Cation Composition in Soil Solution of Two Malaysian Soils

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A study was carried out to determine the cation composition in soil solution of two soils commonly cultivated with rubber (Rengam and Munchong series) and their relationships to exchangeable cations.

The concentration of the cations in the two soil solutions is generally less than 0.5 cmol (+)/kg. The soluble cation concentrations are higher for Rengam soil, an Ultisol than for Munchong soil, an Oxisol, for all the cations studied, viz Ca^{2+}, Mg^{2+}, K^+, Na^+ and Al^{3+}.

Low concentrations of soluble cations result in soil solutions with low ionic strength. The ionic strength of the two soils is less than 0.008 M, with the ionic strength of Rengam soil being higher than that of Munchong soil.

A good correlation was observed between soluble and exchangeable cation concentrations. The percentage of exchangeable cation which is readily solubilised is low. The differences in availability of the cations in soil solution are attributed to the clay mineralogy of the inorganic soil colloids.

Acid soils occupy approximately 72% of the land area in Peninsular Malaysia. The two main orders of acid soils found in Peninsular Malaysia are the Ultisols and Oxisols. Acid soils are usually highly weathered and characterised by low fertility status, low pH and high exchangeable aluminium saturation.

The mineralogy of acid soils is dominated by 1:1 type clay silicates and oxides of iron and aluminium. These minerals have been demonstrated to possess both cation and anion exchange capacities which are dependent on the ionic strength of the ambient medium[1,2].

The solid-phase properties of acid soils of Peninsular Malaysia have been relatively well studied. Unlike the solution-phase, which due to the unawareness of its significance and importance and partly to the difficulty in obtaining a sufficient quantity of the soil solution itself for full elemental analysis, has not been extensively examined.

The soil solution has been defined as a quasi-equilibrium solution of electrolytes that are present in the soil under unsaturated moisture conditions[3]. It is the medium which is in contact with plant roots and is the source from which plants obtain their nutrients.

Knowledge of the characteristics of soil solution is thus essential in understanding the factors controlling the availability and reactivity of plant nutrients. A study was initiated with the following objectives:

- To determine the composition of solutions extracted from two acid soils

- To determine the relationship between the cationic concentration of the soil solution and that of the solid phase.

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A great obstacle to studies on soil solutions is obtaining a sufficient and true quantity of the soil solution which is unchanged by the extraction procedure. For practical purposes, it is always easier and more convenient to extract soil solutions from air dried soil samples. Studies by Gillman and Bell[2,4], Edmeades et al.[5] Elkhatib et al.[6] and Menzies and Bell[7] have shown that the composition of soil solution extracted from pre-wetted air-dry soil is the same as that extracted from field-moist soil.

Soil solutions can be extracted by several ways viz. centrifugation, suction, displacement and compaction. There are advantages and disadvantages for each method. However, extraction by centrifugation is preferred because it is simple, rapid and the pressure applied is mild, well within the available moisture range.

MATERIALS

Soils

Soils used in this study were sampled at 0 – 15 cm depth from two intercropping trials at Sungala Estate, Port Dickson, Negeri Sembilan and at a smallholding in Machang, Kelantan. The treatments involved application of ground magnesium limestone (GML) at 0, 500, 1000 and 2000 kg/ha. The cropping sequence was groundnut, maize, maize and groundnut. Details of the experimental trial have been described in a paper by Mohd. Yusoff et al.[8] The soils studied were Rengam series (Typic Kandiudult) in Machang, Kelantan and Munchong series (Tropeptic Haplorthox) in

Sungala, Negeri Sembilan. The particle size distribution and some of the chemical properties of the two soils are described in Table 1. Munchong and Rengam soils have 80% and 19% clay content while their cation exchange capacities are 4.69 and 2.26 cmol (+)/kg respectively. The exchange capacities of the clay fractions are 19.34 and 8.92 cmol (+)/kg for Rengam and Munchong series respectively[9].

From field observations, in the initial stage, rubber establishes easier on Rengam soil than on Munchong soil. This is attributed to the relatively good physical structure and higher nutrient contents of Rengam soil compared to Munchong soil. The clayey nature of Munchong soil gives it a more compact structure than Rengam soil, thus impeding water infiltration and root growth. However, at later stages of growth, it has been observed that the plants were able to overcome the physical and chemical constraints and growth in the two soils was comparable[10].

Soil samples were taken before and two weeks after the application of lime and after every harvest of the intercrop. The soils were oven dried at 55°C, ground and passed through a 2 mm sieve.

METHODS

Soils Solution

To extract the soil solution, 50 g of oven-dried soil was placed in a centrifugal assembly specially designed for the purpose (Figure 1). The centrifugal assembly is

TABLE 1. PHYSICAL AND CHEMICAL PROPERTIES OF SURFACE SOILS STUDIED[a]

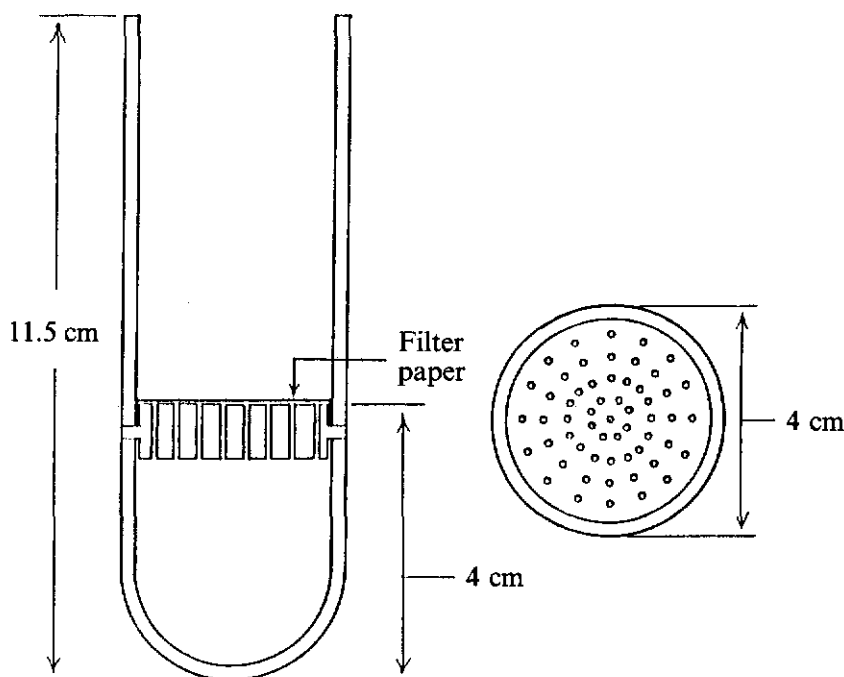| Soil	Clay (%)	Sand (%)	Silt (%)	pH	C (%)	CEC [cmol (+)/kg]	
						Soil	Clay
Munchong	79.9	11.2	8.9	4.2	1.89	4.69	8.92
Rengam	18.9	78.6	2.5	5.3	1.76	2.26	19.34

[a]After Zainol et al.[9]

Figure 1. Centrifugal assembly used for extracting soil solution.

a modification of the one proposed by Gillman[11]. The soil was wetted to field capacity with distilled water. The amount of water added was calculated by determining the field capacity of the soil on a separate soil sample. The wetted soil was equilibrated for 24 h and centrifuged at 3000 r.p.m. for 20 min. The soil solution was passed through a Whatman filter paper No. 4.

K, Ca, Mg, Na and Al in the soil solution were determined by Inductively Coupled Plasma Atomic Emission Spectrometry (ICPAES).

Exchangeable Cations

To measure the exchangeable cations, 20 g soil was placed in a glass column. Ammonium acetate at pH 7 was passed through the soil and the leachate collected over a 6-h period. The concentrations of K, Ca and Mg in the extract were determined by atomic absorption spectrometry.

Calculation of Ionic Strength of Soil Solution

The ionic strength (I) of the soil solution was calculated using the formula:

$$I = 0.5 \ \Sigma C_i Z_i^2$$

where C_i = ionic concentration
Z_i = ionic valency.

Statistical Analysis

Simple linear regression studies were carried out on the data using the Lotus 123 computer programme on an IBM compatible personal computer.

RESULTS AND DISCUSSION

Cation Concentrations

The concentrations of the cations in the soil solution were not corrected for ion pair formation, noting that studies by Gillman and Bell[4] showed that ion pair formation

was not extensive in soil solutions extracted from some highly weathered soils of tropical North Queensland. The concentration ranges of the cations in soil solutions are presented in *Table 2*. The cation concentrations of the two Malaysian soils are generally less than 0.5 cmol/litre for Ca, Mg and K, with the concentration ranges being 0.01–0.4 cmol/litre for Ca, 0.01–0.5 cmol/litre for Mg and 0.02–0.2 cmol/litre for K. The concentrations of K, Ca and Mg in the two soils are generally low and of the same magnitude as those presented by Gillman and Bell[4] for the soils of tropical North Queensland, but are much lower than those reported for temperate soil solutions[12] (2.5–5 cmol/litre for Ca, 4–8 cmol/litre for Mg and 0.5–1 cmol/litre for K).

In addition, the concentrations of the soluble cations K, Ca and Mg are generally higher for the Ultisol than for the Oxisol.

Effect of Liming on Cation Concentration

In general, K concentration in the soil solution decreased while Ca and Mg concentrations increased with increasing rate of application of lime *(Table 3)*. However, the increases in the concentrations of Ca and Mg in the soil solution of Munchong are not as great as those in the soil solution of Rengam series. Cation ratios in soil solution influence their uptake by the plant. The activity ratio (AR) between K and the divalent cations, Ca and Mg in the soil

solution can be calculated by the equation:

$$AR_K = \frac{a_K}{[a_{Ca} + a_{Mg}]^{1/2}}$$

where a_M is the activity of the cation, M.

The activity ratio of K in soil solution decreased with increasing rate of application of lime *(Table 3)*. Le Roux and Sumner[13] and Gillman and Bell[4] have reported that good correlation was obtained between the activity ratio of K in soil solution and that determined by the conventional procedure of ionic equilibra.

Ionic Strength

Ionic strength of the soil solution was calculated taking into account the cations present in significant amounts, *viz*. K, Na, Ca, Mg and Al.

The ionic strength of soil solution is generally low, being in the range of 0.002 to *0.008 M* for Rengam soil and 0.001 to 0.005 *M* for Munchong soil *(Table 4)*. This is in accordance with the higher soluble cation concentrations present in Rengam soil compared to Munchong soil. With increasing cationic concentration in the soil solution on liming, ionic strength increased. The increase in ionic strength was higher for Rengam than Munchong. The application of lime and possibly other agronomic inputs such as fertilisers, alter the soluble cation concentrations in solution. The ionic

TABLE 2. CONCENTRATIONS OF SOLUBLE CATIONS IN RENGAM AND MUNCHONG SERIES AT 0 – 15 CM DEPTH

Cation	Concentration of cations (μm)	
	Rengam series	Munchong series
Ca^{2+}	106 – 3630	222 – 2377
Mg^{2+}	89 – 4798	62 – 1415
K^+	210 – 2143	116 – 1111
Na^+	127 – 855	45 – 759
Al^{3+}	7 – 815	3 – 124

TABLE 3. EFFECT OF APPLICATION OF LIME ON CONCENTRATIONS OF POTASSIUM, CALCIUM AND MAGNESIUM[a]

| Rate of lime applied (kg/ha) | Concentration of cation (μm) | | | | | | AR_k | |
| | K | | Ca | | Mg | | | |
	Rengam	Munchong	Rengam	Munchong	Rengam	Munchong	Rengam	Munchong
0	407	350	265	628	260	217	18	12
500	401	406	426	813	484	356	13	12
1000	394	474	486	660	631	336	12	15
2000	348	336	521	655	777	403	10	10

[a]Soil was sampled two weeks after application of lime.

TABLE 4. EFFECT OF LIMING ON IONIC STRENGTH OF SOIL SOLUTION[a]

Treatment	Ionic strength (M)	
	Rengam	Munchong
R_0 (0 kg/ha lime)	0.0046	0.0029
R_1 (500 kg/ha lime)	0.0062	0.0036
R_2 (1000 kg/ha lime)	0.0050	0.0040
R_3 (2000 kg/ha lime)	0.0076	0.0076

[a]Soil was sampled two weeks after application of lime.

strength of the soil solution also controls the soil pH and variable charge of the alumino silicate minerals as indicated by the double layer theory.

The ionic strengths of the soil solutions extracted from the two soil series are much lower than 0.03 M, the value commonly quoted for soil solutions[14]. However, they are of a similar magnitude to the ionic strengths of other tropical soils[4,13].

Relationship between Soluble and Exchangeable Cations

To relate the concentration of cation in soil solution to the routinely determined exchangeable cations, as measured by $1N$ ammonium acetate at pH 7, simple correlation studies were carried out on the data obtained (Table 5).

A strong relationship exists between the cations in the soil solution and the exchangeable cations (Table 5). K appeared to be more strongly correlated to the exchangeable form than Ca and Mg. Mono-valent cation concentration in the exchangeable form is more strongly related to those in the soluble form. The relationship is even better when the data for the two soils are not pooled together, thus indicating that there are certain inherent characteristics of the soil that influence solubility of the cation. In a study by Bruce et al.[15] on some acid soils in Queensland, it was observed that the release of Ca and Mg from exchange sites to the soil solution was affected by the relative amounts of exchangeable Ca and Mg. When the average concentrations of basic cations in soil solution were expressed as percentages of

TABLE 5. CORRELATION COEFFICIENT BETWEEN SOLUBLE CATIONS AND EXCHANGEABLE CATIONS (0 – 15 CM DEPTH)

Soil series	Correlation coefficient		
	Ca	Mg	K
Munchong (n = 118)	0.76***	0.72***	0.84***
Rengam (n = 238)	0.57***	0.75***	0.66***
Combined (n = 358)	0.49***	0.51***	0.34***

P = < 0.001
n = degrees of freedom

TABLE 6. RELATIONSHIP BETWEEN CATION CONCENTRATION IN SOIL SOLUTION $(M)_s$ AND EXCHANGEABLE CATION $(M)_{ex}$ (0 – 15 cm DEPTH)

Soil series	Ca	Mg	K
Munchong	$[Ca]_s = 0.06 [Ca]_{ex} + 17.32$	$[Mg]_s = 0.11 [Mg]_{ex} + 3.99$	$[K]_s = 0.19 [K]_{ex} + 2.46$
Rengam	$[Ca]_s = 0.17 [Ca]_{ex} + 22.26$	$[Mg]_s = 0.51 [Mg]_{ex} + 6.43$	$[K]_s = 0.46 [K]_{ex} + 9.67$
Combined	$[Ca]_s = 0.06 [Ca]_{ex} + 28.11$	$[Mg]_s = 0.49 [Mg]_{ex} + 8.37$	$[K]_s = 0.15 [K]_{ex} + 16.71$

the exchangeable plus soluble cations, Bell and Gillman[16] found that the release of the cations followed the order Na > K > Mg > Ca. The electrostatic affinities of the ions for the exchange sites were cited as the reason for the trend. On calculation of the data obtained in this study, a similar trend was generally observed, *i.e.* K > Ca > Mg for Rengam soil. However, for Munchong soil the order was K > Mg > Ca.

The relationship between soluble cations and exchangeable cations can be expressed as:

$$M^+_s = \text{Constant} \times M^+_{ex}$$

where M^+_s = Soluble cation

M^+_{ex} = Exchangeable cation

The constant, however, has been shown to be a function of solution ionic strength[17] or electrical conductivity with which the soil solution is in contact. The relationships established for K, Ca and Mg for the two soil series are presented in *Table 6*.

From *Table 6*, it is apparent that an estimate of the concentration of cations in soil solution can be made from the exchangeable cations. The concentration of the cation in soil solution is only a small fraction of the exchangeable cations. In Munchong soil, the percentages of cations in soil solution are 6%, 11% and 19% of the exchangeable cations for Ca, Mg and K respectively. In Rengam soil, the percentages of the exchangeable cations that are soluble are slightly higher, that is 17%, 51% and 46% for Ca, Mg and K respectively. The higher concentrations of cations in the soil solution of the Rengam series compared to Munchong series can be attributed partly to the higher exchange capacity of the clay minerals of Rengam soil and also to higher concentrations of exchangeable cations[9]. Although Munchong soil has a higher clay content than Rengam soil, the exchange capacity of its clay is lower *(Table 1)*.

The Clay fraction of Rengam soil is dominated by kaolinite and that of Munchong soil is dominated by goethite and gibbsite[18]. Goethite and gibbsite confer to the soil system positive charges thus lowering the net negative charge of the soil colloids and therefore the ability to retain cations in the exchangeable form.

CONCLUSION

The composition of the solution of two soils studied showed that the concentrations of the cations K, Na, Ca, Mg and Al in solution are low, that is, generally less than 0.5 cmol/kg. They are generally higher for Rengam soil, an Ultisol than for Munchong soil, an Oxisol. Ionic strength of the soil solution is also low, that is, less than 0.008 *M*.

The relative ease with which the exchangeable cation can go into solution is higher for Rengam soil than Munchong soil. The order of release of the cations into soil solution is K > Ca > Mg for Rengam soil and K > Mg > Ca for Munchong soil. The composition of the clay minerals was one of the reason for the higher cation release in Rengam soil.

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