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出版情報：九州大学大学院農学研究院紀要. 53 (1), pp.171-178, 2008-02-28. Faculty of Agriculture, Kyushu University
バージョン：published

J. Fac. Agr., Kyushu Univ., **53** (1), 171–178 (2008)

Clay Mineralogy of Grey Degraded Soils and Sandy Soils as Problem Soils in Vietnam

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(*Received November 9, 2007 and accepted November 30, 2007*)

Four profiles of grey degraded soils and of sandy soils were collected from different agro–ecological regions in Vietnam and subjected to clay mineral analysis in addition to particle–size analysis. The result showed that those soils had the low clay while high sand contents in the upper layers or throughout the profile. This was ascribed to decomposition of layer silicate minerals in the upper layers and/or downward shifting of clay particles in a profile for grey degraded soils and to inheritance from the parent material for sandy soils. Predominant minerals detected in the clay fraction were kaolin (kaolinite and halloysite (0.7 nm)) and quartz for both soil types.

The present study indicated two opposite processes of soil development. For grey degraded soils, reduction in the clay content with decomposition of layer silicate minerals was enhanced with advancement of soil degradation. As a result, they became sandy–like soils with domination of quartz in the clay fraction. For sandy soils, on the other hand, their particle–size distribution and clay mineralogical composition were changed naturally by enrichment with clay particles from surrounding environment. The latter process suggests a possibility of fertility improvement of poor soils by mixing with more fertile materials such as alluvial soils, river sediments and weathered rock materials, in addition to the traditional measures such as intensive application of chemical fertilizers and addition of large amounts of organic amendments.

INTRODUCTION

Vietnam is an agro–based country with a total national land of 331,000 km^2, and agriculture has faced many limiting factors of which soil is often a dominant one. According to the Vietnamese soil classification system, soils are classified into 13 main soil groups and 31 soil units in the whole country, which have been correlated with soil names in the FAO/UNESCO soil classification system and USDA Soil Taxonomy. Grey degraded soils and sandy soils are considered as two out of five problem soils in Vietnam; the remaining three are acid sulfate soils, saline soils and eroded skeletal soils. In spite of the difference in genesis, grey degraded soils and sandy soils in Vietnam have some common properties. They are characterized by the very coarse texture of surface horizons with the clay content of normally less than 10%, along with the low organic carbon content, leading to the low cation–exchange capacity and hence deficiency in all plant nutrients. This is attributable to the soil degradation for grey degraded soils and the original features for sandy soils (VSSS, 1996; NISF and DSTPQ, MARD, 2002).

Clay minerals in soil generally comprise phyllosilicates or layer silicates which are characterized by the layer structure and layer charge and fulfill a function through the large surface area and high cation–exchange capacity. Clay minerals play an important role in determining physical and chemical properties of a soil. A good understanding on the existing clay minerals of a specified soil can help for scientists not only to diagnose the genetic processes of the soil and to classify it but also to manage the soil effectively and to propose measures for improving or keeping soil productivity.

Clay mineralogy of acid sulfate soils and saline soils was examined in the previous study (Nguyen and Egashira, 2007a). In the present study, we focus on the clay mineralogy of grey degraded soils and saline soils. The purposes of the study are: (1) to examine the clay mineralogical composition of grey degraded soils and sandy soils in Vietnam; and (2) to propose appropriate measures for improving fertility of these soils.

MATERIALS AND METHODS

Soils

Sampling sites of 8 profiles of grey degraded soils and sandy soils are shown on the map of agro–ecological regions of Vietnam in Fig. 1, and general information on the soil profiles is given in Table 1. All soil samples in the present study were taken in the project of *Surveying and Evaluating Soil Quality to Establish Soil Reference, Database and Information*. Four profiles representing grey degraded soils were selected from the Red River Delta (VN06), Northeast (VN12), High Plateau Tay Nguyen (VN22) and East of the South (VN34) regions. They were developed from old alluvium, sandstone sediment, and granite and acid magmatic sediments. Four profiles representing sandy soils were collected along the seashore of the North of Central (VN25 and VN41) and Coastal Area of Southern Central (VN46 and VN53) regions and their parent materials

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Table 1. General information of soil samples

Profile	Location (District, Province)	Parent material	Soil classification by the Vietnamese system (FAO/UNESCO system)	Vegetation
VN06	Socson, Hanoi	Old alluvium	Grey degraded soils on old alluvium (Plinthic Acrisols)	Rice and cash crops
VN12	Phoyen, Thainguyen	Sandstone sediment	Grey degraded soils on sandstone (Haplic Acrisols)	Rice and cash crops
VN22	Eahleo, Daclak	Granite sediment	Grey degraded soils on granite (Ferric Acrisols)	Forest
VN34	Hoathanh, Tayninh	Acid magmatic sediments	Grey degraded soils on acid magmatic rock (Haplic Acrisols)	Cashew
VN25	Dienchau, Nghean	Sand	Sandy soils (Haplic Arenosols)	Cash crops
VN41	Quangninh, Quangbinh	Sand	Yellow and white sandy dune soils (Haplic Arenosols)	*Casuarina*
VN46	Bacbinh, Binhthuan	Sand	Red sandy dune soils (Haplic Arenosols)	Grass
VN53	Thangbinh, Quangnam	Sand	Sandy soils (Haplic Arenosols)	Rice

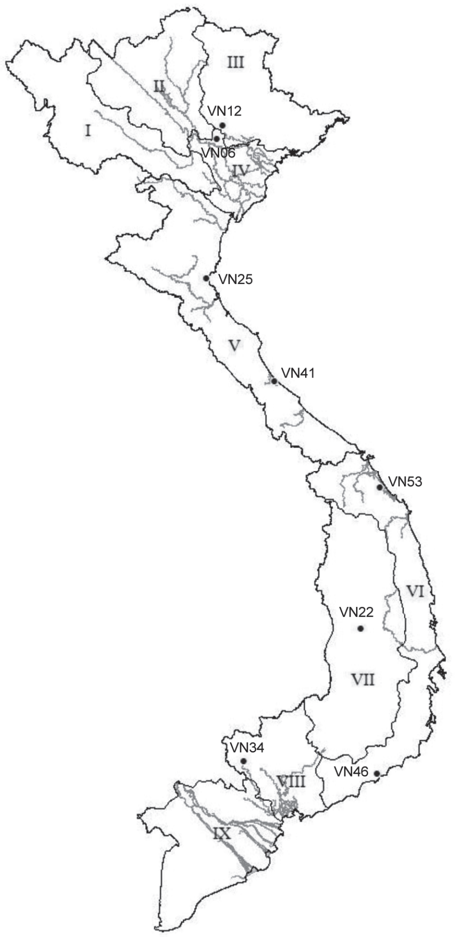

Fig. 1. Soil sampling sites on the map of agro–ecological regions of Vietnam. I. Northwest region; II. Northern region; III. Northeast region; IV. Red River Delta region; V. North of Central region; VI. Coastal Area of Southern Central region; VII. High Plateau Tay Nguyen region; VIII. East of the South region; IX. West of the South region. : river system.

were all sand. The soils of eight profiles have been subjected to cultivation of rice and/or cash crops, and cashew or covered with *Casuarina*, forest and grass.

Soil samples were taken vertically with profile depth based on the genetic horizons, air–dried and gently ground to pass through a 2–mm sieve in Hanoi, Vietnam, followed by particle–size and clay mineral analyses in Kyushu University, Japan.

Particle–size analysis

Organic mater was first decomposed by the treatment with hot 7% H_2O_2. After dispersion by the sonic wave treatment and deflocculation by adjustment of the pH of the suspension to 10 by addition of a small amount of 1 M NaOH, the soil suspension was stood in a 1–L sedimention cylinder for a prescribed time followed by siphoning–out of the clay fraction. The sample was then subjected to repetition of sonification–sedimentation–siphoning with intermittent pH adjustment to separate the whole <2 μm clay fraction. The whole 2–20 μm silt fraction was then separated by repeated sedimentation and siphoning, followed by separation of the 20–200 and 200–2,000 μm sand fractions by wet–sieving. After oven–drying at 105 °C, each fraction was weighed to calculate the particle–size distribution of a soil.

Clay mineral analysis

The <2 μm clay fraction wholly separated from the fine soil was used to examine the clay mineralogical composition by the X–ray diffraction (XRD) method. Duplicate clay sols containing 50 mg clay each were taken into 10–mL glass tubes and then washed twice with 8 mL of an equal mixture of 1 M NaCl and 1 M $NaCH_3COO$ (pH 5.0) by centrifugation to lower the pH. Of the duplicate sets, one was saturated with K and the other with Mg by washing 3 times with 8 mL of 1 M KCl and 0.5 M $MgCl_2$, respectively. Excess salt was removed by washing once with 8 mL of water and the clay in the tube was thoroughly suspended with 1 mL of water. An aliquot of 0.4 mL of the clay sol was dropped onto a glass slide (28×48 mm) covering two–thirds of its area, air–dried and X–rayed (parallel powder mount). The XRD analysis was made with the air–dried and glycerol–solvated specimens for the Mg–saturated clay and the air–dried and heated (at 300 °C and 550 °C for 2 h) specimens for the K–saturated clay. The XRD analysis was conducted using a Rigaku diffractometer with Ni–filtered CuKα radiation at 40 kV and 20 mA and at a scanning speed of 2° 2θ min^{-1} with a scanning step of 0.02° and a continuous scanning mode over a rang of 3 to 30° 2θ.

Relative mineral contents in the clay fraction were semi–quantitatively estimated on the basis of the XRD peak intensities. In the present estimation, the peak height was used as the peak intensity by assuming the relative proportions of the minerals of a sample normal-

Table 2. Particle–size distribution of grey degraded soils and sandy soils

Soil type	Profile and layer	Horizon	Depth (cm)	Particle–size distribution (%)				Soil texture (IUSS)
				Clay (<2 μm)	Silt (2–20 μm)	Fine sand (20–200 μm)	Coarse sand (200–2,000 μm)	
Grey degraded soils	VN06–1	Ap1	0–13	10.2	26.3	62.4	1.1	loam
	–2	Ap2	13–22	9.5	25.1	64.0	1.4	sandy loam
	–3	AB	22–31	11.7	32.4	55.1	0.8	loam
	–4	Btw	31–60	36.2	28.1	35.5	0.2	light clay
	–5	Btv	60–100	54.7	22.4	22.5	0.4	heavy clay
	VN12–1	Ap	0–16	2.3	12.2	71.8	13.7	loamy sand
	–2	ABt	16–40	2.9	22.2	65.4	9.5	sandy loam
	–3	Bt1	40–85	5.2	25.3	62.0	7.5	sandy loam
	–4	Bt2	85–110	16.1	22.7	52.8	8.4	clay loam
	–5	BCv	110–160	29.2	15.9	38.7	16.2	light clay
	VN22–1	Ap1	0–5	10.9	6.1	42.9	40.1	sandy loam
	–2	Ap2	5–20	7.6	4.2	47.7	40.5	loamy sand
	–3	AB	20–50	43.7	3.9	27.1	25.3	light clay
	–4	Bt	50–100	56.8	3.7	19.4	20.1	heavy clay
	VN34–1	Ap	0–20	5.8	5.4	51.7	37.1	loamy sand
	–2	AB	20–35	18.0	4.5	35.8	41.7	sandy clay loam
	–3	BA	35–60	23.5	4.9	33.8	37.8	sandy clay loam
	–4	Bt	60–105	24.7	5.0	33.6	36.7	sandy clay loam
Sandy soils	VN25–1	Ap	0–20	11.2	10.3	77.9	0.6	sandy loam
	–2	AB	20–40	19.0	8.5	72.0	0.5	sandy clay loam
	–3	Bc1	40–90	16.1	5.8	75.6	2.5	sandy clay loam
	–4	Bc2	90–150	5.2	1.5	93.3	+	loamy sand
	VN41–1	Ap	0–30	0.4	+	3.3	96.3	sand
	–2	C	30–150	+	+	1.4	98.6	sand
	VN46–1	Ap	0–20	3.7	0.9	32.0	63.4	sand
	–2	AC	20–35	4.5	1.2	44.8	49.5	sand
	–3	C1	35–90	9.4	1.4	39.8	49.4	loamy sand
	–4	C2	90–120	9.2	1.3	32.9	56.6	loamy sand
	VN53–1	Ap	0–20	3.8	4.8	43.7	47.7	loamy sand
	–2	AB	20–30	6.2	4.8	40.3	48.7	loamy sand
	–3	B	30–55	8.2	4.0	42.0	45.8	loamy sand
	–4	C1	55–90	15.3	3.8	34.7	46.2	sandy clay loam
	–5	C2	90–125	22.1	4.3	37.1	36.5	sandy clay loam

Subordinate distinctions within master horizons and layers:
c – concretions
p – plowing
t – accumulation of silicate clay
v – plinthite composed of iron–rich, humus–poor, reddish materials
w – development of color or structure in a horizon but with little or no apparent illuvial accumulation of materials.
+ : detected but not calculated due to insignificant amounts.

ized to 100% and the same proportionality between the peak intensity and the content for each mineral.

RESULTS AND DISCUSSION

Particle–size distribution

The particle–size distribution of grey degraded soils and sandy soils is given in Table 2. The clay content of grey degraded soils increased with depth, from around or less than 10% in the upper layers to around or more than 30% in the lower layers. This vertical distribution of the clay content was considered as a consequence of decomposition and/or downward–shifting of clay particles in the upper layers of these soils (Do *et al.*, 2002). The silt content varied from 3.7 to 32.4% depending on the parent material of the soils but normally kept constant with depth in a profile. The fine sand content was higher for the two soils derived from old alluvium (VN06) and sandstone sediment (VN12), while the coarse sand content was higher for the two soils derived from granite and acid magmatic sediments (VN22 and VN34).

Sandy soils are situated just on the seashore and were developed mostly from marine sand, leading to their very high sand content (72.5 to nearly 100% as a total of fine and coarse sands contents). The silt content was low and normally less than 10%. The clay content showed a noticeable variation with profiles. If we consider profile VN41 as an original marine sandy soil, the clay and silt fractions observed in other 3 profiles could be a result of flowing–in of finer particles by run–off from surrounding or neighboring sources during soil development

Profile VN25 is located adjacent to the river basin (Fig. 1) where sandy soils and alluvial soils of the Lam River system are found in an associated distribution with each other. River sediments are rich in clay and silt, and they would be transported to the area of sandy soils and

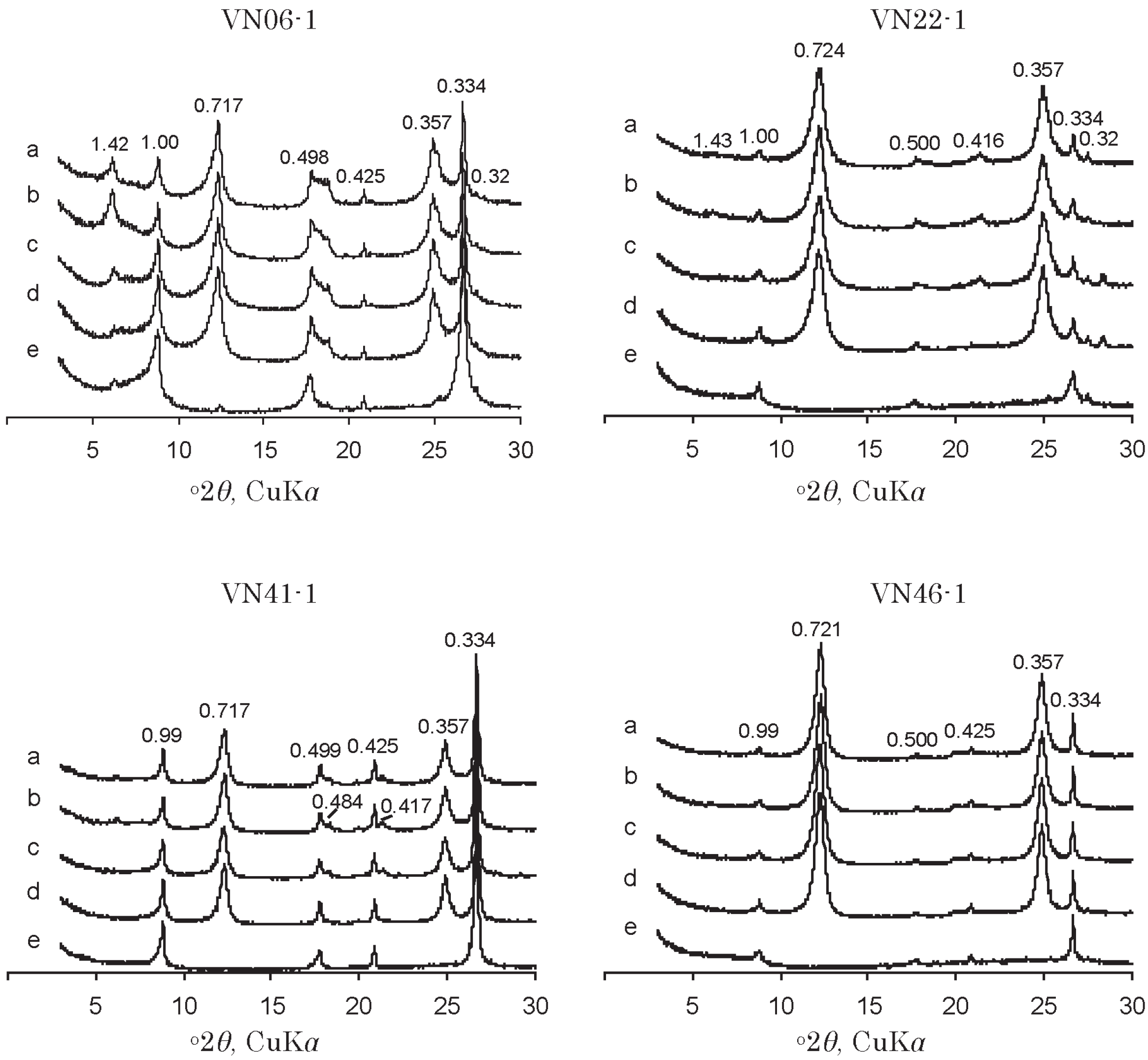

Fig. 2. The XRD patterns of the <2 μm clay fraction from the surface horizon of profiles VN06, VN22, VN41 and VN46. Spacing is in nm. Treatments: a, Mg–saturation and glycerol–solvation; b, Mg–saturation and air–drying; c, K–saturation and air–drying; d, K–saturation and heating at 300 °C; e, K–saturation and heating at 550 °C.

mixed with marine sand. The clay and silt contents of profile VN25 were relatively high in the upper three layers, suggesting that mixing of marine sand with river sediments has mainly occurred in those layers with leaving the fourth layer as the original marine sand. In other context, profile VN46 is located on the seashore surrounded by acid magmatic mountains. Silt and clay particles existing in this profile would be weathered materials of acid magmatic rocks. Profile VN53 is under the microrelief of a combination of those of profiles VN25 and VN46. The increase of the clay content with depth in profile VN53 may be an indication that marine sand overlies the mixture of marine sand with river/acid–magmatic sediments. The origin of clay particles in sandy soils will be discussed later based on the clay mineralogical composition of them.

According to the IUSS system, grey degraded soils had the coarse texture in the upper horizons and the finer texture in the lower horizons, while sandy soils had the coarse texture throughout the profile.

Mineral identification

The XRD patterns of the <2 μm clay fraction from the surface horizon of profiles VN06 and VN22 as representatives of grey degraded soils and those of VN41 and VN46 as representatives of sandy soils are illustrated in Fig. 2. Mica was identified by the presence of the 0.99–1.00 nm peak along with its higher–order reflections at 0.497–0.500 and 0.334 nm. The presence of kaolinite was ascertained by the relatively sharp peaks at 0.717–0.719 and 0.357 nm, while the presence of halloysite (0.7 nm) was by the relatively broad peaks at 0.720–0.729 and 0.357 nm. The peaks reflected by both kaolinite and halloysite (0.7 nm) disappeared by heating at 550 °C in the K–saturated clay. Chlorite was identified by the peak at 1.42–1.44 nm and reflections of its higher–orders and by remaining of the 1.42–1.44 nm peak in the treatment of K–saturation and heating at 550 °C. Vermiculite was identified by the decrease in the intensity of the 1.42–1.44 nm peak with the corresponding increase in the intensity of the 0.99–1.00 nm peak by K–saturation and air–drying.

Table 3. Approximate relative mineral contents (%) in the clay fraction of grey degraded soils and sandy soils

Soil type	Profile and layer	Depth (cm)	Mc	Ch	Vt	Mx	Ch–Vt	Kt	Ht	Gt	Gb	Qr	Fd
Grey degraded soils	VN06–1	0–13	19	4		11	6	37		tr.		21	2
	–2	13–22	18	3	3	12	3	31		4		24	2
	–3	22–31	7		2	6	5	23		10		44	3
	–4	31–60	5		4	17	3	40		4		25	2
	–5	60–100	11		7	20		49		2		10	1
	VN12–1	0–16	2				26	33				37	2
	–2	16–40	tr.				6	18				73	3
	–3	40–85	tr.				7	33				58	2
	–4	85–110	2		5		1	59		10		22	1
	–5	110–160	4		6		1	77		4		8	tr.
	VN22–1	0–5	7		2				78	7		tr.	6
	–2	5–20	7		3				64	8		8	10
	–3	20–50	3						89	8		tr.	tr.
	–4	50–100	3						88	9		tr.	tr.
	VN34–1	0–20					3		85			12	
	–2	20–35					2		91			7	
	–3	35–60					2		90			8	
	–4	60–105					2		92			6	
Sandy soils	VN25–1	0–20	13	2	2	19	5	26		7		26	
	–2	20–40	12	3	6	5	5	31		10		28	
	–3	40–90	22	3	7	9	4	29		17		9	
	–4	90–150	17	2	29	14	1	23		10		4	
	VN41–1	0–30	18		4			31		4	4	39	
	–2	30–150	5		1			6		tr.	tr.	88	
	VN46–1	0–20	5						77			18	
	–2	20–35	5						77			18	
	–3	35–90	4						81			15	
	–4	90–120	4						82			14	
	VN53–1	0–20	1				9		77	3		10	
	–2	20–30	1				10		78	4		7	
	–3	30–55	tr.				8		78	4		10	
	–4	55–90					8		82	3		7	
	–5	90–125					6		88	2		4	

Abbreviations: Mc, mica; Ch, chlorite; Vt, vermiculite; Mx, mica/vermiculite/smectite~mica/smectite mixed–layer mineral; Ch–Vt, chlorite–vermiculite intergrade; Kt, kaolinite; Ht, halloysite (0.7 nm); Gt, goethite; Gb, gibbsite; Qr, quartz; Fd, feldspars; tr., trace.

The mica/vermiculite/smectite~mica/smectite mixed–layer mineral (abbreviated as Mx thereafter) was noticed on the XRD pattern by the poorly defined diffraction effect between 1.0 and 2.0 nm in the Mg–saturated and glycerol–solvated specimen and by the increase in the intensity of the 1.00 nm peak after K–saturation and air–drying (Egashira, 1988). Chlorite–vermiculite intergrade was detected by the 1.42–1.44 nm reflection in the Mg–saturated clay, which shifted toward 1.00 nm by heating at 300 and 550 °C in the K–saturated clay.

Goethite, gibbsite, quartz, and feldspars which are minerals other than layer silicate minerals were identified by the peaks at 0.416–0.418, 0.484, 0.425 and 0.334, and around 0.32 nm, respectively.

Clay mineralogical characteristics of soils in reference to soil genesis

The semi–quantitative estimates of the minerals in the clay fraction of grey degraded soils and sandy soils are shown in Table 3.

Clay mineralogical composition of grey degraded soils

For the grey degraded soil on the old alluvium (VN06), the clay mineral suite was comparable with that of alluvial soils in the Red River Delta region (Nguyen and Egashira, 2005) but the relative content of each mineral was different between them. In profile VN06 kaolinite (23 to 49%) was a predominant mineral followed by quartz (10 to 44%), mica (5 to 19%), and Mx (6 to 20%) which was considered as a transformation product of mica. Minor minerals having contents less than 10% were chlorite, vermiculite, chlorite–vermiculite intergrade as a chloritization product of vermiculite (Nguyen *et al.*, 2006), goethite and feldspars. In profile VN12 representing grey degraded soils on the sandstone sediment, kaolinite and quartz were predominant minerals. The quartz content was over the kaolinite content in the upper three layers but the reverse situation was observed in the lower two layers. The 2:1–type layer silicate minerals were detected with small amounts of mica, vermiculite and chlorite–vermiculite intergrade except chlorite–vermiculite intergrade in the surface layer. Two grey degraded soils on the granite (VN22) and acid magmatic (VN34) sediments were characterized by the fairly to very high halloysite (0.7 nm) content (64 to 92%), in addition to small amounts of mica and vermiculite or chlorite–vermiculite intergraded. This clay mineralogical composition was comparable with that of ferralitic soils derived from granite and at the advanced stage of ferralitization (Nguyen and Egashira, 2008).

Soil degradation in grey degraded soils

The mechanism and process of soil degradation based on the clay mineralogical composition of grey degraded soils was studied in detail by Do *et al.* (2002) using the same soil samples as the present study, followed by Egashira *et al.* (2003) and Nguyen *et al.* (2006). According to Do *et al.* (2002), it was concluded that clay loss in upper layers in the process of soil degradation was attributed to decomposition of layer silicate minerals and/or downward shifting of clay particles. Ferrolysis, observed first by Brinkman (1970, 1977) in grey terrace soils of Bangladesh, was considered as the most probable mechanism of decomposition of layer silicate minerals in the soil subjected to repetition of reduction and oxidization under intensive paddy–rice cultivation such as profiles VN06 and VN12 in the present study.

Profile VN06 was estimated to be at the intermediate stage of soil degradation, because its level of soil degradation was more advanced than the level for the grey degraded soil collected in Bacninh Province neighboring Hanoi City and studied by Nguyen *et al.* (2006). The clay content of profile VN06 was around 10% in the upper three layers (Table 2). Mica was decomposed or transformed into its transformation products such as vermiculite and Mx, leading to the decrease of the mica content with the relative increase of the kaolinite content. This idea is generally understood. However, soil degradation is more advanced for the lower two layers than for the upper two layers in profile VN06, under the assumption that the old alluvium was uniform throughout the profile. This speculation is rather difficult to be accepted, because progression of soil degradation should be faster for upper layers than for lower layers. To overcome this difficulty, we considered that the third layer was exposed on the surface for long time where soil degradation was most advanced with the highest quartz content in the profile and that the upper two layers were deposited later with least advancement of soil degradation. Different deposition of the upper two layers from the lower layers is partially supported by the distribution of the fine sand content in the profile (Table 2).

Profile VN12 was estimated to be at the extremely advanced stage of soil degradation. In this advanced stage even kaolinite was decomposed strongly with leaving quartz behind. The clay content was as low as 2 to 3% in the upper two layers and about 5% in the third layer (Table 2). It is difficult to expect the function of clay in these layers. In addition, quartz was dominating over other minerals. Soil degradation is most advanced in the second layer and the presence of chlorite–vermiculite intergrade in the surface layer is an indication of progression of ferrolysis (Brinkman, 1970, 1977).

The downward–shifting and accumulation process in the soil degradation means deflocculation of clay particles in upper layers and flocculation of them in lower layers (Do *et al.*, 2002). In the grey degraded soils developed on the granite and acid magmatic sediments (VN22 and VN34), decomposition of layer silicate minerals due to ferrolysis was difficult to be considered, since repetition of reduction and oxidization was unlikely to the soils under forest or cashew production. In addition, the relative content of minerals in a profile was kept mostly constant with depth. Therefore, downward–shifting and accumulation of clay particles was considered as the main mechanism of the clay loss in these soils.

Clay mineralogical composition of sandy soils

The mineralogical composition in the clay fraction of sandy soils was different depending on the profiles. Profile VN25 was characterized by the predominance of kaolinite (23 to 31%) followed by a series of 2:1–type layer silicate minerals with various contents, such as mica (12 to 22%), chlorite (2 to 3%), vermiculite (2 to 29%), Mx (5 to 19%) and chlorite–vermiculite intergrade (1 to 5%), and minerals other than layer silicate minerals, such as quartz (4 to 28%) and goethite (7 to 17%). Profile VN41 contained considerable amounts of quartz (39%) and kaolinite (31%), fair amounts of mica (18%), and small amounts of vermiculite, goethite and gibbsite (4% each) in the surface layer. Whereas, the subsurface layer was dominated by quartz (88%) with small amounts of other minerals (trace to 6%). Profiles VN46 and VN53 showed the high halloysite (0.7 nm) content (77 to 88%), along with fair amounts of quartz (14 to 18%) and small amounts of mica (4 to 5%) for the former and less than 10% of quartz, chlorite–vermiculite intergrade, goethite and mica for the latter.

Mineralogical changes in sandy soils

If we follow the idea that clay particles of sandy soils were supplied from sources other than marine sediment, as discussed in the **Particle–size distribution** section, the clay mineralogical composition of sandy soils can be comparable with that of their sources. Starting from profile VN41, the difference in the clay mineralogical composition between the two layers of this profile suggested that clay particles of them originated from different sources. The subsurface layer was mostly composed of clay–sized quartz which originated from marine sediments. On the other hand, layer silicate minerals were detected in the surface layer, even if the clay content was very low, and they seemed to originate from the river sediments. This is because profile VN41 is located near the river (Fig. 1) and the clay mineralogical composition of the surface layer, containing fair to considerable amounts of mica and kaolinite, resembled that of alluvial soils (Nguyen and Egashira, 2005). As stated previously, profile VN41 was considered as an original marine sandy soil, but only the subsurface layer (C horizon) of this soil showed the mineralogical composition characteristic for marine sediments.

Profile VN25 is located in the area adjacent to the Lam River basin and had the clay mineralogical suite comparable with that of alluvial soils from the Lam River system (Nguyen and Egashira, 2005). This supported the supposition that clay particles in this sandy soil were derived from sediments of the Lam River system. The mica content was lower for the sandy soil than for the alluvial soils but the total content of 2:1–type layer silicate minerals was comparable between them with each other. This might be due to the more advanced transformation of mica in the sandy soil into its transformation products (Mx, vermiculite and chlorite–vermiculite intergrade) after deposition. The higher quartz content in the upper two layers of profile VN25 may be a greater contribution of clay–sized quartz from marine sediments. However, the mineralogical composition in the clay fraction of profile VN25 varied considerably with layers.

Profiles VN46 and VN53 had the same clay mineralogical composition as that of grey degraded soils developed on the granite and acid magmatic sediments in the present study. This indicated that clay particles in these profiles were weathered materials of the granite and acid magmatic sediments transported into the sandy soils from the surrounding mountains. Profile VN53 is located near the river but did not seem to receive much clay particles from river sediments.

Soil fertility improvement

Study on the particle–size distribution and clay mineralogical composition of grey degraded soils and sandy soils showed two opposite processes of soil development. In one process observed for grey degraded soils, soil degradation has caused decrease of the clay content to a level of 2 to 3% in an extreme case and the soil became sandy. The 2:1–type layer silicate minerals were first decomposed followed by decomposition of the 1:1–type layer silicate minerals. In the extreme case of degradation, quartz became predominant in the clay fraction of the soil, leading to the poor retention capacity and deficiency in all plant–nutrients in soil.

In another process found for sandy soils, the clay fraction was originally dominated with clay–sized quartz from marine sand sediment and was changed naturally by addition of clayey materials from external sources in the surrounding area. Addition of materials originating from granite and acid magmatic sediments led to the predominance of halloysite (0.7 nm) in the clay fraction, and addition of those from river sediments made soil more fertile with mica and a series of other 2:1–type layer silicate minerals in considerable amounts. The particle–size distribution of the soil was also improved owing to high clay and silt contents of the materials from external sources.

Based on the above statement, appropriate measures for improving fertility of these problem soils can be proposed. It is first recommended to apply intensively chemical fertilizers in combination with large amounts of organic amendments as basic fertilizers in order to overcome deficiency in plant–nutrients of these soils. As another way, particle–size distribution and clay mineralogical composition of the soils can be improved by mixing them with more fertile materials such as alluvial soils, river sediments and weathered rock materials.

CONCLUSIONS

Grey degraded soils and sandy soils in Vietnam were characterized by the low clay content in the upper layers or throughout the profile in a soil. This was attributed to decomposition of layer silicate minerals and/or downward shifting of clay particles for grey degraded soils and to inheritance from the parent material for sandy soils. Kaolin minerals (kaolinite and halloysite (0.7 nm)) and quartz were predominant minerals in the clay fraction of the soils. Grey degraded soils became sandy and poor in the upper layers after long time of soil degradation process, while sandy soils became more clayey and fertile by addition of clayey materials from surrounding sources. The fertility improvement of those problem soils should be concerned not only with application of chemical fertilizers but also with addition of naturally occurring clayey materials.

ACKNOWLEDGEMENTS

We would like to express our sincere thanks to managers of the project of *Surveying and Evaluating Soil Quality to Establish Soil Reference* for their permission of using soil samples and related documents from the Soil Reference and Information Center of Vietnam, National Institute for Soils and Fertilizers, Ministry of Agriculture and Rural Development, Hanoi, Vietnam. Profound appreciation and sincere thanks are also extended to Dr. Ho Quang Duc, Mr. Nguyen Van Ty, and other staffs of the Department of Soil Genesis and Classification Research, National Institute for Soils and Fertilizers, Ministry of Agriculture and Rural Development, Hanoi, Vietnam, who directly managed and conducted the above project.

The first author would like to acknowledge Vietnamese Government for providing the financial support and permission of study–leave to Japan to do this work.

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