46b	2.13a	0.56b	0.16a	1.72d
	2 t GML	5.12a	1.76c	1.21a	0.10c	0.93e

TABLE 4
Changes in the soil pH, organic C, exchangeable Ca and exchangeable Al with depth in the Muchong soil series as affected by POME application

POME (t/ha)	Depth (cm)	pH (H_2O)*	Organic C* (%)	Exch. Ca* ($cmol_c/kg$)	Exch. Al* ($cmol_c/kg$)
0	0–15	4.43c	1.66a	0.09f	2.43a
	15–30	4.11e	1.55b	0.21c	2.18b
	30–45	4.21d	1.09c	0.31a	1.85c
	45–60	4.20d	1.05d	0.17e	1.85c
	60–75	4.47b	0.84e	0.26b	1.61d
	75–90	4.65a	0.71f	0.19d	1.54e
40	0–15	4.46a	2.13a	0.56a	1.72b
	15–30	4.18c	1.54b	0.35b	1.96a
	30–45	4.10d	1.02c	0.28c	1.70b
	45–60	4.07e	0.97d	0.24d	1.51c
	60–75	4.39b	0.83e	0.18e	1.51c
	75–90	4.47a	0.75f	0.17e	1.44d

* For each POME treatment, means within a column with the same letter are not significantly different ($P<0.05$).

Pavan *et al.* (1984) and Gillman *et al.* (1989). Shamshuddin and Ismail (1995) explained that Ca stayed in the zone of lime incorporation due to negative charge increase when pH increased. The mechanism of Ca retention in the POME treatment is similar to that of the lime treatment as explained by Shamshuddin and Ismail (1995).

Effect on Maize Growth

Maize grew poorly in the unamended soils, as is shown clearly by the low plant top dry weight (Table 5). Overall, growth was better on the Munchong than the Kuala Brang soil; the plant top dry weight for the Munchong soil was 1.7 times higher than that on the Kuala Brang soil.

The poorer growth in the Kuala Brang soil was presumably due to the presence of higher exchangeable Al (Table 6). The exchangeable Al in the Kuala Brang soil remained very high even after POME application. There was little difference in the soil pH (H_2O), exchangeable Ca and Mg in either soil type at the time of maize harvest.

The difference in plant height with the treatments followed the same trend as the difference of plant top dry weight. The plant height and the plant top dry weight in the 2 t GML/ha treatment were comparable to the 20 t POME/ha treatment for both soil types. Shamshuddin and Sharifuddin (1993) found in a field trial that 20 t POME/ha were needed to produce a reasonable maize yield grown on an Ultisol. The improved plant growth resulting from POME treatment was also manifested by increased Mg in the tissue (Table 5).

Relationship between Maize Growth and Soil Attributes

Soil pH The relative plant top dry weight *(Fig. 1)* was linearly correlated with soil pH (H_2O). The regression line for the Kuala Brang soil was positioned to the left of the regression line for the Munchong soil, indicating that every unit increase in soil pH results in a greater increase in the growth of maize on the Kuala Brang compared with the Munchong soil. This was consistent with the greater acidity in the Kuala Brang compared with Munchong soil. A 10% drop in the relative plant top dry weight corresponded to soil pH (H_2O) 4.2–4.5. This value was lower than the critical soil pH for maize of 4.7 reported from a liming trial conducted on an Ultisol (Shamshuddin *et al.*, 1989). This shows that POME is a good soil amendment which allows maize to grow satisfactorily even at a low soil pH.

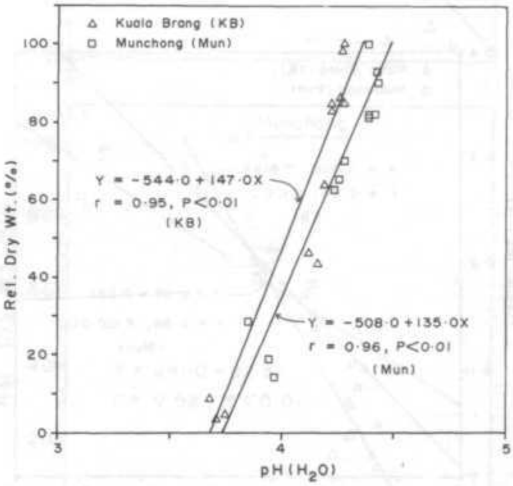

Fig. 1: Relationship between relative dry weight and pH (H_2O) as affected by POME application on two soil series

TABLE 5

The mean plant top weight, plant height and tissue Mg as affected by POME treatment on two soil series

Soil series	Treatment (t/ha)	Plant top wt (g/pot)	Plant height (cm)	Tissue Mg (%)
Kuala Brang	0	9.8	84.3	0.03
	10 t POME	95.7	188.3	0.16
	20 t POME	152.0	201.0	0.31
	40 t POME	173.3	210.0	0.33
	2 t GML	112.6	178.0	0.14
	LSD	15.4	14.9	0.04
Munchong	0	66.2	152.0	0.09
	10 t POME	192.8	236.7	0.16
	20 t POME	239.0	253.0	0.22
	40 t POME	243.6	247.0	0.27
	2 t GML	158.5	198.0	0.18
	LSD	31.9	22.7	0.04

The pH (H_2O) in the zero treatment on the Kuala Brang soil was 3.9, corresponding to the relative plant top dry weight of 5% (Table 7). In the Munchong soil, the pH (H_2O) for the zero treatment was also 3.9, but the relative plant top dry weight was 20%. The 2 t GML/ha treatment gave only 55% of the best growth. The absolute growth in this treatment was less compared with that of the 20 t POME/ha treatment (Table 5). This shows again that POME treatment improves the soil condition, thus promoting better growth than the standard lime treatment.

Exchangeable Mg Exchangeable Mg in the treated soils ranged from 0.11 to 0.58 $cmol_c/kg$ soil, depending on the rate of POME application (Table 6). The increase in the soil exchangeable Mg by POME application resulted in the linear increase of tissue Mg *(Fig. 2)*. The increase in the tissue Mg appeared to be higher in the Kuala Brang than in the Munchong soil. Relative plant top dry weight increased linearly as Mg in tissue increased *(Fig. 3)*. The tissue Mg corresponding to 90% relative plant top dry weight was about 0.3%.

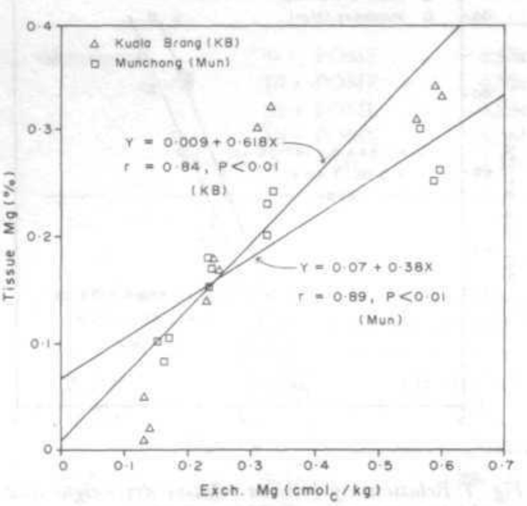

Fig. 2: Relationship between relative Mg and exchangeable Mg as affected by POME treatment on two soil series

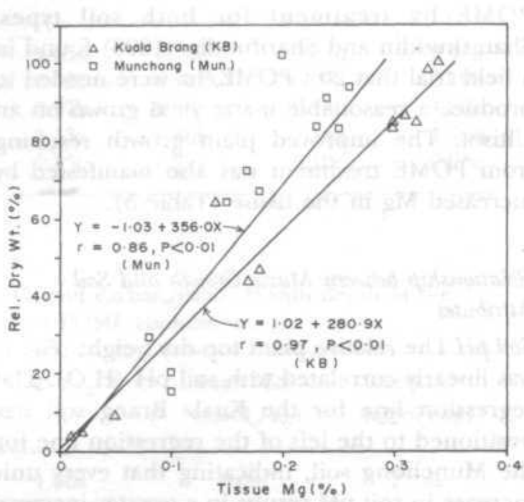

Fig. 3: Relationship between relative dry weight and tissue Mg as affected by POME treatment on two soil series

TABLE 6

The mean soil pH, exchangeable Al, Ca and Mg as affected by POME treatment on two soil series

Soil series	Treatment (t/ha)	pH (H_2O)	Exchangeable cations ($cmol_c/kg$)		
			Al	Ca	Mg
Kuala Brang	0	3.9	10.67	0.50	0.1
	10 t POME	4.1	10.64	0.85	0.24
	20 t POME	4.2	10.43	1.02	0.32
	40 t POME	4.3	9.44	1.51	0.58
	2 t GML	4.3	9.70	2.70	0.15
	LSD	0.1	0.40	0.14	0.02
Munchong	0	3.9	2.32	0.47	0.16
	10 t POME	4.3	1.94	0.73	0.23
	20 t POME	4.4	1.75	0.95	0.32
	40 t POME	4.4	1.58	1.28	0.58
	2 t GML	4.4	1.60	1.92	0.14
	LSD	0.1	0.08	0.11	0.05

Relative plant top dry weight increased when exchangeable Mg increased *(Fig. 4)*. The importance of Mg maize nutrition planted on acid soil has been reported by Shamshuddin *et al.* (1991) and Ismail *et al.* (1993); where the exchangeable Mg corresponding to 90% relative top weight was reported to be about 0.9 $cmol_c$/kg soil. However, in this study critical exchangeable Mg value was about 0.5 $cmol_c$/kg. Hence, POME application tended to reduce the Mg in the soil available for maize growth.

Exchangeable Al Fig 5. shows the relationship between plant top dry weight and the exchangeable Al. The plant top dry weight decreased linearly as the exchangeable Al increased. The exchangeable Al corresponding to a 10% drop in the relative plant top weight for the Kuala Brang and Munchong soils was 9.6 and 1.7 $cmol_c$/kg soil, respectively. Although the critical exchangeable Al was higher for the Kuala Brang compared with the Munchong soil (Table 5). The effect of Al toxicity on maize growth is clearly shown in this study. After amending the soils with POME, maize was able to grow satisfactorily even in the presence of very high concentrations of exchangeable Al (Kuala Brang soil).

The reduction in Al toxicity by POME application can be explained because as the POME contained high amounts of organic matter (23% organic C), it is able to bind Al through chelation. Organically bound Al has been shown

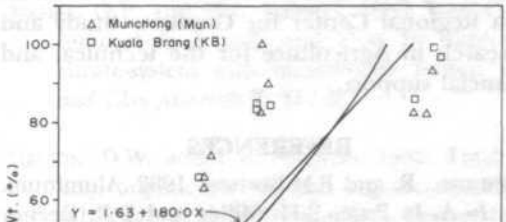

Fig. 4: Relationship between relative Mg and exchangeable Mg as affected by POME treatment on two soil series

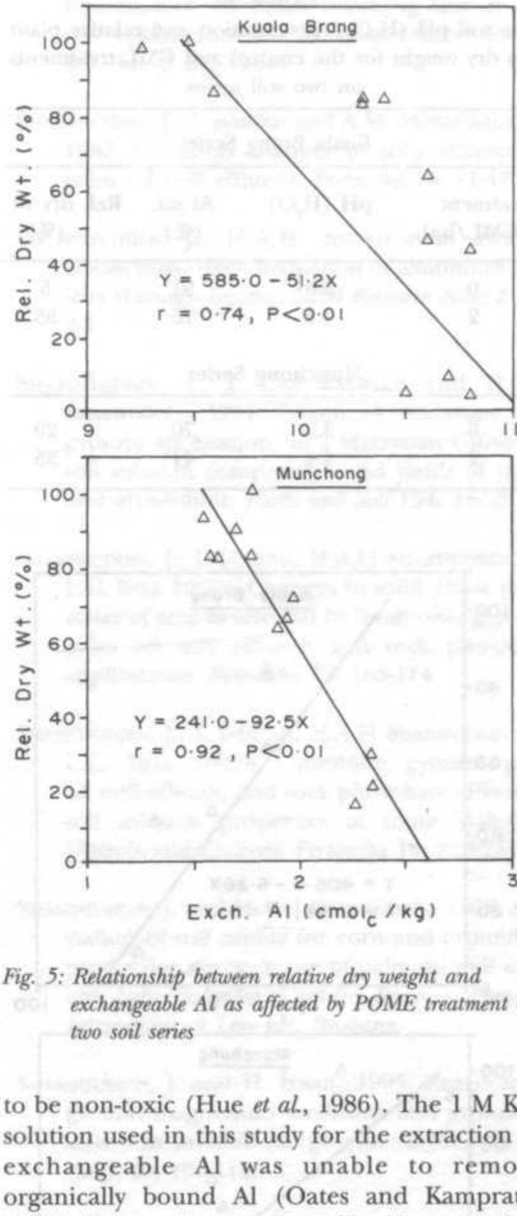

Fig. 5: Relationship between relative dry weight and exchangeable Al as affected by POME treatment on two soil series

to be non-toxic (Hue *et al.*, 1986). The 1 M KCl solution used in this study for the extraction of exchangeable Al was unable to remove organically bound Al (Oates and Kamprath, 1983). Hence, the exchangeable Al reported in this study could have affected maize growth.

Al Saturation The Al saturation in the zero treatment of the Kuala Brang and Munchong soils was 91 and 70%, respectively (Table 7). The respective relative plant top weight was 5 and 20%. On a Nigerian Ultisol under 45% Al saturation, 30% relative growth of maize was reported by Friesen *et al.* (1980), and on a Brazilian Oxisol under 72% Al saturation 48% relative growth of maize was reported by Gonzalez-Enrico *et al.* 1979).

TABLE 7
The soil pH (H_2O), Al saturation and relative plant top dry weight for the control and GML treatments on two soil series

Treatment (t GML/ha)	pH (H_2O)	Al sat. (%)	Rel. dry wt. (%)
Kuala Brang Series			
0	3.9	91	5
2	4.3	76	55
Munchong Series			
0	3.9	70	20
2	4.4	41	55

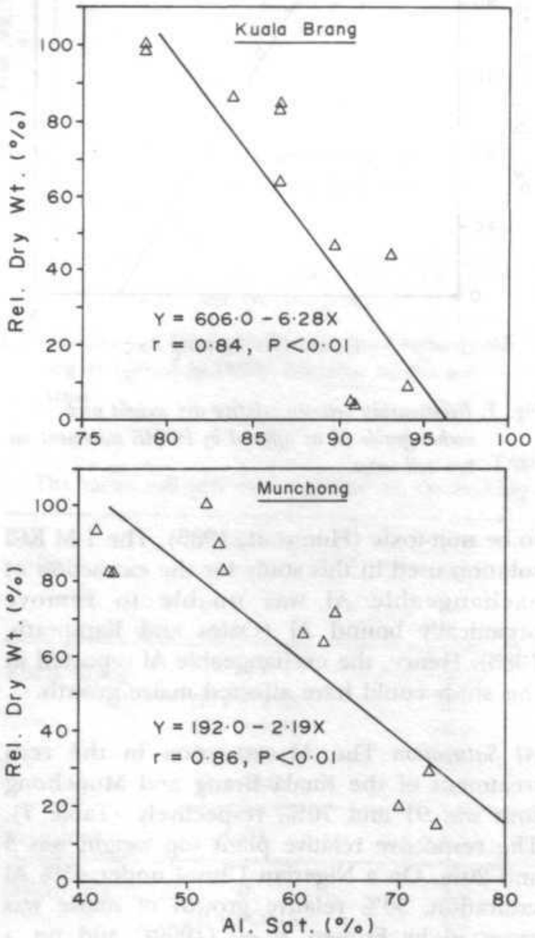

Fig. 6: Relationship between relative dry weight and exchangeable Al saturation as affected by POME treatment on two soil series

The above data indicate that maize growth is affected by Al. When Al saturation decreased maize grew better. This is consistent with the data presented in *Fig. 6*, where relative plant top weight clearly decreased linearly as the Al saturation increased. The critical Al saturation for the Kuala Brang soil was 82%, and 47% for Munchong soil. However, the actual growth was better for the Munchong than the Kuala Brang soils (Table 5). The fact that maize was able to grow under 80% Al saturation (Kuala Brang) shows that POME is able to reduce Al toxicity. Evidently, POME has the capability to bind Al, thus rendering it non-toxic to the maize.

CONCLUSION

Topsoil pH, organic C and exchangeable Mg increased as the rate of POME application increased. Relative plant top weight increased as the soil pH (H_2O) and exchangeable Mg increased. On the other hand, the relative plant top weight decreased as the exchangeable Al and Al saturation increased. With application of POME, the critical pH (H_2O) for maize was 4.2 – 4.5 whereas critical exchangeable Mg was 0.5 $cmol_c/kg$ soil.

Without amendment maize grows poorly on acid Malaysian soils. Palm oil mill effluent, available in large quantities in Malaysia, can be used to alleviate the acid soil infertilities.

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