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Origin of the high sensitivity of Chinese red clay soils to drought: Significance of the clay characteristics

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ABSTRACT

The red clay soils which are widespread in China are known to be highly sensitive to drought during the dry season but the origin of this high sensitivity to drought remains unclear. Several red clay soils were selected in the Hunan province for study. We studied their basic physico-chemical properties and clay mineralogy, their structure and shrinkage properties, as well as their water retention properties. Results show that the amount of water available between −330 and −15,000 hPa water potential is consistent with that recorded in many other clay soils from different parts of the world and thus cannot explain the high sensitivity of the red clay soils to drought. This high sensitivity to drought might be related to the high proportion of poorly available water which was characterized by the amount of available water between −3,300 and −15,000 hPa water potential. Comparison with clay soils located in different parts of the world and for which the sensitivity to drought was not identified showed that this proportion of poorly available water is indeed much higher in the red clay soils studied than in clay soils representing a large range of both clay content and mineralogy. This specific behavior of the red clay soils studied is thought to be related to the history of their parent materials: these materials are continental sediments which may have been submitted to great hydric stress, thus leading to strongly consolidated soils with consequences such as a high proportion of poorly available water, strong aggregation and weak shrinkage properties.

1. Introduction

Soils called red soils are widespread in China. They cover 102 million ha, including ten provinces (Cao and Zhu, 1999; He et al., 2004; Wilson et al., 2004a; Zheng et al., 2008). They develop mainly in alluvial Quaternary sediments which reorganize materials resulting from continental alteration or in continental sediments from the Cretaceous or Eocene (BGMRHN, 1988; Hu et al., 2010; Shi et al., 2010; Wilson et al., 2004a, b). The Chinese red soils are either Ferrallisols (Latosolic red soils or red soil groups) or Semi-Alfisols (Torrid red soil group) of the Genetic Soil Classification of China (Shi et al., 2010). In the International Reference Base System (ISSS Working Group WRB, 2007), Chinese red soils belong to the Alisol, Acrisol or Cambisol group. Most Chinese red soils are Ultisols in the Soil Taxonomy (Soil Survey Staff, 2010), some being Alfisols or Inceptisols (Wilson et al., 2004b). Even when the Chinese red soils have a clay or loamy–clay texture, they are known to be highly sensitive to drought during the dry season (Wang, 1997), thus explaining why the red soil region is called the "red desert of southern China" (Zhao, 2002). The reason for this sensitivity to drought has not yet been elucidated, however. According to Zhang and Zhang (1995), the marked development of micro-aggregation in these red soils may facilitate downward water transfer without enough water storage in the different horizons, thus explaining the poor water storage efficiency of these soils. They also argue that the small amount of water stored in the micro-aggregates is poorly available for biological activity. More recently, Fang et al. (2010) suggested that because of the characteristics of the clays present in the red soils, water retained by these clays is not available enough for biological activity, thus explaining the high sensitivity of the red soils to drought. The clay mineralogy of Chinese red soils has often been described as dominated by kaolinite and oxy-hydroxide minerals (Wilson et al., 2004b). However, several studies have shown a wide variation in the clay mineralogy. Vogel et al. (1995) studied red reference soils from the subtropical Yunnan Province and showed that smectite could be the main clay mineral or present in significant amounts as well as chlorite and illite in addition to kaolinite as the main mineral. Zhang et al. (2004) studied red soils

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in southern China and showed that the clay mineralogy varied according to the parent material, latitude, elevation and topographic position. Kaolinite and halloysite were the most common clays in these soils, the proportion of kaolinite increasing with the degree of weathering. Vermiculite, illite, chlorite and smectite were also identified as secondary clay minerals. Goethite and hematite were the only Fe oxides occurring in significant quantities in the soils studied by Zhang et al. (2004). This wide variety of clay mineralogy encountered in the Chinese red soils probably indicates that the origin of their high drought sensitivity is not closely related to the clay mineralogy. The objective of the present work is to analyze the water retention properties of a few Chinese red clay soils, to relate these properties to the characteristics of the clays and to compare them to the water retention properties of clay soils from different regions of the world. The results will enable the discussion of the clay characteristics which are responsible for the small amount of available water and hence potentially partially responsible for the high sensitivity of Chinese red clay soils to drought.

2. Materials and methods

2.1. The soils studied

The red clay soils of the Taoyuan experimental station (28°55′47″N, 111°26′33″W) in the Hunan province, 200 km west of Changsha were selected for study. This experimental station belongs to the Chinese Ecosystem Research Network. According to the Köppen classification, the climate of the region is Humid Subtropical (Cfa). It is characterized by a dry winter (medium temperature of the coldest month ranging from −3 °C to 18 °C) and maximum rains in summer. The mean annual rainfall in Taoyuan is 1440 mm, 80% of rainfall occurring between March and August. The mean annual temperature is 16.5 °C. The range between winter and summer (difference between the average temperature during winter and summer) is 21 °C (Huang et al., 2004a,b). Soils were selected at three locations along a slope (Fig. 1): a soil at the top of the slope (TS) under a vegetation mainly composed of tea-oil trees (*Camellia oleifera*) and secondarily by camphor laurels (*Cinnamomum camphora*), chestnut trees (*Castanea* sp.) and sandalwood (*Santalum* sp.); a soil at the middle of the slope (MS) in an orchard of orange trees; and a soil on a ledge of the slope (LS) in a cultivated plot after a maize crop, the soil being left bare at the time of soil sampling. The soils are derived from Quaternary red clays. They are Ferric Acrisols in the International Reference Base System (ISSS Working Group WRB, 2007), Udic Ferralosols in the Chinese Soil Taxonomy (CRG-CST, 2001) and Typic Hapludult in the Soil Taxonomy (Soil Survey Staff, 2010). They were sampled in March 2011 after rewetting with 39 and 204 mm of rainfall in February and March, respectively. The soils were thus close to field capacity. A pit 1 m in depth was dug and the different horizons were described. Disturbed samples were collected in every horizon as well as undisturbed samples of different volumes.

2.2. Methods

The bulk density (D_b in g cm^{-3}) and field water content of the horizons at sampling date were measured by using cylinders 1236 cm^3 in volume. The bulk density of undisturbed millimetric clods 20 to 30 mm^3 in total volume was measured using the kerosene method (Monnier et al., 1973). It was measured in triplicate with 5 to 10 millimetric clods at a water content corresponding to sampling conditions and after air-drying in the laboratory (Bruand and Prost, 1987). The particle size distribution was measured using the pipette method after pre-treatment of samples with hydrogen peroxide and sodium hexametaphosphate (Robert and Tessier, 1974). The cation exchange capacity (*CEC*, in cmol$_+$ kg^{-1} of oven-dried soil) and the exchangeable cations were measured using the cobalt-hexamine trichloride method (Ciesielski and Sterckeman, 1997) and organic carbon content (*OC*) by oxidation using excess potassium bichromate in sulphuric acid at 135 °C (Baize, 2000). The gravimetric water content was determined at −60, −100, −330, −1,000, and −3,300 hPa water potential by using in triplicate soil cores 100 cm^3 in volume and at −15,000 hPa water potential by using undisturbed clods (10–15 cm^3 in volume) collected when the soil was near to field capacity (Bruand and Tessier, 2000). The soil cores were thoroughly saturated for one week before they were placed inside a pressure plate chamber (Soil Moisture Equipment Corp, Santa Barbara, USA) to drain at the sequence of pressure from −60 to −3,300 hPa (Jing et al., 2008). The mineralogical composition of the <2 μm material of the horizons B1 and C of each soil was determined by X-ray diffraction (XRD). Samples were air-dried and manually ground to a powder in a mortar. The clay fraction was collected using the sedimentation method at 20 °C after mechanical dispersion. Oriented clay deposits were prepared on glass slides and

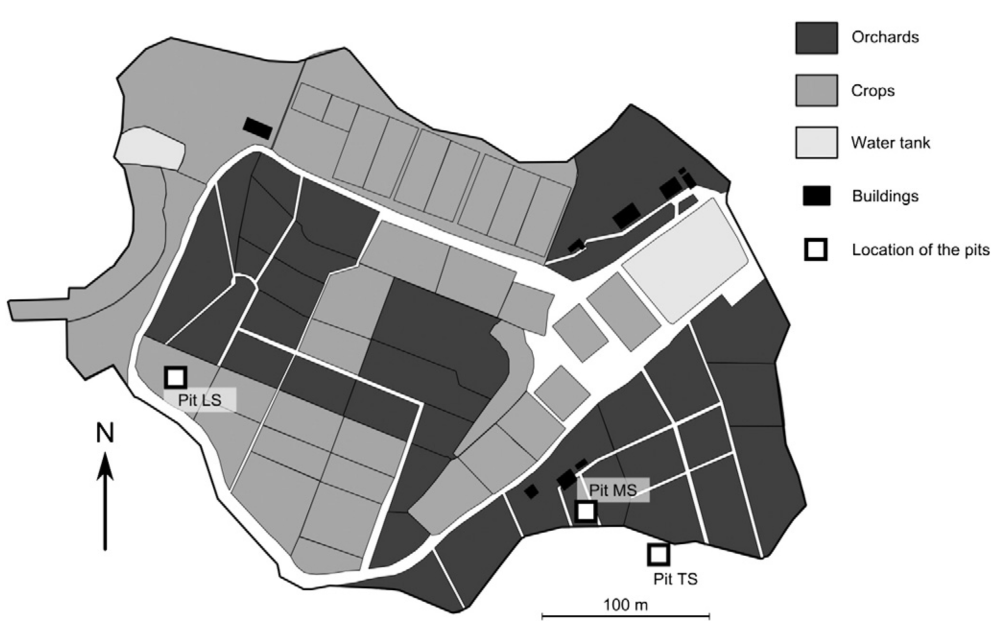

Fig. 1. Location of the soils studied in the Taoyuan experimental station (soil at the top of the slope: TS, middle of the slope: MS and on a ledge of the slope: LS).