CORRELATIONS OF PHYSICAL AND CHEMICAL PROPERTIES OF EASTERN GRANITIC SOILS OF PENINSULAR MALAYSIA

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Correlations of Physical and Chemical Properties of Eastern Granitic Soils of Peninsular Malaysia

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Abstract

Residual soils are formed from weathering process of rocks. In Malaysia, specifically, climate conditions, high temperature and extreme distribution of rainfall expedite the formation of residual soils via chemical and physical weathering. Research on some of chemical composition, mineralogy and microstructure of residual soils, in spite of its important, is still lacking in Malaysia. Properties on mineralogy, microstructure and microfabric and chemical composition can be correlated to physical and engineering characteristics of residual soils. They can also be used in the design of structures placed on and in residual soils. The objective of this research is to determine some of the chemical composition, mineralogy and microstructure of granitic residual soil, as well as to form related correlation charts. The samples of granitic residual soils samples were obtained at various depths at Pulau Chondong, Kelantan in Peninsular Malaysia. The Scanning Electron Microscopy (SEM) and X-Ray Fluorescent (XRF) are used to analyze the mineralogy, microstructure and microfabric of granitic soils. The pH meter and Spectrophotometer are used in determining the chemical compositions and parameter of the residual soils. The results show that quartz and kaolinite are two major minerals present in the granitic residual soils while montmorillonite, illite and muscovite are the minor minerals. The presence of kaolinite minerals forms microfabric of flaky shape whereas quartz exists in granular form with clothed contacts. The study on microstructure of the residual soils show the existence of clay matrix with pH values of between 4.34 to 6.93, which indicate that the residual soils are acidic. The concentration of sulphate and chloride are in the range of 2.21 ppm to 17.58 ppm and 6 ppm to 75 ppm, respectively. The test results also show that the concentration of anion increases while the cation decreases with increasing distance from the surface of clay minerals. The values of cation exchange capacity (CEC) for the soil samples were found to be in the range 0.34 meq/100 g to 12.88 meq/100 g. The correlation between CEC vs pH values, loss on ignition (LOI) versus aluminium oxides (Al_2O_3), sulphate and chloride contents with depths, are developed for soils samples of the Eastern part of Peninsular Malaysia. The results show that CEC values are influenced by the high pH values. The sulphate and chloride, both found existed in the granitic soil samples, increase with depth. The correlation between Silicon Oxide and plasticity index is found to be inversely related; this is due to the existence of quartz minerals which reduce the plasticity of soils, whereas Al_2O_3 and Fe_2O_3 in clay minerals increase the plasticity of soils.

Keywords: physical properties, chemical properties, granitic soils, mineralogy, oxides elements.

1.0 Introduction

The physical weathering processes, which act on granite rocks include unloading and frost action. Rahn (1986) state that, chemical weathering plays an important role on decomposition of granite in Malaysia.

The residuals soils are formed by the weathering of different parent rocks. Most of the residual soils around the world are normally found in tropical regions (Aung *et al*, 2000). The residual soils too, are so much different from the sedimentary soils because they are formed from in-situ response to the local material, climate, topography and drainage conditions. Figure 1 shows the distribution of granitic soils in Peninsular Malaysia.

This paper discusses the physico-chemical composition and mineralogy of granite residual soils from Pulai Chondong, Kelantan.

2.0 Backgrounds and Literature Review

Aminaton *et al* (2001a) states that the annual rainfall data in Malaysia are in the range of 1778 mm to 3556 mm with wet tropical conditions, and daily temperature is 23°C to 32°C. With those wet conditions and high daily temperature, the weathering of granites in Malaysia will occurs rapidly. Some of geotechnical problems and failure to the hill slopes and structure foundations, are occurs in granite residual soils (Mohd Raihan *et al*, 1997).

Minerals make up 50 % of the volume of most soils. They provide physical supports for plants and create the water and air filled pores that make plant growth possible. Mineral weathering releases plant nutrients that are retained by other minerals through adsorption, cation exchange and precipitation. Minerals are indicators of the amount of weathering that has taken place and the presence or absence of particular minerals gives clues as to how soils formed. The physical and chemical characteristics of soils minerals are important considerations in planning, constructing and maintaining buildings, roads and airports.

In Malaysia, chemical weathering plays important roles. The process of chemical weathering involves; (i) the reaction of the original minerals of the rock with water, oxygen and organic acids at the earth's surface so that they are broken down chemically with the production and release of new products, some of which are soluble; (ii) the dissolving of these soluble products by water present in cracks in the rock and their eventual removal from it, and (iii) the continued reaction of the insoluble rock constituents with water, carbon dioxide, oxygen and other atmospheric gases to form stable new assemblages of minerals (Mclean and Gribbles, 1984).

As for research based on mineralogy and chemical compositions in Peninsular Malaysia, there are very limited. Table 1 shows the previous researches dating from1969 until 2002 based on pH values, sulphate (SO_4^{2-}) and chloride (Cl^-) concentration, major weight elements and major relative minerals distribution.
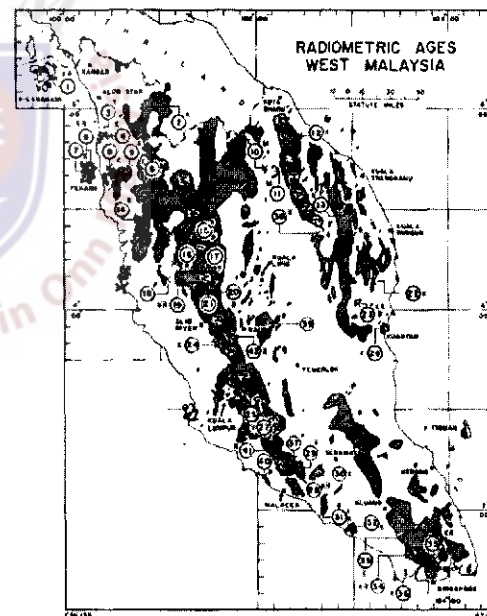

Figure 1: Distribution of Granitic Soils in Peninsular Malaysia (Hutchison and Gobbett, 1973).

Table 1a: Previous Researchers based on Chemical Compositions of Granite Residual Soils of Peninsular Malaysia

Researcher and Soil Sampling	pH Value	SO_4^{2-} (ppm)	Cl⁻ (ppm)
Za-Chieh & Mirza (1969); Thailand	3.85 – 5.77	-	-
Tan (1996); Pen. Malaysia	4.60 – 7.80	0.5 – 45.5	7.09 – 202.1
Mohd Raihan *et al* (1997); Pen. Malaysia	4.50 – 6.00	-	-
Aminaton *et al* (2001a); Southern part of Pen. Malaysia	5.30 – 5.58	-	-
Aminaton *et al* (2001b); Southern Part of Pen. Malaysia	4.68 – 5.92	-	12 – 75
Aminaton *et al* (2002a); Northern part of Pen. Malaysia	5.19 – 6.75	3.26 – 17.58	12 - 26
Aminaton *et al* (2002b); Northern part of Pen. Malaysia	4.69 – 6.33	-	-
Aminaton *et al* (2002c); Eastern part of Pen. Malaysia	-	2.21 – 12.13	7 - 25

-: No research has been conducted

Table 1b: Previous Researchers based on Chemical Compositions of Granite Residual Soils of Peninsular Malaysia.

Researcher and Soil Sampling	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)
West & Dumbleton (1970); Sem. Malaysia	70 - 72	12 – 14	3 – 4
Hamzah & Abdul Ghani (1993); Pen. Malaysia	66 – 69	19 – 20	1.25 – 1.6
Aminaton *et al* (2001b); Southern Part of Pen. Malaysia	38.9 – 87.4	2.5 – 35.2	1.3 - 13.5
Aminaton *et al* (2002b); Northern part of Pen. Malaysia	37.3 – 62.0	19.6 – 32.6	5.5 – 14.7

-: No research has been conducted

Table 2a: Previous Researchers based on Physical Compositions of Granite Residual Soils of Peninsular Malaysia

Researcher and Soil Sampling	Clay (%)	k (1x10 m/s)	w (%)
Chan & Chin (1972); Central part of Pen. Malaysia	35 ~ 53	$1.4x10^{-8}$ ~ $7.8x10^{-8}$	-
Balasubramaniam *et al* (1985); Malaysia	20 ~ 60	$5x10^{-8}$ ~ $5x10^{-9}$	-
Todo & Pauzi (1989); Malaysia and Singapore	0 ~ 50	$1x10^{-7}$	-
Tan & Ong (1993); Northern part of Pen. Malaysia	20 ~ 35	-	-
Kepli (1994); Southern part of Pen. Malaysia	10 ~ 45	-	-
Affendi *et al* (1994a,b); Central part of Pen. Malaysia	32 ~ 48	-	-
Tan (1995); Pen. Malaysia	0 ~ 56.9	-	-
Taha *et al* (2002); Centrel part of Pen. Malaysia	49	-	-
Aminaton *et al* (2002); Eastern part of Pen. Malaysia (WEC2002)	16 ~ 44	-	19 ~ 46
Aminaton *et al* (2002); Southern part of Pen. Malaysia (CTMC2002)	6 ~ 39	2.87 ~ 17.94	14 ~ 44

-: No research has been conducted

Table 2b: Previous Researchers based on Physical Compositions of Granite Residual Soils of Peninsular Malaysia

Researcher and Soil Sampling	LL (%)	PL (%)	PI (%)
Chan & Chin (1972); Central part of Pen. Malaysia	33 ~ 50	19 ~ 33	12 ~ 18
Balasubramaniam *et al* (1985); Malaysia	35 ~ 110	-	15 ~ 70
Tan & Ong (1993); Northern part of Pen. Malaysia	68 ~ 96	40 ~ 50	40 ~ 50
Affendi *et al* (1994a,b); Central part of Pen. Malaysia	56.2 ~ 102	30 ~ 55.1	-
Tan (1995); Pen. Malaysia	29 ~ 96	18 ~ 49	1 ~ 53
Aminaton *et al* (2002); Eastern part of Pen. Malaysia (WEC2002)	46 ~ 86	18 ~ 34	-
Aminaton *et al* (2002); Southern part of Pen. Malaysia (CTMC2002)	52 ~ 74	21 ~ 46	-

-: No research has been conducted

3.0 Soil Samples for Study

The residual soils in this study are taken from Pulau Chondong, Kelantan in Malaysia. Samples have been taken at 1.0 m depth to 4.5 m depth dan it has been coded as it is shows at Table 3. All samples were tested for chemical composition and mineralogy using the SEM, XRD, XRF, AAS, Spectrophotometer DR4000 and meter pH. The preparation of samples for testing needs a special method and some existing methods are not suitable for the tested samples.

4.0 Results and Discussion

Sodium is most common monovalent cation, naturally occurring, with Ca^{2+} and Mg^{2+} the most common divalent cation. Using the SAR equations which has been stated before, it could be stated that the SAR values decrease with increasing depth and it is in range of 3.15 ppm to 3.48 ppm (Table 4). These SAR values are supported with Na^+, Ca^{2+} and Mg^{2+} values, which those concentration values are shown at Table 5. While others, Na_2O and CaO are in range of 0.22 ppm to 0.32 ppm and 0.22 ppm to 0.32 ppm, respectively.

From Table 4, it shows that the pH values decrease with increasing depth. It shows that the upper layer of soils contains higher H^+ ions concentrations than the lower layer. From the experimental works, the pH is in range of 5.27 to 6.33 where clay particles contain OH^- out in the open on their surfaces and edges (Mitchell, 1993). Besides, the tendency for the hydroxyls to dissociate in water strongly influenced by the pH. The higher the pH, the greater the tendency for the H^+ to go to solution and therefore the greater the effective negative charge of the particle. pH values is also can be as an indicator for existence of certain mineral in soils (Shamsudin, 1983). Results show that the pH values for all the soil samples are less than 6.50. Based on past research which had been conducted by Mohd Raihan *et al* (1997), the pH values are in the same range of this research, which is 4.50 to 6.00.

From Table 5, it also shows the concentration of sulphate and chloride is increase with increasing depth for all the soil samples. It shows the sulphate and chloride concentration are in range of 3.34 ppm to 12.13 ppm, and 7 ppm to 25 ppm, respectively. Based on Tan (1996) research, the maximum concentration of sulphate and chloride is 46 ppm and 202 ppm, respectively. These values are higher than the researcher values. Nevertheless, the sulphate and chloride as an anion concentration, is presence in granite residual soils and has a low values at shallow depth.

The correlation between these SAR with depth and other physico-chemical composition, are shows from Figure 2 to Figure 11. While the correlation between SAR with depth shows the coefficient of correlation, R^2, is 0.40, which is this value indicated a medium good correlation. Besides that, the correlation between SAR and percentage of clay contents, and also SAR and permeability, k, the R^2 values indicated that the correlation are medium good and poor. Based on Aminaton (1996), she defines where:-

(i). If $R^2 < 0.25$, the determination of correlation is poor.

(ii). If R^2 is in range between 0.25 to 0.55, determination of correlation is medium good.

(iii) If R^2 is in range between 0.55 to 0.80, determination of correlation is good.

(iv). If $R^2 > 0.80$, the determination of correlation is very good.

The term cation exchange is preferred over the term base exchange, since the reaction also involves H^+ ions. The hydrogen ion is a cation but not a base. The adsorbed cation can be exchanged by other cation, hence the cation are also

called exchangeable cation. The process of replacement is called cation exchange. Table 4 shows the samples from Pulai Chondong, Kelantan in the range of CEC from 5.42 meq/100 g to 12.88 meq/100 g (Table 4). The correlation (1), (2) and (3), shows the coefficient of correlation, R^2, are 0.40 (medium good), 0.53 (medium good) and 0.10 (poor), respectively. Therefore, the correlation which has been produced is:-

$$D = 4536(SAR)^{-6.16} \qquad (1)$$
where D = depth; SAR = sodium absorption ratio.

$$SAR = 0.01(Clay \%)^{6.86} \qquad (2)$$
where SAR = sodium absorption ratio; Clay % = percentage of clay particles presence through samples.

$$SAR = 0.0029e^{2.80k} \qquad (3)$$
where SAR = sodium absorption ratio; e = void ratios.

Besides that, the correlation between SAR and pH values, shows the coefficient of correlation, R^2, is 0.36, which is this values indicated a medium good correlation. From Mitchell (1996), he states that the SAR values, is affected by pH values for its substitution of cation. From Figure 5 and 6, it shows that the SAR values are increase with increasing cation concentrations and also percentages of oxide elements. Eventhough the correlation is poor and medium good, this correlation are based on cation concentrations affecting the double layer systems inside the granitic soils. Mitchell (1996) states that, the higher Na^+ concentration in the soil, it will create the large double layer systems in the soils, while as for Ca^{2+} concentration, as higher the values, the double layer systems will be thin. The correlation (4) to (8); shows the coefficient correlation, R^2, is in the range of 0.13 (poor) to 0.51 (good).

Therefore, the correlation which has been produced are:-

$$SAR = 2.03(pH)^{0.88} \qquad (4)$$
where SAR = sodium absorption ratio; pH = pH value.

$$SAR = 9.82(Na)^{1.31} \qquad (5)$$
where SAR = sodium absorption ratio; Na = natrium concentration.

$$SAR = 0.12(Ca)^{3.49} \qquad (6)$$
where SAR = sodium absorption ratio; Ca = calcium concentration.

$$SAR = 0.12(CaO) - 0.12 \qquad (7)$$
where SAR = sodium absorption ratio; CaO = calcium oxides.

$$SAR = 0.09(NaO) - 0.01 \qquad (8)$$
where SAR = sodium absorption ratio; NaO = natrium oxides.

The correlation between LL, PL and PI with SAR, all of them shows that the R^2 is 0.68 (good), 0.73 (good) and 0.50 (medium good). The range of PI percentages for all the samples is in range of 28 % to 33 %. While, the range for LL and PL percentages is 46 % to 55 % and 18 % to 22 %, respectively. While from Table 6, it also shows the mositure contents, w, which is in the range of 28 % to 46 %. The correlation between SAR and Atterberg limits, shows the coefficient correlation, R^2, is 0.68 (medium good), 0.50 (medium good) and 0.73 (good), respectively.

Therefore, the correlation which has been produced is:-

$$SAR = 17.54(LL) - 6.77 \qquad (9)$$
where SAR = sodium absorption ratio; LL = liquid limit.

$$SAR = 7.26(PL) - 3.27 \qquad (10)$$

where SAR = sodium absorption ratio; PL = plastic limit.

$$SAR = 10.27(PI) - 3.51 \qquad (11)$$

where SAR = sodium absorption ratio; PI = plasticity index.

The correlation between average depth of soil samples, D, with pH values and anion concentrations, shows the coefficient of correlation, R^2, is in the range of medium good to good. Therefore, the correlation which has been produced is:-

$$D = 16.78 - 2.34(pH) \qquad (12)$$

where D = depth; pH = pH values.

$$D = 0.37(SO_4^{2-}) + 0.59 \qquad (13)$$

where D = depth; SO_4^{2-} = sulphate concentration.

$$D = 0.17(Cl^-) + 0.5 \qquad (14)$$

where D = depth; Cl^- = chloride concentration.

Mitchell (1996) states that soil has a capability to exchange (cation) with solution whereas the entire environment in soil has the other kind of ions. Cation exchange is occurred based on several factors. Those factors are isomorphous substitution, broken bonds and replacement of ions by the other ions. On the hand, there will be associated double changes, hence mechanical changes, which is especially if valency of ions differs. The correlation between pH values with cation concentrations shows the coefficient of correlations, R^2, is in the range of 0.21 (poor) to 0.64 (good).

Therefore, the correlation which has been produced is:-

$$Ca^{2+} = 53.04(pH) + 93.89 \qquad (15)$$

where Ca^{2+} = calcium concentration; pH = pH value.

$$Na^+ = 6.64(pH) + 8.56 \qquad (16)$$

where Na^+ = natrium (sodium) concentration; pH = pH value.

$$Mg^{2+} = 8(pH) - 37.96 \qquad (17)$$

where Mg^{2+} = magnesium concentration; pH = pH value.

While, the correlation between CEC with pH values, shows the coefficient of correlations, R^2, is 0.75 (good). Therefore, the correlation which has been produced is:-

$$CEC = 5.72(pH) - 24.39 \qquad (18)$$

where CEC = cation exchange capacity; pH = pH value.

Table 3: Codes of samples for the study

No.	Locations	Codes	Depth (m)
1		DA1	1.5 ~ 2.0
2		DA2	3.0 ~ 3.5
3	Pulai Chondong,	DA3	4.0 ~ 4.5
4	Kelantan	DB1	1.5 ~ 2.0
5		DB2	3.0 ~ 3.5
6		DB3	4.0 ~ 4.5

Table 4a: Chemical Compositions Value

Samples	Na$_2$O (%)	CaO (%)	CEC (meq/100 g)
DA1	0.28	0.30	9.54
DA2	0.30	0.30	7.24
DA3	0.27	0.27	5.42
DB1	0.25	0.25	12.88
DB2	0.32	0.32	9.06
DB3	0.22	0.22	8.81

Na$_2$O: Natrium Oxide; CaO: Calcium Oxide; CEC: Cation Exchange Capacity

Table 4b: Chemical Compositions Value

Samples	SAR (ppm)	pH
DA1	3.48	5.80
DA2	3.15	5.78
DA3	3.15	5.27
DB1	3.32	6.33
DB2	3.46	6.11
DB3	3.21	5.57

SAR: Sodium Absorption Ratio.

Table 5a: Cation Concentrations

Samples	Na^+ (ppm)	Ca^{2+} (ppm)	Mg2+ (ppm)
DA1	51.85	8.03	437.20
DA2	45.73	7.58	413.50
DA3	44.73	6.78	395.73
DB1	51.08	15.63	457.45
DB2	47.60	8.63	370.85
DB3	41.98	4.43	337.38

Na^+: Natrium; Ca^{2+}: Calcium; Mg^{2+} : Magnesium.

Table 5b: Anion Concentrations

Samples	SO_4^{2-} (ppm)	Cl^- (ppm)
DA1	3.34	8
DA2	7.29	16
DA3	9.16	23
DB1	3.60	7
DB2	6.83	17
DB3	12.13	25

SO_4^{2-}: Sulphate; Cl^-: Chloride.

Table 6a: Physical Compositions Value

Samples	Clay (%)	k (1×10^{-9} m/s)	w (%)
DA1	26	1.764	28
DA2	16	1.899	28
DA3	18	0.533	38
DB1	44	4.690	39
DB2	41	5.419	43
DB3	23	9.859	46

Table 6b: Physical Compositions Value

Samples	LL (%)	PL (%)	PI (%)
DA1	55	22	33
DA2	50	20	30
DA3	46	18	28
DB1	53	22	31
DB2	52	21	31
DB3	50	21	29
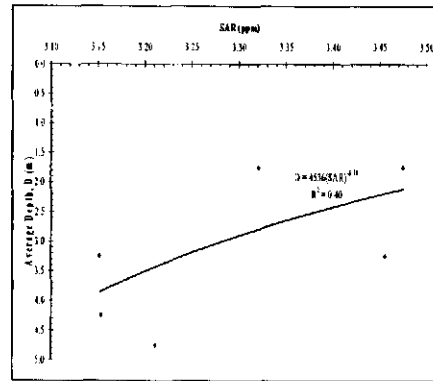
Figure 2: Correlation of SAR and Depth
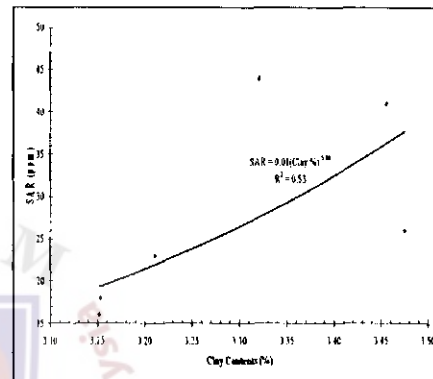
Figure 3: Correlation of SAR and Clay Contents
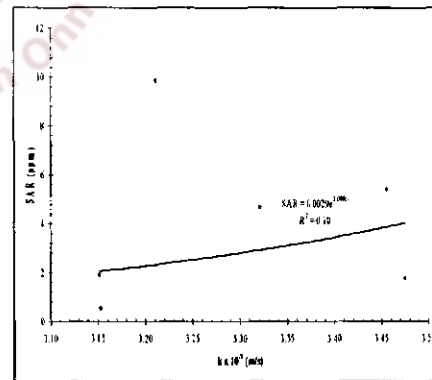
Figure 4: Correlation of SAR and Permeability
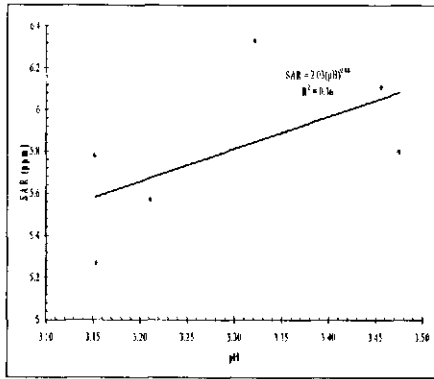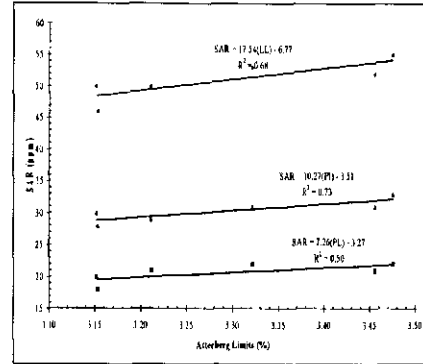
Figure 5: Correlation of SAR and pH Values

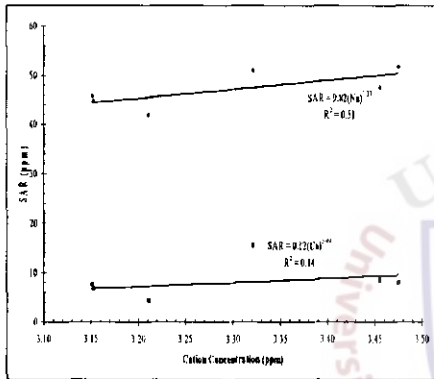**Figure 8: Correlation of SAR and Atterberg Limits**

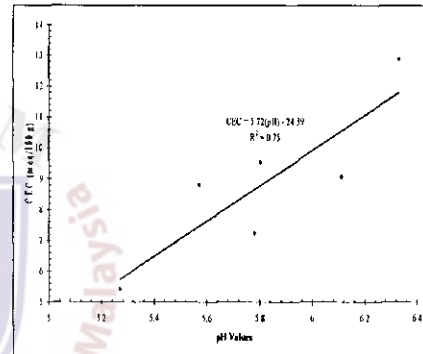**Figure 6: Correlation of SAR and Cation Concentrations**
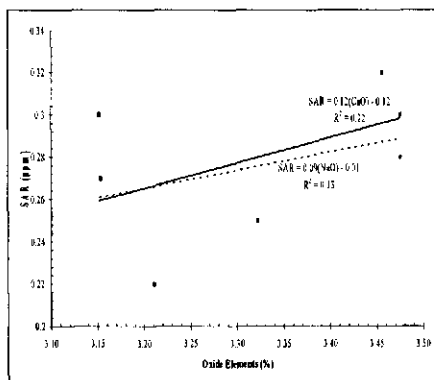

Figure 9: Correlation of pH values with CEC
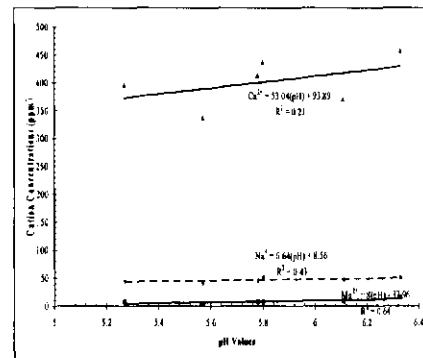

Figure 10: Correlation of pH Values with Cation Concentrations

Figure 7: Correlation of SAR and Oxide Elements

5.0 Conclusions

From the study, the conclusions are:
(i).   The range of pH values for all the soil samples at is 5.27 to 6.33. It shows that the granite residual soils is acidic.
(ii)   For sodium absorption ratio (SAR), it is in range of 3.15 ppm to 3.48 ppm. It shows that the SAR values decrease with increasing depth.
(iii).   For Na_2O and CaO percentages, it found that the range are 0.22 % to 0.32 % and 0.22 % to 0.32 %, respectively.
(iv).   For sulphate and chloride concentration, it found that the range for both anion concentration are 3.35 ppm to 12.13 ppm and 7 ppm to 25 ppm, respectively.
(v)   While for sodium, calcium and magnesium concentration, it found that the range are 41.98 ppm to 51.85 ppm, 4.43 ppm to 15.63 ppm, and 337.38 ppm to 457.45 ppm, respectively.

Acknowledgements

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