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Micromorphological Properties of Thai Paddy Soils

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ABSTRACT

Micromorphological properties of fourteen widely distributed paddy soils from North, Northeast, Central Plain and Eastern part of Thailand were studied. Properties differ between soils, especially texture and macro porosity. The macro porosity of topsoils of coarser-textured soils is less than in subsoils because of puddling. However, the macro porosity of topsoils of the finer-textured soils is greater in the subsoil because of cracking. The pedofeatures of these soils include clay coatings, carbonate and iron oxide concretions and nodules depending on parent material and cyclic wetting and drying. The chemical composition of the clay coatings and mottles is quite similar to that of the matrix, whereas the chemical composition of nodules is quite different indicating that they did not form *in situ*. The Si to Al ratio of these transported nodules is as the same as of kaolin whereas the clay matrix has a composition reflecting the smectite or illite-rich composition.

Key words: micromorphological properties, paddy soils, Thailand

INTRODUCTION

Thailand has a total land area of about 51.4 million hectares of which 25 percent is lowlands where rice, the staple food crop, has been dominantly grown (Changprai, 1987). The total area for rice cultivation is estimated to be approximately 10 million hectares of which 9 million hectares are in lowlands (Kupkanchanakul *et al*., 2001). Rice is grown under a wider variety of climate, soil and hydrological conditions than any other crop; therefore a paddy soil can be any type of soil (Kyuma, 2004) except Gelisols. The occurrence of paddy soils is limited only by the availability of water (Zhang and Gong, 2003). Soils that have long been cultivated for rice sometimes acquire special morphological features which are the focus of this paper. For the cultivation of rice, soils are kept submerged for part of the year as a result, micromorphological characteristics of paddy soils reflect changes induced by alternating submergence and drainage. Waterlogging may induce reduction and mobilization of Fe and Mn.

MATERIALS AND METHODS

The study was carried out on fourteen soil profiles (Figure 1) consisting of three soil series from the Northeast of Thailand namely Roi Et (Re), Tha Tum (Tt) and Phimai (Pm); four soil series, Lop Buri (Lb), Tha Rua (Tr), Khok Krathium (Kk) and Bang Phae (Bph) from the Central Plain; five soil series, Mae Sai (Ms), Hang

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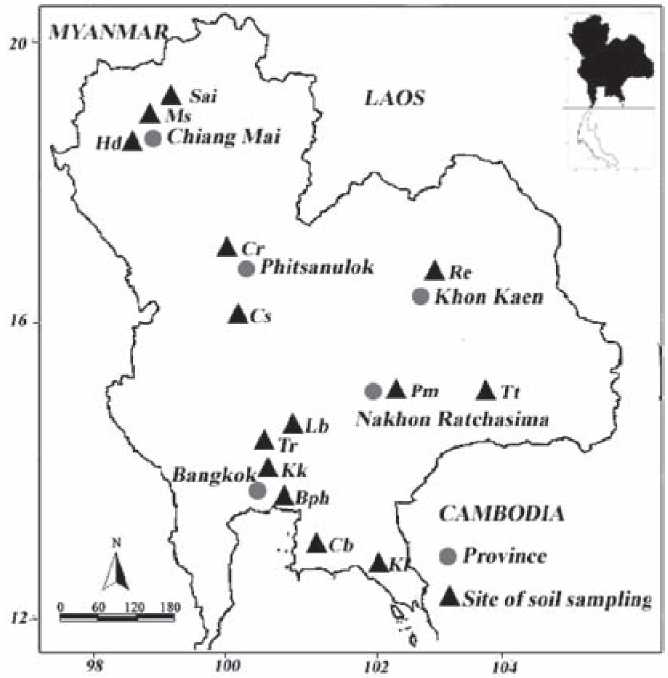

Figure 1 Sampling sites for paddy soils in Thailand.

Dong (Hd), San Sai (Sai), Chiang Rai (Cr) and Chum Saeng (Cs) from the North and two soil series, Chon Buri (Cb) and Klaeng (Kl) from the East. Soil profiles were described and sampled according to standard field study methods (Soil Survey Division Staff, 1993). Some physico-chemical properties of whole soils were determined using the procedures described by National Soil Survey Center (1996). Aluminum, Si, Fe, Na, Ca, Mg, K, P, Mn and S were determined by XRF on pelleted samples using a Philips PW1480 XRF spectrometer (Jones, 1987).

Soil micromorphology was studied on thin section of resin impregnated soils by polarizing microscope and scanning electron microscopy (SEM) with energy dispersive X-ray analysis (JEOL 6400). The backscattered image and ImageJ program were used for determining the areas of coarse (>0.02 mm) and fine (<0.02 mm) fractions and macro porosity (>5 μm) (Burger and Burge, 2006). Analytical data were statistically analyzed using factor analysis and principal component analysis with the Statistica Program (Version 6.1) (StatSoft Inc., 2003).

RESULTS AND DISCUSSION

Soil properties

The soils studied contain 7-96% clay. All soils are deep and poorly drained and, having matrix colour of 10YR hue with low chroma (≤2), resulting from the management induced annual reduction/oxidation cycle. Redox concentrations occur in the form of mottles in all profiles. Soil pH in 1:1 H_2O varies greatly between 4.6-8.2 for topsoils and 5.4-8.8 for subsoils. Organic matter (OM) content also varies greatly and decreases with depth, being 3.7-33.2 g kg^{-1} for topsoils and 0.3-18.5 g kg^{-1} for subsoils. Cation exchange capacity is 3.1-34.2 cmol kg^{-1} for topsoils and 12.0-40.6 cmol kg^{-1} for subsoils.

Factor analysis of standardized data was used to identify affinity groups of soil properties and soil series. Only 61% of the variation in data can be explained by the first two factors which is a consequence of the diverse nature of these soils (Figure 2). Two affinity groups of properties are recognized. The first group consists of total coarse fraction, sand and Si which clearly represents sandy soil materials. The second group is diffuse and consists of clay, silt and fine fractions, pore volume, OC, CEC, pH 1:1 H_2O, pH 1:1 KCl, Al, Fe, Mn, Mg, Ca, K, Na, P and S. Some of these properties relate to the clay content but others to parent material and soil environment. The plot of soil samples in the factor diagram (Figure 2b) shows that soil samples are separated on the basis of soil texture. No clear affinity groups are present with soils distributed in a continuous sequence along the factor 1 axis. Thus the coarser-textured soils (loam to sandy clay loam) comprising Re, Tt, Sai, Cb and Kl are separated from the finer-textured soils consisting of Pm, Ms, Hd, Cr, Cs, Lb, Tr, Kk and Bph (silty clay to clay).

Micromorphological properties

Microstructure

Some of the main micromorphological features of these soils are illustrated in Figure 3. The micromorphological properties of all soils are affected by their parent material and genesis. The coarser-textured soils (Re, Tt, Sai, Cb and Kl) have

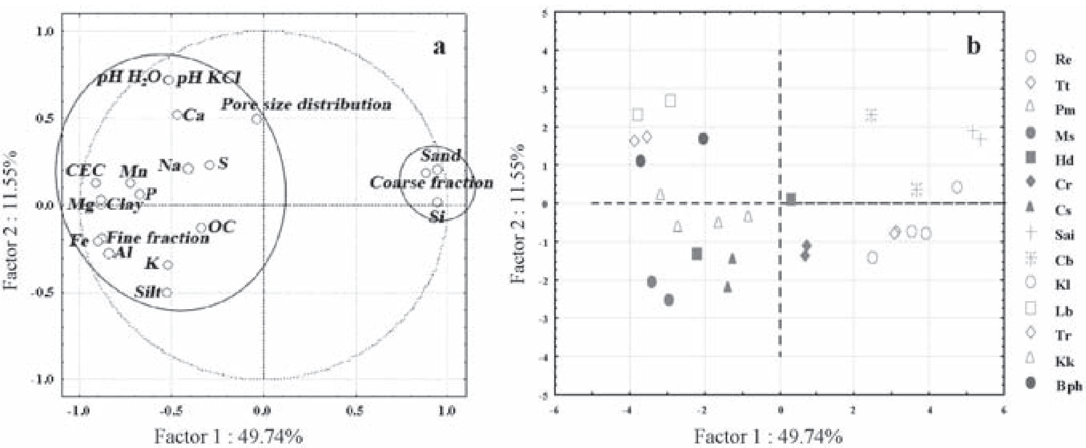

Figure 2 Factor analysis for soil properties (a) distribution of soil properties (variables) (b) distribution of soil samples (cases).

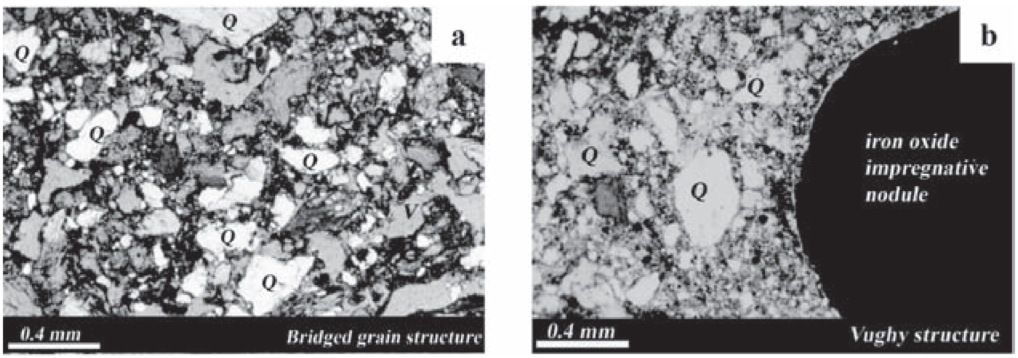

Figure 3 Micromorphology of the soil horizons: (a) Apg1 horizon (0-20 cm) of Chon Buri series; (b) Btg1 horizon (30-53 cm) of Chiang Rai series (all crossed nicols); Q = quartz, V = void.

a compact grain structure while the finer-textured soils (Pm, Ms, Hd, Cr and Cs) have an apedal microstructure in the topsoils. Paddy soils of the Central Plain (Lb, Tr, Kk and Bph) have a dominating crack structure because of smectite present as the dominant clay mineral. The formation of crack microstructures is caused by shrinking and swelling of soil materials as a result of drying and wetting (Fanning and Fanning, 1989; Pale *et al.*, 2001). The macro porosity (>5 µm) of topsoil is seemingly less than of subsoil in Re, Tt, Ms, Hd, Cr, Cs, Sai, Cb, Kl and Bph whereas the macro porosity of topsoil in Pm, Lb, Tr and Kk is greater than that of the subsoil (Figure 4).

Basic organic components

The abundance of organic materials visible in thin sections decreases with depth. For topsoils, the organic components of the soils from the North, Northeast and East are rather similar. They consist of the living plant tissues of various shapes and sizes, while relatively more fine amorphous organic materials and punctuations are present in the subsoil, except for the San Sai profile. The organic components of this soil consist of abundant organic pigment associated with clay and silt fractions forming soil aggregates (500-2100 µm width) which occupy about 25% of the total area of the thin section and with very few fragments of lignified tissue. The soils of the Central Plain have similar organic components comprising moderately to highly decomposed plant tissue residues which occur in voids and decrease in abundance with depth.

Pedofeature

All studied horizons are composed mostly of fine materials, which have mainly grayish brown to light gray colours. The fine fraction of some soils increases with depth (Sai, Cr, Cs, Re, Tt, Pm, Cb and Kl), while it decreases with depth in Hd, Lb and Bph. The fine fraction of Ms, Tr, and Kk is rather uniform throughout the profiles. Most of the soils have a speckeld fabric which is generated by suspension settling or flocculation of fine alluvial material during sedimentation (Fitzpatrick, 1993). Cryptocrystalline calcite impregnative nodules of 20-2000 µm sizes are present in the lower horizons of Lb and Tr indicating the effect of their calcareous parent material. For Bang Phae series, prismatic gypsum (grain size ranges from 10-100 µm) and few gypsum clusters accumulate in some voids possibly as a consequence of the coastal soil environment.

Paddy soils experience distinct wet and dry periods and have amorphous pedofeatures induced by both prolonged wetting and drying. The impregnative ferruginous nodules present in the topsoil are due to transportation (Bullock *et*

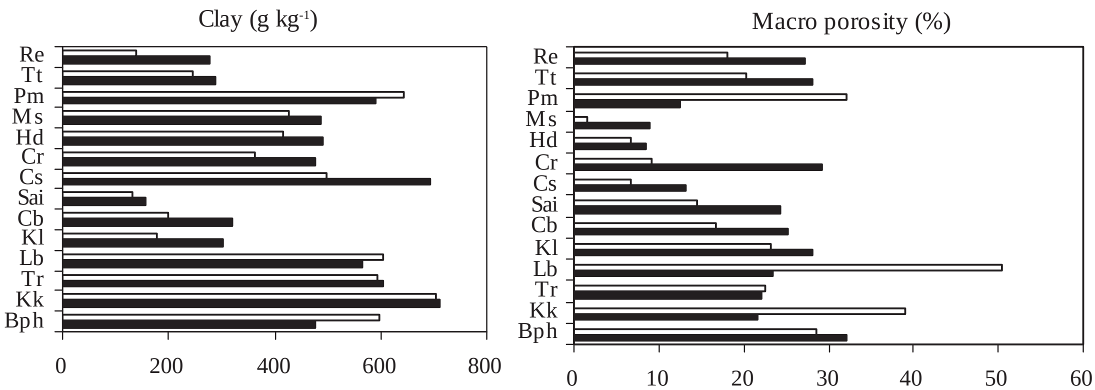

Figure 4 Mean values of clay (g kg^{-1}) and macro porosity (%) of soil profiles (☐ = topsoil, ■ = subsoil).

al., 1985). Iron oxide coatings and hypo-coatings have developed under alternating wet and dry conditions. Some iron oxide coatings in the topsoils may be a result of oxygen diffusion from plant root under an anaerobic condition. Upon draining, some areas around pores, voids and root channels become dry and are aerated more quickly than the rest of the soil, causing precipitation of ferric iron. Both iron and manganese oxides present in these soils are resulted from seasonal water table fluctuations giving rise to cycles of reducing and oxidizing conditions. A soil micromorphological feature related to the mobility of the fine fraction is the presence of clay coatings. Most subsoils have clay coatings, hypocoatings and with fillings. The presence of illuvial clay indicates that water has percolated through the soil and that the soil has experienced periodically dry periods (Boixadera *et al*., 2003).

Element mapping of soil matrix

Element mapping of the clay matrix shows that the major constituent of the soils is Si with lesser amounts of Al and Fe, except for the Lb where calcium is a major constituent of the matrix (Figure 5). Most of the soils contain clay coatings in subsoil horizons. These include impregnative ferruginous nodules and the yellowish brown to strong brown clay with iron oxide mottles present as coatings, hypo-coatings and diffusing into the s-matrix. Impregnative ferruginous nodules in topsoil horizons indicate transportation from the upper areas. The chemical composition of clay coatings is similar to that of the matrix as indicated by the composition in ternary diagram (Figure 6). The chemical compositions of the clay matrix and clay coatings are similar. They are quite variable but consistent with the kaolin/illite composition of the clay. The

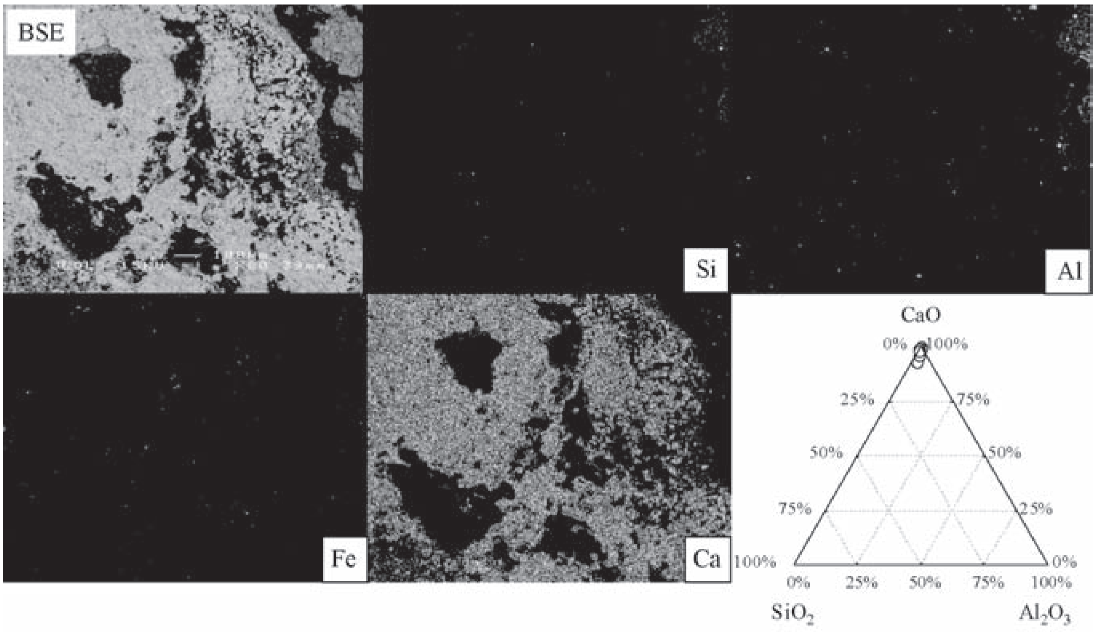

Figure 5 Backscattered electron micrograph (BSE), element mapping (Si, Al, Fe and Ca) and normalized composition triangular graph for the Ap horizon (0-23 cm) of Lop Buri series where the matrix consists of smectite; minor amount of other clay minerals and lesser calcite (○ = matrix).

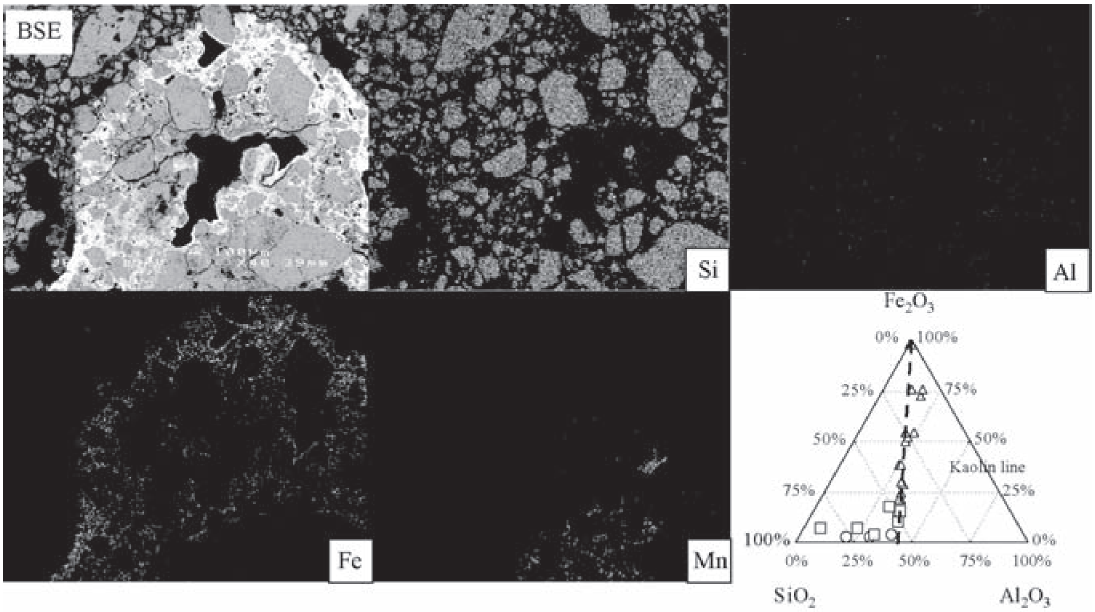

Figure 6 Backscattered electron micrograph (BSE), element mapping (Si, Al, Fe and Mn) and normalized composition triangular graph for the Btg1 horizon (40-50 cm) of San Sai series. The matrix consists mostly of equal amounts of kaolin and illite whereas the composition of nodules falls on the kaolin line which has a lower SiO_2/Al_2O_3 ratio than the matrix (○ = matrix, □ = clay coatings, △ = nodules).

iron oxide impregnated mottles have an Al_2O_3/SiO_2 ratio similar to that of the matrix indicating that they have formed *in situ*. The normalized element composition of transported iron oxide indurated nodules in some soils (e.g. San Sai, Figure 6) falls on the kaolin composition line whereas the matrix has an Al_2O_3/SiO_2 ratio consistent with the kaolin/illite matrix mineralogy. This result suggests that the nodules have been derived from a kaolinitic soil.

CONCLUSIONS

The prominent micromorphological characteristics of paddy soils consist of clay fabric, redoximorphic features, including iron and manganese oxide nodules, and iron and manganese oxide coatings on pore walls together with clay coatings in subsoils. The mobility of the fine material in the soil profiles relates to the seasonal floods, including bypass flow through cracks and large pores. The presence of illuvial clay indicates the occurrence of water percolation through the soil and the periodically dry condition. Iron and manganese oxides in these soils reflect seasonal water table fluctuations that give rise to cycles of reducing and oxidizing conditions. The chemical compositions of the clay coatings are quite similar to that of the matrix. The chemical composition of transported ferruginous nodules is located on the kaolin line rather than being the same as the matrix whereas the Si to Al ratio of mottles that have formed *in situ* is similar to that of the matrix.

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