Chemistry and clay mineralogy of Thai Natraqualfs

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Abstract

Thai Natraqualfs including saline-sodic and sodic soils from eight sites on alluvium or wash over residuum derived from clastic sedimentary rock under a tropical savanna climate were investigated. They have a large variation in EC values ranging from 0.3 - 60.5 dS/m with variable ESP values ranging from 0.1-31.5% and SAR values ≤ 13. Kaolinite is the dominant mineral in the clay fraction with small amounts of smectite and a trace of illite. Transmission electron microscope (TEM) micrographs of kaolinite show a variety of crystal morphologies including euhedral, subhedral and anhedral platy crystals. Anhedral crystals are abundant in saline-sodic soils and a high proportion of euhedral crystals occur in sodic soils. The median size of kaolinite crystal ranges from 43-69 nm. Morphology and size of kaolinite crystals for these Natraqualfs are statistically related to electrical conductivity and soil pH. Decreasing kaolinite crystal size is associated with increasing soil salinity and exchangeable Na.

Key Words

Salt affected soils, salinity, sodicity, kaolinite morphology

Introduction

Salt affected soils are problem soils in Thailand, particularly in the Northeast Plateau basin where salt bearing rocks are common. The soils usually support lowland rice cultivation which is variously affected by salinity. Generally, kaolinite is the dominant clay mineral with a trace of smectite (Suddhiprakarn and Kheoruenromne 1998; Wongpokhom *et al.* 2008). Knowledge of the mineralogy of these soils will be useful in making predictions about soil behavior and responses to management.

Methods

Soil sampling

The study sites were located on the Northeast Plateau, Thailand. Eight representative salt affected soils under a tropical savanna climate were selected. Methods of study included detailed profile description and sampling by genetic horizon according to standard field study methods (Soil Survey Division Staff 1993; Kheoruenromne 2009). Bulk soil samples were air-dried, gently crushed and then passed through a 2-mm sieve. The resultant <2 mm samples were used for laboratory analysis.

Laboratory analyses

The particle size distribution was determined by a combination of sieve and pipette analysis. Soil pH was measured in water and in 1M KCl using 1:1 soil:liquid. Organic carbon was determined by the Walkley and Black method. Extractable bases were measured by 1 M NH_4OAc at pH 7.0 extraction. Cation exchange capacity was measured by saturating the exchange sites and displacing it with 1M NH_4OAc at pH 7.0. Extractable acidity was measured by barium chloride-triethanolamine pH 8.2 extraction. Base saturation percentage was calculated by sum of bases extracted by NH_4OAc pH 7.0 divided by the CEC based on the sum of cations and multiplied by 100. Sodium adsorption ratio was calculated by dividing the molar concentration of the monovalent cation Na^+ by the square root of the molar concentration of the divalent cations Ca^{2+} and Mg^{2+}. Exchangeable sodium percentage was obtained by dividing the exchangeable sodium by the CEC at pH 7.0 and multiplying by 100. Electrical conductivity was determined by the saturation extract method at 25°C.

Soil mineralogy was identified by X ray diffraction (XRD) analysis using monochromatized CuKα radiation with a Philips PW-3020 diffractometer (50 kV, 20 mA). Clay fractions were scanned from 4 to 45° 2θ, using a step size of 0.02° 2θ and a scan speed of 0.04° 2θ/s. Relative proportions of various minerals were calculated by comparing the XRD peak intensities with the intensities for standard minerals (Brown and Brindley 1980). For analytical transmission electron microscopy, representative clay samples were prepared as dispersed samples. One milliliter of clay suspension was transferred into the 10-mL test tube, mixed well with 9 mL of deionized water. A drop of the suspension was deposited on a carbon-coated Cu grid and examined using a Jeol 2000 FX II electron microscope operated at 80 kV.

Results

General soil characteristics

These soils have been formed on alluvium or wash over residuum derived from clastic sedimentary rock on flat to gently undulating terrain (slope ranges 1-2 %) under annual rainfall ranging from 907-1237 mm y^{-1} and temperature of 26-30°C. Land uses at the time of sampling were paddy rice/left idle and a plantation of *Eucalyptus sp*. All soils are deep and the common profile development features of the soils are Apng/Apg - Btg/Btng - 2Btg/2Btng indicating a high stage of profile development. Clay accumulation in subsoils and accumulations of soluble salts in both surface and subsoils indicate the argillic-natric horizon. The soils have low chroma (≤2) and are mottled indicating poorly drainage and a long period of water saturation. Therefore, these soils can be classified as Natraqualfs according to USDA Soil Taxonomy (Soil Survey Staff 2006).

Physico-chemical properties

Particle size distribution results show that soil texture varies from loamy sand to clay. Most soils are fine to medium textured (clay to clay loam) with the coarser textured horizons being due to depositional grading of sediments. The increases in clay size particle at some depths in subsoils where clay coatings can clearly be observed are due to clay illuviation and lessivage. Soil pH in water is in a range of very strongly acid to slightly alkaline (pH 4.9-7.7). The high pH values are largely due to the hydrolysis of sodium carbonate as occurs in sodic soils. The low pH values of soils are consistent with the pH values of tropical soils that experience leaching (van Wambeke 1992). The pH values measured in KCl are smaller than those measured in water indicating that the minerals have a net negative charge. Their organic matter contents decrease with depth ranging from very low to medium (0.35-22.01 g/kg). The soils have very low to high CEC values, ranging from 0.65–29.47 $\text{cmol}_{/kg}$ and the variation in CEC closely reflects the clay content and mineralogy. The sum of exchangeable bases of these soils is very low to high and Na is the dominant exchangeable base. The extractable acidity of the soils ranges from medium to high indicating highly leaching conditions (Buol *et al.* 2003). All soils have high base saturation percentage of more than 35 percent.

Soil salinity and sodicity

There is a large variation in the EC values of these soils from very low to very high (Figure 1a). The highest EC values in the surface of some soils are due to a salt patch at the surface. A low surface EC and increasing EC with depth may be due to these soils being at intermediate stage of salt leaching (desalinization). All soils have low SAR values (SAR ≤ 13), whereas the ESP values vary substantially ranging from 0.1-31.5%. According to the criteria for classifying salt affected soils (Soil Survey Staff 2006), there are two groups of salt affected soils consisting of saline-sodic soils (Pedons 1-4) and sodic soils (Pedons 5-8) (Figure 1b).

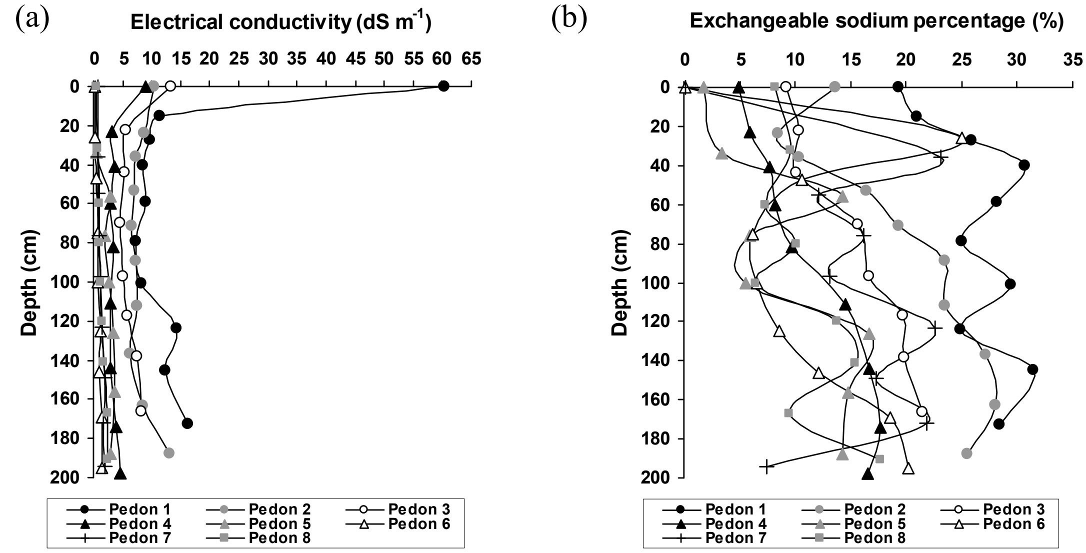

Figure 1. Depth function diagram for electrical conductivity (a) and exchangeable sodium percentage (b) of the soil profiles.

Clay mineralogy

Kaolinite is a dominant mineral in the clay fraction of these salt affected soils with small amounts of smectite and a trace of illite. All soils have kaolinitic mineralogy (Soil Survey Staff 2006). Most soils have experienced leaching of Si and basic cations in the tropical climate with high rainfall under a former pedogenic regime prior to salinization. The small amount of quartz in the clay fraction may be inherited from sandstone and siltstone. Halite is a dominant salt mineral in these salt affected soils.

The morphology of kaolinite from electron micrographs for these soils includes anhedral, subhedral and euhedral platy crystals (Figure 2) and most crystals are subhedral. Anhedral crystals are most abundant in saline-sodic soils and show a strong negative relationship with soil pH in KCl (R^2 = -0.82) and a positive relationship with EC (R^2 = 0.57) (Figure 3), whereas, sodic soils have higher proportions of euhedral kaolinite crystals. The abundance of euhedral crystals in these soils has a negative relationship with EC (R^2 = -0.45) and a strong positive relationship with soil pH in KCl (R^2 = 0.95).

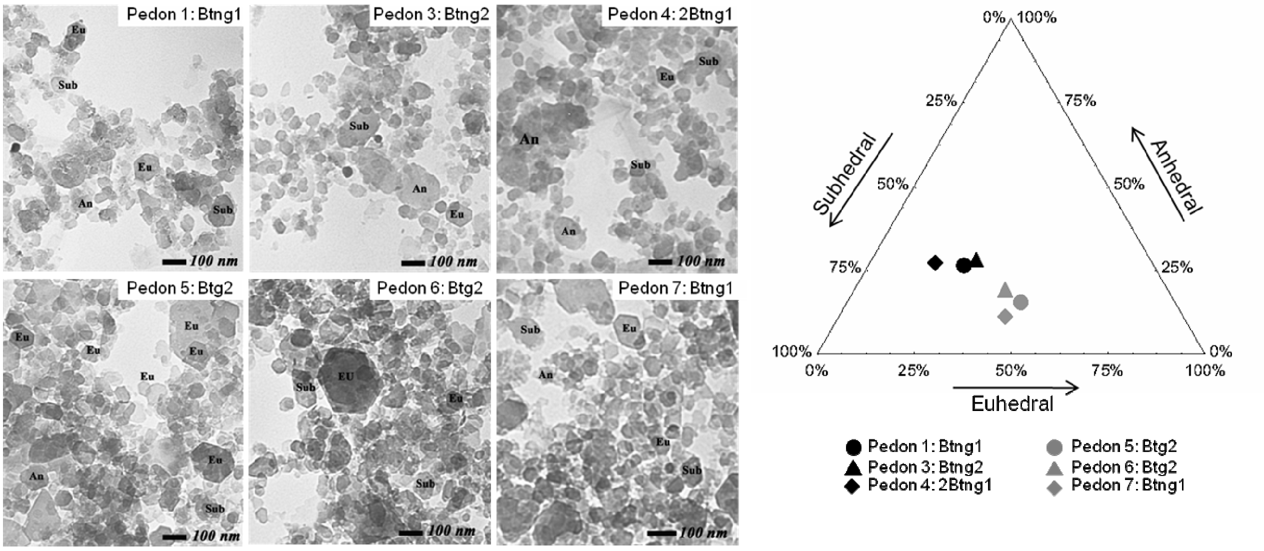

Figure 2. Transmission electron microscope (TEM) micrographs of kaolinite from representative salt affected soils showing the wide ranges of crystal morphology and size. Various morphologies are indicated in the Figure: Eu=euhedral crystal, Sub=subhedral crystal and An=anhedral crystal. The triangle graph shows the relative abundance of crystal shapes for kaolinite (0 plane faces=Anhedral, 1-3 faces=Subhedral, 4-6 faces=Euhedral).

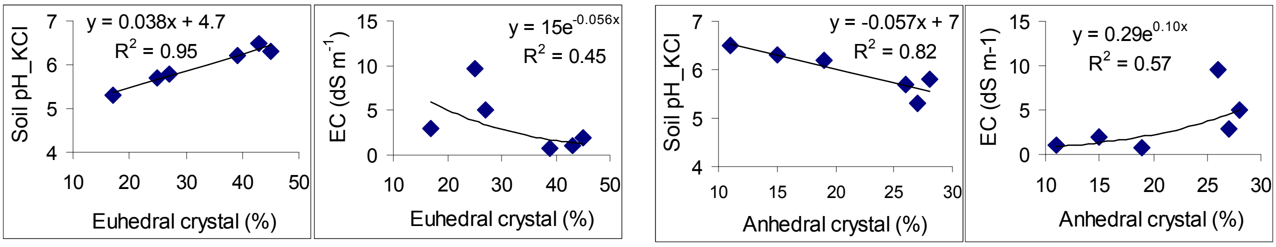

Figure 3. The relationships between percentage of kaolinite crystal morphologies determined by TEM and some chemical properties of representative salt affected soils.

The median size of kaolinite crystals ranges from 43-69 nm with the standard deviation in size ranging from 13-25 nm and furthermore the smaller kaolinite crystals are more abundant in saline-sodic soils (Figure 4). Generally, kaolinite crystals in these salt affected soils are smaller than for Thai soils investigated by Trakoonyingcharoen *et al.* (2006) with values of median size from 58-124 nm. Kaolinite crystal size shows a negative relationship with EC and exchangeable Na for these salt affected soils (Figure 5).

Conclusion

Thai Natraqualfs under a tropical savanna climate are saline-sodic and sodic soils. The clay fraction is predominantly kaolinite. Kaolinite morphology includes anhedral, subhedral and euhedral crystals. Smaller kaolinite crystals are more abundant in saline-sodic soils. Anhedral crystals are abundant in saline-sodic soils but sodic soils have higher proportions of euhedral crystals. Morphology and size of kaolinite crystals in these salt affected soils are statistically related to salinity and pH.

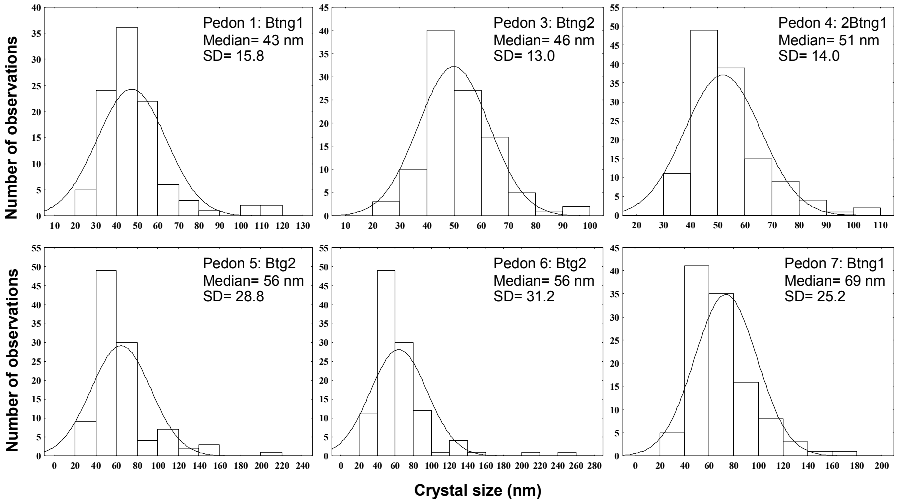

Figure 4. Histograms showing the size distribution of kaolinite crystals from representative salt affected soils.

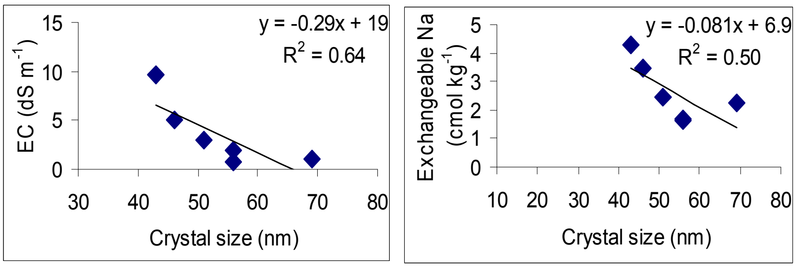

Figure 5. Relationships between kaolinite crystal size observed from TEM and some chemical properties.

Acknowledgments

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