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Alleviating Acid Soil Infertility Constrains Using Basalt, Ground Magnesium Limestone and Gypsum in a Tropical Environment

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ABSTRACT

Ultisols and Oxisols in the tropical regions are often acidic, with high Al but deficient in Ca and/or Mg. This limits maize production. Studies were conducted to investigate the efficacy of basalt, ground magnesium limestone (GML) and gypsum as acid soil ameliorants. Results showed that basalt improved soil fertility by increasing soil pH, cation exchange capacity (CEC) and exchangeable Ca, Mg and K and available P, with a concomitant lowering of exchangeable Al. In the soils treated with GML, Ca remained in the zone of incorporation. When GML was applied together with gypsum, Ca moved deeper into the soil profile. Sulfate, SO_4^{2-}, adsorption onto the surfaces of oxides resulted in an increase in pH and negative charge. The increase in pH was due to the replacement of OH^- by SO_4^{2-}. Beneficial effects of GML application at the rate of 4 t ha^{-1} lasted for about 8 years with the effect being comparable to application of 1 t GML ha^{-1} annually.

Keywords: Basalt, ground magnesium limestome, gypsum, Oxisols, soil acidity, Ultisols

INTRODUCTION

Currently, the main agricultural exports of Malaysia are palm oil, rubber and cocoa. Apparently, these plantation crops are mostly grown on acid and highly weathered soils which are classified as Ultisols and Oxisols. IBSRAM (1985) estimates that these soils cover approximately 72% of the country's land surface. It is known that the clay fraction of the soils is dominated by kaolinite, gibbsite, goethite and hematite (Tessens and Shamshuddin 1983; Anda *et al*. 2008; Shamshuddin and Anda 2008), with charges on the mineral surfaces that change with changing pH (Uehara and Gillman 1981; Shamshuddin and Ismail 1995).

These soils are usually used for maize production during the early phase of rubber and oil palm cultivation. But the yield of maize is limited by low pH, high Al and Ca and/or Mg deficiencies in the topsoil (Shamshuddin *et al*. 1991). Likewise, in the cultivation of cocoa, subsoil acidity affects growth of the plant (Noordiana *et al*. 2007).

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Subsoil acidity has been a common phenomenon in highly weathered soils of the tropics as Ca from lime application usually accumulates in the topsoil (Pavan *et al*. 1984; Gillman *et al*. 1989). This has led to plant roots restricting their growth to the plow layer where lime is originally incorporated. During the dry season, the plant suffers from water stress because its functional roots are unable to tap the underground water.

Aluminum toxicity is a major factor in acid soil fertility. It has been identified that Al^{3+} inhibits root growth either by inhibition of cell division, cell elongation or both (Marshner 1991). Deficiency in Ca and/or Mg in the soil aggravates the limitation of root growth by Al toxicity. These acid soil infertility constrains can be ameliorated effectively by applying amendments. Among amendments available in Malaysia are limestone, basalt and gypsum. This study was aimed at investigating the efficacy of basalt, ground magnesium limestone (GML) and gypsum as acid soil ameliorants.

MATERIALS AND METHODS

Soils and the Ameliorants

Relevant chemical properties of the soils used in the study are given in Table 1. The soils of Bungor (Ultisol) and Prang Series (Oxisol) were used for pot and leaching experiments, while the Rengam soil (Ultisol) was used for the field trial. The three soils were selected on the basis of their mineralogy and charge properties that were determined prior to the conduct of the study proper. The ameliorants tested in the study were ground basalt, GML and gypsum. The elemental composition of the GML and gypsum are given in Table 2. Basalt, obtained from a private company in Australia, contained 216,000 mg/kg Si, 65,400 mg/kg Ca, 64,400 mg/kg, 12,500 mg/kg K, 3,030 mg/kg P and 2,150 mg/kg S.

Pot Study

Basalt treatment. Soil of Bungor Series was treated with ground basalt at rates of 0, 5, 10 and 20 t ha^{-1} for 6 months. The soils were maintained under moist condition (at the matric suction of 10 kPa) throughout the experimental period. Sub-samples were taken every 2 months for analyses.

GML and Gypsum Treatments.

Air-dried surface soil (0 – 15 cm depth) from each of the Bungor and Prang series were mixed with GML, gypsum and their combinations. Application rates were 0, 0.5, 1.0, 2.0, and 4.0 t ha^{-1}. The response of maize (*Zea Mays*) to the ameliorants was assessed in a glasshouse trial, using a complete randomized 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^{-1} as urea, 150 kg P_2O_5 ha^{-1} as triple super phosphate and 75 kg K_2O ha^{-1} as muriate of potash) for 30 days prior to seeding of maize. Plants were watered 3 times daily with 250 mL H_2O each time and grown for 40 days, after which they were harvested. The water

TABLE 1

Relevant chemical properties of the topsoil (0-15 cm depth) and subsoil (30-45 cm depth) of Bungor, Prang and Rengam soils

Soil	Depth cm	pH (H_2O)	Cations					ECEC*	Al Saturation	Free Fe	O.C	Clay
			Ca	Mg	K	Na	Al					
			cmol$_c$ kg^{-1}						%	g kg^{-1}		
Bungor	0 - 15	4.29	1.05	0.30	0.22	0.02	4.02	5.16	72	36	19.5	250
	30 - 45	4.76	0.83	0.18	0.06	0.02	3.98	5.07	79	38	8	300
Prang	0 - 15	4.86	0.4	0.07	0.08	0.02	1.62	2.19	74	91	5.17	540
	30 - 45	5.04	0.6	0.03	0.04	0.01	1.08	1.77	62	117	18.2	590
Rengam	0 - 15	4.83	1.05	0.17	0.08	0.02	2.68	4.00	67	35	21.3	400
	30 - 45	4.43	0.72	0.14	0.05	0.01	2.83	3.74	76	39	12.1	450

*ECEC = effective cation exchange capacity

TABLE 2
Elemental composition of GML and gypsum

	Elemental composition						
	Ca	Mg	Fe	P	Mn	Cu	Zn
	g kg^{-1}		mg kg^{-1}				
GML*	185	6.7	2120	1.7	97.3	16.6	29.5
Gypsum	251	<1	103	<0.1	26.7	7.2	7.8

*GML contained 0.4% S.

was allowed to drain out of the pot and the leachates collected and analyzed. After harvest, the soils in the pot were air-dried, well mixed and sub-sampled for laboratory analysis. Plant tops were sampled and dried in an oven at 60^{0}C and relative top weight calculated.

Leaching Experiment in PVC Columns

The Bungor and Prang soils were sampled in the field at depth intervals of 15 cm to a depth of 90 cm. The soil samples were air-dried, ground, and carefully packed into PVC columns according to their depths. Gypsum, GML and combinations of GML and gypsum were incorporated into the soil at 0 – 15 cm depth. A complete randomized experimental design with three replications was used. The treatments were 0, 0.5, 1.0, 2.0, 4.0, and 8.0 t ha^{-1} of GML and gypsum in all combinations. The treated soils were watered twice weekly at a rate equivalent to a rainfall of 2500 mm year^{-1}. Leachates were collected and analyzed every 30 days. The soils in the PVC columns were sampled at a depth interval of 15 cm after 180 days.

Field Experiment

A field experiment was established within the Chembong Department of Agriculture Complex, Negeri Sembilan, Malaysia. The area receives an annual rainfall of 2300 mm. The plots were originally treated with GML at the rate of 0 (without fertilizer), 0, 0.5, 1.0, 2.0, 4.0, and 8.0 t GML ha^{-1} incorporated into 0 – 30 cm depth (henceforth referred to respectively as T_1, T_2, T_3, T_4, T_5, T_6 and T_7). The current experiment started 5 years later with yearly GML application at the rate of 0, 0.5, 1.0 and 2.0 t ha^{-1} in plots T_1, T_2, T_3 and T_4, respectively. Plots T_5, T_6 and T_7 received no further treatment and were regarded as residual plots. Each treatment was replicated 4 times and arranged in a randomized complete block design with each plot measuring 4 x 4 m.

Maize seeds (*Zea mays var. Mas Madu*) were planted 30 days after treatments. Fertilizers at the rate of 120 kg N, 100 kg P and 150 kg K ha^{-1} were applied prior to planting of maize. A composite sample of 5 cores was taken from each of the experimental plots subsequent to the maize harvest at depths of 0 – 15 and 15 – 30 cm. The experiment was continued up to 4 crops of maize.

Analyses of Soil and Soil Solution

Soil pH was measured in suspensions of soil samples in water (1:2.5) after 1 hour of intermittent shaking and left standing overnight. Basic exchangeable cations were extracted with 1M NH_4OAc buffered at pH 7. Calcium, Mg, K and Na were determined by atomic absorption spectrophotometry. Cation exchange capacity was determined by an unbuffered solution of NH_4Cl. Exchangeable Al was extracted with 1M KCl and determined colorimetrically. Charge properties of the untreated soils were determined by the method of Gillman and Sumpter (1986) where negative charge as measured by Ca adsorption is termed CEC_B. That measured by Ca and Al adsorption is termed CEC_T while positive charge as measured by Cl^- adsorption is termed AEC.

Soil solutions were extracted from the moist soils by centrifugation at 2000 rpm for 1 hour. The air-dried soils from the PVC columns and the pot experiments were made moist by incubation for 1 day at a matric suction of 10 kPa. Soil solution pH and EC were determined immediately from 2 mL sub-samples. The remaining solution was stored at 5^0C to determine metals by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPAES) and ligands by High Performance Liquid Chromatography (HPLC). The activities of Al species and other ions in the soil solution were calculated by the GEOCHEM –PC (Version 2.0) computer program (Parker *et al*. 1990).

RESULTS AND DISCUSSION

Effects of Basalt Application

Within 6 months of basalt application, pH had increased significantly (Table 3). The increase in pH resulted in the reduction of exchangeable Al. As the soil contained variable charge minerals, the increase in pH resulted in an increase in CEC. The CEC increase may also be due to the lowering of pHo as the reaction of silicate in soils is known to lower pHo (Uehara and Gillman 1981). The term pHo is the pH at which net charge on the surface of variable charge colloids is zero. Cation Exchange capacity is dependent on the difference between soil pH and pHo. When pHo is decreased, the difference is widened causing CEC to increase. The dissolution of basalt released Ca, Mg, K and P into the soil, causing exchangeable Ca, Mg and K, and available P to increase significantly. This means that acid soil infertility can be somewhat ameliorated by basalt application.

Movement of Ca

The movement of Ca in the PVC columns was studied in the leaching experiment of the GML treated soils. It was observed that Ca remained in the zone where the lime was originally incorporated, that is in the topsoil (0 – 15 cm depth). This finding is similar to that of other studies that have been reported (Pavan *et al*.

TABLE 3

Effects of basalt application on the chemical properties of Bungor Series

Treatment t/ha	pH	Avail. P ppm	Exch. cations Al	Ca	Mg	K	Na	CEC
			------------------------- cmol$_c$/kg					---------------------
0	3.83	6.40	1.66	0.76	0.10	0.11	0.05	3.66
5	4.73	14.72	1.04	1.83	0.73	0.43	0.08	5.93
10	4.96	20.84	0.82	2.01	0.96	0.74	0.10	6.22
20	5.12	26.78	0.68	2.09	1.05	0.83	0.15	7.08
LSD$_{0.05}$	0.20	2.28	0.03	0.09	0.07	0.03	0.01	0.19

1984; Gillman *et al*. 1989). The accumulation of the Ca in the topsoil can probably be explained in the following manner: the highly weathered soils of Malaysia are dominated by kaolinite and sesquioxides (Tessens and Shamshuddin 1983), and the charge on the exchange complex of these minerals increases with increasing pH (Uehara and Gillman 1981). When the GML was applied, pH increased, followed by an increase in CEC. Hence, Ca was held by the negatively-charged surfaces. As long as the pH remained high, the Ca would not move down the soil profile. The increase in negative charge and the decrease in positive charge as a result of the pH increase are depicted in *Fig. 1.*

When GML was applied together with gypsum, the Ca moved deeper into the soil profile. In this case, the amounts of Ca in the soil were higher than those required to neutralize the CEC raised by the increase in soil pH. The excess Ca naturally moved into the subsoil. The recommended rate of application is 2 t GML + 1 t gypsum ha^{-1}. This caused GML to detoxify Al in the topsoil, while the Ca that moved downwards alleviated Ca deficiency in the subsoil.

Adsorption of SO$_4$

When gypsum was applied, SO_4^{2-} from the gypsum was adsorbed specifically onto the oxide surfaces. As a consequence, the pH and negative charge on the oxides increased. The mechanism of charge development on the oxides is illustrated in *Fig. 2.* However, the resultant increase in pH was only observed in the Oxisol of the Prang soil series (Table 4). In the Ultisol of the Bungor series, the pH tended to decrease.

An opposing reaction took place simultaneously along with SO_4^{2-} adsorption when gypsum was applied. The second reaction was the replacement of Al on the exchange complex by Ca. In this case, the replaced Al went into the solution and pH was lowered accordingly. Both SO_4^{2-} adsorption and Al replacement by Ca occurred in the Oxisol and Ultisol, but the former was more dominant in the Oxisol as the soil contains high amounts of oxides. On the other hand, as exchangeable Al was high in the Ultisol, Al replacement was dominant. Thus, the beneficial effect of gypsum application is only observed in the Oxisol. This suggests that gypsum can be used to ameliorate Oxisols, but not Ultisols. In fact, the Ultisol becomes more acidic with gypsum application.

The presence of SO_4^{2-} in the soil implies that other anions can be exchanged and subsequently removed out of the system. This is especially true for NO_3^-. It was observed that SO_4^{2-} that was replaced in the Oxisol, in turn, moved downwards and accumulated in the subsoil. In the subsoil, the NO_3^- was attracted and adsorbed onto the positive charge sites on the surfaces of the oxides. The NO_3^- is therefore not lost to the groundwater but retained in the soils.

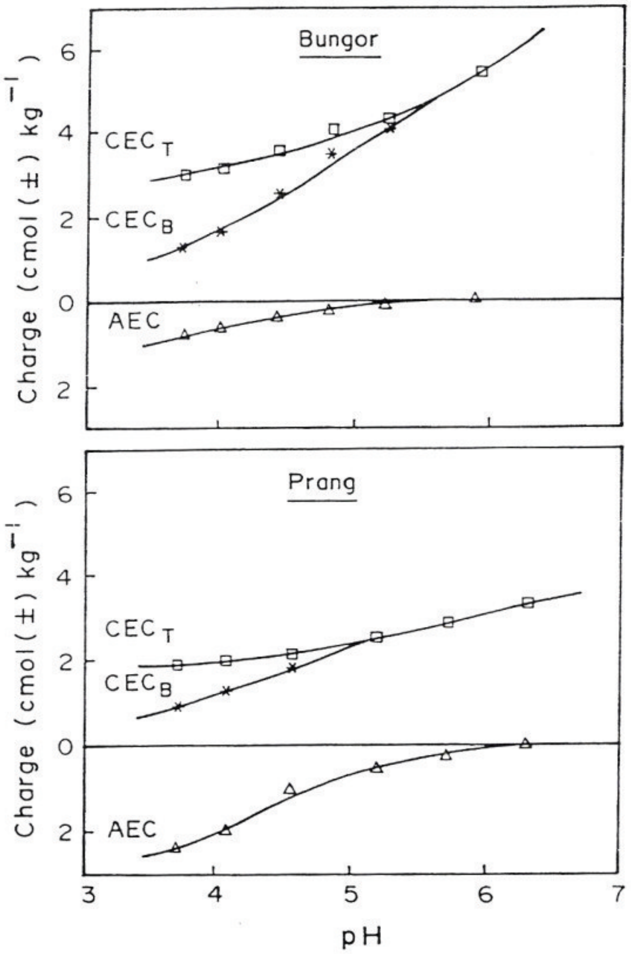

Fig. 1: Relationship between pH and CEC_T, CEC_B and AEC in the topsoil of Bungor and Prang soils.

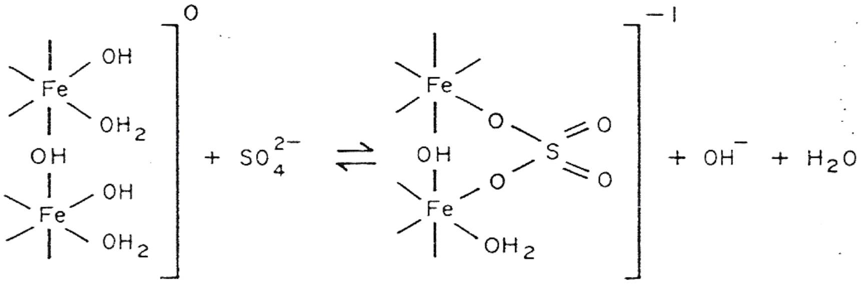

Fig. 2; Development of negative charge resulting from adsorption of SO_4^{2-} onto oxide of Fe

Alleviation of Acid Soil Infertility

Aluminum toxicity is one of the major factors limiting crop growth in the tropics. It inhibits root growth and consequently reduces crop yield. A past study (Shamshuddin *et al*. 1991) and the current study indicate that Al toxicity can be overcome by basalt application at the rate of 10 t ha^{-1}. It can also be overcome by GML application at the rate of 2 t ha^{-1} or to a limited extent by gypsum application at an appropriate rate. It appears that a good agronomic option is to apply GML together with gypsum in the topsoil. Unlike GML, basalt takes time to dissolve completely in soil and therefore offers long-term beneficial effects

In the Oxisol, SO_4^{2-} adsorption increases pH and negative charge which consequently reduces Al, rendering soil conditions more conducive for plant growth. Aluminum toxicity can also be reduced by gypsum application via another mechanism. The SO_4^{2-} from gypsum forms soluble $AlSO_4^+$ ion pairs which find their way into the groundwater.

It is known that Ca is able to detoxify Al to a certain extent. When GML and/or gypsum are applied onto the soils, Ca is made available in large quantities, and consequently reduces Al toxicity. As such, there exists a Ca/Al concentration ratio, above which crop yield is no longer affected by Al toxicity. Relative top maize weight % was plotted against soil solution Ca/Al concentration ratio (data not shown). A 10% drop in relative top maize weight corresponds to a Ca/Al concentration ratio of 79. It shows that Ca needs to be considerably high in the soil solution of Ultisols and Oxisols in order to alleviate Al toxicity. The Ca/Al concentration can, therefore, be used as an index of soil acidity.

Long-term Effect of GML Application

The changes of exchangeable Ca with time and depth are shown in Table 5. Note that plots $T_5 – T_7$ were started 5 years earlier and that no further GML was applied, whereas in $T_1 – T_{4,}$ GML was applied yearly according to the rates mentioned earlier.

In the residual treatments ($T_5 – T_7$), the exchangeable Ca in July 1991 remained reasonably high although GML was applied 5 years earlier (Table 5). After 1991, the exchangeable Ca began to decrease. In the case of T_5, where 2 t GML ha^{-1} was applied, the exchangeable Ca was reduced to the level of the untreated soil (Table 1). However, in the T_6 and T_7 where GML application rates were 4 and 8 t ha^{-1}, respectively, the exchangeable Ca was considered within the range suitable for maize growth. This means that the beneficial effect of GML at the rates of 4 t ha^{-1} or higher can last up to 8 years.

In T_3 (1 t GML ha^{-1} was applied annually), the amount of exchangeable Ca was reasonably high. The exchangeable Ca was higher in T_4 (2 t GML ha^{-1} were applied annually) than that of T_3. But, as it is too costly to apply GML at 2 t ha^{-1} annually, it is reasonable to recommend liming at a rate of 1 t ha^{-1} be applied annually. The beneficial effect of liming at this rate is comparable to those of T_6 and T_7. Applying GML at a rate lower than 1 t ha^{-1} annually is not effective for alleviation of Al toxicity.

The change in exchangeable Al (Table 6) is consistent with those of the exchangeable Ca shown in Table 5. The amount of exchangeable Al present in T_6 and T_7 is below the toxic level for maize growth. Maize yield (data not shown) was not affected by Al toxicity in these treatments. The exchangeable Al was low throughout the experiment period in T_4 but in T_3, the value either increased or decreased depending on whether the soils were sampled before or after GML application.

Soil pH (data not shown) followed the changing trend of the exchangeable Al. When the exchangeable Al increased, pH decreased and vice versa. In T_7, the topsoil pH (H_2O) remained above 5.0 up to 1992, after which it decreased to less than 5.0.

TABLE 4

Effects of gypsum application on the pH of the Bungor and Prang topsoils

	pH (H_2O)	
Rate (t gypsum ha^{-1})	Bungor	Prang
0	4.21	4.18
2	4.16	4.48
4	4.08	4.54
LSD	0.32	0.21

TABLE 5

Changes in exchangeable Ca in Rengam soil with time and depth as affected by GML application

Treatment	Depth (cm)	Dates of soil sampling			
		JULY 91	AUG 92	FEB 93	FEB 94
		Exch Ca (cmol$_c$ kg^{-1})			
T1	0 - 15	1.35	0.69	0.36	0.67
	15 - 30	0.89	0.80	0.15	0.12
T2	0 - 15	1.87	0.86	0.48	1.24
	15 - 30	1.28	0.16	0.14	0.35
T3	0 - 15	1.86	1.35	0.73	0.98
	15 - 30	1.16	0.31	0.22	0.43
T4	0 - 15	3.10	1.64	1.50	1.21
	15 - 30	2.15	0.90	1.07	1.28
T5	0 - 15	1.17	0.53	0.58	0.43
	15 - 30	1.44	0.32	0.53	0.38
T6	0 - 15	2.33	1.16	1.12	1.15
	15 - 30	1.71	0.80	0.99	0.84
T7	0 - 15	3.88	1.64	0.85	1.24
	15 - 30	2.73	1.27	1.38	0.75

TABLE 6

Changes in exchangeable Al in Rengam soil with time and depth as affected by GML application

Treatment	Depth (cm)	Dates of soil sampling JULY 91 (Maize 1)	AUG 92 (Maize 2)	FEB 93 (Maize 3)	FEB 94 (Maize 4)
		Exch Al ($cmol_c\ kg^{-1}$)			
T1	0 - 15	2.18	0.83	1.1	2.12
	15 - 30	2.15	1.08	1.1	2.31
T2	0 - 15	1.45	1.03	1.09	1.77
	15 - 30	1.94	1.34	1.32	1.94
T3	0 - 15	1.61	0.54	1.34	1.58
	15 - 30	2.22	1.12	1.04	1.97
T4	0 - 15	0.48	0.06	0.52	0.49
	15 - 30	1.17	0.82	0.58	1.27
T5	0 - 15	1.55	1.37	1.55	2.51
	15 - 30	1.79	1.09	1.05	2.6
T6	0 - 15	1.62	1.05	1.02	1.64
	15 - 30	1.92	1.04	0.8	2.01
T7	0 - 15	0.37	0.29	0.53	0.9
	15 - 30	0.94	0.53	0.53	1.51

CONCLUSION

Ground magnesium limestone application is only able to alleviate topsoil acidity. In order to alleviate subsoil Ca deficiency of Ultisols and Oxisols, GML has to be applied together with gypsum. Gypsum can be used to ameliorate Oxisols with a high oxide content, but is not to be applied in isolation in Ultisols with high exchangeable Al. Sulfate, SO_4^{2-}, adsorption of oxides increases pH and negative charge via replacement of OH^- by SO_4^{2-}. Liming at a rate of 4 t ha^{-1} or higher is effective for about 8 years with the beneficial effect being comparable to the application of 1 t GML ha^{-1} annually.

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REFERENCES

Anda, M., J. Shamshuddin, I. Fauziah and S.R. Syed Omar. 2008. Mineralogy and factors controlling charge development of three Oxisols developed from different parent materials. *Geoderma* **143**:153-167.

IBSRAM. 1985. Report of the inaugural workshop and proposal for implementation of the acid tropical soil management network. International Board for Soil Research and Management, Bangkok, Thailand.

Gillman, G.P. and E.A. Sumpter. 1986. Surface charge characteristics and lime requirements of soils derived from basaltic, granitic and metamorphic rocks in high-rainfall tropical Queensland. *Australian Journal of Soil Research* **24**: 173-192.

Gillman, G.P., K.L. Bristow and M.J. Hallman. 1989. Leaching of applied calcium and potassium from Oxisol in humid tropical Queensland. *Australian Journal of Soil Research* **27**: 183-198.

Marschner, H. 1991. Mechanisms of adaptation of plants to acid soils. *Plant and Soil* **134**: 1-20.

Noordiana, N., S.R. Syed Omar, J. Shamshuddin and N.M. Nik Aziz. 2007. Effects of organic-based and foliar fertilizers on cocoa (*Theobroma cocoa* L.) grown on an Oxisol in Malaysia. *Malaysian Journal of Soil Science* **11**:29-43.

Parker, D.R., W.A. Norvell and R.L. Chaney. 1990. *Geochem-PC.* Version 2.0. Department of Soil and Environmental Sciences. University of California, Riverside, USA.

Pavan, M.A, F.T. Bingham and P.F. Pratt. 1984. Redistribution of exchangeable calcium, magnesium, and aluminum following lime or gypsum applications to a Brazilian Oxisol. *Soil Science Society of America Journal* **48**: 33-38.

Shamshuddin, J., I. Che Fauziah and H.A.H. Sharifuddin. 1991. Effects of limestone and gypsum applications to a Malaysian Ultisol on soil solution composition and yield of maize and groundnut. *Plant and Soil* **134**: 45-52

Shamshuddin, J and H. Ismail 1995. Reactions of ground magnesium limestone and gypsum in soils with variable-charge minerals. *Soil Science Society of America Journal* **59**: 106-112.

Shamshuddin, J. and M. Anda 2008. Charge properties of soils in Malaysia dominated by kaolinite, gibbsite, goethite and hematite. *Bull. Geol Soc. Malaysia* **54**: 27-31.

Tessens, E. and J. Shamshuddin. 1983. *Quantitative Relationship between Mineralogy and Properties of Tropical Soils*. UPM Press, Serdang, Selangor, Malaysia.

Uehara, G. and G.P. Gillman. 1981. *The Mineralogy, Chemistry and Physics of Tropical Soils with Variable Charge Minerals*. Westview Press, Boulder, CO.