Some T_2 Terrace Soils of Peninsular Malaysia: III.
Surface Charge Properties*

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ABSTRAK

Sifat-sifat cas 8 siri tanah telah dikaji. Kajian tanah ini menunjukkan ada pertalian di antara gibsit dengan pH. Cas negatif melebihi cas positif pada julat pH 3 hingga 6. Oleh itu TCNS tanah-tanah ini tidak boleh ditentukan. Campuran Al dan bes didapati lebih baik digunakan untuk penaksiran KPKB daripada untuk penaksiran CT tanah itu sama ada tanah ini berada di peringkat luluhawa baharu atau pertengahan, dapat ditunjukkan oleh pH$_o$ yang rendah dan indeks luluhawa yang tinggi.

ABSTRACT

The charge properties of 8 soil series were studied. The study shows that gibbsite is related to the pH$_o$ of these soils. Negative charges exceed positive charges at the pH range of 3 to 6, thus the PZNC of these soils cannot be obtained. The sum of Al and bases is a better estimate of ECEC than of the PC of the soils. These soils are either in the recent or intermediate stage of weathering, shown by the low pH$_o$ and high weathering index.

INTRODUCTION

Surface charge properties of soils containing important amounts of variable charge colloids are a subject of current academic interest because of their important impact on the physico-chemical properties of tropical soils. Theoretical considerations on charging mechanisms taking place in soils have been dealt with at length (Uehara and Gillman, 1980; Bowden *et al.*, 1980) and the applicability of the principles involved have been tested experimentally (Gillman and Uehara, 1980).

Soils with variable charge colloids have a wide geographical distribution. They occupy a great part of tropical and subtropical regions. The physico-chemical properties and fertilizer requirements of these soils can be partly extrapolated by having a systematic study of their charge properties. The objective of this study is to report the charge properties of some T_2 terrace soils of Peninsular Malaysia and to use them for characterizing the soils as well as for the estimation of clay minerals in the soils.

MATERIALS AND METHODS

8 soil series have been selected for this study. They represent a range of textural classes of the so called T_2 terrace soils of Peninsular Malaysia.

TABLE 1
Taxonomic classification of the studied soils

Series	Subgroup	Family
Nangka (1)	Typic Dystropept	Coarse loamy, siliceous, non-acid, isohyperthermic
Bt. Tuku (3)	Plinthaquic Dystropept	Fine loamy, mixed, acid, isohyperthemic
Kerayong (4)	Oxic Dystropept	Fine clayey, kaolinitic, non-acid, isohyperthermic
Lintang (6)	Oxic Dystropept	Coarse loamy, siliceous, acid, isohyperthermic
Sg. Buloh (7, 8)	Typic/Orthoxic Quartzipsamment	Coated, acid, isohyperthermic
Napai (15)	Typic Paleudult	Coarse loamy over clayey-skeletal, kaolinitic, acid
Awang (17)	Aquic Dystropept	Course loamy, siliceous, acid, isohyperthermic
Holyrood (18)	Typic Paleudult	Fine loamy, mixed, acid isohyperthermic

The series selected are Nangka (1), Bukit Tuku (3), Kerayong (4), Lintang (6), Sungai Buloh (7, 8), Napai (15), Awang (17) and Holyrood Series (18). The taxonomic classification of these soils is given in Table 1.

The % of kaolinite in the soils was estimated by TGA, while the % of gibbsite was estimated by DSC. Textural composition, Fe_2O_3 and OC used in this study are taken from the earlier paper (Shamshuddin and Tessens, 1983b). Soil pH in this study is taken to be the pH (1:1) in 0.01N KCl solution, taken after 1 day of equilibration.

pH_o was determined by the method of Gillman and Uehara (1980) except that the sample was not washed prior to the determination. Negative (K^+ adsorption) and positive (Cl^- adsorption) charges at 6 pH levels $(3-6)$ were also determined by the method of Gillman and Uehara (1980).

RESULTS AND DISCUSSION

Introduction

The studied soils are acidic in nature, implying that Al dominates the exchange complex. Al saturation of these soils is very high (Shamshuddin and Tessens, 1983b). Potentiometric titration indicates that Al is the most important component of acidity below pH 5.5

(Shamshuddin and Tessens, 1983a). Above pH 5.5, clays play a dominant role in the buffering action of the soils; the most important clay mineral taking part is kaolinite. pH_o of the broken edges of kaolinite is 7.3 (Rand and Melton, 1975).

The most important mineral in the soils is kaolinite. Other minerals are mica, chlorite and their mixed layers. Some gibbsite is also present. The amount of goethite in the soil is low. The charge properties of these soils are related in some way to the chemical and mineralogical composition of the soils.

Determination of pH_o

General Consideration

pH_o is the pH where the net sum of the charge of the variable charge colloids is zero (Uehara and Gillman, 1980). This does not imply, in any way, an absence of either negative or positive charges on the variable charge colloids at pH_o. pH_o can be determined by potentiometric titration as proposed by Van Raoj and Peech (1972) or Gillman and Uehara (1980).

Oxides and hydroxides of Fe and Al tend to place pH_o at a higher value, whereas phyllosilicates and soil organic matter will bring the pH_o to a lower value (Arnold, 1978). This means that

as the soil becomes more weathered and subsequently more oxides are formed, the pH$_o$ will go up. To bring pH$_o$ to a lower value, organic matter or even phyllosilicates can be incorporated into the soils.

Charging Reactions

The reaction taking place on the surface of colloids can be considered as an acid-base reaction. At high hydrogen activity, the surface is positively charged, while at low hydrogen activity, the surface is negatively charged. The pH at which the net sum of charge is zero is termed at pH$_o$. Some of the pH$_o$ values of

variable charge colloids found in soils are given in Table 2.

In the soils, there are other minerals which react with H$^+$ and consequently have their pH$_o$. Kaolinite and quartz, for example, are known to have a low pH$_o$, with values of 4.5 and 2.2 respectively (according to Dixon, 1977 and Parks, 1965 respectively). The pH$_o$ reported in this study is actually the resultant value of the whole system, considering only the variable charge colloids. The value is thus related to the mineralogical composition of the soil.

For the purpose of illustration, one complete result of the determination is presented in Table 3. A graph of delta pH against pH in 0.002N KCl was plotted (not shown) to determine pH$_o$. In all cases, it is noted that pH$_o$ is lower in Ap than in the B horizons (Table 4). This is the consequence of the presence of more organic matter in the upper than in the lower horizons.

Effect of Al on pH$_o$

A point of clarification is to be made with regard to the effect of Al on the value of pH$_o$. As mentioned earlier, the data in Table 3 are obtained without prior washing of the samples.

TABLE 2

pH$_o$ values of common variable charge colloids found in soils (Parks, 1965; Dixon, 1977)

Mineral	pH$_o$
Gibbsite (Al (OH)$_3$)	$5.0 - 5.2$
Al$_2$O$_3$	$7 - 9$
Goethite (FeOOH)	$6 - 7$
Kaolinite	4.5
Quartz (SiO$_2$)	2.2

TABLE 3

The pH$_o$ of Ap and B$_{22}$ horizons of Bukit Tuku Series (3)

SERIES		pH KCL		$\triangle$pH	pH$_o$
		0.002N	0.05N		
Bt. Tuku (3)	Ap	3.37	3.67	$+0.30$	4.08
		3.74	3.90	$+0.16$	
		3.97	4.04	$+0.07$	
		4.20	4.12	-0.08	
		4.43	4.23	-0.20	
		5.60	4.50	-1.10	
	B$_{22}$	3.41	3.84	$+0.43$	4.20
		3.60	3.95	$+0.35$	
		3.94	4.11	$+0.29$	
		3.94	4.11	$+0.17$	
		4.54	4.25	-0.29	
		5.40	4.43	-0.97	

TABLE 4
The effect of chemical and mineralogical composition on the point of zero charge (pH_o) of the variable charge colloids

SERIES	HOR	pH_o	Al meq/100 g	$Fe_2O_3\%$	O.C%	MINERAL % SOIL gibb	kaol	clay %
Nangka (1)	Ap	4.10	0.43	0.21	1.27	0.49	4.11	8.5
	B_{22}	4.18	0.90	0.29	0.12	1.04	6.29	12.1
Bt. Tuku (3)	Ap	4.08	2.14	0.36	0.81	0.29	7.98	17.9
	B_{22}	4.20	3.60	1.04	0.06	0.13	18.77	31.5
Kerayong (4)	Ap	4.14	0.11	1.77	1.74	1.33	25.89	53.5
	B_{22}	4.24	4.21	2.29	0.09	1.03	26.32	54.4
Lintang (6)	Ap	4.18	0.58	0.57	0.85	1.28	8.31	14.9
	B_{23}	4.28	0.55	0.93	0.19	1.99	12.88	23.1
Sg. Buloh (7)	Ap	4.60	0.55	0.51	0.97	1.39	0.33	2.2
	C	7.40	0.08	0.33	0.05	0.35	0.05	0.7
Sg. Buloh (8)	Ap	4.10	1.08	0.52	1.64	0.51	3.54	5.9
	AC_3	4.20	0.71	0.52	0.08	0.94	5.17	9.3
Napai (15)	AII	3.80	1.17	1.25	1.68	0	7.02	12.2
	B_{23tcn}	4.00	3.36	4.89	0.32	0	29.62	53.1
Awang (17)	Ap	3.88	0.11	0.13	0.42	0	2.82	4.2
	B_3/BC	3.70	1.17	0.50	0.03	0	14.99	25.2
Holyrood (18)	Ap	3.91	0.94	0.88	1.92	0	12.64	21.2
	B_{23t}	4.15	1.50	1.44	0.15	0	21.86	34.6

It is thus expected that Al present on the exchange complex or in the solution will have some effect on the pH_o value.

The explanation is as follows. K will partially replace the Al on the surface and the replaced Al will hydrolyse and subsequently release H^+ into the solution. Without Al, the pH reported in column 1 (0.002N KCl) and column 2 (0.05N KCl) would have been higher. The effect is more important in column 2 than in column 1 because of a higher KCl concentration in the solution of column 2. It has been shown (Shamshuddin and Tessens, 1983a) that a more concentrated KCl solution extracted more Al than the less concentrated KCl solution. Thus, the pH_o obtained in this study would have been higher without the presence of Al (in the case where the sample was washed prior to the determination).

Effect of Weathering on pH_o

The correlation between pH_o and mineralogy is rather poor. The regression equation is given by:

$$pH_o = 3.91 + 0.0044\,(\%\ Kaol) - 0.00004$$
$$(Mica/Chlo). + 0.18\,(\%\ Gibb)$$
$$- 0.0059\,(\%\ Fe_2O_3)$$
$$F_{4;9} = 2.39, R^2 = 0.52$$

It is not significant at 5% level. But the correlation between pH_o and gibbsite alone is significant. The regression equation is given by:

$$pH_o = 3.96 + 0.185\,(\%\ Gibb)$$
$$F_{1;12} = 10.99^{**}, R^2 = 0.48$$

Thus gibbsite appears to be related to pH_o of these soils. This point is well illustrated by the soils of Sg. Buloh Series (7), in which the pH_o of C horizon is 7.4 (Table 4). This soil contains 50.5% gibbsite and 7.4% kaolinite in the clay fraction. According to Parks (1965), the pH_o of gibbsite and amorphous Al $2O_3$ is $5.0-5.2$ and $7-9$ respectively. These materials coat the sand grains and thus the soil appears as if it is dominated by gibbsite and/or amorphous Al_2O_3, hence giving it a high pH_o.

It is also seen that the pH_o in the studied soils fluctuates around 4 (Table 4). One possible explanation of the rather low values is due to the effect of organic matter and/or quartz, both of which have low pH_o.

pH_o reflects the stage of weathering of soils. This point is shown by the soils of Awang Series (17), in which the respective pH_o in the Ap and B3/BC is 3.88 and 3.70. This soil belongs to the recent stage of weathering. Soils of Kerayong (4) and Lintang Series (6) register higher values, indicating that these soils are more weathered than the Awang Series (17). The increase of pH_o with the increase of the stage of weathering has already been reported by Gallez et al., (1976). This phenomena can simply be explained by the fact that as the soil becomes more weathered, more sesquioxides are formed (not necessarily valid for Andepts).

Measurement of Charges in Soils

General Consideration

Point of zero net charge (PZNC) is the pH at which the net sum of charges of the mixed system is zero (Uehara and Gillman, 1980). This value can be obtained by ion adsorption measurement. Note that the pH_o defined earlier includes only the variable charge colloids; permanent charge colloids are not taken into account.

Permanent Charge (PC)

The surface chemistry of the variable charge colloids is largely controlled by the reaction of exposed AlOH and FeOH groups. SiOH, MnO_2 and TiO_2 and organic matter may also play a part.

At pH_o, it is assumed that the negative charges contributed by the variable charge colloids are equal to the positive charges because at this pH, equal amounts of negative and positive charges are absorbed. Provided that this assumption is correct, it is then possible to estimate the permanent charges on the colloids. Permanent charge is then:

$$PC = (Total\ Neg.\ Charges - Pos.\ Charges)\ at\ pH_o$$

To illustrate the application of the above equation, one is referred to *Figure 1,* where the charge characteristics of Holyrood Series (18) are given. In the Ap horizon, the pH_o is 3.91. At this pH, then K^+ adsorption is 1.93 meq/100 g soil and Cl^- adsorption is 0.40 meq/100 g soil. The permanent charge is then calculated to be 1.53 meq/100 g soil. Similarly, the PC of other horizons of other soils can be calculated.

The permanent charge of the soils under study is given in Table 5. These values are then compared with those obtained by another method. PC is sometimes defined as the sum of bases and $KCl - Al$. A t-test on paired observations was carried out to know if they measure the same value. The calculated value of t is 2.359, to be compared with $t_{0.05;15} = 2.131$. It is significant at 5% level. Therefore it can be concluded that the sum of bases and Al can be used to estimate PC in these soils.
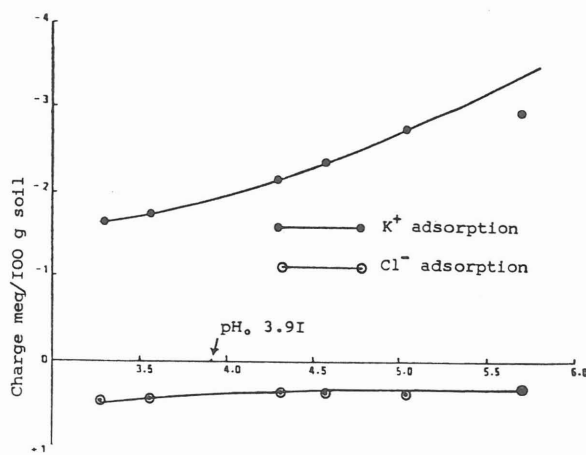

Fig. 1. *The change of negative and positive charge with pH in soil from Ap horizon of Holyrood Series (18).*

TABLE 5

Comparison between PC obtained by the net charges at pH_o and by sum of bases and Al

SERIES	HOR	PC (meq/100 g soil)	
		$(-ve - +ve) pH_o$	ALl + BASES
Nangka (1)	Ap	1.60	3.10
	B_{22}	1.05	3.75
Bt. Tuku (3)	Ap	1.29	2.91
	B_{22}	3.78	4.09
Kerayong (4)	Ap	5.30	6.44
	B_{22}	6.05	4.89
Lintang (6)	Ap	0.69	0.94
	B_{23}	0.88	0.78
Sg. Buloh (8)	Ap	0.58	1.80
	AC3	1.02	1.26
Napai (15)	All	1.00	2.19
	B_{23tcn}	3.57	3.91
Awang (17)	Ap	0.86	0.64
	B3/BC	2.34	1.80
Holyrood (18)	Ap	1.53	1.79
	B_{23t}	2.17	2.37

Change of Charge with pH

One distinct feature of the graph given in *Figure 1* is that the rate of increase of negative charges with pH is not compensated by the rate of decrease of positive charges. In the Ap, where the pH changes from 3.28 to 5.74 negative charges increase from 1.64 to 2.91 meq/100 g soil. This means that there is an increase of negative charges of 1.27 meq/100 g soil. But the corresponding decrease of positive charges, within the same pH range, is only 0.19 meq/100 g soil. The surface reactions, which tend to increase the net negative charges of the system, are in this case due to the organic matter.

Point of Zero Net Charge (PZNC)

For all the studied soils, the same pattern as that given in *Figure 1* is noted. Negative charges are always higher than the positive charges within the pH range under study. This implies that there is no point of equal negative and positive charges, and therefore PZNC as defined by Uehara and Gillman (1980) cannot be obtained within the pH range studied. This phenomenon is always encountered in soils dominated by permanent charge colloids (Arnold, 1978;

Zulkifli, 1981). Zulkifli (1981) also pointed out that soils with this characteristics seem to have less than 10% Fe and Al oxides.

Estimation of Mineralogical Composition

At pH$_o$, there are equal amounts of negative and positive charges adsorbed on the clay surfaced. The difference between the negative and positive charges, at this pH, is the PC of the soil. This PC comes from clay minerals; in this case mica, chlorite, vermiculite, smectite, mixed layers or even kaolinite.

The respective average PC of kaolinite and mica/chlorite are estimated at -0.02 and -0.2 meq/g clay (Tessens, 1982). Using these values, it is possible to estimate the amount of mica/chlorite present in the soil. Such an estimate is presented in Table 6. Note that it is not possible to estimate the total mineralogical composition of soil containing vermiculite and/or smectite as no fixed value for the charge of these minerals is given at the moment. Therefore the total mineralogical composition of Nangka Series (1), which contains some vermiculite, is not calculated.

TABLE 6

The permanent charge and the amount of kaolinite and mica and/or chlorite per 100 g soil

SERIES	HOR	TOTAL PC meq	KAOL %	PC KAOL meq	PC MICA/ CHLO meq	MICA/CHLO %
Bt. Tuku (3)	Ap	1.29	7.98	0.16	1.13	5.65
	B$_{22}$	3.78	18.77	0.38	3.40	17.00
Kerayong (4)	Ap	5.30	25.89	0.52	4.78	23.90
	B$_{22}$	6.05	26.32	0.53	5.52	27.60
Lintang (6)	Ap	0.69	8.31	0.17	0.52	2.60
	B$_{23}$	0.88	12.88	0.26	0.62	3.10
Sg. Buloh (8)	Ap	0.58	3.54	0.07	0.51	2.55
	AC3	1.02	5.17	0.10	0.92	4.10
Napai (15)	All	1.00	7.02	0.14	0.86	4.30
	B$_{23tcn}$	3.57	29.62	0.59	2.98	14.90
Awang (17)	Ap	0.86	2.82	0.06	0.80	4.00
	B3/BC	2.34	14.99	0.30	2.04	10.20
Holyrood (18)	Ap	1.53	12.64	0.25	1.28	6.40
	B$_{23t}$	2.17	21.86	0.44	1.73	8.65

As an example, take the case of the Ap horizon of the Holyrood Series (18) (Table 5). The PC of this soil is -1.53 meq/100 g soil. The amount of kaolinite in the clay fraction is 59.6% and the clay content in the soil is 21.2%. Therefore the amount of kaolinite in the soil is 12.64% (59.6 $\times$ 21.2%). PC due to kaolinite is -0.25 meq/100 g soil (12.64 $\times$ 0.02). This soil does not contain vermiculite, nor does it contain smectite. Therefore the -1.28 meq/100 g soil charge (1.53 $-$ 0.25) is due entirely to mica/chlorite. The amount of mica/chlorite in the soil is calculated to be 6.40% (1.28/0.2). The total mineralogical composition of this soil will be:

Mineral	%
Kaolinite	12.64
Gibbsite	0
Fe_2O_3	0.88
Mica/chlo	6.40
Silt + sand	65.40
Total	98.72

The quantitative estimate of the mineralogical composition of other soils is given in Table 7. It is seen that the total mineralogical composition of the studied soils varies from 96% to 105%. This means that the estimate of the % of kaolinite and gibbsite by thermal analyses and the estimate of charges on the clay surfaces are reasonably accurate.

Note that the soils of Lintang (6) and Sg. Buloh Series (8) do not show the presence of mica and/or chlorite in the untreated XRD samples. But when these samples were deferrified, for the study of anatase (Shamshuddin and Tessens; 1985), chlorite peaks appeared.

The Relationship Between Al and Mineralogy

The amount of Al present in the soil depends on the mineralogy. To test the validity of this assumption, the correlation between Al (KCl) and the minerals in the soil was determined. The regression equation is given by:

$$Al\,(KCl) = 0.30 - 0.02\,(\%\ Kaol) + 0.15\,(\%\ Mica/Chlo) - 0.087\,(\%\ Gibb) + 0.27\,(\%\ Fe_2O_3)$$

$$F_{4;8} = 11.44^{**},\ R^2 = 0.85$$

TABLE 7

Total mineralogical composition of the studied soils

SERIES	HOR	KAOL	MICA/CHLO	GIBB	Fe_2O_3	Si + S	TOTAL
		(g per 100 g soil)					
Bt. Tuku (3)	Ap	7.98	5.65	0.29	0.36	82.1	96.4
	B$_{22}$	18.77	17.00	0.13	1.04	68.5	105.4
Kerayong (4)	Ap	25.89	23.90	1.33	1.77	46.5	99.4
	B$_{22}$	26.32	27.60	1.03	2.29	45.6	102.8
Lintang (6)	Ap	8.31	2.60	1.28	0.57	85.9	98.7
	B$_{23}$	12.88	3.10	1.99	0.93	76.9	95.8
Sg. Buloh (8)	Ap	3.54	2.55	0.51	0.52	94.1	101.2
	AC$_3$	5.17	4.10	0.94	0.52	90.7	101.4
Napai (15)	All	7.02	4.30	0	1.25	87.8	100.4
	B$_{23tcn}$	29.62	14.90	0	4.89	46.9	96.3
Awang (17)	Ap	2.82	4.00	0	0.13	95.8	102.8
	B3/BC	14.9	10.20	0	0.50	74.8	100.5
Holyrood (18)	Ap	12.64	6.40	0	0.88	78.8	97.8
	B$_{23t}$	21.86	8.65	0	1.44	65.4	97.4

The regression equation with mica/chlorite is given by:

$$Al = 0.25 + 0.16\,(\%\ M/Chl),$$
$$R^2 = 0.83,\ F_{1;11} = 50.35**$$

The r value for the correlation with kaolinite is 0.78. The Ap horizon of Kerayong Series (4) is left out, as the soil has probably been disturbed by liming (pH in water is 5.9).

The Effect of Mineralogy on Charges

pH of the soil is taken to be the pH (1:1) in 0.01N KCl solution. The negative and positive charges present on the colloids at this pH were determined (Table 8). The negative charges are related to mineralogy by the equation:

$$\text{Negative charges} = 0.28 + 0.03\,(\%\ Kaol)$$
$$+ 0.21\,(\%\ M/Chl)$$
$$F_{2;4} = 352.7***,\ R^2 = 99$$

The regression equation with mica/chlorite is given by:

$$\text{Negative charges} = 0.59 + 0.24\,(M/Chl)$$
$$F_{1;5} = 353.7**,\ R^2 = 0.98$$

The r value for the correlation with kaolinite is 0.78.

Effective CEC

The negative charges at the pH of the soil are given in Table 8. Negative charge, as measured by K^+ adsorption, is a measure of the CEC of the soil. As this CEC is estimated at the soil pH, it is more appropriate to call it effective CEC (ECEC). The ECEC obtained by this method is then compared with Al plus bases given in Table 5. A t-test on paired observations was carried out to know if both measure the same value. The calculated value of t is 0.756, to be compared with $t_{0.50;7} = 0.711$. Thus there is only a slight difference between the ECEC obtained in this study and the sum of bases and Al. The sum of bases and Al can therefore be used as an estimate of the ECEC of the soil.

Earlier, it was found that the sum of bases and Al can be used to estimate PC. However, the level of significance of the t-test is lower in this case than for the t-test of bases plus Al with ECEC. Hence, it is better to use the sum of bases and Al as an estimate of ECEC than as an estimate of permanent charge.

Weathering Index

The negative and positive charges present in the soils can be used to calculate the weathering

TABLE 8
The charges on the studied soils at pH 0.01 N KCl

SERIES	HOR	pH (0.01 N) kcl	− CHARGE	+ CHARGE	NET CHARGE	WI
			meq/100 g soil			
Nangka (1)	B_{22}	4.4	1.72	0.48	− 1.24	72.1
Bt. Tuku (3)	B_{22}	3.9	4.21	0.79	− 3.42	81.2
Kerayong (4)	B_{22}	4.2	7.15	1.25	− 5.90	82.5
Lintang (6)	B_{23}	4.3	1.51	0.60	− 0.91	60.3
Sg. Buloh (8)	AC_3	4.2	1.33	0.53	− 0.80	60.2
Napai (15)	B_{23tcn}	4.0	4.37	0.80	− 3.57	81.7
Awang (17)	B3/BC	4.1	2.90	0.56	− 2.34	80.7
Holyrood (18)	B_{23t}	4.0	2.76	0.60	− 2.16	78.3

index of the soil. Weathering index is defined as (Tessens and Shamshuddin, 1982):

$$WI = \frac{net\ charge}{-\ charge} \times 100$$

Tessens (1982) uses this WI to define the stage of weathering of tropical soils:

WI	Stage of Weathering
+ 75	recent
75 − 50	intermediary
50 − 0	ultimate ($-$)
− 0	ultimate ($+$)

Based on this proposal, the 8 soils given in Table 7 are either in the recent or in the intermediate stage of weathering. A comparison of the stage of weathering based on this method with those of other methods points to similar conclusions.

The weathering index is an expression of the mineralogy of the soils. The lower the WI, the more weathered the soil. To confirm this, the correlation between the WI and the mineralogy was determined. The regression is given by:

$$WI = 63.25 + 0.78\,(\%\ Kaol) + 0.40$$
$$(\%\ Mica/Chlo) - 6.5\,(\%\ Gibb)$$
$$- 2.3\,(\%\ Fe_2O_3)$$
$$F_{4;2} = 18.93**,\ R^2 = 0.97$$

The individual r value in order of importance is kaolinite $>$ mica/chlorite $>$ gibbsite $>$ Fe_2O_3. As expected, phyllosilicates increase WI, while sesquioxides decrease it.

CONCLUSION

pH_o of T_2 terrace soils is higher in the Ap than in the B horizons. This is due to the effect of organic matter. Gibbsite is related to the pH_o of the studied soils. pH_o occurs around 4 and WI varies from 60% to 80%, indicating that the soils are either in the recent or intermediate stage of weathering. It is found that negative charges exceed positive charges within the pH range of 3 to 6. This study shows that the sum of Al and bases is a better estimate of ECEC that of the PC of the soils.

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