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Comparison of the surface chemical properties of four soils derived from Quaternary red earth as related to soil evolution

Jun Jiang [a,b], Ren-kou Xu [a,*], An-zhen Zhao [a]

[a] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China
[b] Graduate University of the Chinese Academy of Sciences, Beijing 100049, PR China

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ABSTRACT

The surface chemical properties of soil samples i.e., surface charge and zeta potential, and the mineralogy of soil clay fraction were investigated with reference to soil weathering extent for four different soils derived from Quaternary red earth using the ion adsorption method, a micro-electrophoresis method and the X-ray diffraction analysis. Results indicated that all these soil samples contained kaolinite and gibbsite. The Ultisols from Guizhou, Hunan and Jiangxi possessed the 2:1 type clay minerals of mica and vermiculite. Hematite and magnetite were found in the Ultisols from Guangxi, Hunan and Jiangxi. Goethite was found in the Ultisols from Jiangxi, Hunan and Guizhou. The positive surface charge for these soils decreased with the order: the Ultisol from Guangxi ≅ the Ultisol from Guizhou > the Ultisols from Hunan and Jiangxi from south to north when $\mathrm{pH} < 5.0$. This is consistent with the content of free Fe/Al oxides present in these soils. On the other hand, the value of negative surface charge on the Ultisol from Guangxi was found much lower than the other soils perhaps because of the intensive weathering of the soil. Both permanent and variable negative charges for the former were also lower than the latter, whereas the point of zero salt effect (PZSE) for the former was greater than that of the latter. The variability of soil negative surface charge followed the order: the Ultisol from Guangxi > the Ultisol from Guizhou > the Ultisol from Jiangxi ≅ the Ultisol from Hunan. The zeta potential and isoelectric point (IEP) of soil colloids and soil net surface charge followed the same order: the Ultisol from Guangxi > the Ultisol from Guizhou > the Ultisols from Hunan and Jiangxi. A good correlation between zeta potential and net surface charge of these soils was observed. Therefore, the magnitudes of the PZSE, IEP and zeta potential of these soils were in agreement with the weathering extent of the soils and can be employed as reference criteria for classification and evolution of soils.

1. Introduction

Large areas of red soils are distributed in tropical and subtropical regions of China and also the world. These soils are developed under relative intensive weathering and leaching conditions. Moreover, at the advanced stage of weathering, the clay fraction mineralogy of red soils is dominated by kaolinite, gibbsite, goethite, hematite, and amorphous minerals (Qafoku et al., 2004). These soils carry both positive and negative charge on their surfaces. The magnitude and sign of their surface charge change with the alteration of the environmental conditions such as pH and ionic strength (Yu, 1997). The organic matter is electronegative in a majority of circumstances and the edges of mineral particles can carry variable charge (Wieland and Stumm, 1992). The end products of the weathering processes, Fe/Al oxides usually possess a net positive surface charge under acidic conditions typical for variable charge soils (Qafoku et al., 2004).

During the development of the soils in tropical and subtropical regions, weathering towards a "no or little net charge state" causes changes in the clay mineralogy of the soils (Qafoku et al., 2000). Different soils reach different steady states, that is to say the contents and thus the proportions of mineralogical constituents, particle size distribution and specific surface areas are different in different soils (Qafoku et al., 2004). Mineral evolution during pedogenesis is accompanied by measurable changes in the surface properties of soil particles, which affects an array of biogeochemical processes including adsorption of nutrient or toxic ions, mineral weathering reactions, particle aggregation, and organic matter retention (Chorover et al., 2004). The point of zero charge (PZC) of soils is the pH value at which the surface of the soil possess net zero charge. More commonly, PZC infers the pH value at which a suspension flocculates rapidly or at which the particle electrophoretic mobility vanishes (IEP) (Sposito, 1998). Soil PZC can be used as an index of pedogenic development (Hendershot and Lavkulich, 1978). The higher the PZC of a soil, the more the weathering of the soil (Hendershot and Lavkulich, 1978; Anda et al., 2008). Similarly, Gallez et al. (1976) suggested the use of PZC as an appropriate criterion for soil taxonomy of tropical soils. The electrokinetic potential

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* Corresponding author. Tel.: +86 25 86881183; fax: +86 25 86881000.
E-mail address: rkxu@issas.ac.cn (R. Xu).

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(zeta potential) is the electric potential at the plane of shear within the electric double layer on colloidal particle. Operationally, the isoelectric point (IEP) can be regarded as the pH at which the zeta potential is zero (Breeuwsma and Lyklema, 1973). Zhang and Zhang (1992) suggested that soil electrokinetic properties as expressed by the IEP, IEP-pH_{KCl}, and zeta potential values could also be used as reference criteria for classification of Ferralsols.

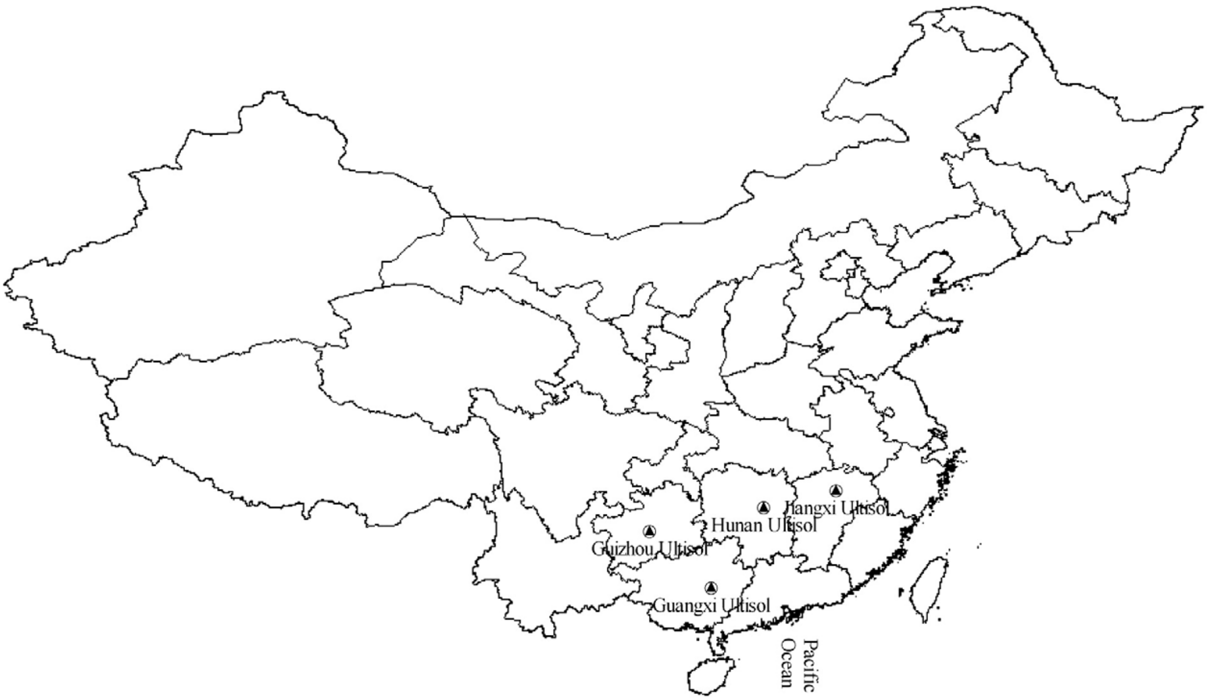
The point of zero net charge (PZNC) of soils is the pH value at which the net adsorbed ion charge vanishes (Sposito, 1989). At the PZNC, the sum of soil permanent charge and net proton charge becomes zero. An important chemical difference between PZNC and PZC is that a diffuse swarm can exist at the former pH value, whereas it cannot happen at the latter pH value (Sposito, 1998). The proton charge is normally measured by titration in the presence of an indifferent electrolyte at several ionic strengths. If the proton charge–pH curves intersect at one point, the pH value at the point is the point of zero salt effect (PZSE) (Sposito, 1989). At the PZSE, soil net proton charge is zero, but soil net surface charge is not necessarily zero.

Surface chemical properties of soils were extensively investigated (Raij and Peech, 1972; Gillman and Uehara, 1980; Theng, 1980; Uehara and Gillman, 1981; Gillman and Sumner, 1987; Chorover and Sposito, 1995; Yu, 1997; Bolan et al., 1999; Chorover et al., 1999; Qafoku et al., 2000; Noble et al., 2001; Chorover et al., 2004; Qafoku et al., 2004). The changing trends of surface chemical properties for the soils located in different climatic zones were also compared previously (Trangmar et al., 1985; Webster, 1985; Hseung and Li, 1990). Soil genesis of Quaternary red earth was investigated in subtropical regions of China, the results indicated that zonal factors affected soil properties to some extent, whereas the factors like parent material were also important (Yuan and Gong, 1990). While Zhu (1995) ascribed the differences in the development of the soils derived from Quaternary red earth to parent materials completely. However, only few reports are available on the comparison of the surface chemical properties of soils derived from similar parent materials and located at different climatic zones. Therefore, four Ultisols derived from Quaternary red earth were collected from different subtropical regions in the south of China and their mineralogy and surface chemical properties are investigated in this study. Further, the relationship between soil surface chemical properties and the weathering extent is also discussed in the present investigation.

2. Materials and methods

2.1. Soil samples

Four Ultisols derived from Quaternary red earth were collected respectively from Liuzhou, Guangxi Province (24°19′N, 109°24′E), Changsha, Hunan Province (28°11′N, 112°59′E), Jinxian, Jiangxi Province (28°25′N, 116°17′E) and Guiyang, Guizhou Province (26°34′N, 106°42′E). The locations of soil samples were presented in Fig. 1. All these soil samples were pristine under natural trees. Soils were sampled by genetic horizon. For the Ultisols from Guizhou and Jiangxi, only top soil and subsoil were used in this study. The air-dried samples were ground to pass a 60-mesh sieve for the surface charge quantification and other basic soil properties. The clay fraction less than 2 μm in diameter was separated from the soil samples by pipette method, in which particles in the upper portion of the suspension were collected at a definite time intervals followed by stirring (Pansu and Gautheyrou, 2006). The clay fraction was dried at room temperature and ground for use in the determination of zeta



Location	Longitude/Latitude	Altitude	Temperature	Wet precipitation
Guangxi	24°19'N, 109°24'E	102m	20.5℃	1400mm
Guizhou	26°34'N, 106°42'E	1600m	15.3℃	1200mm
Hunan	28°11'N, 112°59'E	45m	17.2℃	1360mm
Jiangxi	28°25'N, 116°17'E	25m	17.5℃	1600mm

Fig. 1. The locations of soil samples.