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Limestone, Gypsum, Palm Oil Mill Effluent and Rock Phosphate Effects on Soil Solution Properties of Some Malaysian Ultisols and Oxisols

J. SHAMSHUDDIN[1], I. JAMILAH[1], H.A.H. SHARIFUDDIN[1] and L.C. BELL [2]
[1]*Department of Soil Science, Faculty of Agriculture,*
UPM 43400, Serdang, Selangor Darul Ehsan, Malaysia
[2]*Department of Agriculture, University of Queensland, Qld 4072, Australia*

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ABSTRAK

Tanah Ultisol dan Oksisol di Malaysia dicirikan oleh pH yang rendah, tepuan Al yang tinggi, KPKE yang rendah dan kekurangan Ca dan/atau Mg. Ini menghadkan pengeluaran tanaman bermusim. Satu kajian berpasu telah dijalankan untuk menilai perubahan kimia fasa larutan tanah daripada beberapa tanah Ultisol dan Oksisol selepas dirawat dengan batu kapur, gipsum, efluen kilang kelapa sawit dan fosfat batuan. Keputusan kajian menunjukkan bahawa 2-4 batu kapur/ha diperlukan untuk meningkat pH, Ca, Mg dan SO_4^{2-}, dan menurunkan Al dan Mn di dalam larutan tanah ke tahap yang sesuai. Rawatan efluen kelapa sawit dengan kadar 0.5 -1.0 t/ha (equivalen kapur) memberi kesan pengapuran sama seperti batu kapur. Rawatan gipsum meningkatkan kepekatan Al, tetapi apabila rawatan bertambah kebanyakan Al wujud di dalam bentuk $AlSO_4^+$. Rawatan tanah siri Rengam, Bungor dan siri Prang dengan gipsum dengan kadar 1t/ha telah mengurangkan $pAlOHSO_4$ kepada 17. Ini menunjukkan jurbanit boleh terbentuk di dalam tanah Ultisol dan Oksisol setelah dirawat dengan gipsum.

ABSTRACT

Ultisols and Oxisols in Malaysia are characterized by low pH, high Al saturation, low ECEC and Ca and/or Mg deficiencies, which are limiting to annual crop production. A pot experiment was conducted to assess the chemical changes in the properties of the soil solution phase of soils of some representative Ultisols and Oxisols following application of limestone, gypsum, palm oil mill effluent and rock phosphate. The results showed that 2-4 t limestone/ha were needed to increase pH, Ca, Mg and SO_4^{2-}, and to reduce Al and Mn to an acceptable level in the soil solution. Palm oil mill effluent application at 0.5–1 t/ha (lime equivalent) gave similar liming effects to those of limestone. Gypsum application increased Al concentration, but at high rate of application the Al existed mainly in the form of $AlSO_4^+$. Gypsum application in Rengam, Bungor and Prang series soils at 1 t/ha reduced $pAlOHSO_4$ to 17, suggesting that jurbanite can be formed in Ultisols and Oxisol when gypsum is applied.

INTRODUCTION

Ultisols and Oxisols occupy about 72% of Malaysia (IBSRAM 1985) and are acid and highly weathered, with the variable charge minerals such as kaolinite, gibbsite and/or goethite dominating the clay fraction (Tessens and Shamshuddin 1983). Additionally, the soils have low cation exchange capacities (CEC), high Al activity and are deficient in Ca and/or Mg, and low in available phosphate which are limiting to maize and groundnut production on these soils (Shamshuddin *et al.* 1991; Zaharah *et al.* 1982). It is important to delineate ameliorants which can be used economically to increase CEC and Ca, Mg and P availability and decrease phytotoxic Al. Potential ameliorants available in Malaysia include dolomitic limestone, rock phosphate, gypsum, and palm oil mill effluent. Little is known of the ability of these materials to ameliorate acid soil infertility in Malaysian soils. The objective of this paper was to assess the chemical changes in the properties of the solution phase of samples of some representative Malaysian Ultisols and Oxisols following application of various rates of limestone, gypsum, rock phosphate and palm oil mill effluent; changes of interest include those properties important for crop growth such as pH, bases and Al species.

MATERIALS AND METHODS

Soils

Six soil series which are very widespread in the upland areas of Peninsular Malaysia were selected for the study. The soils were Rengam (Kandiudult), Bungor (Paleudult), Serdang (Paleudult), Munchong (Hapludox), Katong (Hapludox) and Prang series (Acrudox). Relevant chemical properties of the six soils are given in Table 1. Detail mineralogy and charge properties of these soils have already been reported (Tessens and Shamshuddin 1982; Tessens and Shamshuddin 1983); major minerals in the clay fraction of the soils are kaolinite, gibbsite and/or goethite. Soil samples for the study were taken from the surface (0-15 cm) and subsoil (30-45 cm). Only the topsoils were used for the pot trials.

Experimental

Air-dried surface soil (0-15 cm, < 2mm) from each of the Rengam, Bungor, Serdang, Munchong, Katong and Prang series was mixed with ground magnesium limestone (GML), gypsum, palm oil mill effluent (POME) and rock phosphate (carbonate rock phosphate) as a precursor to a glasshouse trial to assess the response of maize to the various ameliorants. Results of the plant response will be the subject of a subsequent paper. The rates of application were 0, 0.5, 1.0, 2.0, 4.0 and 8.0 t/ha calculated on the basis of lime equivalent. The elemental composition of the GML, gypsum, POME and rock phosphate is given in Table 2. The pot trial involved equilibrating the ameliorants and basal nutrients (180 kg N/ha as urea, 150 kg P/ha as superphosphate and 75 kg K/ha as muriate of potash) for 30 days prior to the growth of maize for 30 days. The soils were kept moist at field capacity by adding distilled water. After harvest the soils in the pots were air-dried, well mixed and subsampled for laboratory analysis.

Soil Analysis

Some of the untreated soil samples were taken to the laboratory for determination of basic chemical properties (Table 1), where pH in water (1:2.5) and in $CaCl_2$ (1:1) was determined after 1 h of intermittent shaking and being left to stand overnight. 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. Al was extracted by 1 M KCI and determined colorimetrically (Barnhisel and Bertsch 1982). Free iron oxide was determined by the method of Mehra and Jackson (1960), while organic carbon was estimated by the Walkley-Black method (Nelson and Sommers 1982). Clay

TABLE 1
Relevant chemical properties of surface soils (0 - 15 cm) of Rengam, Bungor, Munchong, Katong, Serdang and Prang Series

Series	pH		Exchangeable Cations					ECEC	Al.Sat.	Fe_2O_3	Org. C	Clay
	H_2O (1:2.5)	$CaCl_2$ (1:1)	Ca	Mg	K	Na	Al					
			cmol (+)/kg						%			
Serdang	5.23	4.70	1.79	1.00	0.16	0.05	0.77	3.77	20	4.4	1.68	47
Bungor	4.29	4.09	1.05	0.30	0.22	0.02	4.02	5.16	72	3.6	1.95	25
Rengam	4.97	4.39	1.05	0.20	0.18	0.03	2.68	4.14	65	1.2	2.13	41
Munchong	4.68	4.12	0.26	0.17	0.09	0.02	1.76	2.30	77	5.0	1.27	81
Katong	4.87	4.20	0.17	0.17	0.12	0.05	1.32	1.83	72	8.0	2.50	87
Prang	4.39	3.90	0.03	0.05	0.05	0.02	1.58	1.73	91	9.1	1.16	81

TABLE 2
Elemental composition of GML, gypsum, POME and rock phosphate

Material	Elemental Composition							
	N	P	Ca	Mg	Fe	Mn	Cu	Zn
	%				mg/kg			
GML*	nd	1.7×10^{-6}	18.5	6.7	2119	97.3	16.6	29.5
Gypsum	nd	$<1\times10^{-7}$	25.1	tr	103	26.7	7.2	7.8
POME	1.3	0.44	2.7	1.8	1.2	tr	tr	tr
Rock phosphate	nd	7.29	37.2	0.3	2.0	tr	tr	tr

tr = trace (<0.1)
nd = not determined
* = GML contained 0.4%S

% was determined by the pipette method of Gee and Bauder (1982). ECEC was calculated as the sum of basic exchangeable cations and exchangeable Al.

Soil Solution Extraction and Analysis

The air-dried soils from the pot experiment were incubated for 1 day at a matrix suction of 10 kPa following recommendations of Menzies and Bell (1988). This study assumes that a state of equilibrium is reached between the liquid and solid phase of the soils during the incubation period. Soil solutions were extracted by centrifuge at 2000 RPM for 1 h. pH and EC were determined immediately from a 2 ml subsample. The rest of the solutions was kept for determination of Ca, Mg, Na, K, Al, Mn, Fe and S by inductively coupled plasma atomic emission spectroscopy (ICPAES). Nitrate in the soil solution was determined by an autoanalyser.

Al Speciation

Activities of Al species and other ions were calculated by the GEOCHEM computer programme of Sposito and Mattigod (1980), which was modified and improved by Chaney (1987). Soil solution pH, ionic strength, Al, Ca, Mg, Na, K, Mn, SO_4^{2-} and NO_3^{-1} were used as input in the computer programme. Ionic strength of the soil solution was estimated from the EC (Griffin and Jurinak 1973). Monomeric Al species in soil solution are Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2^+$, $Al(OH)_3^\circ$ and $AlSO_4^+$ (Blamey *et al.* 1983) Al_{sum} was calculated as the sum of the activities of these Al species.

RESULTS

Soil Properties

The soils under study listed in order of increasing degree of weathering (on the basis of the data presented in Table 1) are: Bungor < Rengam < Munchong < Katong < Prang. However, Serdang series soil does not fit into this trend; presumably the soil was limed prior to sampling as soil pH and exchangeable Ca in this soil are too high for an unlimed Ultisol in a strongly leaching environment. Exchangeable Ca, Mg and ECEC decrease from Bungor to Prang series soils, while exchangeable Al and Al saturation increase. Generally, Fe_2O_3 and clay are lower in the Ultisols than in the Oxisols. Soil solutions from the 6 soils series were investigated in order to evaluate the effects of GML, gypsum, POME and rock phosphate applications. Soil solutions of Rengam, Bungor, Munchong and Prang series soils were selected for detailed investigation into their ionic activities in relation to soil acidity. Soil solutions from Serdang and Katong series were also analysed and studied, but not discussed in detail as soil solution properties of Serdang and Katong series were similar to those of Rengam and Prang series, respectively.

Effects of GML

Data in Table 3 show that application of 4 t GML/ha in Rengam series soil increased soil solution pH from 4.1 to 5.5, Ca from 559 to 1498 µM and Mg from 206 to 1615 µM, respectively. GML application at 2 t/ha increased SO_4^{2-} concentration from 235 to 483 µM, but reduced Al concentration from 23 to 13 µM. The increase in SO_4^{2-} concentration was due partly to the addition of S from GML (Table 2) and partly to replacement of SO_4^{2-} by OH^-. Al^{3+} and Mn^{2+} activities were reduced from 9 to 4 µM and from 8 to 4 µM, respectively, by the application of 2 t GML/ha (Table 4). Bungor series soil is more acid than Rengam, shown by a higher exchangeable Al in Bungor series (Table 1), thus more GML is needed to increase soil solution pH in Bungor than in Rengam series (Table 5). Al^{3+} activity in Bungor series was decreased from 21 to 4 µM by the application of 2 t GML/ha (data not presented).

Soil solution pH of Munchong series was low, with a value of 3.6 in the control (Table 6). This value increased to 4.6 by application of 4 t GML/ha. GML application at this rate reduced Al concentration from 56 to 14 uM and reduced Mn

TABLE 3

Concentration of cations and anions in the soil solution of Rengam series soil as affected by GML, gypsum, POME and rock phosphate application

Treatment	Rate	pH	EC	Al	Ca	Mg	K	Na	Fe	Mn	SO_4^{2-}	NO_3^{-1}
	(t/ha)		(dS/m)					µM				
GML	0	4.11	1.23	23	559	206	340	5712	1.8	11	235	1768
	0.5	4.39	1.16	13	477	258	245	5902	0.7	7	420	1636
	1.0	4.42	1.13	12	608	492	197	5724	0.9	8	321	1887
	2.0	4.49	1.20	13	685	553	212	5370	0.5	6	483	1653
	4.0	5.53	1.54	13	1498	1615	247	6166	0.5	7	716	2289
	8.0	6.63	1.73	12	2392	3177	259	5645	0.1	2	1802	2276
	LSD	0.78	0.06	5	665	812	131	1045	1.1	6	217	836
Gypsum	0	4.48	1.31	24	332	150	286	5169	1.2	10	271	1812
	0.5	4.30	1.16	19	598	119	237	5393	1.0	8	601	985
	1.0	4.08	1.23	26	1011	164	213	5539	1.5	11	3517	417
	2.0	4.00	2.03	91	3949	375	363	5987	5.8	29	7953	351
	4.0	4.10	2.80	159	9410	543	291	6267	10.7	45	12546	239
	8.0	4.03	3.22	141	10656	618	311	6336	10.9	51	14272	184
	LSD	0.52	0.23	31	493	61	111	1479	2.0	6	1486	379
POME	0	4.86	1.27	45	706	287	455	7945	9.0	13	275	2637
	0.5	6.17	1.97	30	3344	3644	378	8415	0	12	647	4017
	1.0	6.57	2.48	23	4586	6032	366	6410	0	5	1663	4724
	2.0	7.08	3.25	28	7349	9288	517	6651	0	3	3216	7629
	4.0	7.60	4.57	32	11521	12716	760	5659	0	2	4408	9197
	8.0	7.42	5.54	35	14667	15269	977	5458	0	3	6967	11301
	LSD	0.42	0.69	18	2177	1835	176	1337	8.1	6	808	2780
Rock phosphate	0	4.91	1.03	28	297	105	281	5820	1.4	5	567	1088
	0.5	5.09	0.85	25	264	74	214	5322	2.0	5	530	966
	1.0	5.13	0.91	21	297	79	239	6007	1.7	4	483	992
	2.0	5.19	0.84	19	426	93	217	5423	2.1	5	541	610
	4.0	5.36	0.92	26	542	94	167	6508	1.8	4	1047	806
	8.0	5.53	0.92	18	532	98	199	5545	1.5	4	986	706
	LSD	0.52	0.25	8	39	48	99	1513	2.2	3	513	553

TABLE 4
Activities of Al and Mn species in the soil solution of Rengam, Munchong and Prang series

Treatment	Rate (t/ha)	Activities (μM)											
		Al_{sum}	Al^{3+}	$AlSO_4^+$	Mn^{2+}	Al_{sum}	Al^{3+}	$AlSO_4^+$	Mn^{2+}	Al_{sum}	Al^{3+}	$AlSO_4^+$	Mn^{2+}
		Rengam				Munchong				Prang			
GML	0	13	9	2	8	24	22	2	205	25	12	11	14
	0.5	8	4	2	5	21	18	2	207	13	7	5	8
	1.0	7	4	1	6	18	14	2	180	11	5	5	10
	2.0	9	4	2	4	8	6	1	123	9	4	4	9
	4.0	12	<1	<1	4	7	3	1	58	7	2	4	5
	8.0	12	<1	<1	1	6	<1	<1	9	9	<1	<1	1
Gypsum	0	15	7	2	7	40	34	3	269	15	9	6	11
	0.5	12	4	6	5	19	13	5	210	28	10	15	15
	1.0	17	4	12	6	36	23	10	196	39	10	28	15
	2.0	53	8	44	12	33	15	17	177	65	12	50	20
	4.0	85	10	73	15	49	9	39	225	81	9	71	24
	8.0	74	8	65	17	65	6	50	198	78	7	70	26
POME	0	32	7	2	9	32	27	3	234	18	8	7	10
	0.5	29	<1	<1	7	7	3	2	39	13	5	7	8
	1.0	23	<1	<1	3	13	<1	<1	8	13	2	6	3
	2.0	25	<1	<1	1	14	<1	<1	1	23	<1	<1	<1
	4.0	30	<1	<1	1	17	<1	<1	1	23	<1	<1	<1
	8.0	29	<1	<1	1	21	<1	<1	1	12	<1	<1	<1
Rock phosphate	0	23	4	2	4	21	17	2	15	15	8	5	14
	0.5	21	2	1	4	29	25	3	201	13	2	1	10
	1.0	16	1	<1	3	17	15	2	149	14	<1	<1	8
	2.0	17	<1	<1	4	15	12	2	156	16	<1	<1	6
	4.0	12	<1	<1	3	9	7	2	105	16	<1	<1	6
	8.0	16	<1	<1	3	8	6	2	107	14	<1	<1	5

concentration from 305 to 99 μM. However, Ca and Mg concentrations increased from 577 to 2964 μM and from 302 to 2175 μM, respectively. Al^{3+} activity was reduced from 22 to 3 μM and Mn^{2+} activity was reduced from 205 to 58 μM by application of 4 t GML/ha (Table 4). GML application at 4 t/ha or less alleviates Al^{3+} toxicity, but does not alleviate Mn^{2+} toxicity in the soil.

Likewise, soil solution of Prang series is acid, with pH of 3.8 (Table 7). This value was increased to 4.2 by the application of 4 t GML/ha. GML application at this rate reduced Al and Mn concentrations from 42 to 11 μM and from 21 to 9 μM, respectively. On the other hand, Ca and Mg concentrations increased from 191 to 1447 μM and from 109 to 2126 μM, respectively. It was also observed that SO_4^{2-} concentration increased from 950 to 2786 μM by GML application at that rate. However, it needed only 2 t GML/ha to reduce Al^{3+} activity from 12 to 4 μM (Table 4).

Effects of Gypsum

Increasing level of gypsum application increased the concentration of Al, Ca, Mg, Na, Mn and SO_4^{2-} in the six soil solutions of the soils under study. In the Rengam series application of 8 t gypsum/ha increased Al concentration from 24 to 141 μM (Table 3), while in Bungor series Al concentration increased from 88 to 652 μM (Table 5). The corresponding increase in the Al concentration of Prang series soil was from 25 to 158 μM (Table 7). Mn concentration in the soil solutions of Rengam and Prang series increased from 10 to 51 μM and from 17 to 89 μM, respectively by application of 8 t gypsum/ha. Mn concentration in the soil solution of Munchong series was very high, with a value of 409 μM (Table 6) and this value increased further with gypsum application. In some soils it was also observed that Mg and Na concentrations increased significantly by gypsum

TABLE 5

Concentration of cations and anions in the soil solution of Bungor series soil as affected by GML, gypsum, POME and rock phosphate applications.

Treatment	Rate (t/ha)	pH	EC (dS/m)	Al	Ca	Mg	K	Na	Fe	Mn	So_4^{2-}	NO_3^-
								µM				
GML	0	4.16	1.66	71	1662	922	476	6032	4.0	16.9	281	2292
	0.5	4.32	1.73	54	1702	1178	440	920	2.8	14.3	316	2169
	1.0	4.33	1.64	35	1729	1364	407	1644	2.1	12.2	393	2424
	2.0	4.50	1.85	33	2518	2389	529	8044	1.4	14.0	455	3137
	4.0	5.06	2.15	26	3191	3596	415	5062	1.0	9.5	791	4045
	8.0	5.35	2.31	14	4372	5742	447	3542	0.9	6.3	1689	4921
	LSD	0.29	0.40	25	725	818	182	4210	0.9	3.4	247	907
Gypsum	0	4.24	2.25	88	1800	1052	574	3110	4.9	35.9	239	3492
	0.5	4.31	1.84	113	2227	875	416	8743	3.2	17.1	1292	2589
	1.0	4.14	2.64	330	6119	1918	951	3000	6.7	39.8	2187	3804
	2.0	4.31	2.65	317	6979	1556	492	9688	6.0	32.6	8552	2191
	4.0	4.20	3.70	595	15452	2310	507	10593	9.0	51.2	22641	1414
	8.0	4.30	4.25	652	17568	2746	588	13093	8.7	61.6	22965	1755
	LSD	0.19	0.70	130	2305	684	367	3744	2.7	20.3	1721	1089
POME	0	4.54	1.72	98	1790	962	429	8975	4.9	17.3	335	2688
	0.5	4.69	2.33	61	3186	2958	424	9526	2.5	15.2	756	4063
	1.0	4.98	3.61	57	6397	7433	636	9004	2.5	19.2	1447	6817
	2.0	5.28	6.14	64	18552	17955	819	9700	2.1	19.2	2979	14064
	4.0	5.76	10.11	81	23638	31641	1330	9639	2.0	15.0	6774	22166
	8.0	5.93	13.34	92	35600	47787	2170	8172	2.0	12.6	13142	32533
	LSD	0.29	1.54	23	3494	4981	195	1108	0.7	5.8	741	2863
Rock Phosphate	0	4.23	1.70	93	1587	788	468	8357	4.4	15.4	277	2470
	0.5	4.21	1.83	94	1860	863	531	9120	4.6	16.6	289	2657
	1.0	4.26	1.89	85	1919	881	515	9059	3.2	16.8	296	2703
	2.0	4.34	1.94	90	2164	894	465	10031	3.6	16.8	331	2758
	4.0	4.35	1.96	86	2771	930	365	10115	2.6	16.5	452	2781
	8.0	4.53	1.82	66	3329	982	307	8798	1.5	16.2	578	2766
	LSD	0.16	0.35	36	837	272	97	1411	2.1	5.1	66	457

application due to replacement of Na and Mg by Ca from the gypsum (data not presented).

There was no clear trend in the change of Al^{3+} with increasing rate of gypsum application. In all the four soils Al^{3+} activity increased and later decreased with increasing level of gypsum application (Table 4). However, $AlSO_4^+$ and Al_{sum} activities increased significantly with increasing rate of gypsum application.

There was no significant pH change in the soil solutions of Rengam and Bungor series by gypsum application, but EC increased from 1.31 to 3.22 dS/m and from 2.25 to 4.25 dS/m, respectively by application of 8 t gypsum/ha. The corresponding EC increases in the soil solutions of Munchong and Prang series were from 1.83 to 3.06 dS/m and from 2.11 to 4.63 dS/m, respectively.

Effects of POME

POME application increased soil solution pH and EC significantly. In the Rengam series pH increased from 4.86 to 6.17 by application of 0.5 t POME/ha (Table 3). This same rate of POME application did not increase soil solution pH of Bungor and Prang series (Table 5, 7). Application of 1 t POME/ha in Bungor and Prang series increased soil solution pH from 4.54 to 4.93 and from 4.21 to 4.72, respectively. EC of Bungor series increased from 1.72 to 13.34 dS/m by application of 8 t POME/ha; this has important management implications.

TABLE 6
Concentration of cations and anions in the soil solution of Munchong series soil as affected by GML, gypsum, POME and rock phosphate applications

Treatment	Rate	pH	EC	Al	Ca	Mg	K	Na	Fe	Mn	So_4^{2-}	NO_3^-
	(t/ha)		(dS/m)	µM								
GML	0	3.63	1.68	56	577	302	453	7456	0.9	305	107	2525
	0.5	3.50	1.66	49	920	722	393	7679	1.3	319	123	2556
	1.0	3.96	1.52	38	982	695	243	6533	0.7	268	127	2390
	2.0	4.06	1.76	20	1504	1558	285	6532	0.4	197	195	2764
	4.0	4.59	2.16	14	2964	2175	362	6718	0	99	583	3610
	8.0	6.03	2.50	17	3801	5376	311	5943	0	19	2988	3800
	LSD	0.77	0.58	27	1500	663	209	1694	0.7	99	518	1265
Gypsum	0	3.84	1.83	94	704	357	618	8265	1.9	409	115	2696
	0.5	3.88	1.76	53	930	229	329	6961	1.4	329	756	2307
	1.0	4.04	1.69	79	2205	292	332	7461	2.3	355	513	2397
	2.0	3.75	1.84	64	2584	264	271	7631	3.7	311	1433	2352
	4.0	3.84	3.00	96	8808	474	301	8379	3.0	562	7842	2732
	8.0	3.70	3.66	116	15452	505	230	7472	2.2	641	17741	1940
	LSD	0.58	0.57	72	1799	187	221	2290	2.1	207	1773	880
POME	0	3.65	1.87	72	694	384	607	8487	3.5	354	130	2549
	0.5	4.47	1.66	13	1864	2123	214	6335	0	66	812	2687
	1.0	5.89	2.04	14	3089	4214	284	5713	0	16	3392	3312
	2.0	7.36	3.31	16	6809	8640	432	4618	0	3	6511	4522
	4.0	7.42	4.38	20	9445	11600	600	4378	0	3	8432	6760
	8.0	7.45	6.29	25	13684	15650	911	4363	0.1	4	10831	10542
	LSD	1.00	0.51	21	967	1166	94	698	1.0	73	1018	1218
Rock phosphate	0	3.27	1.65	42	391	198	467	7195	2.9	218	147	2316
	0.5	3.47	1.73	65	795	285	400	7632	1.6	305	116	2556
	1.0	3.38	1.58	36	720	207	342	6904	1.6	218	138	2432
	2.0	3.60	1.70	31	1142	229	323	7313	1.6	235	176	2423
	4.0	3.47	1.57	21	1709	224	210	7094	1.5	164	387	2260
	8.0	3.50	1.73	19	2360	253	231	7145	0.7	175	503	2437
	LSD	0.41	0.21	14	364	58	111	781	1.3	58	46	430

Ca and Mg concentrations in the soil solutions of Rengam, Bungor, Munchong and Prang series increased significantly by application of 0.5 t POME/ha (lime equivalent).But concentrations of NO_3^- and SO_4^{2-} only differed significantly from the control by application of 1.0 t POME/ha. POME application at the rate of 1.0 t/ha reduced Mn and Al concentrations in Munchong series from 354 to 16 µM and from 72 to 14 µM, respectively (Table 6).

It needed 0.5 t POME/ha to reduce Al^{3+} activity in the soil solution of Rengam and Munchong series to < 4 µM (Table 4). For Prang series, 1 t POME/ha was needed to reduce Al^{3+} activity to the same level.

Effects of Rock Phosphate

Rock phosphate application increased soil solution pH of Rengam and Prang series, but did not change soil solution pH of Bungor and Munchong series. There was a decreasing trend in the value of EC, Al and NO_3^- with increasing rate of rock phosphate application in the soil solution of Rengam and Prang series. Conversely, Ca and SO_4^{2-} level increased with increasing level of rock phosphate application.

DISCUSSION

Alleviation of Soil Acidity

Al^{3+} is considered the most toxic Al species in soil solution (Alva *et al.* 1986a) and reduction in Al^{3+}

TABLE 7
Concentration of cations and anions in the soil solution of Prang series soil as affected by GML, gypsum, POME and rock phosphate applications

Treatment	Rate (t/ha)	pH	EC (dS/m)	Al	Ca	Mg	K	Na	Fe	Mn	So_4^{2-}	NO_3^-
								µM				
GML	0	3.79	2.08	42	191	109	952	5944	3.9	21	950	2587
	0.5	3.95	1.69	22	312	282	393	6093	3.2	13	804	1970
	1.0	4.01	1.99	19	633	562	586	5590	2.8	16	1001	2306
	2.0	4.00	1.94	15	780	590	596	5919	2.3	15	1149	2264
	4.0	4.22	2.16	11	1447	2126	523	5287	0.1	9	2786	2097
	8.0	6.12	2.89	10	3925	5737	642	4258	0	3	5424	3027
	LSD	0.34	0.58	6	710	1125	332	1099	2.1	7	556	745
Gypsum	0	3.69	2.11	25	155	83	917	5451	2.9	17	632	2319
	0.5	3.91	2.30	43	720	103	730	6717	4.3	25	1700	2402
	1.0	3.74	2.23	63	1338	117	536	6326	6.0	28	3237	1889
	2.0	4.17	2.95	113	3542	185	674	8191	9.6	47	6039	2247
	4.0	3.96	4.06	154	9471	284	952	9311	8.8	73	13449	2120
	8.0	4.00	4.63	158	15699	345	667	10533	11.0	89	21219	1728
	LSD	0.30	0.47	36	2079	47	235	1117	2.4	11	2468	432
POME	0	4.21	2.05	31	262	105	506	8040	0.8	15	861	2518
	0.5	4.17	2.67	29	3516	4504	313	9338	0.3	16	2316	4346
	1.0	4.72	4.00	28	6737	9413	441	7342	0	6	5146	6260
	2.0	6.91	4.84	24	10400	13164	621	6263	0.3	2	9257	7342
	4.0	7.44	6.02	24	13331	15896	758	5683	0.3	1	10026	10471
	8.0	7.58	7.00	13	15609	19402	997	5288	0.7	1	12690	11909
	LSD	0.87	1.02	4	1618	1152	162	1394	0.2	7	629	2362
Rock phosphate	0	4.11	2.13	25	282	220	1013	6515	4.5	22	652	2823
	0.5	4.94	1.97	17	430	86	590	7610	1.5	16	761	2399
	1.0	5.21	1.74	16	461	71	342	8266	1.7	12	933	1907
	2.0	5.51	1.47	18	445	61	257	7307	2.4	9	1412	1656
	4.0	5.68	1.82	18	1037	111	291	7922	1.5	11	1864	2023
	8.0	5.62	1.44	16	1038	120	204	7251	1.4	9	2514	1118
	LSD	0.56	0.36	7	252	50	240	1702	2.6	7	502	512

TABLE 8
Calculated ion-activity product values of soil solutions treated with gypsum[1]

Rate (t/ha)	Basaluminite ($pAl_4(OH)_{10}SO_4$)				Alunite ($pKAI_3(OH)_6(SO_4)_2$)				Jurbanite ($pAlOHSO_4$)			
	Rengam	Bungor	Munchong	Prang	Rengam	Bungor	Munchong	Prang	Rengam	Bungor	Munchong	Prang
0	118	119	123	126	82	82	86	86	18	18	19	19
0.5	120	118	123	122	82	81	86	83	18	17	18	19
1.0	121	118	121	123	82	81	85	84	17	17	18	17
2.0	120	118	124	118	80	80	85	80	16	17	18	17
4.0	117	117	121	119	78	79	81	80	16	16	17	16
8.0	117	117	120	119	78	79	82	80	16	16	17	16

[1] Reference : Basaluminite 117.7, Alunite 85.4 and Jurbanite 17.8 (Hue *et al.* 1985)

activity in Ultisol by liming increases corn and groundnut yields significantly (Shamshuddin *et al.* 1991). In this study it was observed that GML application at the rate of 2-4 t/ha increased pH, Ca and Mg to a sufficient level for corn production. In the Rengam and Prang series soil Al^{3+} activity was reduced to 4 μM by application of GML at this rate, making it suitable for soybean growth; critical Al^{3+} activity for soybean is 4 μM (Bruce *et al.* 1988).

There are indications that Malaysian Ultisols are deficient in Mg (Shamshuddin *et al.* 1991). Data in Table 3, 5, 6 and 7 suggest that Mg deficiency can be alleviated by application of 2-4 t GML/ha; the lime used in this experiment, which was manufactured locally, contains 6.7% Mg (Table 2).

Rock phosphate has a tendency to increase soil solution pH, Ca and SO_4^{2-} concentrations. Its liming effects are not as good as those of GML. Additionally, rock phosphate is too expensive to use as liming material to alleviate soil acidity.

Gypsum application increases Ca concentration in the soil solution. Ca, if present at an adequate level in the soil solution, helps reduce Al toxicity (Alva *et al.* 1986a). An increase in concentration of SO_4^{2-} in soil solution of gypsum-treated soils may alleviate Al toxicity by formation of less phytotoxic $Al\text{-}SO_4$ complex. The toxicity of Al may be further decreased by a reduction in activity of Al^{3+} due to an increase in soil solution ionic strength in gypsum-treated soils.

It was observed that gypsum application increased Al concentration significantly, associated with an increase in ionic strength. The relationship between Al concentration (uM) and soil solution (Iss) ionic strength (mM) is given by the following equation:

$$\log_e Al = 0.66 + 1.44 \log_e I_{ss}, \ P<0.01$$

But most of the Al present in the soil solution at high rates of gypsum application is in the form of $AlSO_4^+$ (Table 4) which is less phytotoxic than Al^{3+} (Alva *et al.* 1986b).

POME gives comparative liming effects to those of GML. Generally it needs 0.5 to 1.0 t POME/ha (lime equivalent) to reduce Al and to increase Ca and Mg concentrations to an acceptable level. In terms of real weight of POME,it is about 3.5 to 7.0 t POME/ha; data in Table 2 suggest that GML contains 7 times more Ca than POME. However, POME applied at a high rate may cause a temporary increase in EC, which may affect plant growth. An EC of 4 dS/m is considered detrimental to crop growth (Wong 1986).

POME is readily available in Malaysia; production of POME was 8-9 million tonnes yearly in the early eighties (Chan *et al.* 1983). In the nineties, Malaysia is expected to produce about 6 million tonnes of palm oil. Considering 3 tonnes of effluent are produced for every tonne of palm oil, Malaysian factories are now producing about 18 million tonnes of effluent per year. N, P, Ca and Mg concentrations in POME are reasonably high (Table 2). POME is an organic matter that can detoxify Al by chelation (Tan and Binger 1986). Zin *et al.* (1983) reported that POME applied in oil palm estates did not pollute groundwater. The use of POME as a soil ameliorant will not only lead to sustained food crop production, but also result in nutrient recycling and a safe environment.

Formation of Al-hydroxy Minerals

GEOCHEM computer programme predicts that increases in soil solution pH resulting from GML and POME application produce $Al(OH)_3$. Curtin and Smillie (1983) believed that crystalline $Al(OH)_3$ would not form by this process; the presence of organic ligands in the soil solution hamper crystallization of $Al(OH)_3$ (Kwong and Huang 1979).

In the POME experiment Al concentration was not reduced to zero even though pH was increased to a value > 7 in some treatments. At this pH level the Al in the soil solution existed in the form of $Al(OH)_3$.

Table 8 gives the calculated ion-activity product of soil solution treated with gypsum. This table gives an indication of the possibility of Al-hydroxy-sulfate formation in the soil solution treated with gypsum. It was observed that soil solutions of Munchong and Prang series were undersaturated with respect to basaluminite. However, application of 4 t gypsum/ha reduced $pAl_4(OH)_{10}SO_4$ to 117, suggesting the soil solution was supersaturated with respect to basaluminite.

Soil solutions of Rengam and Bungor series were supersaturated with respect to alunite as $pKAl_3(OH)_6(SO4)_2$ was less than 85.4, suggesting that alunite can be formed in this soil if environmental conditions are favourable for its formation. Application of 0.5 and 1.0 t gypsum/ha in the soils of Prang and Munchong series, respectively, decreased $pKAl_3(OH)_6(SO_4)_2$ to 85 or less, indicating that the solutions were then supersaturated with respect to alunite. It took 4 t gypsum/ha to bring down $pAlOHSO_4$ to 17 in Munchong series soil and 1.0 t gypsum/ha in Rengam and Prang series soils. In the Bungor series soil only 0.5 t gypsum/ha was needed to lower $pAlOHSO_4$ to 17.

It seems that Ultisols and Oxisols respond differently to gypsum application (Table 8). Less gypsum was needed in Ultisols than Oxisols to bring the solutions to supersaturation with respect to basaluminite, alunite and jurbanite. Thus, these minerals are more likely to be precipitated in Ultisols than Oxisols due to application of sulphur-bearing amendments, such as gypsum and/or sulphate of ammonia.

It seems reasonable to suggest the formation of jurbanite in Oxisols and Ultisols is due to gypsum application. This is in agreement with that reported by Hue *et al.* (1985). Data in Table 8 suggest that gypsum application at the rate of 8 t/ha in Oxisols will not precipitate basaluminite. However, gypsum application may precipitate alunite in Oxisols, although Nordstrom (1982) argued that the formation of alunite is not likely to occur in a short-term experiment.

CONCLUSION

Soil solution studies indicate that Ultisol and Oxisol infertility factors can be alleviated by the application of palm oil mill effluent, which is available in large quantities in Malaysia. A rate of 2-4 t GML/ha is required to alleviate soil acidity and Ca and/or Mg deficiencies in Ultisols and Oxisols. However, 0.5-1 t POME/ha was found to give similar ameliorative effects to those of GML application at 2-4 t/ha. Continuous application of a sulphur-bearing amendment, such as gypsum, may result in the precipitation of jurbanite in these soils.

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