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Original Research Article

Clay Mineralogy of Selected Acid Soils of Southern China

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Abstract

This study investigated the clay mineralogy of selected acid soils of southern China: Yellow brown soil (YBS), Alfisol in America Soil Taxonomy and Argosol in China Taxonomy; Red soil (RS), Ultisol in the American classification system; Latosol soil (LS) and Lateritic red soil (LRS), Oxisols in America Soil Taxonomy and Ferralosols in China Taxonomy, collected from Hubei, Hainan, and Guangxi provinces in China. Soils derived from these soil orders were randomly collected, air-dried, sieved and analysed in the laboratory. Clay mineralogical analysis was carried out using clay fractions less than two microns in size from selected A- horizons of the various profiles. Results showed that the dominant minerals in the clay fractions were kaolinite, vermiculite, and illite while goethite occurred in Latosol soil (Oxisol). Soil properties that are related to soil fertility status particularly, cation exchange capacity (CEC) and pH were higher in Yellow brown soil (Alfisol). While organic matter concentration was higher in Latosol soil (Oxisol).

Keywords: clays, mineralogy, soil order, acid soils, southern China.

Introduction

Variable charge soils (Ultisols, Andisols, Oxisols and acid Alfisols) cover about 22 % of the earth's surface. These soils are dominated by minerals and amorphous colloids possessing amphoteric surfaces. They have developed under intensive weathering in tropical and subtropical regions or from volcanic ash parent material. The magnitude and sign of the surface charge of variable charge constituents depend on the chemistry of the contacting solution (pH and ionic strength). The physical, chemical and mineralogical characteristics of these soils are different from those observed in soil systems of temperate regions [1]. This poses far-reaching implications for soil management in agriculture and retention of ionic soil contaminants [2, 3]. Variable charge soils are widely distributed in the tropical and subtropical areas of South China, which are characterized by high content of iron and aluminum oxides and dominated by 1:1-type clay minerals, such as kaolinite. These factors make the surface charge properties of variable charge soils distinctly different from those of the constant charge soils in temperate regions, which may greatly have an effect on the environmental behaviours of heavy metals and veterinary medicines [4, 5]. These types of soils are widespread in the tropical region in south China, such as Fujian, Guangdong, Guangxi, and Hainan provinces [6]. These soils generally have low surface charge density with predominant pH-dependent charge, particularly at pH value of 4.0-5.0 [7] and heavy metals may become mobile in such soil under certain conditions [8]. Unlike soils with permanent charge where the charge arises from isomorphous substitution within the layer lattice of clay minerals, variable charge soils exhibit the property of being able to alter charge in response to changes in the ambient soil solution. The major factors determining this variable charge include pH, ionic strength, nature of electrolyte ion and metals, and ligands in the soil solution capable of specific sorption [2]. Variable charge soils are generally more vulnerable to heavy metal contamination because of their low organic matter content and a small cation exchange capacity as well as being acidic [9].

To assess inherent soil fertility for appropriate large – scale management, it is important to know as well as understand how clay mineralogy relates to geological and weathering conditions [10].

The physico-chemical properties of different soils are predetermined by the clay mineralogy and the environmental condition in which the soils have been formed. The content of the minerals such as kaolinite, montmorrillonite, illite and different amorphous minerals, as well as the content of organic matter is to be known to describe and explain any physical or chemical property of the soil [11], The knowledge of mineralogy is useful for an understanding of many important characteristics related to soil nutrient status [12]. Consideration of the characteristics of minerals found in soils, and their transformation from one form to another, is essential in understanding both the nature of soils chemical properties and the origin of its fertility [16]. Important processes in the formation of clay minerals are the neoformation of gibbsite, kaolin minerals and smectite, and the transformation of mica. Neoformation is mainly controlled by H4SIO4 activity. Gibbsite forms under conditions of strong desilication, where H4SIO4 activity is low [13]. Kaolin minerals forms under moderate H4SIO4 activity conditions and smectite under high activity [14]. Mica which is commonly present in felsic and sedimentary rocks, weathers to vermiculite and smectite, with a decrease in the layer charge and release of alkaline metals. The increased resistance to weathering of dioctahedral mica means that dioctahedral vermiculite is more common in soils than trioctahedral vermiculite [15]. Kaolinite formation is favoured in acidic soils low in base and montmorillonite is favoured by high magnesium in the weathering environment. Montmorillonite originates from weathering of basalt where magnesium remains in the soil [16].

To anticipate the effect of clay on the way soil will behave. It is not enough to know only the amount of clay in a soil. It is necessary to know the kinds of clays present. As home builders and highway engineers know all too well, certain clayey soils, such as those high in smectite clays, make very unstable material on which to build because the clays swell when the soil is wet and shrink when the soil dries. This shrink – and – swell action can easily crack foundations and cause even heavy retaining walls to collapse. These clays also become extremely sticky and difficult to work when they are wet. Other types of clays, formed under different conditions, can be very stable and easy to work with. Clay minerals in the upper horizons were not very different from those in the lower horizons [17]. Research involving clay minerals is important in understanding the origin, classification and utilization of soils [17].There is little research on nature and properties of clay minerals of china, there are a variety of opinion about the composition of clay minerals. According to Xiong and Li [18], the major component of the chao soil is Hydromica (illite), and the yellow chao soil is mainly composed of Hydromica, with chlorite and smectite as minor components. Therefore studying the different types of clay minerals in soils will help us understand many of the physical and chemical differences among soils in various parts of the world [19]. The goal of the study was to investigate the mineralogical properties of soils of selected acid soils of southern China.

MATERIALS AND METHODS

Soil samples and basic properties

Four representative variable charge soils were used in this study: Yellow brown soil (YBS), Alfisol in the American classification system; Red soil (RS), Ultisol in the American classification system; Latosol soil (LS) and Latosolic red soil, Oxisols in the American classification system. These soils were collected from Hubei, Hainan and Guangxi provinces in China (Fig. 1). The parent material of the soils from Hubei, Hainan and Guangxi are alluvium, acid igneous and basalt respectively.

Soil pH value was measured in de-ionized water at a soil: water ratio of 1:2.5. Cation exchange capacity (CEC) and organic matter content were determined by the methods described by Rhoades and Walkley – Black respectively [20]. Particle size distribution was determined using the pipette method [21]. Amorphous iron (Fe) and aluminium (Al) oxides were determined by the oxalate extraction [22]. Crystalline Fe and Al oxides were determined by the oxalate – ascorbic acid extraction method of Shuman [24]. The clay mineralogical composition of the soils was determined with Cu-Ka radiation on X –ray diffractometer (D8 Bruker Advance X –ray diffractometer).

Fig-1: Map of China showing the study areas.

***= study areas.**

Clay minerals

0.5 g of soil was added into 5 ml tube and DCB (3 ml sodium citrate-sodium bicarbonate and 0.1 g sodium dithionite) was added. It was heated at 80^0C for 15 min and stirred occasionally. It was allowed to cool and then centrifuged. The supernatant was discarded to remove free iron. 3ml of 0.5 mol/ L $MgCl_2$ was added. It was stirred and centrifuged. This process was done 3 times. It was saturated with 5 % glycerol. Then 1 ml water was added and it was centrifuged and the supernatant was discarded. The suspension was taken and put in a glass slide and air dried. The clay mineral was determined using X-ray diffracting meter.

RESULTS AND DISCUSSION

Physicochemical and mineralogical properties of soils

The results of the physicochemical properties showed that YBS had higher CEC and pH (27.4 cmol kg^{-1} and 5.2) respectively than the other soils while LS had higher organic carbon and crystalline Fe_2O_3 and Al_2O_3 (13.1 g kg^{-1}, 84 g kg^{-1} and 5.2 g kg^{-1}) respectively than the other soils (Table-1). The particle size analysis showed that LS was clay, YBS was silt loam while RS and LRS were clay loam.

Clay mineralogical composition of soils samples treated with magnesium-saturated glycerol and air dried showed that LS mainly consisted of kaolinite 75 %, hydroxyinterlayed vermiculite 15 % and goethite characterized by diffraction peaks at 0.71nm, 0.48 nm and 0.27 nm respectively. YBS consisted of illite 45 %, vermiculite 25 % and kaolinite 30 % characterized by diffraction peaks at 1 nm, 1.396 nm and 0.717 nm respectively. RS consisted of vermiculite 35 %, kaolinite 40 %, and illite 25 % characterized by diffraction peaks at 1.404nm, 0.723 nm, and 0.493 nm respectively. LRS consisted of kaolinite 60%, and illite 40% characterized by diffraction peaks at 0.719 nm and 1nm respectively (Fig-2). Kaolinite was found in every soil. Kaolinite was the major minerals in the soils, minor minerals include illite, vermiculite and goethite.This result is contrary to Xiong and Li [18] work on chao soil, who suggested that Hydromica (illite) was the major mineral in the soil with smectite, kaolinite and vermiculite as minor components.

Table-1: Basic properties of the tested soils

Items	YBS soil	LS soil	RS soil	LRS soil
Sample site	Hubei	Hainan	Hubei	Guangxi
Order	Alfisol	Oxisol	Ultisol	Oxisol
pH (H_2O)	5.2	4.5	4.2	4.1
O.M (g/kg)	10.8	13.1	6.2	9.9
CEC (cmol/kg)	27.4	15.9	20.9	21.9
2-0.2mm Sand (g/kg)	64.8	270.7	304.4	279.2

0.2-0.02mm Silt (g/kg)	678.7	313.4	405.7	359.6
< 0.002mm clay (g/kg)	256.5	415.9	359.6	361.2
Crystal Fe (g/kg)	16.0	84.0	21.3	21.0
Amorphous Fe (g/kg)	13.8	8.7	5.9	3.5
Crystal Al (g/kg)	1.3	5.2	2.3	2.1
Amorphous Al (g/kg)	4.2	9.4	7.6	6.2
Clay minerals	I, V, K	GE, HIV,K	K, I, V	K, I

YBS: Yellow brown soil, **LS:** Latosol soil, **RS:** Red soil, **LRS**: Latosolic red soil
O.M: Organic matter, **CEC:** Cation exchange capacity
I: illite, K: kaolinite, **V:** vermiculite, **GE:** geothite, **HIV:** hydroxyinterlayed vermiculite.

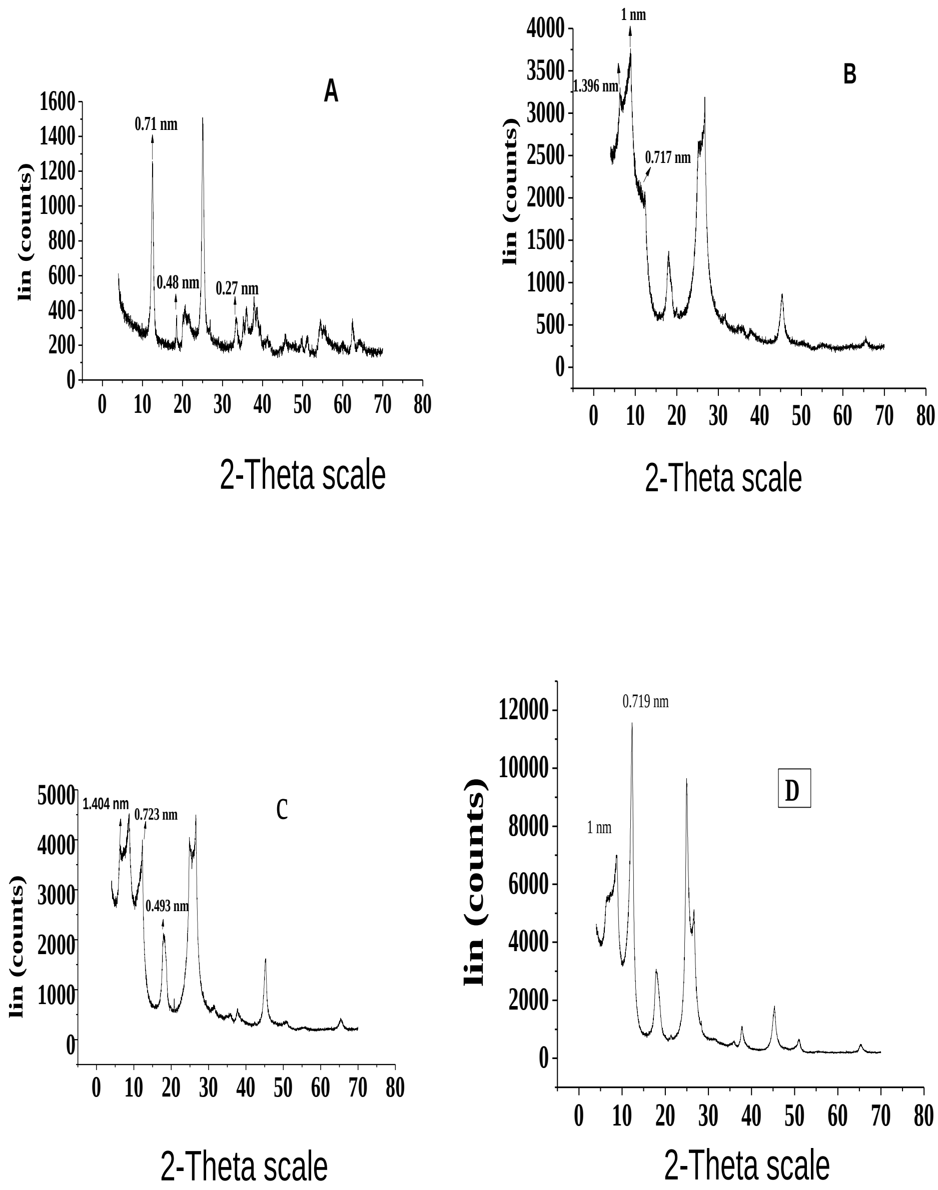

Fig-2: X-ray diffraction patterns of four soils, a. LS; b. YBS; c. RS; d. LRS

The result of particle size analysis agrees with Foth [16] that oxisols with high Fe oxide content are rich in clay; showever, the soils exhibit moisture characteristics of sands (Table-1).

The lower pH of LRS soil compared with the other soils brought about by higher percentage of kaolinite (Fig-2) implies that the soil will have lower adsorption capacity than the other soils. The YBS had higher pH and CEC due to higher percentage of illite and vermiculite content and lower percentage of kaolinite content (Fig-2). These observations agree with reports by Nkwopara, [9] and Nkwopara [23] that the presence of kaolinite brought about low pH and CEC while that of 2: 1 clay minerals like vermiculite, illite and montmorrilonite brought about higher pH and CEC. The clay mineralogy shows that kaolinite is the dominant clay mineral. The clay mineralogy is also in accordance with extractable Al and Fe. The high contents of cystal Fe and relatively low contents of amorphous Fe in the soils except YBS are consistent with the weathering and dominance of goethite in ultisol and oxisols [25, 26].The presence of goethite which is an iron oxide clay in the latosol soil is justified by the fact that the soil is highly weathered and the mineral generally form the last stage of weathering of tropical soils. They give rise to the typical reddish or dark reddish brown colour of such soil. The amount of amorphous Al exceeds crystal Al, that is Al_{OX}/Al_{DCB} ratio > 1 (Table-1) showing substantial amounts of poorly ordered aluminium oxides in all soils. These observations are in accordance with report by Gimsing [25] on variable soils from Tanzania. This suggests that YBS is capable of receiving and retaining more pollutant while LRS retains less pollutant compared with the other soils. Among the various soils, LRS will be most susceptible to pollution as more metals will be leached into the soil solution. It can be deduced from the results that the mineralogy of the clay fraction of latosol and lateritic red soil were generally dominated by kaolinite and goethite whereas the mineralogy of yellow brown soil and red soil were dominated by vermiculite and illite. This shows that the yellow brown soil and red soil are consequently less leached and have a higher ability to hold water and nutrients for plant use. They can attract, retain and fix a lot of nutrients without their being washed away. They have higher negative charges for binding nutrients to themselves and when fertilizer is applied, they are able to hold the nutrients and will not allow them to be washed away easily. They therefore have higher agricultural potentials. Their agricultural potential is in this order yellow brown soil > red soil > latosol = lateritic red soil. Secondly, yellow brown soil soils are possible sink for contaminants like divalent lead in the environment because of the presence and dominance of 2:1 lattice clay such as vermiculite and illite that have higher cation exchange capacities than kaolinite [27]. They can retain or hold low molecular mass organic acids, which help to increase their adsorptive capacity for pollutants such as cadmium and lead by forming bridging bonds [28]. The higher pH, CEC and illite content (Table-1 and Fig-2) imply that YBS had higher potential for receiving and holding cations than the other soils. These observations agree with reports by Coles and Yong [29], Yang [30] that soil pH and CEC were positively correlated with cadmium and lead retention implying that lower soil pH can release more metals from soil. Malandrino [31], Hu [32] and Huang [28] observed that the presences of vermiculite and illite increased adsorption of lead and cadmium by soils.

Conclusions

The result revealed that YBS had highest amount of CEC, 2:1 clay minerals and pH. YBS had higher potentials for receiving and retaining more Pb^{2+} compared with the other soils. The greater content of illite and the moderate content of vermiculite provide YBS with greater exchange capacity than the other soils, as this minerals have larger net surface than kaolinite. In YBS cation will be commonly adsorbed than anions compared to other soils. In general, the soils are acid, of low fertility and poor in organic matter. Low 2:1 clay mineral is attributable to the high weathering of the soils. It is recommended that the mineralogical properties of these soils be considered in their management for the production of crops, trees and other purposes. There is need for scanning electron microscopy of soils studied for the purposes of corroboration.

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