Kasetsart J. (Nat. Sci.) 40 : 1 - 8 (2006)

Minerals in Clay Fractions of Some Alfisols in Thailand

Wimolnan Kanket[1]* , Anchalee Suddhiprakarn[1], Irb Kheoruenromne[1] and R. J. Gilkes[2]

ABSTRACT

The study on minerals in clay fractions was conducted on thirty selected Alfisols in Thailand. X-ray diffraction (XRD) was used to identify and quantify clay minerals in the samples. The results revealed that minerals in their clay fraction were kaolinite, illite, quartz, smectite, anatase and vermiculite. Kaolinite and quartz were present in every profile, but illite, smectite, anatase and vermiculite were present only in some profiles. With kaolinite having small size and defect structure as the major clay mineral species and small amounts of vermiculite and illite in the soils, the fertility status of these soils was moderate. Kaolinite alone could contribute substantially on capacity to retain cations in some of these soils. Basing on these findings, nature of these minerals in clay fraction should be carefully considered in soil-fertilizer management for intensive crop production on these soils.

Key words: alfisols, clay minerals, kaolinite

INTRODUCTION

Alfisols in tropical region vary considerably in their chemical and physical characteristics. Permeability and bulk density are relatively low in most Alfisols. Alfisols naturally have a high base saturation so they are generally not deficient in Ca, Mg and K. However, the high base saturation of Alfisols does not necessary mean that they are rich in bases (Singh, 1991). Many tropical Alfisols have low cation exchange capacities and exchangeable cations as they also contain low activity clay such as kaolinite (Moncharoen and Vijarnsorn, 1978; Soil Survey Staff, 1999). Some Alfisols may have high activity clay minerals such as smectite, vermiculite, illite or chlorite as the dominant clay species (Yoothong, 1997). The cation exchange capacity (CEC) of a soil indicates its ability to exchange cations and retain nutrients and it is a measure of the soil quality (Bear, 1965). The type of clay minerals and their relative amount in the clay fraction should reflect the CEC values of the soils (White, 1987). Kaolinite has a low CEC (about 10 cmol kg^{-1}) (Bain and Smith, 1987). The presence of smectite and vermiculite could increase the CEC of the soils (Yong *et al.*, 1992).

The total area of Alfisols in Thailand is about 49.5 square kilometers. Alfisols (9% of the total area) occur in drier areas of the country, mainly in the Central, North and Northeast. Most Alfisols have variably high pH, low values of CEC, low plant available nutrients, and medium to high base saturation. The dominant minerals of their

[1] Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
[2] School of Earth and Geographical Sciences, Faculty of Natural and Agricultural Science, University of Western Australia, Crawley, WA 6009, Australia.
* Corrsesponding author, e-mail:g4281022@ku.ac.th

clay fraction may be kaolinite, smectite, vermiculite, illite with lesser amounts of aluminum interlayered 14 Å clay mineral (HIV) together with sesquioxides (Changprai, 1987). This paper is an attempt to present an account on the distribution of clay mineral assemblages of some Alfisols in Thailand which would reflect their chemical systems vital to fertilizer application in agricultural management practices.

MATERIALS AND METHODS

Topsoil horizons of Alfisols (Soil Survey Staff, 2003) were sampled for 30 sites representing every region (Northern, Central, Northeast, Southeast Coast and Peninsular region) of Thailand. A brief description of site properties including their classification were given in Table 1. All of samples were taken by a hand auger from depths ranging 0-50 cm. Laboratory analyses of soil samples were conducted according to standard methods (National Soil Survey Center, 1996). Mineralogical analysis of the clay fraction was by X-ray diffraction (XRD) analysis (Jackson, 1965). Identification and quantity estimation of clay minerals in the samples were based on comparison with standard minerals (Whittig, 1965; Singh and Gilkes, 1992).

RESULTS AND DISCUSSION

Types and abundance of minerals in the clay fraction of Alfisols

Results obtained from XRD analysis revealed that kaolinite was the dominant silicate clay mineral conforming with typical situation of the soils in the Tropics. Smectite and illite in small amounts can also be detected in these soils. Quartz is present in the clay fraction in all soils, anatase and vermiculite are also found in trace amounts in some soils. The XRD patterns of basally oriented specimens of representative Alfisols (Pran Buri=Pr, Muak Lek= Ml, Phak Kat= Pak, Phan= Ph and San Sai= Sai), were given in Figure 1 and electron micrographs of representative kaolinite were shown in Figure 2.

Nature of minerals in the clay fraction

A summary on mineral species in the clay fraction and some soil fertility parameters of these Alfisols were shown in Table 2. The presence of kaolinite in the clay fraction was reflected well in the XRD pattern of these soils. The XRD pattern also showed quartz and anatase in most of these soils that were due to the effect of their parent materials.

Kaolinite: Kaolinite was evidently the major clay mineral in these soils and was present in all of samples (Figure 3a). About 80 % of these soils had more than about 40 % kaolinite in the clay fraction. The presence of kaolinite was consistent with the quite highly weathered condition of most of these soils (Dixon, 1989). Similar observations have been made for highly weathered soils from various parts of the world (Juo, 1980). San Sai (Sai) and Phan (Ph) soil series representing soils under aquic moisture regime and Phak Kat (Pat) soil series the udic moisture regime had more dominant kaolinite than Pran Buri (Pr) and Muak Lek (Ml) (ustic moisture regime) (Kheoruenromne and Suddhiprakarn, 1984) (Figure 1 and Table 2). It might be expected that, with current soil forming processes, soil under udic moisture regime should have more advanced development stage due to a more continuous condition of leaching and oxidation (Kheoruenromne and Suddhiprakarn, 1984).

Electron micrographs of representative kaolinite were shown in Figure 2. Kaolinite in the clay fraction had relatively poor crystal order and quantitative electron microscopy had clearly shown that kaolinite in these soils had small crystal size (100 to 218 nm) as compared to Georgia reference kaolins (280 and 370 nm) and other Thai soils (20 to 750 nm) (Hart et a.l, 2003) and with euhedral to subhedral platy shape (Kanket et al, 2005).

Table 1 Series names, classification, parent materials and distribution of the studied Thai Alfisols.

Series	Region[1]	Parent materials	Classification
Land condition: Lowlands			
Deambang (Db)	C	Old alluvium	Aeric (Plinthic) Endoaqualfs; Fine, kaolinitic
Khao Yoi (Kyo)	C	Old alluvium	Aeric Endoaqualfs, Fine-loamy, mixed, semiactive
Manorom (Mn)	C	Semi-recent alluvium	Aeric (Plinthic) Endoaqualfs; Fine, mixed, semiactive
Nakhon Pathom (Np)	C	Semi-recent alluvium	Aeric Endoaqualfs; Fine, mixed, active
Hang Dong (Hd)	N	Alluvium	Typic Endoaqualfs; Fine, mixed, semiactive
Phan (Ph)	N	Alluvium	Typic (Plinthic Endoaqualfs; Fine, kaolinitic
San Sai (Sai)	N	Alluvium	Aeric Endoaqualfs; Coarse-loamy, siliceous, subactive
Mae Sai (Ms)	N	Alluvium	Aeric Endoaqualfs; Fine-silty, mixed, semiactive
Lampang (Lp)	N	Old alluvium	Typic (Aeric) Endoaqualfs; Fine-silty, mixed, semiactive
Tha Tum (Tt)	NE	Old alluvium	Aeric (Plinthic) Endoaqualfs; Fine, mixed, semiactive
Langu (Lgu)	S	Relatively old alluvium	Typic Endoaqualfs; Fine, kaolinitic
Land condition: Uplands			
Pran Buri (Pr)	C	Alluvium	Oxic Paleustalfs; Fine-loamy, mixed
Thap Khwang (Tw)	C	Alluvium	Ultic Paleustalfs; Fine, mixed
Kamphaeng Sean (Ks)	C	Semi-recent alluvium	Typic Haplustalfs; Fine-silty, mixed, subactive
Phetchaburi (Pb)	C	Semi-recent alluvium	Oxyaquic Haplustalfs; Fine-loamy, mixed, active
Wichain Buri (Wb)	C	Old alluvium	Aquic Haplustalfs; Fine-loamy, mixed, actived
Muak Lek (Ml)	C	Residuum and colluvium from shales and slate	Ultic Haplustalfs; Coarse-skeletal, mixed, semiactive, shallow
Kamphaeng Phet (Kp)	N	Alluvium	Oxyaquic (Ultic) Haplusalfs; Fine-silty, mixed
Li (Li)	N	Residuum and colluvium from shale and phyllite	Ultic Haplustalfs; Coarse-skeletal, mixed, semiactive, shallow
Phayao (Pao)	N	Residuum and colluvium from sandstone	Plinthic Paleustalfs; Coarse-skeletal, mixed, Semiactive
Khambong (Kg)	NE	Old alluvium	Typic Haplustalfs; Sandy, siliceous
Wang Hai (Wi)	NE	Old alluvium	Oxyaquic (Ultic) Paleustalfs; Fine, mixed, active
Loei (Lo)	NE	Residuum and local colluvium from granite and shale	Ultic Pelaustalfs; Fine, kaolinitic
Wang Saphung (Ws)	NE	Residuum&/or colluvium of shale (sandy shale)	Typic Haplustalfs; Fine, mixed, active
Chatturat (Ct)	NE	Calcareous siltstone and fine grain sandstone	Typic Haplustals; Fine, mixed active
Nam Pong (Ng)	NE	Washed deposit on sandstone	Arenic Haplustalfs; Loamy, siliceous, Semiactive
Sikhiu (Si)	NE	Washed deposit of calcareous sandstone	Typic Rhodustalfs; Fine-loamy, mixed, semiactive
Phak Kat (Pat)	S	Relatively old alluvium	Plinthaquic Paleudalfs; Fine, mixed, Semiactive

[1]C= Central, N= North, NE= Northeast, S= Southeast Coast and Peninsular Thailand

Illite: Illite was present in 26 out of 30 samples, and some soils had moderate amounts of this clay mineral (Figure 3b). Illite could be formed in the saprolite zone of lateritic profiles from the weathering of K-feldspar or biotite (Gilkes *et al*., 1973). Illite in these soils might have altered to kaolinite when it experience more intense weathering during development of the laterite profiles but if the laterite subsoil was exposed by erosion, some illite might be present in the present

Table 2 Minerals in the clay fraction and some soil properties of Alfisols.

Soil series	Mineral species in clay fraction						pH	CEC	Clay
	Ver	Sme	Ill	Kao	Qtz	Ana	(1:1) H_2O	(cmol kg^{-1})	(g kg^{-1})
Land condition: Lowlands									
Deambang (Db)	-	-	tr	xxx	xxx	tr	7.2	11.40	188
Khao Yoi (Kyo)	-	x	x	xxx	x	tr	6.1	16.90	224
Manorom (Mn)	-	-	x	xxx	x	tr	6.0	12.10	244
Nakhon Pathom (Np)	-	tr	x	xx	x	tr	7.8	20.00	268
Hang Dong (Hd)	-	xxx	-	xx	tr	tr	7.9	27.20	368
Phan (Ph1)	-	tr	x	xx	x	tr	4.8	13.90	216
Phan (Ph2)	-	tr	tr	xx	x	-	5.3	7.83	248
Phan (Ph3)	-	tr	tr	xx	xx	tr	4.8	12.90	300
San Sai (Sai)	-	tr	x	xx	x	tr	6.5	4.13	128
Mae Sai (Ms)	-	tr	x	xx	x	tr	5.7	23.98	448
Lampang (Lp)	-	-	tr	xxx	x	tr	5.4	8.91	268
Tha Tum (Tt)	-	x	tr	xx	x	tr	5.0	21.81	420
Langu (Lgu)	-	tr	tr	xxx	tr	tr	5.6	10.58	272
Land condition: Uplands									
Pran Buri (Pr)	-	x	x	x	x	-	7.2	6.90	188
Thap Khwang (Tw)	-	tr	-	xxx	x	-	8.3	14.61	168
Kamphaeng Sean (Ks)	-	-	x	xx	x	tr	7.7	19.91	352
Phetchaburi (Pb)	-	-	x	x	xxxx	-	5.9	5.36	96
Wichain Buri (Wb)	-	x	tr	xx	xx	tr	5.6	3.30	60
Muak Lek (Ml)	tr	-	x	xx	x	tr	6.2	19.50	268
Kamphaeng Phet (Kp)	-	tr	x	xx	x	tr	5.7	20.75	136
Li (Li)	tr	-	-	xxxx	tr	-	4.6	25.23	500
Phayao (Pao)	-	x	tr	xxx	tr	-	4.9	7.01	212
Khambong (Kg)	-	-	tr	xxx	x	tr	6.0	3.24	64
Wang Hai (Wi)	-	tr	tr	xxx	x	tr	5.5	5.40	108
Loei (Lo)	-	-	-	xxxx	tr	tr	5.3	12.73	360
Wang Saphung (Ws)	-	-	x	xx	x	-	7.0	22.35	408
Chatturat (Ct)	-	-	x	xxx	x	-	7.8	14.02	220
Nam Pong (Ng)	-	-	tr	xxx	x	-	5.6	0.90	52
Sikhiu (Si)	-	tr	xx	xx	x	tr	7.3	23.67	512
Phak Kat (Pat)	-	tr	tr	xxx	x	tr	4.6	17.75	264

Ver = Vermiculite, Sm = Smectite, Ill = Illite, Kao = Kaolinite, Qtz = Quartz, Ana = Anatase
tr= trace (<5%), x= few (5-20%), xx= moderate (20-60%), xxx= large, xxxx= dominant (>60%)

day surface soil as dioctahedral mica (Singh, 1991).

Smectite: Smectite was present in 18 samples. The corresponding frequency distribution was givien in Figure 3c. Smectite occurs in soils developed from alluvial deposits, in relatively young soils. Pran Buri (Pr), Phak Kat (Pat), Phan (Ph) and San Sai (Sai) series developed on alluvium had smectite in their clay fractions.

Quartz: Quartz was present in all samples (Table 2). Phetchaburi (Pb) series had a dominance of quartz that might be due to its parent material. The presence of quartz was consistent with the quite highly weathered condition of most of these soils (Dixon, 1989).

Anatase: Anatase was present in most of samples but in trace amounts (Table 2). Anatase was the most common TiO_2 mineral in soils. It is a major constituent in some highly weathered soils in the Tropics (Anand and Gilkes, 1984).

The effect of minerals in clay fraction on soil fertility parameters

The pH values of most of these soils in water (1:1) ranged from very strong acid to moderately alkaline (4.6-8.3). The results showed

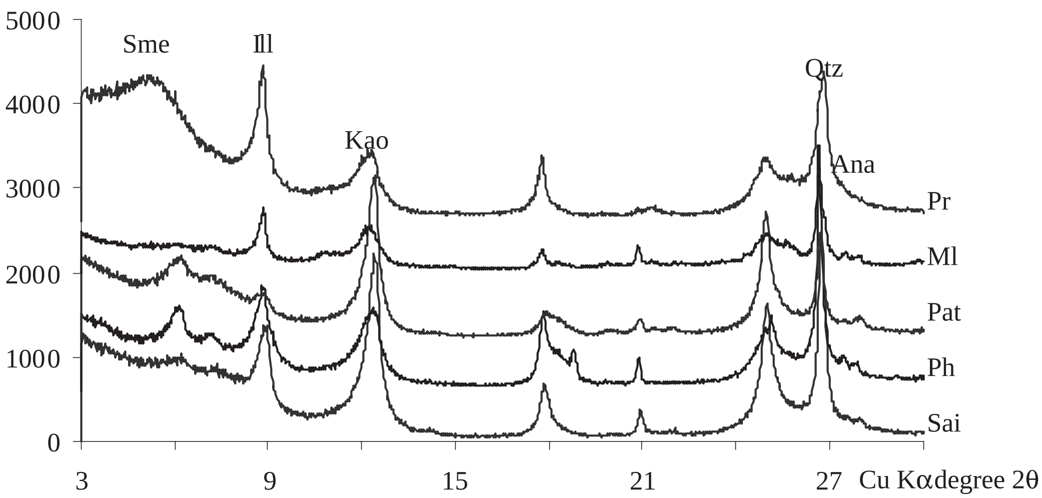

Figure 1 XRD patterns of the basally oriented clay fraction on representative Alfisols. The clay consists much of kaolinite (Kao) and illite (Ill) but also has a small amount of smectite (Sme). (Pran Buri= Pr, Muak Lek= Ml, Phak Kat= Pak, Phan= Ph and San Sai= Sai).

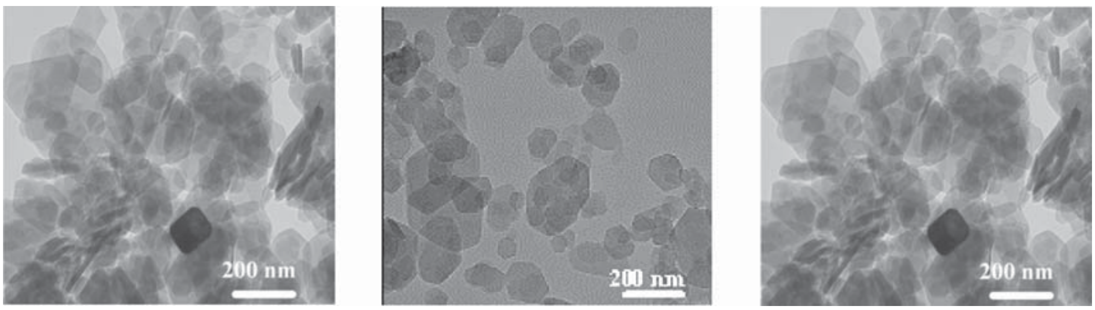

Figure 2 Transmission electron micrographs (TEM) of clay in some Alfisols.

that the dominance of kaolinite was consistent with high leaching and acid conditions. Hang Dong (Hd) and Thap Khwang (Tw) series had high pH so that they had smectite in the samples. The high pH was required to stabilize the smectite initially present in the soils (Singh, 1991). CEC of these soils ranged from 0.9 to 27.2 cmol kg^{-1} (Table 2). CEC was quite variable within and between mineral groups. For example, the CEC of the kaolinite and illite was relatively low, whereas the CEC was high for smectite and vermiculite. Hang Dong (Hd) series had the highest CEC because this soil contained large amounts of smectite, whereas Loei (Lo) series had lower CEC because it was dominated by kaolinite. The clay fraction of Li series was also dominated by kaolinite but the CEC was high. This might be due to the small size and defect structure of kaolinite in this samples.

These soils consisted of kaolinite as the dominant species whereas smectite and illite could also be found in some samples in variable quantity depending on the parent materials. This dominance of kaolinite was consistent with the highly weathered condition of these soils and similar observations have been made for highly weathered soils from other parts of the world (Juo, 1980). The large surface area and chemical reactivity of soil kaolinite, which resulted from the small size and defect structure will be important for sorption reactions in some of these soils which were often sandy and containing little organic matter to adsorb plant nutrients and other ions. Consequently, kaolinite might provide a substantial part of the capacity of some soils such as Li series (Table 2) to retain cations and anions (Kanket *et al*., 2005).

CONCLUSION

The physical and chemical properties of a soil were controlled to a very large degree by the soil minerals, especially by the minerals constituting the clay fraction. Kaolinite was the most common and abundant clay mineral in these

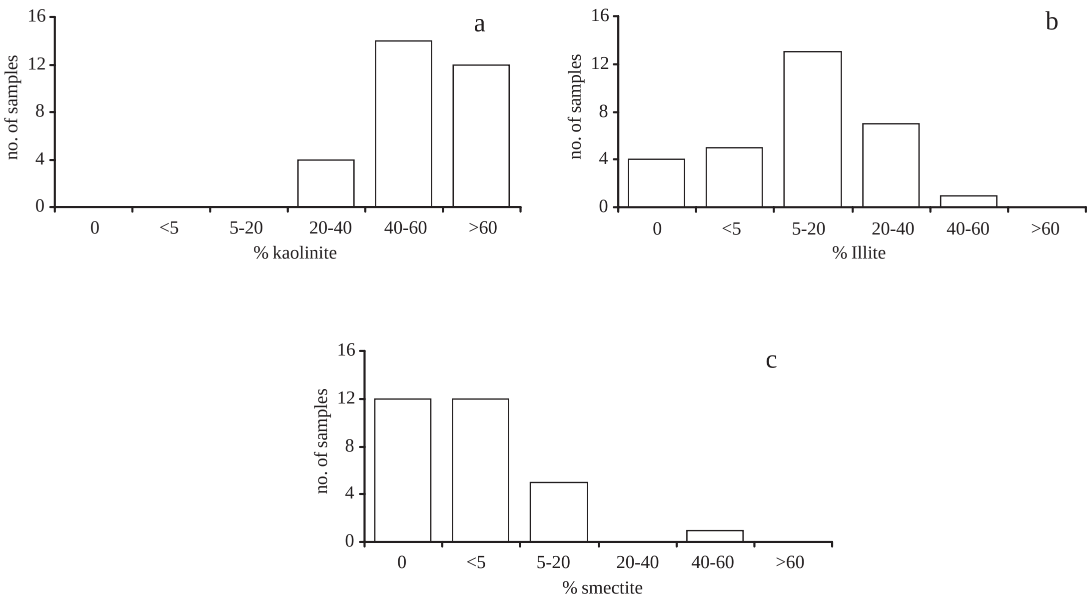

Figure 3 Frequency distribution of the abundance of clay mineral species in the clay fraction of 30 samples of Thai Alfisols; (a) kaolinite, (b) illite (not present in 4 samples) and (c) smectite (not present in 12 samples).

soils and was present in all samples. About 80% of the samples had more than 40% kaolinite in the clay fraction. Variable amounts of illite and smectite were also constituents of these soils along with quartz and anatase. Results of semi-quantitative study on minerals in clay fraction of Thai Alfisols corresponded well with their chemical properties. With kaolinite, illite and smectite as the major clay mineral species in the clay fractions, the fertility status of these soils was moderate. In addition, the large surface area and chemical reactivity of soil kaolinite, which resulted from the small size and defect structure were also important for sorption reactions in these soils which were often sandy and containing little organic matter to adsorb plant nutrients and other ions. Consequently, kaolinite alone might contribute a substantial part to the capacity of some soils to retain cations and anions. The nature of the dominant minerals in these soils therefore, should be considered carefully in soil-fertilizer management for intensive crop production on these soils.

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