

FTIR and XRD Analyses of Highly Weathered Ultisols and Oxisols in Peninsular Malaysia

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ABSTRACT— For this study, four soil series with two depth levels (0-15cm, 15-30cm) were collected namely: Bungor, Kuala Brang, Segamat and Kuantan Series. The former two represent Ultisols, while the latter two represent Oxisols in Malaysia. All the samples were subjected to Fourier transmission infrared (FTIR) and X-ray diffraction analysis to determine the functional groups and mineralogical composition. All the soils were found to be acidic in nature (pH 3-5) with Al toxicity, which is an indication of low fertility. From the FTIR analysis, hydroxyl (OH) functional group showed the presence of kaolinite $[Al_2Si_2O_5(OH)_4]$, halloysite and gibbsite $[Al(OH)_3]$ in both Ultisols and Oxisols. In addition, the carboxylate (C=O) stretching band (Si-O) silicate impurities confirmed the dominance of kaolinite in both soil types. The XRD analysis showed the presence of kaolinite as the major constituent in both Ultisols and Oxisols under study. Besides that, gibbsite, quartz and mica were common in the Ultisols, while mica, goethite and hematite were in trace amount in the Oxisols. Cation exchange capacity which ranged from 7.5 to 12 $cmol\cdot kg^{-1}$ were low for all the soils, while exchangeable Al were above the threshold value for the growth of Al sensitive crops. This may indicate the potential of Al toxicity in the soils. Base saturation was in the range of 1.3 to 10.9%, which was very low. All soils were deficient in available P ($<9.96\text{ mg kg}^{-1}$). Meanwhile, free iron (Fe_2O_3) contents were the lowest in Bungor (43 g kg^{-1}) and the highest in Kuantan with the value of 419 g kg^{-1} , indicative of hematite dominance shown supported by XRD analysis. Analysis of variance showed significant differences among exchangeable base cations, carbon, nitrogen and Fe oxides in the topsoil at $p<0.05$. The soils were acidic and too low in macronutrients (Ca^{2+} , Mg^{2+} and K^+) to sustain agricultural production. Thus, applying appropriate amendments and/or fertilizers containing necessary nutrients is required to enhance soil fertility for crop production.

Keywords— Aluminium toxicity, FTIR spectroscopy, highly weathered soil, Oxisol, Ultisol

1. INTRODUCTION

Acidic soils dominates about 30% of the global soils [1]. They are often developed under udic or ustic moisture regimes marked as Ultisols and Oxisols [2] soil Order, often located within 5-10° latitude of the Equator [3]. At this latitude, weathering process is intense resulting in low cation retention (Ca, Mg and K) which has significant role to play in crop growth and development. The deficiency in nutrients (Ca, Mg and P) and Al toxicity under the condition of low pH become a major constraint for the productivity of Malaysian Ultisols and Oxisols [4]. In Malaysia, Ultisols and Oxisols occupy about 72% of the country's land surface that are scattered in the upland area with flat to undulating terrains, with kaolinite, hematite, goethite and gibbsite as major minerals present in these highly weathered soils. The hematite and gibbsite form the significant part of the clay fraction, providing positive charges in the well-drained Ultisols and Oxisols [5]. Ultisols and Oxisols constitute 36.2% of the tropical aerial extent, thus 16.0% of the first and 20.2% of the latter [6]. However, Ultisols are found to be more common than Oxisols worldwide, but in the tropics, Oxisols tend to be more common compared to Ultisols.

The mineralogy of highly weathered soils has strong influence on soil fertility condition [7]. Soils with high amount of Al can lead to soil-plant toxicity interaction; thus, the study of the mineralogical composition and their functional groups in the Ultisols and Oxisols can give better understanding of the soil condition. These soils exhibit low pH values [8], often related to soil acidification process. It involves solubilisation of aluminium and the loss of cation nutrients from the soil [9, 10]. These give rise to the problem of aluminium toxicity and hence becoming a major growth limiting factor in acid, highly weathered soils [11]. Malaysian Ultisols and Oxisols are usually clayey in texture. Some Ultisols were

found to be sandy clay loam or silty clay with varying structures. The presence of oxides serving as cementing agents results in low water holding capacity; hence, unfavourable for crop production [5].

The main rationale in employing the Fourier transform or transmission infra-red spectroscopy (FTIR) is its non-destructive nature that requires minimum sample preparation [12], which enables to identify the functional groups in a soil sample. This technique does not involve the use of any precarious chemicals in identifying the functional groups which are well associated with soil fertility status. Thus, it provides quantitative information in a rapid and accurate fashion [13]. For example, high amount of hydroxyl group in a soil sample can indicate dominance of negative charge in the soils. Using FTIR, the difficulties in extraction procedures which may distort original soil properties are eliminated [14]. This is because all of the frequencies are measured simultaneously. Most measurements by FTIR are made in a matter of seconds [15] and can accommodate large number of samples. This provides a powerful tool for the discrimination and identification or even quantification of single component such as mineral in soils [16, 17, and 18]. Fourier transform infrared spectroscopy is an alternative technique for qualifying the interactive effect of soil clay and soil organic materials [19]. It is a physical process centred on the interactions of infrared radiation with matter.

X-ray diffraction technique, on the other hand, was used to identify minerals in the clay fraction of the soils under study. This technique provides detailed information about the atomic structure of crystalline substances in soils. X-ray diffractometry is qualitative/quantitative method of mineralogical assessment in the form of relative diffraction intensities; the detection limit varies with the kind of mineral and degree of crystallization. The bulk of the clay fraction of many soils is crystalline, but clay particles are too small for optical crystallographic methods to be applied. Therefore, this makes XRD analysis unique and becomes a mainstay in the identification of clay-sized minerals in soils as well as coarser soil fractions [20]. It provides an unambiguous mineral determination with relatively straight forward data interpretation, consequently the most applicable to soil mineralogy [7].

The foregoing explained the suitability of FTIR Spectroscopy and XRD analysis for mineralogical characterization of Ultisols and Oxisols, providing an overview on the distribution of clay mineral assemblages. By combining FTIR and XRD methods, it is possible to record the modal (realistic) composition of the mineralogical constituents with adequate accuracy and also to correlate them with their chemical composition. Therefore, the objectives of this study were: i) to determine the functional groups (FTIR) and mineralogical composition (XRD) of the selected Ultisols and Oxisols in Peninsular Malaysia; and ii) to determine the physical and chemical characteristics of the soils. The functional group data in the Ultisols and Oxisols, coupled with XRD data can shed light on the relationship between minerals and soil fertility status.

2. MATERIALS AND METHODS

2.1 Description of location and soil samples

A total of four sampling sites in the Peninsular Malaysia were selected for the current study (Figure 1). At each site, soil samples were collected at two depth; 0-15 cm (topsoil) and 15-30 cm (sub-surface) using a soil auger. The surface samples were designated as Ap and the subsurface as B horizons in typifying the pedon with different morphological characteristics [21]. Detailed description of the sampling sites are given in Table 1. Peninsular Malaysia is in the hot and humid tropical region with average annual rainfall of 2500-3000 mm/year, and the temperature ranges between 25 and 35°C throughout the year. Relative humidity often ranges between 80 and 90 %. Köppen-Geiger climatic system classifies Peninsular Malaysia as *Af*, that is tropical rainforest climate. Selection of sampling sites was based on soil pH and mineralogical properties, which are important fundamentals in soil-crop productivity and sustainability.

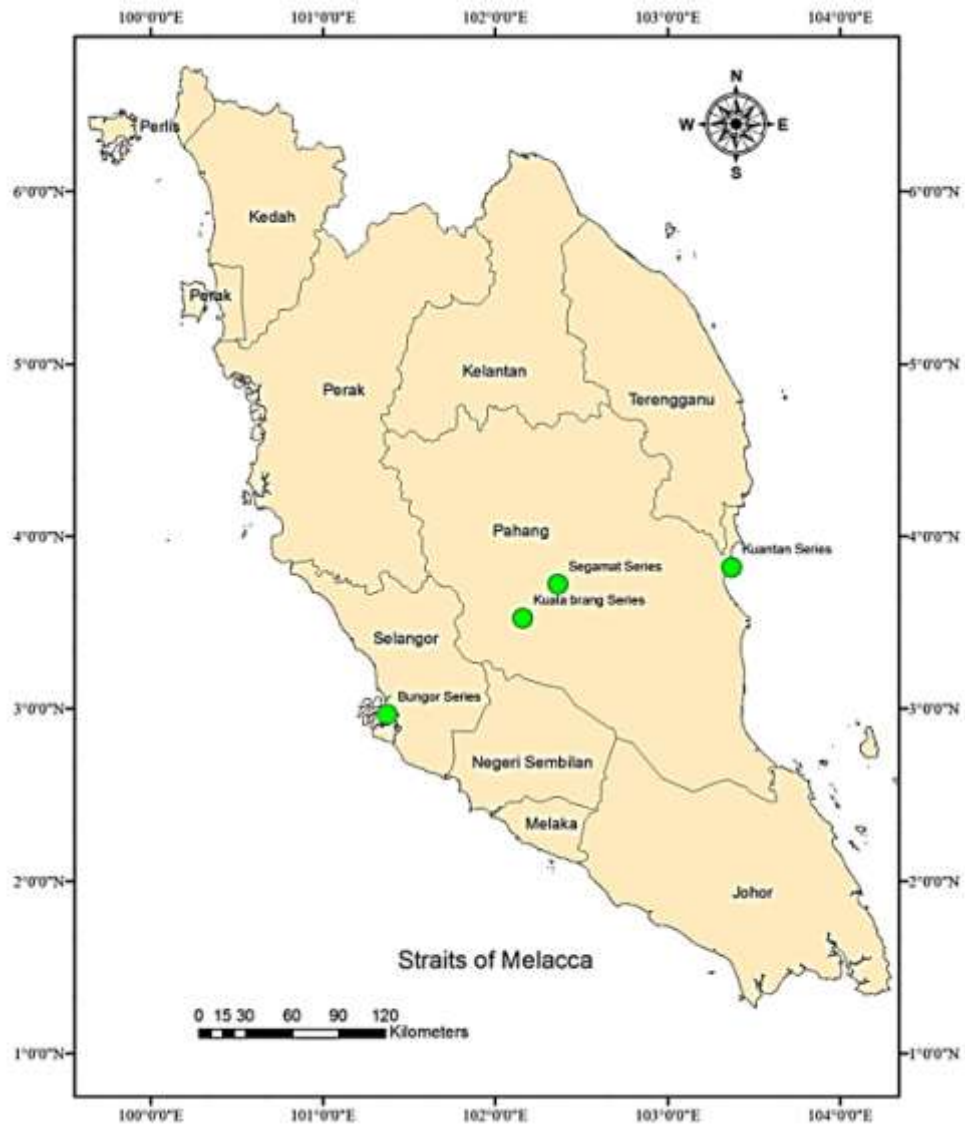


Figure 1: Location of the sampling sites in Peninsular Malaysia (marked green)

Table 1: Vital information about the sites and soils under study

Series	Parent Material and Depth	Coordinates	Mean Temp. (°C)	Mean Annual Rainfall (mm)	Land Use and Vegetation	and Geology
Bungor (Typic Paleudult)*	Shale ^a (<150 cm)	2°58.844 N; 101°2.722 E	22.5 ^d (1985-2004)	2426.4 ^d (1985-2004)	Common crops planted includes: rubber, oil palm, fruit trees and cocoa with some areas under primary forest vegetation. ^a	Quaternary deposits of Cenozoic Era ^e
Kuala Brang (Typic Paleudult)*	Shale ^a (<150 cm)	3°31'32.04"N; 102°09' .37.76"E	na	na	Fruit trees are dominant. Cocoa in some areas others under primary forest vegetation.	Pyroclastic tuff and agglomerate with minor lava flows (Late Paleozoic to Early) ^e Mesozoic. ^e
Segamat (Rhodic Hapludox)*	Andesite ^a (<100 cm)	3°43'22.36" N; 102°21' .56.75" E	na	na	Rubber and oil palm are the commonest crops. Tapioca, maize and sorghum occasionally grown on these soils. ^a	Quaternary sediments of Cenozoic Era ^e
Kuantan (Typic Hapludox)*	Basalt ^a (<100 cm)	3°49'15.64" N; 103°2' .21.87" E	23.2 ± 1.0 ^b (1981-2008)	2969 ^b (1981-2008)	Forest most of the areas have been developed for agriculture. The common crops are fruit trees rubber, and oil palm. ^a	Early Pleistocene ^e

a- [21]

b- Kuantan Meteorological station

c- Temaloh Meteorological station

d- Selangor Meteorological station

e- [22]

na- not available

*Soil classification given in parentheses based on Soil Taxonomy (23)

2.2 Physical and chemical analysis

Physical analysis

Particle-size analysis was carried out using the pipette method [24]. The soil textural classification was based on Soil Taxonomy [23] which described the size of clay (< 2µm), silt (2 – 50 µm) and sand (50 – 2000 µm). Bulk density (the ratio of the mass of dry solids to the bulk volume of the soil) was determined using a core ring method. The core ring (7.62 cm diameter ring) was hammered evenly into the soil at depth of 20 cm then gradually removed to keep the volume of the sample, then dried at 105°C, weighed and calculated following the formula described by [24] and expressed as g cm⁻³: $Db = \text{Weight of soil, dried at } 105^{\circ}\text{C} / \text{Volume of soil}$. Soil porosity was determined by dividing the bulk density over the particle density and expressed in percentage (%).

Chemical analysis

Soil pH was determined in soil-water solution at ratio of 1:2.5 [25] using 10 g air-dried samples sieved through 2-mm sieve. The samples were weighed into a plastic vial and 25 mL water was added into the vial and mixed thoroughly for 5 min with a mechanical stirrer. Soil–water suspension was allowed to stand for 30 min. The soil pH was measured at room temperature (25±1 °C). Cation exchange capacity (CEC) was determined by 1M NH₄OAc solution buffered at pH 7 [26]. The absorbed NH₄⁺ was washed with 100 ml alcohol (ethanol) to remove excess NH₄⁺ and consequently replaced by 100 ml 1 N K₂SO₄, then analysed the displaced NH₄⁺ with an auto-analyser (AA). Calcium, magnesium, and potassium in the NH₄OAc solution were determined by Atomic Absorption Spectrophotometer (AAS). Total carbon (C) was determined by dry combustion technique using a LECO CR-412 carbon analyser (LECO, Corporation, St. Joseph, USA) with one gram soil weighed into a tarred ceramic boat and determined by carbon analyser. Total nitrogen was determined as reviewed by [27] Kjeldahl method. One gram of air-dried soil sample having particle sizes of less than 2 mm was placed in 50 mL capacity digestion tubes, 10 mL of sulphuric acid and salicylic acid mixture (5% salicylic acid

in concentrated H₂SO₄) was added, followed by 0.3 g of Na₂S₂O₃ (sodium thiosulphate) and one tablet of digestion mixture. The samples were digested at 350°C for five hours and analysed using an auto analyser Quickchem® 8000series (Lachat Instruments, USA). Available phosphorus was analysed using Bray and Kurtz-2 method [28]. Two grams of air dried soil sample having particle sizes of less than 2 mm were placed in 50 mL capacity extraction vessel and added 14 mL of extracting reagent (0.03 N NH₄F and 0.1 N HCl). The mixture was shaken for 45 seconds, and then filtered through filter paper. The P content of the filtrate was determined using auto analyser. Exchangeable Al was extracted by 1 M KCl and the Al in the solution was determined using an inductively coupled plasma emission spectrometry (ICP-OES). 5 g of soil was weighed into a plastic vial, then 50 mL of 1 N KCl was added, and agitated for 30 min, decanted the supernatant slowly passing it through Whatman no.42 filter paper. Free Fe determined by shaking 1 g air-dry soil (<0.5 mm) with 50 mL 22% of sodium citrate and 1 g sodium dithionite on an end-over-end shaker continuously for 16 hours at 25 °C. 50 mL deionised water and 5 drops super floc solution was added and shaken vigorously for 5 seconds, centrifuged and filtered with filter paper Whatman No. 42. Then diluted the extract (1 + 9) with deionised water and leave loosely stoppered for about 3 days. A blank was included throughout the analysis as described by [29].

2.3 Fourier transmission infrared analysis

One gram each soil sample was pressed into film form and analysed. The transmission of infrared spectra bands were analysed in the range between 280 and 4000 cm⁻¹ at room temperature (25±1°C). Fourier transmission infrared (FTIR) spectroscopy analysis was carried out using a Perkin-Elmer Model 1750x FTIR spectrometer. The sample chamber was purged with purified compressed air to remove water vapour and CO₂ prior to scanning the pellet. The spectra were collected at a certain resolutions Figure 2, by performing a series of interleaved sample and background scans.

2.4 X-ray diffraction analysis

Clay fraction (<2 mm) of Bungor, Kuala Brang Kuantan and Segamat was used for the identification of the minerals. Approximately, 1 g of clay fraction was diluted with deionized water and spread evenly on to the microscope glass slides. Henceforth, the slides were subjected to X-ray diffraction analysis using a Philips PW 3440/60 Diffractometer X'Pert Pro under room temperature (25±1°C).

2.5 Statistical analysis

Significant differences in chemical characteristics among soil series were determined using t-test (p<0.05). All statistical analyses were done using SAS version 9.4.

3. RESULTS AND DISCUSSION

3.1 Physical and chemical characteristics of the soils

Bungor (Ultisol) had sandy clay loam texture and recorded the highest bulk density of 1.30 g cm⁻³, while Kuantan (Oxisol) has clay texture with the lowest bulk density of 0.90 g cm⁻³ among the soils studied. Effect of sand content on soil bulk density was significant. Thus, clayey soils tend to have lower bulk densities and higher porosities than those of the sandy soils. These findings confirmed their difference in pedogenetic development. Kuantan soil was more intensely weathered, whereas Bungor was relatively less intensely weathered. Higher bulk density values were observed in the coarser soils (Ultisols) due to the presence of more sand percent; the more coarsely the texture is, the higher the bulk density would be. The bulk density decreased in the order of: Bungor > Kuala Brang > Segamat > Kuantan soils. This came up due to the higher particle densities (2.65 and 2.40 g cm⁻³) of Ultisols compared to those of the Oxisols (1.80 and 2.00 g cm⁻³). Soil porosity were greater in Oxisols than Ultisols. Surface area is directly proportional to total pore space or total porosity; hence, clayey soils (Oxisols) have higher total pore space than either loamy or silty soils (Ultisols), table 2.

Table 2: Selected soil physical parameters and taxonomic classification

Sample	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (D_b) ($g\ cm^{-3}$)	Particle density (D_p) ($g\ cm^{-3}$)	% Porosity	Soil Classification*
Bungor	0-15	60	9	31	Sandy clay loam	1.30	2.65	48	Typic Paleudult
	15-30	48	9	43	Sandy clay loam	-	-	-	Typic Paleudult
Kuala Brang	0-15	12	46	42	Silty clay	1.10	2.40	44	Typic Hapludult
	15-30	10	47	43	Silty clay	-	-	-	Typic Hapludult
Kuantan	0-15	8	34	58	Clay	0.90	1.80	50	Typic Hapludox
	15-30	10	30	60	Clay	-	-	-	Typic Hapludox
Segamat	0-15	34	19	47	Clay	0.94	2.00	53	Rhodic Hapludox
	15-30	26	19	55	Clay	-	-	-	Rhodic Hapludox

*Soil Taxonomy – [24]

All the soils have low pH in water (Table 3), ranging from very strongly acid (pH 3.50) to moderately acidic (pH 5.29). The higher pH values in the Oxisols (Kuantan and Segamat) can be associated with the presence of low in exchangeable Al. The hydrolysis of Al in the soils released protons (H^+) into the soil solution system and increased soil acidity, which was the case of Bungor and Kuala Brang (Ultisols). The soil particles hold hydrogen ions more strongly than other ions, resulting in the formation of insoluble amorphous hydrous oxides of aluminium and iron, along with kaolinite; hence, becomes the dominant solids in the soils. According to [10] whenever one of the acidification reactions caused hydrogen ion concentration in the soil to increase, some of the hydrogen ions would then displace these base ions, which became susceptible to leaching out of the soil. Over time, soils become quite acid and devoid of base ions.

The cation exchange capacity (CEC) of Segamat soil (Oxisol) was lowest among the soils. This was attributed to the high amount of the sesquioxides contents in this Oxisol, which was supported by low cation retention (Ca^{2+} , Mg^{2+} and K^+). The soil low was poor in fertility shown by low exchangeable Ca ($<0.48\ cmol_c\ kg^{-1}$), Mg ($<0.12\ cmol_c\ kg^{-1}$) and K ($<0.11\ cmol_c\ kg^{-1}\ K$). The CEC values were moderate to average, ranging from 7.5 to 12.3 $cmol_c\ kg^{-1}$ for both Ultisols and Oxisols. The base saturation had values less than 60% in all of the soil samples. This further indicates low retention of the cations by all the soil samples. Due to the low pH some H and Al find their way onto the surface of the soil mineral and organic particles and that drops the base saturation to less than 100. It is important to note that, base saturation is not a soil testing index and does not necessarily imply nutrient fertility of a soil. But it indicate that the soil should be limed, as compared along with a number of other parameters. Fertilizer input are often recommended to be applied on Ultisols and Oxisols in Peninsular Malaysia that are used for crop production. The chemical analyses of soils under study was an indicative of low total nitrogen with $<0.13\% N$ ($1300\ mg\ kg^{-1}$). These soils contained a low amount of total carbon, having a maximum value of 1.9% in the topsoil, and the values decreased regularly with depth in all the studied soils.

Table 3: Chemical characteristics of Ultisols and Oxisols in Peninsular Malaysia

Soil	Depth (cm)	pH H ₂ O (1:2.5)	Total C	Total N	Ca	Mg	K	Al	ECEC	CEC	Avail. P	BS	Free Fe ₂ O ₃
			(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Bungor	0-15	4.77	1.91	0.19	0.33	0.16	0.11	3.99	4.59	8.90	9.96	50.2	4.25
	15-30	4.69	1.86	0.11	0.06	0.03	0.02	3.93	4.04	8.50	4.42	9.2	
Kuala Brang	0-15	4.31	1.03	0.11	0.17	0.06	0.04	2.51	2.78	11.4	4.70	23.4	9.70
	15-30	3.50	0.90	0.09	0.11	0.01	0.01	2.47	2.48	11.4	4.03	12.1	
Kuantan	0-15	5.11	0.62	0.08	0.48	0.11	0.05	1.67	2.31	12.3	7.70	59.4	22.0
	15-30	4.85	0.60	0.05	0.21	0.02	0.03	1.65	1.91	12.2	3.56	23.3	
Segamat	0-15	5.29	0.89	0.10	0.17	0.21	0.02	1.41	1.81	7.60	tr	38.3	41.9
	15-30	4.49	0.79	0.07	0.16	0.06	0.06	1.41	1.69	7.50	tr	22.8	

ECEC- Effective cation exchange capacity, CEC- Cation exchange capacity, BS- Base saturation, tr- trace

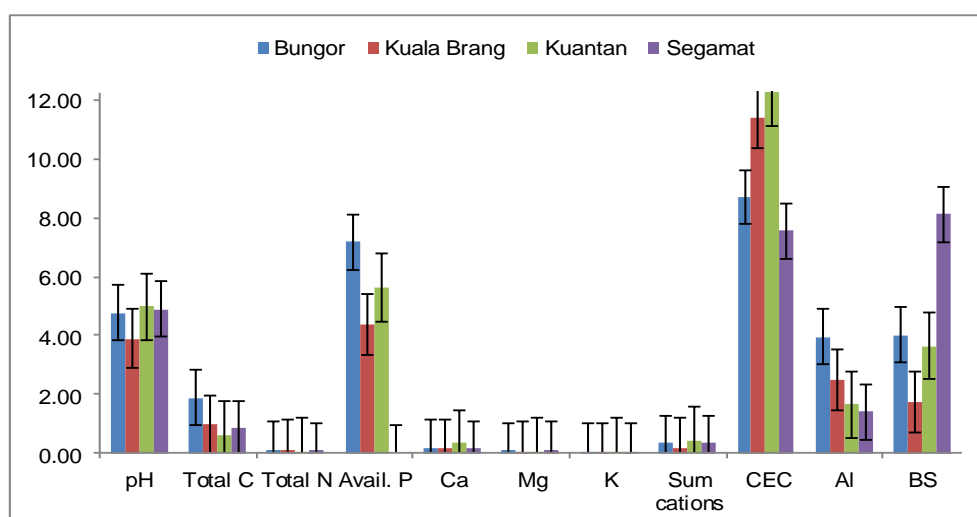


Figure 2: Means of chemical characteristics of Ultisols and Oxisols in Peninsular Malaysia

Available phosphorus were found to be in low (<9.96 mgkg⁻¹) amount due to the presence of high exchangeable Al (1.41 to 3.99 cmol.kg⁻¹). The reduction in availability of phosphorus (P) was attributed to the formation of Al-P compounds. Furthermore, [30] earlier suggested that Ultisols and Oxisols are naturally deficient in available phosphorus and significant portion of applied phosphorus is immobilised due to precipitation of P as insoluble Fe/Al-phosphates or chemisorption to Fe/Al-oxides and clay minerals. This might be responsible for the low available P value in Kuantan Series (Oxisol) and trace amount in Segamat (Oxisol) as compared to Bungor and Kuala Brang soils (Ultisols). Soil aluminium concentration of 2–5 parts per million (ppm) is toxic to the roots of sensitive plant species, and above 5 ppm is toxic to tolerant species [31]. Phosphate fixation is another important aspect of the acid infertility of the studied soils. This might be related to the fixation of soluble inorganic P which is fixed by Al and Fe [32]. The P fixation is directly related to the surface area, and the clay contents of the soil material (Table 1). The smaller the particle size is, the greater the total surface area in a given volume of soil of the studied samples and the smaller the P fixation would be. From the table for physical analysis, Oxisols were clayey while Ultisols were sandy and silty with Oxisols having more total pore space or total porosity.

Bungor and Kuala Brang soils were earlier described by [21] having high Al saturation (78-95%) and low free iron while Kuantan and Segamat have low Al saturation (20-79%) and high free iron. These further confirm that Oxisols (Kuantan and Segamat) are known for P immobilisation due to high contents of Fe₂O₃ than the Ultisols (Table 3). P immobilization was in the order of: Bungor <Kuala Brang<Segamat and <Kuantan. Kuantan (Oxisol) had the highest Fe₂O₃ which can exist in the form of hematite. Further detailed in statistical analysis and means of chemical properties are given in Figure 2.

The statistical variance in the exchangeable base cations was significant in the topsoil, while not significant in the subsoil among all soil series. This shows that cations when supplied into the soil system have the tendency to leach very slow and/or at the minimal rate. There was a significant difference between (0 to 15 cm) and (15 to 30) depths in total carbon and total nitrogen among Ultisols and Oxisols (Table 3). The greater values in carbon and nitrogen contents found at the surfaces was attributed to accumulation of leaf litter and previous fertilizers applied on their soil surfaces, as shown Table 4 and Figure 2. The means significant difference in the soil chemical characteristics are well illustrated in Figure 2 for both surface and subsurface horizons and among soils studied.

3.2 FTIR Spectroscopy

For all the topsoil (0-15 cm), silicate spectra were observed in 3,690-3,388 cm^{-1} region (Figure 3). This indicates the absorption peak of free hydroxyl (OH) group arising from stretching vibrations of OH groups in octahedral layers. This is a clear indicative characteristics of silicate present in the topsoil samples.

The spectra at 3434 cm^{-1} and 3388 cm^{-1} in Bungor series (Figure 3a) and Kuantan (Figure 3c) are OH functional groups. The hydrogen bonding in wavenumbers transmits with medium intensity in stretches. The OH stretching (H bonded OH groups) frequency indicates water molecules (halloysite and gibbsite) in the studied samples. The peaks at 3690 which (Figure 3b) and 3685 cm^{-1} (Figure 3c) noted in Kuala Brang and Segamat soils were characteristics for kaolinite [$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$]. Similar findings by Madari [33] in Brazilian tropical soils were found. In addition to that, several other peaks below 1100 cm^{-1} in all the four soil series (Ultisols and Oxisols) also representative of kaolinite [$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$]. Therefore, kaolinite dominance in the topsoil were clearly noted. Besides hydroxyl groups (-OH), carboxylate (C=O) groups were also eminent as stretching band at 1636 cm^{-1} (Figure 3a) and 1638 cm^{-1} (Figure 3c), similar to observation by [34]. Meanwhile, the C-O group stretches at 1018 cm^{-1} and 1008 cm^{-1} (Figure 3a and Figure 3d) in Bungor and Kuantan Series were indicative of polysaccharides or polysaccharides like substances, which were silicate impurities. FTIR data shows the Si-O of silicate impurities as noted by Stevenson in similar study [35], with predominant kaolinite in all soils. The peaks between 3695 and 3620 cm^{-1} and various peaks below 1100 cm^{-1} are clear characteristic of dominant kaolinite minerals. The spectra average above 1,000 cm^{-1} and near 500 cm^{-1} in all the soil reflects structural and chemical changes of the soil inter-structure with functional groups mainly due to the presence of micas. The number of tetrahedral aluminium ions in micas can be relatively estimated by the shape of the Si-O stretching bands in the 1,100-1,000 cm^{-1} region. The strong absorption in Figure 2a, 2b, 2c and 2d shows Si-O bonds with bending vibrations. These vibrations affect structural and compositional variations as stated by Raphael [36]. Du et al. [37] stated that the spectral information related soil constituents can be used to discriminate between soils. This further explain that such discrimination among soils can improve the estimation of nutrients and hence overall soil fertility status [38].

Thus, with presence of mainly kaolinite and traces of mica, indicative of low to medium fertility status of these topsoil. Kaolinite may further release aluminium and silicate from its structure to give rise to halloysite and gibbsite at the surface soils from this findings.

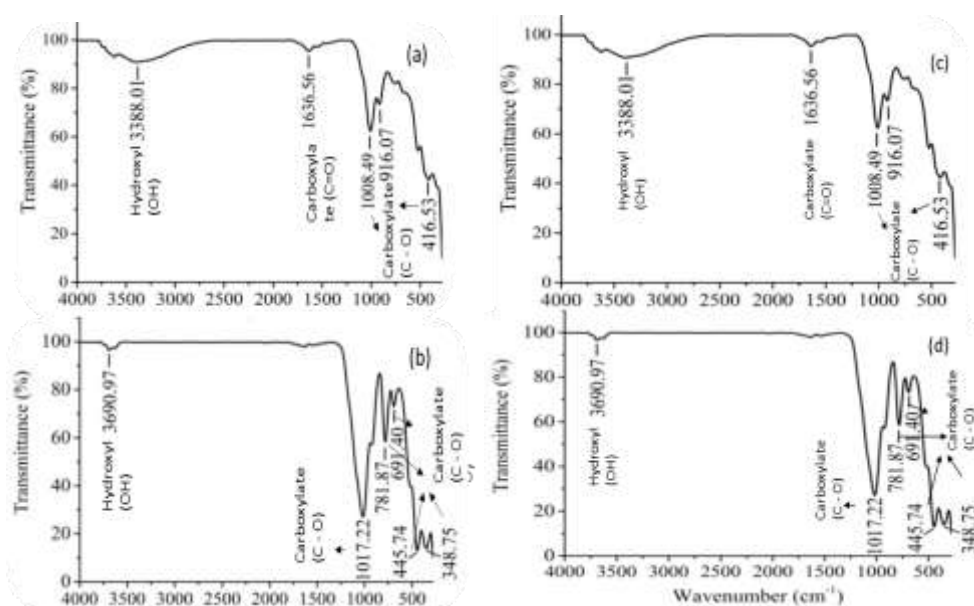


Figure 3: FTIR spectra of topsoil in Bungor (a), Kuala Brang (b), Kuantan (c), and Segamat (d)

3.3 XRD of the clay fraction

X-ray diffractogram of the clay fraction of Bungor soil (Figure 3a) showed peaks at 7.16 and 3.57 Å (kaolinite), 4.86 Å (gibbsite) and 3.34 Å (quartz). Meanwhile, Kuala Brang soil (Figure 3b) showed peaks at 10.07 and 5.01 Å (mica), 7.17 and 3.58 Å (kaolinite) and 4.26 Å (quartz). The reflections (Figure 3c) at 3.37 Å confirmed the presence of mica [7], 2.72 Å goethite [39] and 2.55 Å hematite [40]. Besides that, Figure 3d indicated kaolinite (7.24 Å and 3.55 Å), goethite (4.16 Å), and kaolinite (2.38 Å). The peak intensities (Figure 3 a, b, and d) were similar with that of Harris and White [7] in soil mineral identification. Shamshuddin et al. [4] showed the presence of kaolinite and goethite in Segamat soil. Furthermore, they showed the presence of kaolinite and goethite in Kuantan and Segamat soils. They also showed the occurrence of hematite in Kuantan soil. The minerals in the clay fraction of these soils play a crucial role in assessing their major physical and chemical properties (Table 2 and Table 3). The reflections of these mineralogy affects the overall fertility status of the studied soil. This findings affirmed the low exchangeable bases and CEC present in the soils, reflecting the mineralogy dominated by kaolinite.

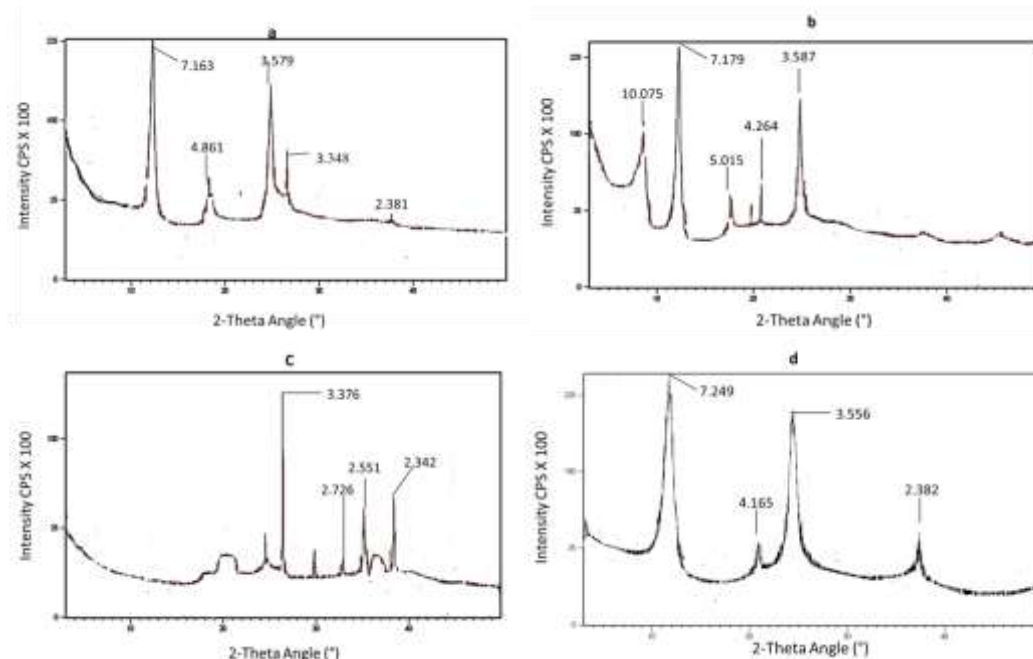


Figure 4: XRD diffractogram of the top soil in Bungor (a), Kuala Brang (b), Kuantan (c), and Segamat (d)

Kaolinite $[Al_2Si_2O_5(OH)_4]$ was found to be common to all the studied soils. It was found along with quartz, gibbsite, micas and hematite. The presence of these minerals also accounts for the low activity clay and nutrient depletion [41].

4. CONCLUSION

All the soil samples are acidic, with high acidity to moderate acidity (pH 3.5-5.5). The low pH of < 5 allows free aluminium in the soil solution to hydrolyse and consequently produces more acidity. Cation exchange capacity (CEC) were low for all soil studied. Exchangeable aluminium were above threshold value indicating potential toxicity accompanied by P deficiency which decreases as the aluminium level increases. High free iron (Fe_2O_3) contents in the Oxisols (22 to 42 %) indicate more intense pedogenetic process than the Ultisols with lower values (4 to 10 %). FTIR and X-ray analyses showed mainly the presence of kaolinite and sesquioxides in both Ultisols and Oxisols. The fertility status of Bungor, Kuala Brang, Kuantan and Segamat soils are different, thus requires site-specific management practice to alleviate their infertility. The availability of plant nutrients were low; thus, high fertilizer application is necessary to improve their fertility.

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