

The charge properties of highly weathered tropical soils

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Abstract: Phyllosilicates are the major minerals of soils. These minerals change to oxides or hydroxides on weathering in tropical environments. Charges are developed in the phyllosilicates via isomorphic substitution of Si by Al; these termed negative permanent charges. In highly weathered tropical soils, oxides or hydroxides are predominant. The minerals become positively charged when the soil pH is lowered. In such soils, negative charges develop when soil pH increases. Hence, it would be possible to change charges in soils by agronomic manipulation. In soils dominated by oxides, positive charges in the B-horizon can be higher than negative charges.

Abstrak: Filosilikat merupakan mineral major pembentuk tanah. Mineral-mineral ini berubah kepada oksida atau hidroksida apabila terluluhawa dalam sekitaran tropika. Caj-caj terbentuk dalam mineral filosilikat melalui penggantian isomorf Si dan Al; caj-caj ini diistilahkan sebagai caj negatif kekal. Mineral oksida atau hidroksida berlimpahan dalam tanah tropika yang terluluhawa teruk. Mineral-mineral ini akan bercaj positif apabila pH diturunkan. Dalam tanah sebegini, caj negatif terbentuk apabila pH tanah bertambah. Oleh itu, caj dalam tanah boleh diubah melalui manipulasi agronomi. Dalam tanah yang kaya dengan mineral oksida, caj positif dalam horizon-B boleh jadi lebih tinggi daripada caj negatif.

INTRODUCTION

The majority of the upland soils in Malaysia are derived from granite, sandstone and shale. Exposed to the tropical climate, these soils are highly weathered. The dominant minerals in the clay fraction are kaolinite, gibbsite and goethite (Table 1). The soils given in Table 1 are some of the most weathered soils in the country. The pH of these soils is usually 4 to 5, being higher in the more weathered ones. This phenomenon is attributed to the occurrence of more oxides/hydroxides in these soils. It is to be noted, however, that the parent materials for the soil series are different and this actually influence the said degree of weathering.

Oxidic soils are characterized by low charge. Under normal circumstances, negative charge (CEC) decreases with weathering, while positive charge increases. The objectives of this paper are to explain the charging phenomenon in soil minerals and subsequently characterize the charge properties of tropical soils.

DEVELOPMENT OF CHARGES IN MINERAL

Permanent charge

Figure 1 explains how negative charge is developed on the surface of a silicate. The ideal formula for muscovite would have 4 tetrahedral Si. In reality, the Si is partly replaced by Al, resulting in an excess of negative charge. The negative charge so developed is compensated by adsorption of K^+ . The structure is now somewhat stabilized

and further charge development would need a long time. As such, the charge is termed as negative permanent charge. In more weathered soils where oxides are predominant, Ti may replace Fe^{3+} . This leads to the development of positive permanent charge.

In principle, the occurrence of the two types of charge in the soils is not fixed forever. Its magnitude (either positive or negative) does change, depending on the rate of weathering. Negative charge is high in young soils dominated by silicates. In highly weathered soils dominated by sesquioxides, positive charge can exceed negative charge, especially in the B-horizon.

Variable charge

Some of the charges on the surfaces of oxides/hydroxides in highly weathered soils are pH-dependent. When soil pH is increased, the minerals are negatively

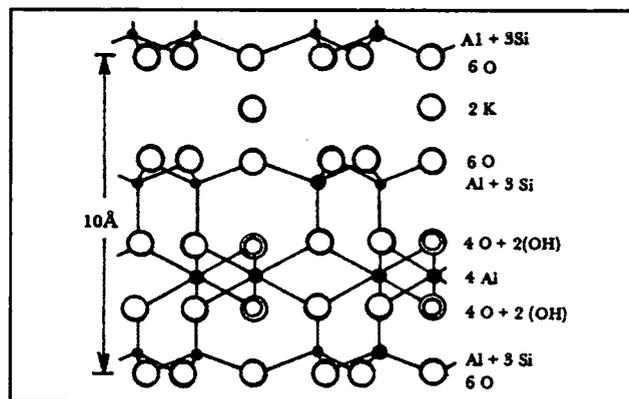


Figure 1. Structure of muscovite.

charged (Figure 2). On the contrary, the mineral is positively charged when the soil pH is lowered. The pH at which the net charge on the surfaces of the minerals is zero has been termed as pH_0 . This unique soil attribute is found to increase with the degree of weathering (Table 2), which may also be related to the mineral composition of the original parent materials. Data in Table 2 also suggest that soil pH increases linearly with its pH_0 (Tessens and Shamsuddin, 1983). This means that the charges in the soils can be manipulated by agronomic practices.

QUANTIFICATION AND MANIPULATION OF CHARGES IN SOIL

Quantification of charges

Total charge in the soil can be subdivided into permanent and variable-charge components, and represented by the following equation:

$$Q_T = Q_p + Q_v$$

Where

- Q = charge
- T = total
- P = permanent
- V = variable

The amount of total charge in the soils can be manipulated by changing the variable charge (Q_v). Q_v is represented by the equation (Uehara and Gillman, 1981):

$$Q_v = \left[\frac{2nDkt}{\pi} \right]^{1/2} \sinh z l.15(pH_0 - pH)$$

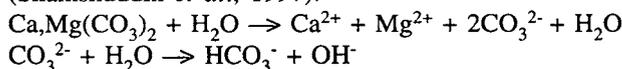
where,

- n = electrolyte concentration
- D = dielectric constant
- k = Boltzmann constant
- t = absolute temperature
- z = counterion valency

In theory, therefore, the charges in soil can be changed by changing the difference between pH_0 and pH. It is known that pH_0 can be lowered by phosphate and organic matter application. On the other hand, pH can be increased by liming.

The effect of liming on charge

In Malaysia, the lime material that is usually used is dolomitic limestone. Dolomite reacts in soils as follows (Shamsuddin *et al.*, 1997):



The OH^- so produced will increase soil pH, the magnitude of increase depending on the rate of lime applied. For highly weathered soils, the recommended rate is 2 t/ha; this can raise the pH to about 5.0 – 5.5.

As highly weathered soils are dominated by variable charge minerals, any pH change would affect the overall charge of the soils. As Figure 3 shows negative charge increases with pH, and the positive charge would decrease

Table 1. Minerals in the clay fraction of the B-horizon of selected highly weathered soils (Tessens and Shamsuddin, 1983).

Soil Series	Kaolinite	Gibbsite	Goethite	Mica	Parent Bedrock
Serdang	78.8	1.57	3.86	2	Sandstone
Rengam	75.4	12.34	7.98	1	Granite
Segamat	35.7	1.53	10.91	0	Andesite
Jeranggau	33.5	14.12	19.22	0	Granodiorite
Kuantan	41.1	32.01	24.41	0	Basalt
Prang	55.4	2.85	10.52	0	Schist
Sg. Mas	32.7	0.82	23.82	0	Serpentine

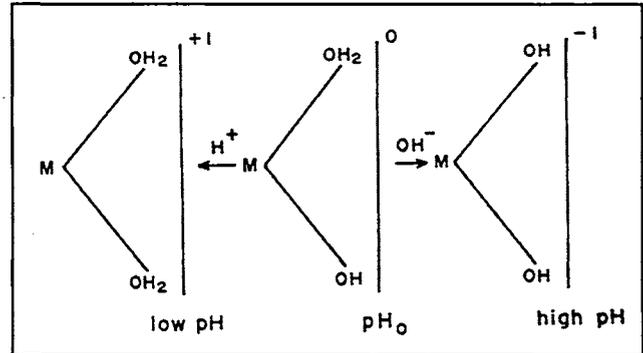


Figure 2. Development of charge on the surface of hydroxides (Bowden *et al.*, 1980)

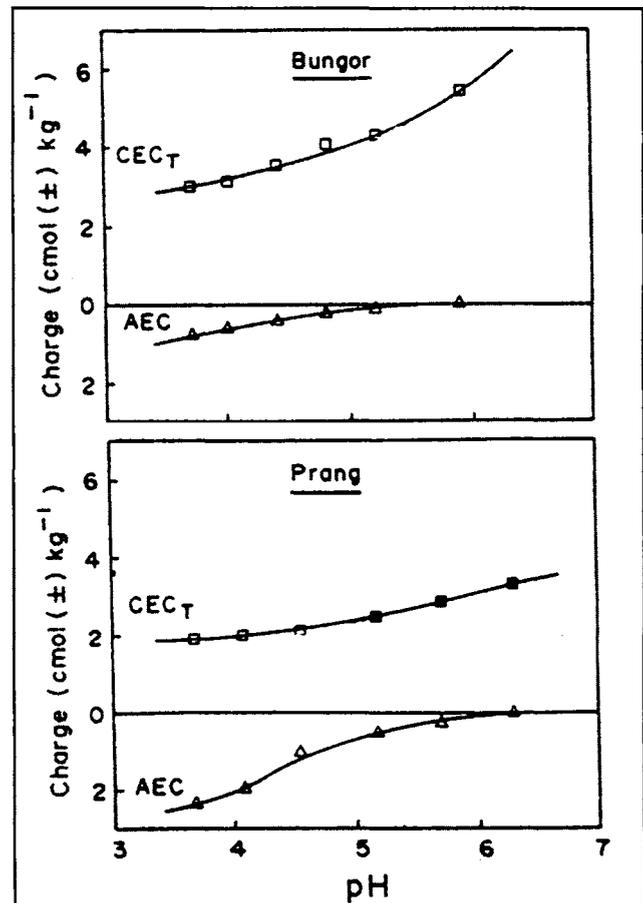


Figure 3. The change of charge with pH.

Table 2. The pH and pH_0 of the B-horizon of selected highly weathered soils (Tessens and Shamshuddin, 1983)

Series	pH	pH_0	Parent Bedrock
Serdang	4.16	4.27	Sandstone
Rengam	4.38	4.30	Granite
Segamat	3.61	4.34	Andesite
Jeranggau	4.67	4.55	Granodiorite
Kuantan	4.72	4.85	Basalt
Prang	4.77	4.45	Schist
Sg. Mas	5.29	6.24	Serpentine

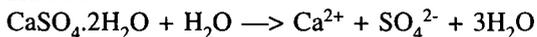
Table 3. Effects of gypsum application on the pH of the Bungor and Prang topsoils (Shamshuddin and Ismail, 1995).

Gypsum (t/ha)	pH	
	Bungor	Prang
0	4.21	4.18
2	4.16	4.48
4	4.08	4.54

accordingly. Figure 3 shows clearly that the Bungor soil which is less weathered compared to the Prang soil, has higher negative charge (CEC) at the soil pH; soil pH is expected to be 4–5. The increase in negative charge in the soils means that the loss of cations via leaching under tropical environments is minimized.

The effect of gypsum application on charge

Gypsum is sometimes used as a soil ameliorant. In Malaysia, this material is available in abundance as factory by-product. The reaction of gypsum in soil solution is as follows:



The reaction produces large amounts of Ca^{2+} and SO_4^{2-} . This Ca^{2+} would eventually replace Al^{3+} on the exchange complex. The Al^{3+} in the soil solution undergoes hydrolysis producing acidity (Table 3). On the other hand the SO_4^{2-} reacts with hydroxides to produce OH^- (Figure 4). The slight increase in pH would result in the development of negative charge (Table 3).

Gypsum's effect on soil is, therefore, dependent on which reaction is dominant. In soils containing large amounts of silicates, exchangeable Al is abundant. In this situation, gypsum application would deteriorate soil fertility as shown by the Bungor soil (Table 3). For soils classified as Oxisols (highly weathered soils) containing

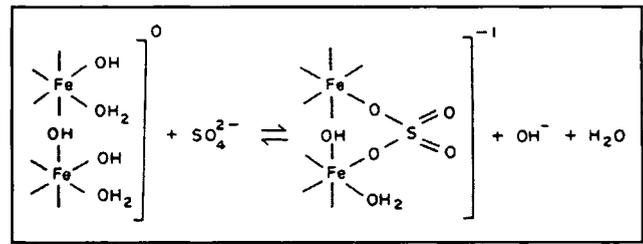


Figure 4. The effect of sulphate adsorption on charge of hydroxides.

abundant amount of oxides/hydroxides, gypsum application would alleviate soil infertility by increasing soil pH and negative charge. This is clearly shown by the Prang Soil (Table 3).

CONCLUSION

Low charges in highly weathered soils contribute to low fertility. The infertility of these soils can be alleviated somewhat by applying lime or gypsum. The eventual increase in soil pH by their application would raise the negative charge. The loss of cations via leaching is minimized by the charge increase.

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