Clay mineralogy and heavy metals in paddy soils from the Khorat Basin, Thailand

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Introduction

Rice is the most important food crop in Thailand and it is dominantly grown under paddy conditions on lowland soils (Prakongkep *et al.*, 2007). Soils used for the intensive cultivation of rice in Thailand vary considerably in mineralogy and geochemistry. Some paddy soils have been polluted with heavy metals and other elements which is a potential problem for producing rice for export (Wong *et al.*, 2002). Several studies on the geochemistry of Thai paddy soils revealed that the concentration of elements and the physical and chemical properties of paddy soils mostly depend on soil parent materials. In the present work the soils have developed on rocks of the Khorat Group that comprise continental red and gray sandstone, siltstone and shale with some paralic and thick rock salt layers and gypsum beds with total thickness of more than 600 meters. Some soils have developed on basalt and basaltic colluvium. Many of the arable soils in Northeast Thailand are sandy, acidic and infertile. Their sand and clay minerals are mainly quartz and kaolinite, respectively. This is because their parent materials are highly weathered. Others soils in the region are younger and contain diverse clay minerals. The mineralogy of soils is known to be useful in making predictions about soil behavior and response to management including fertility and soil chemistry (Trakoonyingcharoen *et al*., 2006). This study determined the clay mineralogy and associated heavy metals in paddy soils on diverse soil parent materials and in various environments in the Khorat basin, Northeast Thailand. This knowledge can be used in planning and developing agricultural management practices for food safety and food security. Other work has measured the heavy metal concentration in rice plants.

Material and methods

The study investigated 20 soil series that occur in this region. One hundred sites under paddy cultivation were sampled at three depths (Ap, Ap-60 and 60–100 cm). The soil were derived from alluvium, alluvium over residuum, residuum derived from sedimentary rock, wash over residuum and residuum and colluvium from basalt. Physico-chemical properties of whole soils were determined using the procedures described by National Soil Survey Center (1996). Soil texture was determined using the pipette method. Soil pH was determined with a pH electrode in 1:1 suspension (soil: 1M KCl and soil: H_2O). Cation exchange capacity (CEC) was measured by the ammonium saturation method at pH 7. Total carbon and nitrogen were determined on an Elementar CNS (Vario Macro) analyzer. Chemical composition was determined by X-ray fluorescence (XRF). Heavy metal contents were determined by extraction with aqua regia followed by ICP-OES analysis. Clay minerals were identified by X-ray diffraction (XRD). The < 2 μm fraction was examined by XRD using basally oriented samples variously saturated with Mg, Mg with glycerol, K and K-heated at 550 °C for 2 h (Brown and Brindley, 1980). Traces 5.0.5 (Diffraction Technology 1999) software was used for data manipulation and Brindley and Brown (1980) for mineral identification.

Results

General soil characteristics

Soil texture varies from loamy sand to clay. Values of soil pH in water ranged from 3.6 to 9.3. The organic carbon content varies from 0.1-21.2 g kg^{-1}. Total N varies from 0.05 - 1.66 g kg^{1}. Available P (Bray II) is 1.0-85.2 mg kg^{-1}, Available K ranged from 0.2-442.7 mg kg^{-1}, Cation exchange capacity from 0.2-50.8 cmol kg^{-1}, Extractable acidity from 0.5-21.5 cmol kg^{-1} and base saturation percentage from 3.7-96.7%.

Factor analysis and principal component analysis

The concentrations of heavy metals and other properties of Thai paddy soils mostly depend upon soil parent materials. For soils developed on sediments the texture of the depositional layers is important. In the present research factor analysis was used to enable statistical analysis of the physical properties and chemical composition of the soils. Properties were compared both within and between profiles. Factor analysis and principal component analysis were used to determine elements of similar geochemical behavior and also to group soil samples on the basis of their geochemical affinity (Bellehumeur, *et al*., 1994). Factor analysis of standardized raw data was used to identify affinity groups of elements, with texture, pH and CEC being included in the data set. Only 61% of the variation in data for the soils is explained by the first two factors which is a consequence of the diverse nature of these soils (Fig 1).

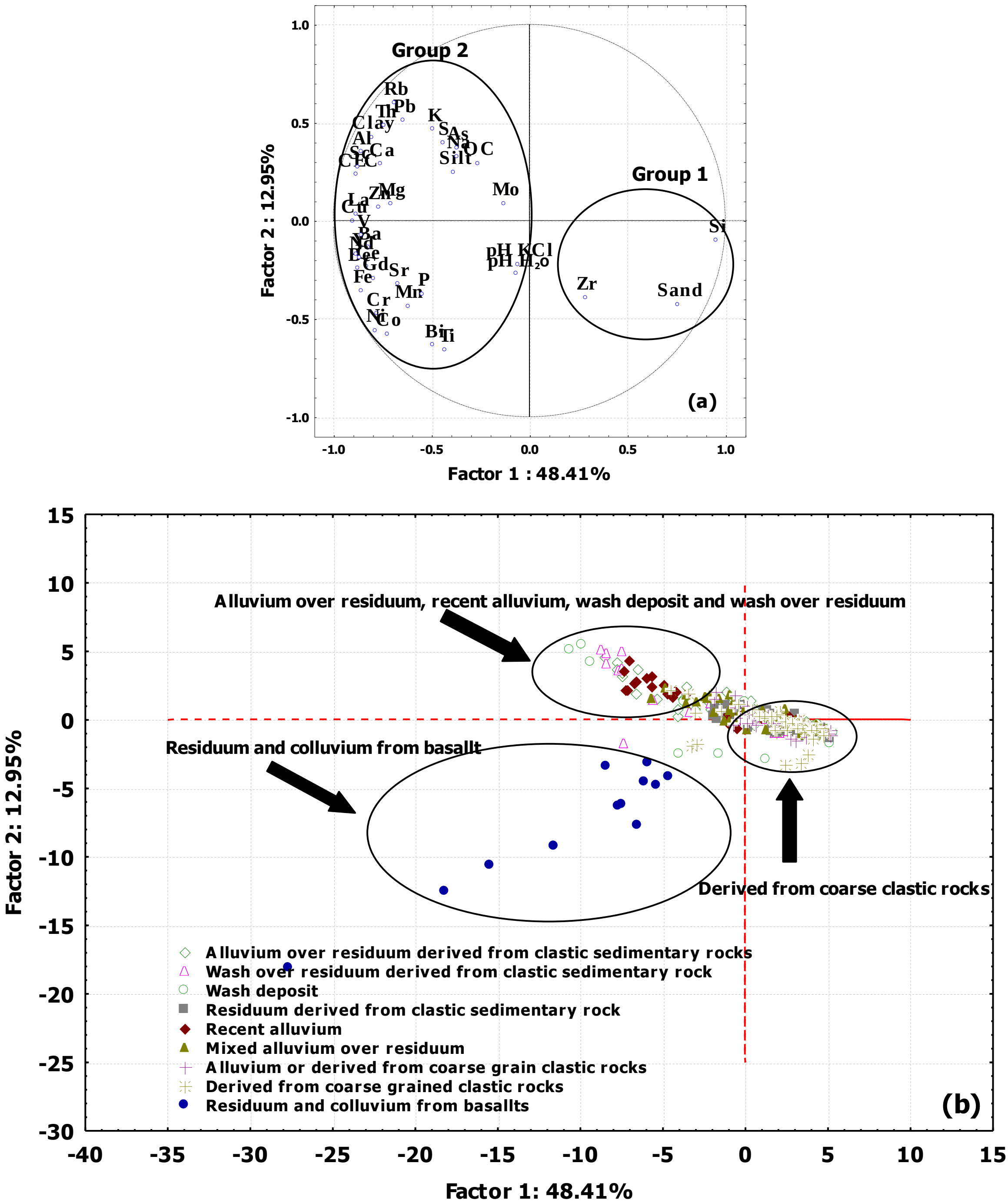

Fig. 1. Factor analysis for the chemical composition and some additional properties for whole soil materials. (a) distribution of chemical and other soil properties (variables) (b) distribution of soil samples (cases).

The first group consists of sand, Si and Zr which simply relates to the texture of the soils. The sand fraction is mainly quartz (SiO2) and in sedimentary rocks Zr is mostly present in sand-size zircon crystals. The second group is diffuse and consists of clay, silt, CEC, pH H_2O, pH KCl, OC, Al, As, Ba, Be, Bi, Ca, Ce, Co, Cr, Cu, Fe, Gd, K, La, Mg, Mn, Mo, N, Na, Nd, Ni, P, Pb, Rb, S, Sc, Sr, Th, Ti, V, Y and Zn This group of properties relates to the clay content as many of these elements are constituents of clay minerals and oxides or occur as adsorbed species (Kabata- Pendias, 2010). Other elements (C, N) are associated with organic matter. The plot of soil samples in the factor diagram (Figure 1b) shows that the soils on residuum and colluvium derived from basalt have a homogeneous population that is well separated from other soils formed on sediments. Heavy metal concentrations in all paddy soils increase with depth and with the increase in clay content. Only the soils on residuum and colluvium derived from basalt have median concentrations of Bi, Co, Cr, Mn and V higher than values for worldwide normal soils and approaching critical concentrations for environmental concern.

Mineralogy of the clay fraction

All soils show clay accumulations in the subsoil. Kaolin is the major clay mineral present in the clay fraction of most soil samples. Small or trace amounts of smectite, vermiculite, illite, chlorite, gibbsite, goethite and quartz occur in many samples. A relatively high amount of quartz is present for the soils developed on sandstone. Anatase is relatively abundant in most of the soils derived from basalt which may be due to the relative abundance of Ti in mafic rocks and it is concentrated considerably during weathering of basalt (Anand & Gilkes, 1987).

Conclusions

Heavy metal concentrations in all paddy soils increase with depth with the increase in clay content. Soils on residuum derived from basalt have median concentrations of Bi, Co, Cr, Mn and V higher than values for worldwide normal soils and approaching critical concentrations for environmental standards. Variations in chemical composition due to contamination of soil by application of impure fertilizers or wastes are minimal or absent. Most paddy soils in the Khorat basin that have developed on sedimentary rocks contain much much kaolin, traces of vermiculite and illite. A relatively high amount of quartz is present in the clay fraction for the soils developed on sandstone. Various amounts of smectite are present in soils where leaching is retarded. Smectite also occurs in soils formed from basaltic materials. The large variations in chemical composition and clay mineralogy of paddy soils in the Khorat basin mostly reflect differences in parent material composition.

Acknowledgments

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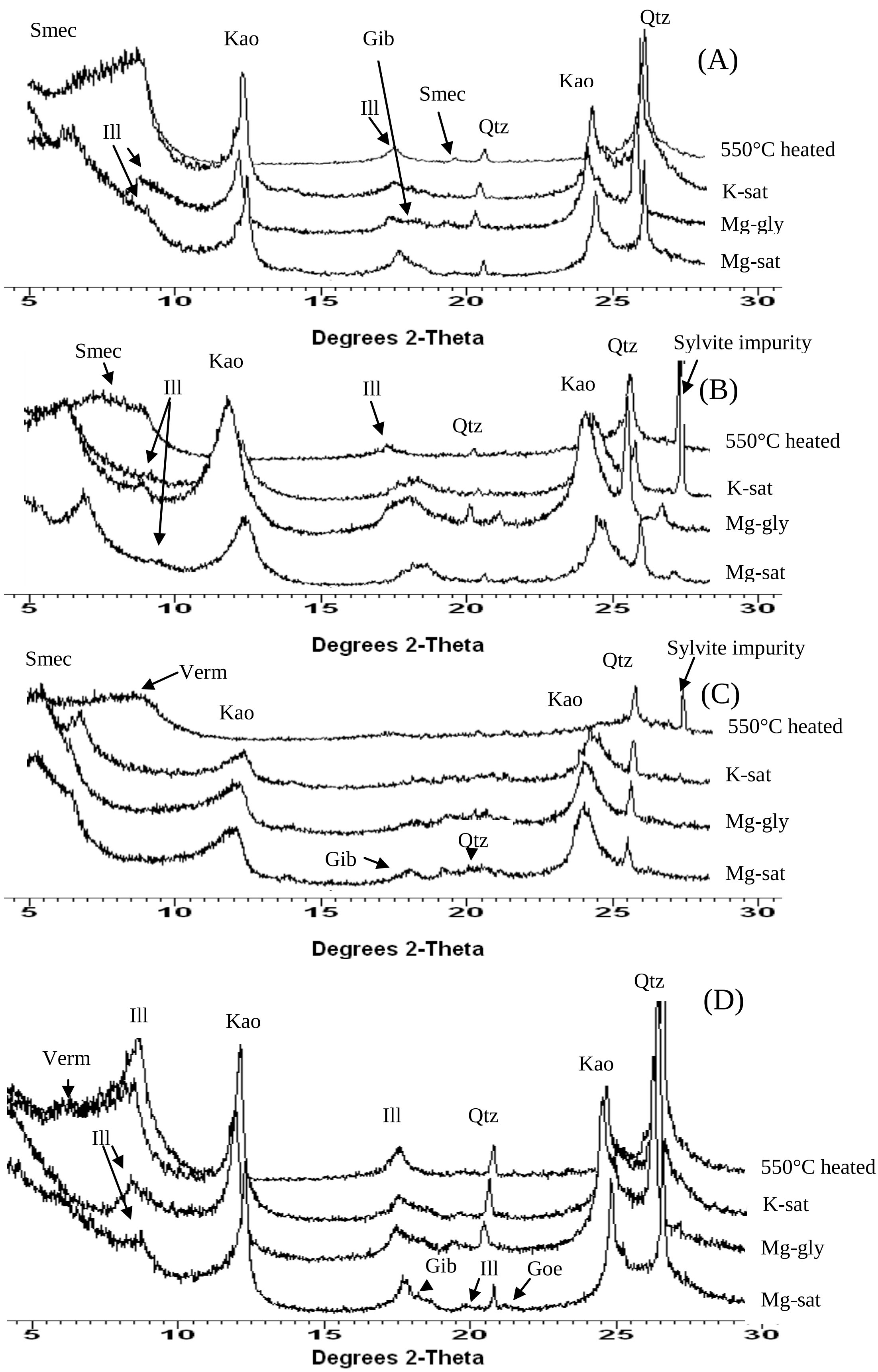

Fig. 2. XRD patterns showing major minerals in the clay fraction of A. alluvium over residuum B. residuum derived from sedimentary rock C. residuum and colluvium derived from basalt D. wash over residuum. The sylvite impurity is due to insufficient washing of the K-saturated plates.