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Effect of Dolomitic Limestone and Gypsum Applications on Soil Solution Properties and Yield of Corn and Groundnut Grown on Ultisols

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ABSTRACT

A study was conducted to determine soil solution properties and relative tolerance of corn and groundnut plants to soil acidity. Corn followed by groundnut was planted on Ultisols one month after lime or gypsum was incorporated into the topsoil. Soil samples were collected after corn and groundnut harvest. Soil solutions were extracted by the immiscible replacement method of soil water with fluorocarbon trichlorofluoroethane. Results showed that total Al, inorganic Al, Ca, and Mg concentrations were erratically affected by the treatments. However, total Al values were indicated to be high when solution pHs were low, especially at treatments with low amounts of lime or high amounts of gypsum. It appeared that Ca released from the dissolution of gypsum had replaced Al in the exchange complex, causing the high concentrations of Al in the solution. Solution pH, corresponding to 90 % relative yields of corn and groundnut, were 4.7 and 4.3, respectively. This means that groundnut is more tolerant to soil acidity than corn. Liming Ultisols at low rates may be necessary for groundnut cultivation. For corn cultivation, the liming rate is 2 t ha^{-1}, which supplies adequate amounts of Ca and Mg for the growth of corn plants.

Keywords: Aluminium corn, dolomitic limestone, groundnut, gypsum, peanut, Ultisol

INTRODUCTION

Acid soils (Ultisols and Oxisols) are widespread in Southeast Asia. They are found scattered in the low- and upland areas of Malaysia, Thailand and Indonesia. In Malaysia, (Paramananthan 2000) said that Ultisols planted with oil palm, rubber, cocoa and miscellaneous fruit trees have achieved mixed success. When oil palm or rubber is up for replanting, corn or groundnut is usually grown as cash crops between the rows during their early years of growth. The yields of these cash crops (especially corn) are low, because of the strongly acidic soil reaction, caused presumably by high amounts of Al in the soil solution. Furthermore, the soils are highly weathered and consequently exhibit low cation exchange capacities

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(CEC). The latter results in heavy losses of Ca and Mg due to leaching, given the prevailing heavy rainfall common in tropical climates.

Liming experiments on typical Ultisols (Shamshuddin et al. 1991; Ismail *et al.* 1993) and Oxisols (Shamshuddin *et al*. 1992) have indicated the need for liming for annual crop production. Applying lime in combination with gypsum would bring more Ca and/or Mg further down the soil profile (Shamshuddin and Ismail 1995), thus alleviating to some extent subsoil acidity. Applications of ground magnesium limestone (GML), usually known as dolomitic limestone, would also supply the necessary Ca and Mg needed for corn and groundnut growth. The presence of more Ca in the soils arising from lime and/or gypsum applications is also beneficial because Ca can to a certain extent alleviate Al toxicity (Alva *et al.* 1986).

One of the methods to study the effects of soil acidity on crop production is to determine the chemical properties of the soil solution. Therefore, this investigation was conducted to study soil solution properties and its nutrient element concentration, their effects on soil acidity and on corn and groundnut grown on Ultisols in Malaysia

MATERIALS AND METHODS

Location and Soils

Field experiments using a random design with three replicates were conducted at Puchong and Chembong, located 30 and 80 km, respectively, south of Kuala Lumpur, Malaysia. The soil at Puchong was classified as the Serdang series, a loamy, siliceous, isohyperthermic Typic Paleudult, whereas the soil at Chembong was classified as the Rengam series, a clayey, kaolinitic, isohyperthermic Typic Paleudult. Topsoil (0-15 cm depth) was sampled in the experimental plots at both locations after the corn and groundnut were harvested. The physico-chemical properties in the major horizons of both the soils are given in Table 1.

TABLE 1

Selected physico-chemical properties of Serdang and Rengam Series

Hor.	Depth (cm)	pH	Exch. cations					CEC	Org. C	Clay
			Ca	Mg	Na	Ka	Al			
			……………..$cmol_c/kg$………………						………%..........	
				Serdang						
Ap	0-27	4.91	1.05	0.03	0.02	0.22	4.02	13.90	1.95	25
B21t	27-75	4.76	0.83	0.18	0.02	0.06	3.98	9.08	0.80	30
B22t	75-125	4.92	0.81	0.16	0.01	0.04	3.07	7.15	0.33	28
B23t	125-150	5.01	0.77	0.16	0.02	0.04	3.24	6.43	0.26	25
				Rengam						
Ap	0-20	4.83	1.05	0.17	0.02	0.08	2.68	8.80	2.13	40
B1t	20-60	4.43	0.72	0.14	0.01	0.05	2.83	7.98	1.21	45
B2t	60-98	4.44	0.69	0.14	0.01	0.04	2.30	7.22	0.82	44
BC	98-150	4.44	0.79	0.15	0.02	0.03	2.45	5.75	0.41	35

Experimental

Two separate experiments using GML or gypsum were carried out at Puchong (University Agricultural Park, Universiti Putra Malaysia) and Chembong (Department of Agriculture, Peninsular Malaysia) sites. In Experiment 1, GML was incorporated to 15 cm depth, and in Experiment 2 gypsum was incorporated to 15 cm depth. The contents of Ca, Mg and other components in the GML and gypsum are given in Table 2. The GML used in this study contained 18.5 and 6.7 % Ca and Mg, respectively, whereas gypsum contained 25.1 % Ca. Both GML and gypsum contained substantial amounts of Fe, amounting to 2819 and 103 mg/kg, respectively. The additional Fe could have some effects on the chemical properties of the soil solutions.

TABLE 2
Elemental composition of ground magnesium limestone and gypsum

Element	GML	Gypsum
Ca (%)	18.5	25.1
Mg (%)	6.7	tr
P (mg/kg)	1.7	tr
Cu (mg/kg)	17.6	7.2
Fe (mg/kg)	2819.0	103.0
Mn (mg/kg)	97.0	27.0
Zn (mg/kg)	29.0	8.0

At each site, the treatments consisted of 0, 0.5, 1.0, 2.0, 4.0 and 8.0 t/ha GML or gypsum. The size of each experimental plot was 6.5 m x 4.5 m. Sweet corn (*Zea mays*) was the first crop planted 1 month after GML or gypsum was applied, and this crop was immediately followed by groundnut (*Arachis hypogaea*). At harvest, the yield of corn and groundnut were recorded, and relative corn and groundnut yields from the GML treated plots were subsequently calculated. These values were later plotted against the corresponding soil solution pH to find the pH values most critical for both the crops in the experiments.

Basal fertilisers for the crops were applied on the basis of past experiences and leaf analysis of each crop (Table 3). For the corn crop, 120 kg/ha N, 100 kg/ha P and 150 kg/ha K were applied, whereas no fertiliser was applied for the groundnut crops.

TABLE 3
Nutrient rates for corn and groundnut cultivation

Crop sequence	N*	P**	K***
Corn	120	100	150
Groundnut	0	0	0

*= as urea; ** = as triple super phosphate; *** = as muriate of potash

Extraction of Soil Solutions

Selected samples from the Puchong and Chembong sites were incubated with deionised water at a matric suction of 10 kPa for 24 hours. The soil contained approximately 20 % moisture by weight. The soil solutions were then extracted by immiscible replacement using fluorocarbon trichlorofluoroethane (specific gravity >1) and collected by centrifugation (at 34,800 RCF) for 30 minutes. Soil solutions recovered were filtered through 0.22 μm Millipore filters. The extraction of the soil solutions were carried out at the Department of Agriculture, University of Queensland, Australia.

Analysis of Soil and Soil Solution

Soil pH was determined in water at a soil to water ratio of 1:1. Cation exchange capacity was determined by 1 M NH_4OAc buffered at pH 7. The Ca, Mg, K and Na (exchangeable bases) in the extracts were determined by atomic absorption spectrophotometry (AAS). Exchangeable Al was extracted by 1 M KCl and the Al in the extract was determined by AAS. Organic carbon was determined by Walkley-Black method. Clay content was determined by successive sedimentation.

Soil solution pH was determined immediately after extraction. Total Al (Al_T) in the soil solution was determined by inductively coupled plasma atomic emission spectroscopy (ICPAES). Inorganic Al (Al_{inorg}) was determined by the short-term pyrocatechol method of Kerven *et al.* (1989).

RESULTS AND DISCUSSION

Natural Characteristics of the Soils

The Serdang series contains 30 % or less clay and is of loamy texture (Table 1). Soil pH in the upper part of the profile is less than 5 and exchangeable Al is very high, especially in the topsoil, with a value of 4.02 $cmol_c$/kg soil. In general, exchangeable cations are low. Likewise, the Rengam soil is strongly acidic in nature, with a pH of less than 5 throughout the profile. Exchangeable bases are low and exchangeable Al is high. In our opinion, both soils require liming at a suitable rate in order to raise soil pH above 5 in order to decrease exchangeable Al below 1 $cmol_c$/kg soil for corn cultivation.

Effects of Treatments on Solution Characteristics

Solution pH: Tables 4 and 5 show the chemical characteristics of the soil solutions of the Serdang Series as affected by GML and gypsum treatments, whereas Table 6 shows the chemical characteristics of the soil solutions of the Rengam Series as affected by GML treatment. Checking through the rates of application and duplicates thoroughly, the change in solution pH is observed to be rather erratic. This is probably due to soil variability in the experimental plots as well as imperfections during soil sampling. Soil erosion occurring during the experiment could have also contributed somewhat to these inconsistent results. Nevertheless, in the GML treatments (Tables 4 and 6), pH showed an increasing trend with the rate of application. For the Serdang soil, the lowest pH was 3.71 (the control treatment), whereas the highest was 6.54 (soil treated with 8 t/ha) (Table 4). On the other hand, the lowest pH observed for Rengam soil was 3.70 and the highest 6.18 (Table 6).

TABLE 4
Chemical properties of solutions extracted from Serdang soil as affected by ground magnesium limestone treatment

Rate t/ha	Repl.	pH	EC mS/cm	Al_T	Al_{inorg}	Si	Ca	Mg	Fe	Mn	S
				………………….µM…………………………………….							
0	1	3.71	0.75	232.2	265.9	25.9	4550.0	1134.0	116.4	34.5	59.3
	2	4.10	0.45	37.0	37.8	21.4	5000.0	578.0	25.1	18.2	156.0
0.5	1	4.22	0.85	96.0	115.2	24.9	5675.0	1606.0	21.5	32.8	187.0
	2	5.58	0.52	25.9	26.5	10.7	3475.0	1071.0	7.2	9.1	156.0
1.0	1	5.25	0.60	33.3	nd	24.9	2675.0	1401.0	10.7	12.7	125.0
	2	4.26	0.68	37.0	35.7	24.9	4075.0	1277.0	12.5	18.2	156.0
2.0	1	4.62	0.57	14.8	17.1	17.8	3150.0	1442.0	5.4	5.5	343.0
	2	5.23	0.67	18.5	19.4	17.8	3675.0	1772.0	9.0	7.3	218.0
4.0	1	4.93	0.54	11.1	nd	17.8	3500.0	1813.0	5.4	5.5	343.0
	2	5.80	0.46	3.7	1.3	10.7	2300.0	1524.0	3.8	1.8	343.0
8.0	1	6.54	1.10	3.7	0.7	7.1	5550.0	3790.0	9.0	1.8	2434.0
	2	5.68	0.67	3.7	1.2	14.2	3575.0	2183.0	3.6	1.8	873.0

TABLE 5
Chemical properties of solutions extracted from Serdang soil as affected by gypsum treatment

Rate t/ha	Repl.	pH	EC mS/cm	Al_T	Al_{inorg}	Si	Ca	Mg	Fe	Mn	S
				………………….µM…………………………………….							
0	1	4.83	0.35	37.0	36.3	21.4	2050.0	453.0	19.7	12.7	125.0
	2	4.30	0.59	92.6	178.3	24.9	3725.0	494.0	19.7	25.5	562.0
0.5	1	4.28	0.65	107.4	117.1	28.5	3300.0	659.0	43.0	25.5	156.0
	2	4.22	2.54	381.5	455.1	21.4	12625.0	453.0	68.0	60.1	16380.0
1.0	1	4.25	0.37	50.8	54.0	18.7	4700.0	263.0	26.9	12.7	449.0
	2	5.38	0.25	16.3	7.3	20.2	3050.0	267.0	0.4	10.9	81.0
2.0	1	4.66	2.54	192.9	211.7	19.4	12725.0	871.0	9.0	65.5	17784.0
	2	4.67	0.60	24.9	23.7	4.3	6735.0	547.0	2.5	16.9	237.0
4.0	1	4.47	0.42	29.7	30.0	tr	4325.0	575.0	1.8	13.3	100.0
	2	4.26	0.96	244.9	280.5	1.4	9250.0	477.0	57.3	36.4	2930.0
8.0	1	4.55	0.80	129.5	127.0	tr	8500.0	645.0	28.6	32.8	2917.0
	2	4.52	0.41	49.0	48.0	23.8	4825.0	366.0	23.3	10.9	496.0

TABLE 6
Chemical properties of solutions extracted from Rengam soil as affected by ground magnesium limestone treatment

Rate t/ha	Repl.	pH	EC mS/cm	Al_T	Al_{inorg}	Si	Ca	Mg	Fe	Mn	S
				....	....	....	....µM....	....	....	....	....
0	1	3.70	1.43	687.5	781.9	9.7	8150.0	1615.0	159.3	136.5	144.0
	2	4.01	1.15	199.2	243.9	0.4	8675.0	986.0	53.7	118.3	153.0
0.5	1	4.97	0.95	24.1	25.1	tr	7625.0	1804.0	19.7	36.4	140.0
	2	4.22	1.02	101.2	121.6	11.1	7425.0	2396.0	77.0	49.1	150.0
1.0	1	4.17	1.08	171.4	191.5	8.3	7525.0	2482.0	93.1	56.4	112.0
	2	4.49	1.25	53.1	56.6	0.7	8425.0	2487.0	26.9	58.2	140.0
2.0	1	4.37	0.98	92.4	104.2	8.3	6900.0	2708.0	53.3	32.8	122.0
	2	4.65	1.05	59.0	64.2	0.4	7250.0	3078.0	28.6	30.4	190.0
4.0	1	6.00	1.32	8.2	4.1	11.2	8625.0	3806.0	9.7	12.4	509.0
	2	5.80	1.10	8.9	9.0	5.8	9550.0	440.0	0.9	14.6	365.0
8.0	1	6.18	2.31	3.3	1.0	tr	10800.0	4180.0	9.7	2.4	1045.0
	2	6.13	2.31	4.5	3.2	tr	11400.0	801.0	0.7	14.9	711.0

The increase in solution pH resulting from GML application is due to production of hydroxyl ions when GML is dissolved and subsequently hydrolysed:

$$Ca,Mg\,(CO_3)_2 \;+\; H_2O \;\rightarrow\; Ca^{2}+ + Mg^{2}+ + 2CO_3^{2-}$$

$$CO_3^{2-} + H_2O \;\rightarrow\; HCO_3^{-} + OH^{-}$$

The hydroxyl ions then reacts with Al in the solution to precipitate as aluminum hydroxide, which over time may crystallize into gibbsite [Al $(OH)_3$]:

$$Al^{3+} + 3OH^{-} \;\rightarrow\; Al\,(OH)_3$$

The increase in solution pH would certainly affect the availability of other metals, such as Fe and Mn (Tables 4 and 6).

The clay fraction of Ultisols in Malaysia is dominated by kaolinite and sesquioxides (Tessens and Shamshuddin 1983; Paramananthan 2000). Serdang and Rengam soils (Ultisols) used in this study are soils with variable charge minerals. It means that when soil pH increases as a result of liming, the CEC of the soils increases in tandem with the pH increase. As such, losses of cations like Ca, Mg and K will be prevented because of leaching under a tropical environment (Shamshuddin and Ismail 1995).

The dissolution of gypsum ($CaSO_4.2H_2O$) is not expected to have a significant effect on solution pH. Results presented in Table 5 prove this assumption beyond doubt. However, gypsum application may affect the availability of Al in Ultisols dominated by exchangeable Al in the exchange complex (Shamshuddin and Ismail 1995). This happens when Ca released from the dissolving gypsum replaces Al:

$$\text{clay-Al}^{3+} + \text{Ca}^{2+} \rightarrow \text{clay-Ca}^{2+} + \text{Al}^{3+}$$

The hydrolysis of this newly available Al lowers solution pH slightly. The magnitude of pH change would depend on the extent of the exchange taking place between Al and Ca. We would expect this to happen at a high rate of gypsum application. However, for the soils under study, this phenomenon did not take place significantly (Table 5).

Al in the solution: By and large, the solutions were colourless indicating that fulvic or humic acid is low. Some Al in the solution may exist as a complex of fulvic acid, a low molecular weight organic acid. Al determined by ICPAES is considered as total Al (Al_T) and those determined by pyrocatechol is considered as Al inorganic (Al_{inorg}). Total and inorganic Al in the soils of Serdang and Rengam Series are listed in Table 4 and 6, respectively. If Al_T exceeds Al_{inorg} value, there is a possibility of some Al existing in the organic form. However, from data obtained from this study, it is difficult to make a conclusive statement as the values were erratic. As mentioned earlier, failure to obtain consistent values is probably due to imperfections during their determination.

A very high Al_T value of 232.3 µM was obtained in the control treatment of Serdang soil (Table 4). The corresponding value for the Rengam soil was 687.5 µM. These values were consistent with the low pH of 3.71 and 3.70, respectively. It is well known that Al decreases exponentially with an increase in solution pH (Shamshuddin and Auxtero 1991; Shamshuddin *et al*. 1991). In the Serdang soil, Al_T was less than 20 µM for samples treated with 2 t GML/ha. The corresponding value for Rengam soil was more that 50 µM. These have important implications on corn and groundnut cultivations on these soils, in terms of their yield and economic viability.

Mn in the soil solution: In the Serdang soil, Mn concentration in the control treatment was moderately high (Tables 4 and 5). However, the corresponding Mn concentration in the Rengam soil was high with a value exceeding 100 µM (Table 6). Manganase concentration in the soil solutions decreased exponentially with increasing pH (Tables 4 and 6). This finding is similar to that of Shamshuddin and Auxtero (1991).

Fe in the soil solution: Fe concentration in the soils under study was not expected to cause any problem to the growing corn or groundnut. Its concentration was above 100 µM in replicate 1 of the control treatment of Serdang soil (Table 4) and Rengam soil (Table 6). Like Mn concentration, the values decreased with an increase in the liming rate.

Ca and Mg in the soil solution: The Ca and Mg concentrations were at best erratic, like those of pH and Al_T. From field observations, at a high rate of GML application, corn or groundnut grew extremely well. Hence, the uptake of these macronutrients was expected to be higher compared to those at a low rate (or control treatment for that matter). As such, the absolute amounts of Ca and Mg in the solutions would not increase significantly although the dissolving dolomitic limestone resulted in additional Ca and Mg. However, for the gypsum-treated soils, the Ca story is different. At a high rate of application (4 t/ha or higher), Ca concentration was very high with values exceeding 10,000 μM. Like GML treated soils, Mg concentration in the gypsum-treated soils remained unchanged. In fact the values were lower compared to those at a low rate of application. The reason being corn or groundnut grew better on soils treated with 4 t gypsum/ha or higher and thus used more Mg for their growth.

Gypsum contains 25.1 % Ca (Table 2) and when this gypsum is dissolved after its application onto Ultisols, this Ca is adsorbed to the soil colloids, joining the existing Ca pool. It is possible that some of the Ca replaces the Al in the exchange complex resulting in a concomitant decrease in pH due to the hydrolysis of the newly available Al. Ca has an ability to ameliorate soil acidity (Alva *et al.* 1986). Due to gypsum application, Ca/Al ratio in the soil solution is expected to increase substantially. According to Shamshuddin *et al.* (1991), for good growth of corn, Ca/Al ratio should be > 79. It appears that at a high rate of gypsum application (> 4 t/ha), the ratio approaches this value. Hence, there is justification to apply gypsum to ameliorate acid soils, such as Ultisols. The best practice is to apply lime in combination with gypsum. According to Shamshuddin and Ismail (1995), by doing this some Ca moves down the soil profile, resulting in amelioration of subsoil acidity.

Si and S in soil solution: The concentration values of Si and S in the GML treated soils were also erratic. Si is not a plant nutrient, but S is. S concentration in some samples of the gypsum treated soils was very high (Table 5). This is expected since gypsum contains about 18% S. This uneven distribution of S was probably due to soil variability, soil erosion or uneven distribution amendments during their application.

Relative Tolerance of Corn and Groundnut to Soil Acidity

It was observed that the relative corn or groundnut yield increased exponentially with increasing pH (Fig. 1). This figure was drawn using yield and pH data from the experimental plots treated with GML in the Serdang and Rengam soils. The pH value corresponding to 90 % relative corn yield was 4.7, while that of groundnut was 4.3. These values can be regarded as the critical pH for the growth of corn and groundnut grown on acid Ultisols in Malaysia, respectively. This means that corn and groundnut will not produce satisfactory yields unless the pH is raised to values above these levels.

The critical pH values obtained in this study indicate clearly that corn is less tolerant to soil acidity than groundnut. It is known that the natural pH of soils under field conditions is mostly below 4.7 for Malaysian Ultisols (Tessens and

Shamshuddin 1983; Paramananthan 2000). As such, liming at an appropriate rate is necessary to make soil conditions suitable for corn cultivation.

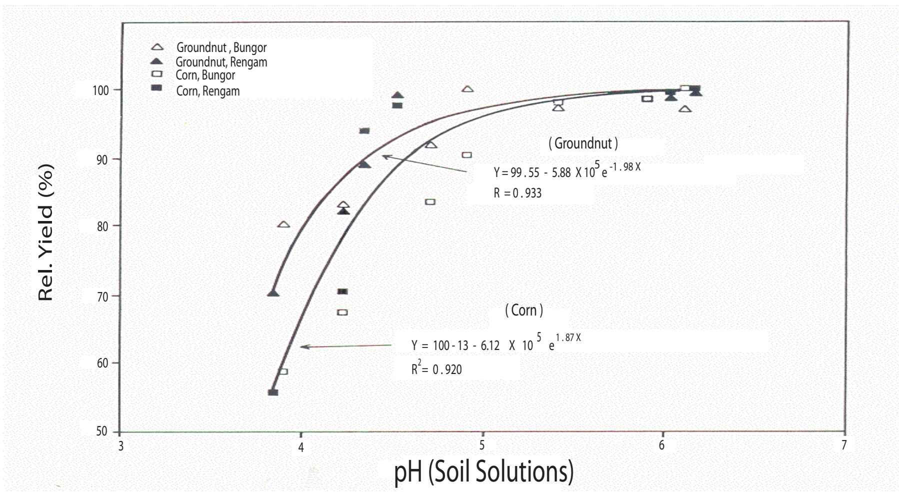

Fig. 1: Relationship between relative corn and groundnut yields with soil solution pH

Unlike corn, groundnut is moderately tolerant to soil acidity. Under normal circumstances, Ultisols in Malaysia do not need to be limed for growing groundnut as the pH is about 4.3. However, this study found groundnut yield to be slightly better for experimental plots treated with GML (data not shown). Therefore, it would be a viable practice to apply a small dosage of GML on Ultisols cultivated with groundnut. Beside a small increase in soil pH, this practice would add sufficient amounts of Ca and Mg to the soils, a requirement for the healthy growth of the crop. This is because Ultisols in Malaysia are known to be deficient in Ca and Mg (Tessens and Shamshuddin 1983; Paramananthan 2000).

Looking at Fig. 2, we can now approximate the critical value of Al_T for corn and groundnut. The Al_T corresponding to solution pH of 4.7 was 30 µM. This value is, however, higher than that obtained earlier by Shamshuddin *et al*. (1991), which was 22 µM. This finding indicates that corn grown on Ultisols in Malaysia will not experience healthy growth if the Al in the soil solution is > 30 µM. For the more acid tolerant groundnut, the critical Al_T was 70 µM. To bring the Al concentration to below the critical level of corn, the soils need to be limed at an appropriate rate. Likewise, the critical Mn concentration can also be approximated (Fig. 3). The value obtained for corn was 20 µM and that for groundnut was 34 µM. Mn toxicity is a common phenomenon for acid tropical soils, especially the Ultisols and Oxisols. Fortunately, when the soils are limed to increase soil pH with concomitant addition of Ca and Mg, Mn in the soils will also be reduced. This is shown clearly by data given in Tables 4 and 6.

The next phase is to approximate liming rate to make the soils suitable for corn and groundnut cultivation on Ultisols of Malaysia. The rate to be proposed should satisfy the following criteria: (i) it should bring the pH up and bring the Al and Mn concentrations down to a level below the critical value; and (ii) the rate of liming should be affordable to the local farming communities. Based on pH, Al_T and Mn concentration data presented in Tables 4 and 6, it is proposed that a viable and appropriate liming rate for corn cultivation on Ultisols in Malaysia is 2 t GML/ha. This rate (lime requirement) is similar to the finding of Shamshuddin et al. (1998).

For the cultivation of corn, followed by groundnut, this liming rate would be able to increase soil pH to the level that Al and Mn concentrations are reduced to a level below the critical value, and this would simultaneously alleviate Ca and Mg deficiencies. At this rate of application of lime, Shamshuddin *et al.* (1998) found that the ameliorative effects would last more than 4 years. If we were to grow groundnut alone, we suggest that 1 t GML is sufficient to supply enough Ca and Mg to the growing crop.

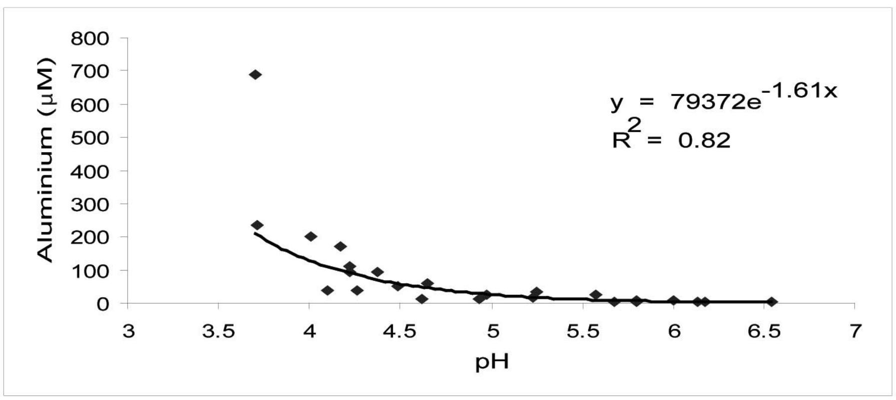

Fig. 2:Relationship between soil solution Al and pH

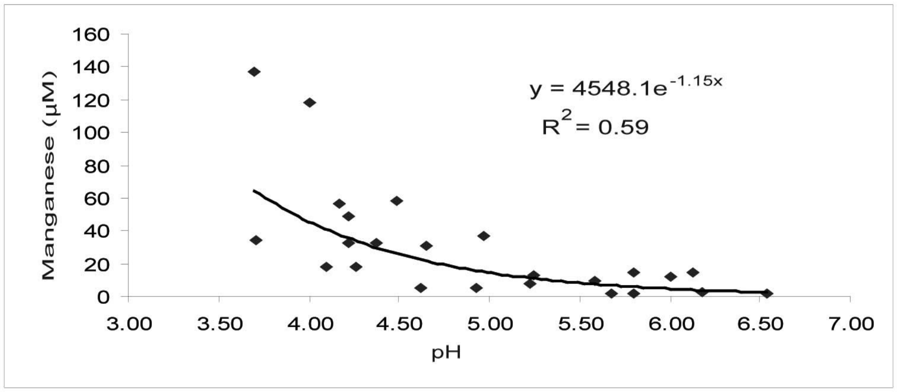

Fig. 3: Relationship between soil solution Mn and pH

CONCLUSION

This study found that the critical pH values for growing corn and groundnut on Ultisols in Malaysia were 4.7 and 4.3, respectively, indicating that corn is slightly less tolerant to soil acidity than groundnut. The respective critical Al concentrations were estimated to be about 30 and 70 μM, while those for Mn were 20 and 34 μM. Lime application required to ameliorate these soils for corn cultivation on these soils is 2 t GML/ha.

It appears that growing groundnut on Ultisols in Malaysia does not require lime application. However, lime application has an additional advantage. Liming at a low rate of 1 t GML/ha would add the extra Ca and Mg needed for the growing groundnut.

Gypsum application did not significantly change solution pH, Al, Fe and Mn. Calcium and S concentrations in the soil solutions did not show any trend with respect to the rate of gypsum application. However, we could assume the advantage of having additional Ca and S from the dissolving gypsum, which can be taken up by corn or groundnut for healthy growth for we know that Ca is able reduce the effects of Al toxicity. We cannot completely discount the possibility of increasing solution Al when a high rate of gypsum is applied on Ultisols.

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