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Impact of Agriculture on Chemical Properties of Soils on Basalt from Mindanao, the Philippines

R. Boniao, E. Van Ranst,[1] J. Shamshuddin and G. Baert[1]

Department of Soil Science
Faculty of Agriculture
Universiti Putra Malaysia
43400 Serdang, Selangor, Malaysia

[1]Laboratory of Soil Science
Department of Geology and Soil Science
University of Gent
Krijglaans 281(S8)
B-9000, Gent, Belgium

ABSTRACT

Uncultivated and cultivated soils from Mindanao, the Philippines were sampled and studied to determine the impact of agriculture on their chemical properties. The results of the study showed that cultivated soils, having lost some organic matter due to oxidation, have a lower CEC and a higher point of zero charge (pH_o). The capacity of these soils to retain cations has decreased to a certain extent. In the subsoils of both soil types, there is a tendency for soil pH to coincide with pH_o, reflecting development of positive charge in the soil of that zone. The sum of exhangeable bases and Al (ECEC) is found to be a good estimate of the CEC of the soils.

Keywords: cultivated and uncultivated soils, CEC, pH_o, organic matter

INTRODUCTION

Soils of the humid tropics are usually strongly leached and highly weathered. In such a condition, kaolinite is usually the dominant clay mineral. However, in iron rich tropical soils an important proportion of the exchange sites in the soils is generated by oxides and hydroxides of Fe and Al. The charges on the exchange complex are variable, thus they are easily altered by changing management practices.

For variable-charge soils, the point of zero charge (pH_o) is a useful reference for predicting the charge-dependent behaviour (Van Raij and Peech 1972; Gallez *et al.* 1976; Hendershot *et al.* 1979). The position of pH_o on the pH scale determines the cation exchange capacity and anion exchange capacity of such soils (Gillman 1985). This position of pH_o is influenced by several factors, such as the presence of organic matter and oxides of Fe and Al. The CEC of the topsoils is almost entirely attributable to organic matter. Thus, the loss of organic matter through oxidation and breakdown when the

soil is cultivated not only reduces the ability to supply N, P and S for crops, but also its ability to retain cations in a readily available form. In general, highly weathered soils have limited nutrient holding capacity, resulting in low productivity.

The Philippines, an archipelago of about 7,100 islands scattered between latitudes 4°30' and 21°30' N and longitudes 116° and 127°E, is wholly situated in the humic tropical belt. A large proportion of the soils have the conditions specified above; many of these soils have large amounts of variable-charge minerals (Shamshuddin *et al.* 1996). Because soils with variable-charge minerals have different chemical and physical properties from those with predominantly permanent charge, they need to be managed differently. Thus, studies on the chemical behaviour of such soils under cultivated and uncultivated conditions would lead to the development of better management practices for the soils in the region.

The main objective of the study was to determine the impact of cultivation on the important chemical properties of the highly weathered soils of the southern part of the humid tropical Philippines. This helps us to obtain a better understanding of the electrochemical properties of the soils and, thus, provide a rational basis for improvement of local agronomic practices in order to increase productivity. Specifically, the objectives were:

a) to evaluate the chemical and surface charge characteristics of the soils; and
b) to assess the impact of agricultural practices on organic matter and its consequent change on surface charge properties.

MATERIALS AND METHODS

Location, Climate and Geology of the Study Area

The study areas were in the provinces of Misamis Oriental and Lanao del Sur, both located on the island of Mindanao, in the southern Philippines. The study site in Lanao del Sur was in the vicinity of Marawi City, at an elevation of 726 – 800 m a.s.l. In the Misamis Oriental province, the study site was situated in the Municipality of Cleveria, about 45 km northeast of Cagayan de Oro City, at an elevation of 400 – 650 m a.s.l.

The average annual rainfall of the Lanao del Sur Province is around 2,685 mm, evenly distributed throughout the year. The area enjoys a relatively cool temperature, ranging from 21°C in January to 23°C in April. Claveria has a very pronounced wet season with most rainfall occurring from January to June. The total annual rainfall is about 2,000 mm. There is normally no dry season. The mean monthly temperature ranges from 23°C in February to 26°C in May.

Lanao del Sur consists of a succession of plateaus, highland basins, hills, volcanoes and peaks. It is basically formed by several eruptions of Miocene and Recent volcanoes, with lava flows occurring on the plateaus which mainly consist of basalt, andesite and pyroclastics (Bureau of Soils 1984). Pyroclastics

are generally composed of intermediate to basic volcanic ejecta, consisting mainly of a heterogeneous unsorted assemblage of volcanic materials including ash, sand, bombs and tuffs.

The study area in the vicinity of Claveria is mapped as Quaternary Volcanic Pyroclastics (Bureau of Soils 1986). The unit occupies the biggest area in the Misamis Oriental Province. The pyroclastics are accumulated at the apron or footslopes of the identified volcanic cones (non-active), some on hills, mountains and plateaus (Bureau of Soils 1983).

Soils

Soil samples were taken from 5 profiles in the two separate provinces of Mindanao. Four profiles (Misamis soils) were situated in the upland, at two different sites. At each location, two profiles were dug; one to represent a profile of a cultivated soil, the other for virgin soil. Only one profile was studied in the Lanao del Sur area, representing a soil under non-agricultural use.

For each profile, horizons were delineated and samples collected. For routine physico-chemical analyses and other more specific laboratory analyses, only soil samples from the topsoils and of the B horizons were considered and used.

In this study, the profiles were marked according to the following notation. HIP and TAM refer to Hinaplanan and Tamboboan soils, respectively of the Misamis Oriental area (Oxisols), while MAR refers to Marawi soil of the Lanao del Sur area (Inceptisol). The Arabic numerals indicate identification numbers of profiles. HIP 2, TAM 5, and MAR 9 represent uncultivated soils while HIP 3 and TAM 7 represent cultivated soils. The Lanao del Sur soil (MAR), no cultivated representative, is presented for comparison purposes only.

Soil Analysis

Routine physico-chemical analyses were carried out using standard methods available at the Laboratory of Soil Science, University of Gent. CEC was determined by 1 M NH_4OAc buffered at pH 7. The basic exchangeable cations (Ca, Mg, K, Na) in the NH_4OAc solution were determined by AAS. Aluminium was extracted by 1 M KCl. pH was measured in H_2O and KCl, in ratio 1:2. Determination of the charge properties of the soils was carried out by the methods outlined by Gillman (1984) and Gillman and Sumpter (1986 a, b).

Particle-size separation was carried out by successive sedimentations. The clay from this analysis was used for identification of soil minerals by XRD analysis using a Philips X-ray apparatus with C_oK_α radiation at 1000 counts per second. X-rays were run on DCB treated and Mg^{2+} and K^+ saturated clay fractions, glycolated Mg^{2+} saturated sample, and K^+ saturated sample successively heated at 350 and 550°C.

RESULTS AND DISCUSSION

General Soil Properties

Table 1 gives selected chemical properties of the soils under investigation. The soils are known to be deep and highly weathered, with clay content exceeding 50%, except the topsoil of MAR 9. The soils' reaction is acidic (HIP 2, TAM 7) to slightly acidic (HIP 3, TAM 5, MAR 9) with pH(H_2O) ranging from 4.4 (TAM 7, B horizon) to 5.7 (TAM 5, A horizon). Organic carbon is high in the topsoil, but low in the subsoil. The values are higher in the uncultivated soils (HIP 2, TAM 5). The organic carbon is extremely high in the uncultivated topsoil of MAR 9, which occurs under depressions and is, therefore, submerged most of the year. Exchangeable Ca is high in the topsoil of HIP 3, TAM 5 and MAR 9, while exchangeable Al is moderately high in the topsoil of HIP 2.

Mineralogy

Data in Table 2 suggest that the soils have high amounts of amorphous materials, a common property of soils derived from volcanic rocks. The DCB-extractable oxides of Fe and Al are present in large proportions in the clay fraction. This may cause problems in the identification of minerals in the clay fraction by XRD. Nonetheless, analysis was carried out and minerals present identified (XRD not presented).

The dominant mineral in the HIP soils is kaolinite, that of TAM and MAR 9 soils is gibbsite. Hydroxy-Al vermiculite is absent in HIP soils, but present in minor amounts in the other soils. Goethite and/or hematite are present in very minor amounts in all the soils under study. Clearly, the soil can be divided into kaolinitic soils (HIP profiles) and gibbsitic soils (TAM and MAR 9 profiles) on the basis of the mineralogy of the clay fraction. Both kaolinite and gibbsite are considered variable-charge minerals, meaning that the charges on the mineral surfaces are altered by changing conditions in the soils, as a result of cultivation (Uehara and Gillman 1981).

Charge Characteristics

Cation-exchange capacity by NH_4OAc (CEC_{NH4OAc}). Clear differences in the CEC_{NH_4OAc} were observed among the soils and within the profiles (Table 1). The upper horizons of all soils have higher values than the lower horizons. This trend is related positively to the organic matter content, which contributes much to the CEC_{NH_4OAc}.

The CEC_{NH_4OAc} of TAM and MAR 9 soils have values in the upper horizons exceeding 20 $cmol_c\,kg^{-1}$ soil; the values are 4 to 6 units higher than those of the topsoils of HIP profiles. The higher values can be attributed to the presence of vermiculite in the TAM and MAR 9 soils (Table 2). These minerals are absent in the HIP soils.

TABLE 1
Selected physico-chemical properties of the studied soils

Profile	Horizon	Depth (cm)	Clay	O.C. %	pH (H_2O)	pH_o	Cations					ECEC	CEC
							Ca	Mg	K	Na	Al		
							$cmol_o kg^{-1}$						
HIP 2	A	0 - 12/14	81	5.2	4.9	4.2	0.78	0.55	0.30	0.06	1.63	3.32	18.04
	B	85/90 - 110	91	0.5	5.2	7.1	0.10	0.60	0.02	0.11	0.34	0.63	12.45
HIP 3	A	0 - 12/16	87	3.0	5.4	4.7	5.02	0.38	0.09	0.03	0.05	6.37	18.61
	B	84/86 - 100	94	0.4	5.3	6.8	0.25	0.11	0.01	0.02	0.35	0.75	12.25
TAM 5	A	0 - 12/15	56	3.4	5.7	4.2	5.53	0.90	2.46	0.04	0	8.94	24.19
	B	70/80 - 100	70	0.4	5.1	6.0	0.62	0.11	0.54	0.01	0	1.28	16.25
TAM 7	A	0 - 12/13	51	2.8	4.6	4.2	1.20	0.05	0.26	0.02	0.60	2.13	22.23
	B	45/47 - 100	68	0.9	4.4	5.5	0.08	0.01	0.07	0	0.06	0.25	17.13
MAR 9	A	0 - 9/10	21	16.0	5.4	3.8	6.24	2.08	0.21	0.19	0.16	8.90	43.92

TABLE 2
The DCB-extracted Fe and Al in fine earth and clay fraction, and the mineralogical composition of the clay faction

Profile	Horizon	DCB-Soil		DCB-Clay		Mineral in the clay*				
		Fe_2O_3	Al_2O_3	Fe_2O_3	Al_2O_3	Al - v	K	Gi	G_o/He	Fp
		%								
HIP 2	A	7.87	2.16	8.97	2.07	-	xxx	-	s	t
	B	6.71	1.47	7.15	1.71	-	xxx	-	s	t
HIP 3	A	5.98	2.11	8.46	2.15	-	xxx	-	s	t
	B	7.66	1.78	7.44	1.93	-	xxx	-	s	t
TAM 5	A	9.84	5.45	12.69	5.49	x	x	xx	s	t
	B	10.35	5.12	10.65	5.75	x	x	xx	s	t
TAM 7	A	10.35	5.84	12.76	5.87	x	x	xx	s	t
	B	11.23	7.42	13.05	7.43	x	x	xx	s	t
MAR	A	0.79	1.48	4.16	6.65	x	x	xx	s	-

Al - v = hydroxy-Al vermiculite; K = kaolinite; Gi = gibbsite; G_o/He = goethite/hematite; Fp = feldspar 5.
xxx = dominant; xx = important; x = minor; s = very minor, t = traces; – = absent.

The CEC_{NH_4OAc} plotted against the cation-exchange capacity obtained by compulsive exchange method (CEC_{CE}) is given in *Fig. 1*. The CEC_{NH_4OAc} is linearly correlated with the CEC_{CE}, with r = 0.65. CEC_{CE} can be regarded as the CEC of the soil under field conditions. Clearly, CEC determined by NH_4OAc overestimated the CEC of the soils under field conditions. This is understandable as the pH of the soils under field conditions is about 5, whereas the pH of NH_4OAc is 7. It is known that the CEC of variable-charge minerals increases with increasing pH of the ambient solution with magnitude, depending on the mineralogy (Uehara and Gillman 1981).

Effective CEC (ECEC)

The ECEC, defined as the sum of exchangeable cations, is given in Table 1. The ECEC values for all soils were plotted against their corresponding CEC_{CE} values (*Fig. 2*). The ECEC is observed to be highly correlated with the CEC_{CE}, having r = 0.91. The points on the graph are very close to the 1:1 line, suggesting that the values of ECEC are almost similar to those of the CEC_{CE}. Thus, the CEC of the soils under field conditions can easily be estimated by summation of the exchangeable cations (Ca, Ma, K, Na, Al) present in the 1 M NH_4OAc extract and Al extracted by 1 M KCl.

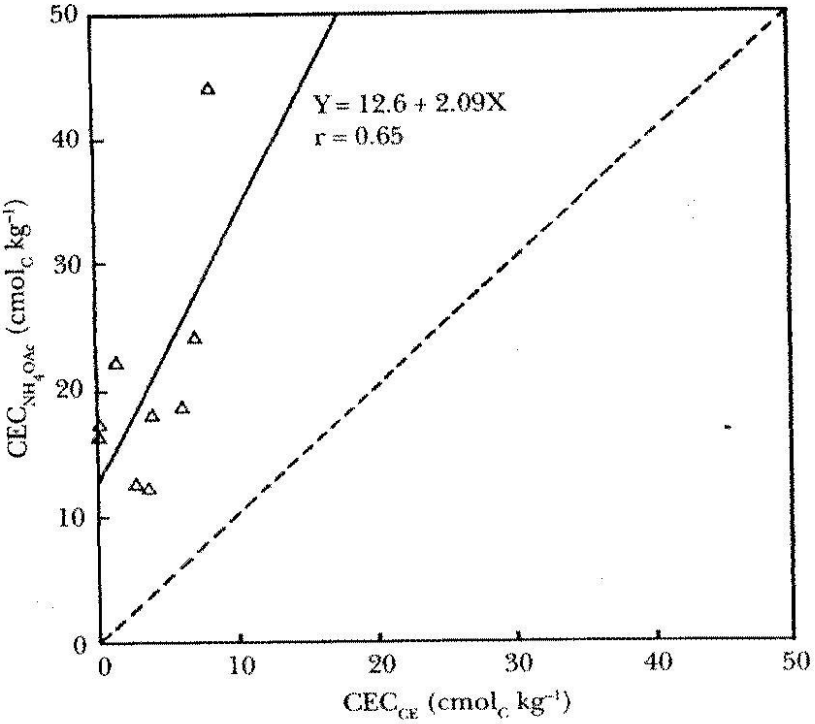

Fig. 1. Relationship between CEC_{NH4OAc} and CEC determined by compulsive exchange

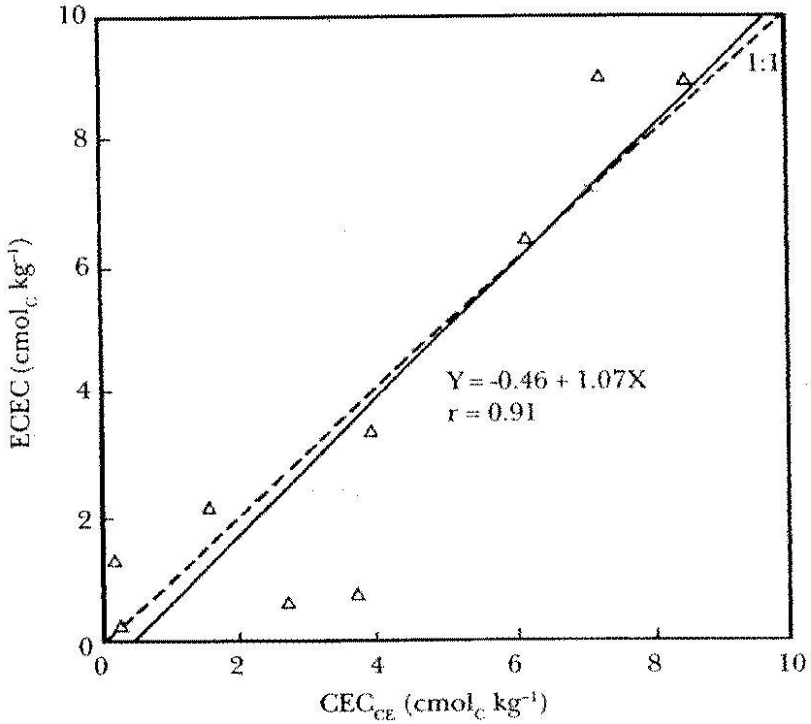

Fig. 2. Relationship between effective CEC and CEC compulsive exchange

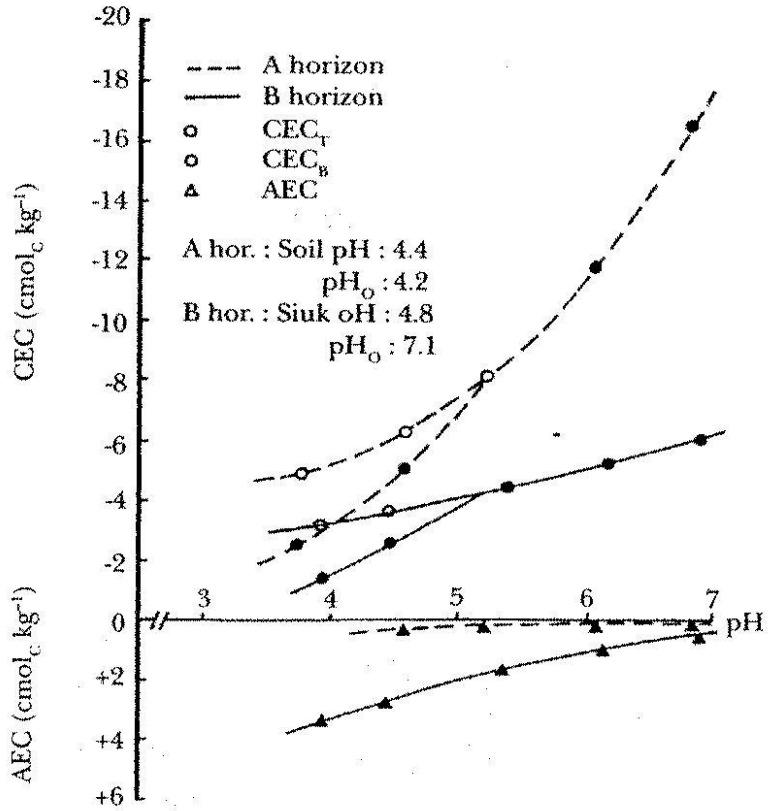

Fig. 3. The charge curves of the uncultivated soils (HIP 2)

Point of Zero Charge (pH_o)

The average pH_o of the topsoil is about 4.2 (Table 1), but much higher, even above 7 (HIP 2, B horizon), in the subsoil. Organic matter and silicate tend to lower the pH_o, whereas the oxides and oxyhydrates of Fe and Al tend to increase the pH_o. The latter constituents have pH_o values ranging between 6 – 9 (Greenland and Mott 1978; Van Ranst 1995). The low values of pH_o in the topsoils are related to the presence of more organic matter in the topsoil. Baert (1995) reported that pH_o of basaltic soils of Cameroon and Lower Zaire decreased linearly as organic carbon increased.

In the subsoil, where oxides and oxyhydrates of Fe and Al are dominant over organic matter, pH_o is high. The difference in the organic matter content causes differences in pH_o value between the soils. The pH_o of the topsoil of HIP 2 (uncultivated) is 4.2, while that of the HIP 3 (cultivated) is 4.7. Such trend in pH_o value with depth has been reported by Baert (1995) for some highly weathered soils of Lower Zaire. It has been known that pH_o can be brought to a lower value by organic matter or silicate application.

Changes of CEC with pH

The charge curves of the topsoil and the subsoil of the HIP 2 (uncultivated) are given in *Fig. 3*. It seems that at any particular pH value, the CEC_B and

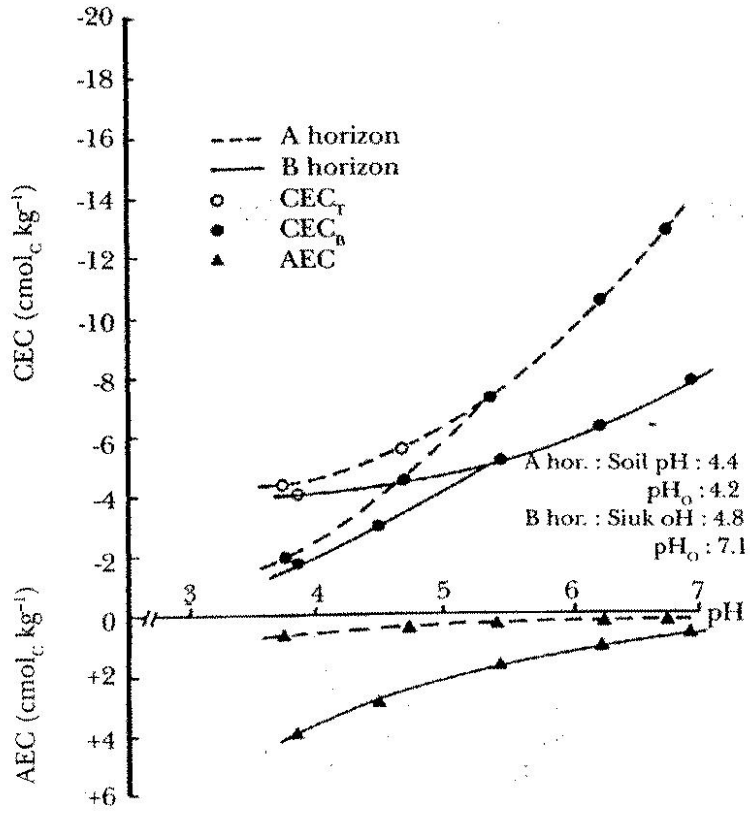

Fig. 4. The charge curves of the cultivated soils (HIP 3)

CEC_T (Ca adsorption and Ca plus Al adsorption, respectively) of the topsoil are higher than those of the subsoil. On the other hand, the AEC (Cl adsorption) is the opposite. This is similar to the result published by Baert (1995).

In *Fig. 4*, where the charge curves of the HIP 3 soil (cultivated) are presented, the CEC_B and CEC_T at any particular pH value have decreased slightly, while the AEC has increased slightly in response to the decrease in the organic matter content. A similar trend has been reported by Van Ranst (1995) for an Oxisol derived from metamorphic rocks under rainforest and under sugarcane of Southern Cameroon. It means that cultivation has effectively reduced negative charge of the topsoil.

CONCLUSION

Surface horizons have higher CEC compared to the subsoils due to the presence of higher amounts of organic matter in the former. Cultivated soils, which suffer a reduction in organic matter content due to oxidative processes, have a lower CEC and a higher pH_o than uncultivated soils. Therefore, the capacity of cultivated soils to retain cations has decreased to a certain extent. In the subsoil, there is a tendency for soil pH to coincide with pH_o, reflecting

development of positive charge in that zone. This study indicates that CEC determined in NH_4OAc buffered at pH 7 overestimates the CEC under field conditions. The CEC is better determined by the compulsive exchange method or by the sum of cations (ECEC). The unique electrochemical properties of these soils require a specific management strategy to improve the fertility, that is, to increase the negative surface charge. The most promising method is the addition of silicates and phosphorous to lower the pH_o. The concept, however, is far from simple and requires further investigation.

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REFERENCES

BAERT, G. 1995. Properties and chemical management aspects of soils on different parent materials in the Lower Zaire. Ph.D. thesis, Faculty of Science, University of Gent, Belgium.

BUREAU OF SOILS. 1983. Soils/land resources evaluation project, Misamis Oriental, D.A., The Philippines.

BUREAU OF SOILS. 1984. Land resources evaluation project physical land resources. Vol. 1. Province of Lanao del Sur, D.A. The Philippines.

BUREAU OF SOILS. 1986. Geological Map, Province of Misamis Oriental. Scale 1: 250,000. D.A. The Philippines.

GALLEZ, A., A.S.R. JUO and A. J. HERBILLON. 1976. Surface charge characteristics of selected soils in the tropics. *Soil Sci. Soc. Am. J.* **40**: 601-608.

GILLMAN, G.P. 1984. Using variable charge characteristics to understand the exchangeable cations status of oxic soils. *Aust. J. Soil Res.* **22**: 71-80.

GILLMAN, G.P. 1985. Influence of organic matter and phosphate content on point of zero charge of variable charge component in oxidic soils. *Aust. J. Soil Res.* **23**: 643-646.

GILLMAN, G.P. and E.A. SUMPTER. 1986a. Modification of compulsive exchange method for measuring exchange characteristics of soils. *Aust. J. Soil Res.* **24**: 61-66.

GILLMAN, G.P. and E.A. SUMPTER. 1986b. Surface charge characteristics and lime requirements of soils derived from basaltic, granitic and metamorphic rocks in high-rainfall tropical Queensland. *Aust. J. Soil Res.* **24**: 173-192.

GREENLAND, D.J. and C.J.B. MOTT. 1978. Surfaces of soil particles. In *The Chemistry of Soil Constituents*, ed. D.J. Greenland and M.H. Hays, p. 321-353. N.Y.: Wiley.

HENDERSHOT, W.H., G.A. SINGLETON and L.M. LAVKULICH. 1979. Variation in surface charge characteristics in a soil chronosequence. *Soil Sci. Soc. Am. J.* **43**: 387-389.

SHAMSHUDDIN, J., RUZIAH SALLEH, M.H. AHMAD HUSNI and KAMIS AWANG. 1996. Charge characteristics in relation to mineralogy of selected soils from South-east Asia. *Pertanika J. Trop. Agric. Sci.* **19**: 45-56.

UEHARA, G. and G.P. GILLMAN. 1981. *The Mineralogy, Chemistry and Physics of Tropical Soils with Variable Charge Clays.* Westview Tropical Agric. Series No. 4.

VAN RAIJ, B. and M. PEECH. 1972. Electrochemical properties of some Oxisols and Alfisols of the tropics. *Soil Sci. Soc. Amer. Proc.* **36**: 587-593.

VAN RANST, E. 1995. Rational soil management in the humid tropics. *Meded. Zitt. K. Acad. Overzeese Wet.* **40**: 209-233.