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Clay Mineralogical Composition of Tea Garden Soils in Shandong Province, China

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For assistance of the appropriate plant–nutrient management practice to keep the sustainable tea production in Shandong Province, particle–size and clay mineral analyses were carried out to the surface layer of soils collected in tea gardens of Laoshan region of Qingdao City and Dahainanchun region of Jimo City, Shandong Province, People’s Republic of China. Variation of the particle–size distribution with sites was small in each region. The clay content ranged from 17.6 to 22.7% for soils from Laoshan region and from 16.1 to 18.6% for soils from Dahainanchun region, and the texture was clay loam for the former and sandy clay loam for the latter.

All the soils showed the similar X–ray diffraction patterns of the clay fraction, and vermiculite, mica, serpentine and quartz were identified in common. Among them, vermiculite was predominant followed by mica and serpentine. Similarity in the clay mineralogical composition, along with the regional similarity in the particle–size distribution, suggests origination of soils from eolian dust in an extensive area and is easy for the comprehensive performance of the plant–nutrient management practice to soils in the tea garden in Shandong Province.

INTRODUCTION

Shandong Province in People’s Republic of China is located in 34°22’–38°23’ north latitude and 114°19’–122°43’ east longitude. Shandong Province is bordered on the west by the Huabei Plain and extends between the Bo and Yellow Seas in the eastern part. The total land area of Shandong Province is 157,800 km². The whole province is classified as the temperate, continental monsoon climate zone. The annual precipitation is in a range of 600 and 900 mm and gradually decreases from southeast to northwest. Eighty–five to 90% of the annual precipitation occurs in May through October with a maximum in July to September. The mean annual temperature is 11 to 13 °C.

In the 1980s of the twentieth century the local government of Shandong Province issued the policy to maintain the economic effect due to tea production by keeping the tea cultivation area, increasing the tea production per unit area, and improving the quality of tea leaves. As a result, while the tea cultivation area has been kept, the quality of tea leaves was improved and the yield was increased. The area of tea garden was as large as 11,400 ha and the gross production reached to 4×10⁸ kg in 2002, and at present tea production becomes a main agricultural production in Shandong Province.

In the present study, particle–size distribution of soil and clay mineralogical composition of the clay fraction

were examined to soils collected from tea gardens in Laoshan region of Qingdao City and Dahainanchun region of Jimo City, Shandong Province, in order to approach the appropriate plant–nutrient management practice for keeping the sustainable tea production.

MATERIALS AND METHODS

Soil samples

Soil samples are the same as those used in the previous study (Han *et al.*, 2007). Twelve surface soil (0–20 cm) samples were collected at different tea gardens in Laoshan region of Qingdao City and in Dahainanchun region of Jimo City, Shandong Province, on the early October of 2005. Collected soil samples were air–dried under the natural condition and subjected to particle–size and clay mineral analyses. Fertilization in the tea cultivation in Shandong Province was described in the previous paper (Han *et al.*, 2007).

Chemical analyses

The measurements of pH, organic carbon, and total nitrogen and phosphorus are referred to the previous paper (Han *et al.*, 2007). Cation–exchange capacity was determined by the method proposed by Muramoto *et al.* (1992).

Particle–size analysis

Air–dried fine soil (<2 mm) was treated with hot 7% H₂O₂ to remove organic matter. After washing with water, the soil was dispersed by sonic wave treatment for 15 min, deflocculated by adjusting the pH to 10 by addition of 1 M NaOH, and allowed to stand for an appropriate time in a 1–L sedimentation cylinder to separate the clay fraction (<2 μm) by siphoning. By repeating

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sonification–sedimentation–siphoning with intermittent pH adjustment, the clay fraction was wholly separated and then flocculated by addition of a small amount of NaCl. The whole silt fraction (2–20 μm) was separated by repeated sedimentation and siphoning, and the sand fractions (20–200 and 200–2,000 μm) were by wet-sieving. The weight of each fraction was measured to calculate the particle-size distribution.

Clay mineral analysis

The mineralogical composition of the <2 μm clay fraction was analyzed by X-ray diffraction (XRD) using a Rigaku diffractometer. The oriented powder samples saturated with K and Mg were prepared by mounting the clay suspension containing 30 mg clay on a glass slide (28×48 mm), followed by air-drying. XRD of the K-saturated clay (air-dried and heated at 300 and 550 °C) and of the Mg-saturated clay (air-dried and glycerol-solvated) was conducted under the following conditions: Ni-filtered CuK α radiation at 40 kV and 20 mA; scanning range, 3 to 30° 2 θ ; scale range, 2,000 cps; time constant, 1 s; scanning speed, 2° min⁻¹; chart speed,

1 cm min⁻¹; slit system, 1°–0.3–1°.

RESULTS

Chemical properties of soils in the tea garden

Chemical properties of soils in the tea garden of Shandong Province are shown in Table 1. The data was quoted from Han *et al.* (2007) and explained already in it, except cation-exchange capacity (CEC). The measurement of chemical properties was done in triplicate and the average was taken. The CEC ranged from 18.2 to 18.7 cmol_c kg⁻¹ in the soils of Laoshan region, Qingdao City and from 17.5 to 17.9 cmol_c kg⁻¹ in the soils of Dahainanchun region, Jimo City. The CEC was in a very narrow range among the soils in each region and was not essentially different between the soils of the two regions.

The organic matter and clay contents in soil (Table 2), and the vermiculite content in the clay fraction (Table 4) were higher for the soils from Laoshan region of Qingdao City than for the soils from Dahainanchun region of Jimo City, except the clay content of samples A3 and A4. As a result, the CEC was expected to be

Table 1. Chemical properties of soils in the tea garden

Region/City	Sample No	Depth (cm)	pH	Organic matter	Total N	Total P ₂ O ₅	Total K ₂ O	CEC
				(g kg ⁻¹)				(cmol _c kg ⁻¹)
Laoshan/ Qingdao	A1	0–20	4.7	28.1	0.60	2.57	1.76	18.5
	A2	0–20	5.3	28.3	0.71	2.00	1.76	18.6
	A3	0–20	5.5	26.5	0.60	2.38	1.68	18.5
	A4	0–20	5.4	27.2	0.68	2.18	1.73	18.7
	A5	0–20	5.2	26.7	0.60	2.67	1.72	18.2
	A6	0–20	5.3	23.8	0.58	2.26	1.70	18.3
Dahainanchun/ Jimo	B1	0–20	5.4	16.6	0.52	1.42	2.30	17.8
	B2	0–20	5.4	18.4	0.58	1.68	2.12	17.9
	B3	0–20	5.5	15.6	0.50	1.56	2.23	17.5
	B4	0–20	5.3	17.8	0.56	1.12	2.27	17.7
	B5	0–20	5.4	18.6	0.57	1.07	2.24	17.6
	B6	0–20	5.0	18.7	0.58	1.10	2.23	17.7

The data was quoted from Han *et al.* (2007) except CEC.

Table 2. Particle-size distribution of soils in the tea garden

Region/City	Sample No	Depth (cm)	Particle-size distribution (%)				Soil texture ¹⁾ (IUSS)
			Clay (<2 μm)	Silt (2–20 μm)	Fine sand (20–200 μm)	Coarse sand (200–2,000 μm)	
Laoshan/ Qingdao	A1	0–20	21.8	28.1	46.9	3.2	CL
	A2	0–20	20.7	29.2	45.9	4.2	CL
	A3	0–20	18.8	26.8	49.6	4.8	CL
	A4	0–20	17.6	23.9	52.8	5.7	CL
	A5	0–20	22.7	29.2	45.0	3.1	CL
	A6	0–20	21.9	28.7	45.6	3.8	CL
Dahainanchun/ Jimo	B1	0–20	18.2	19.2	57.0	5.6	SCL
	B2	0–20	16.7	18.3	58.7	6.3	SCL
	B3	0–20	17.9	18.7	57.3	6.1	SCL
	B4	0–20	18.6	18.8	56.9	5.7	SCL
	B5	0–20	16.1	17.6	59.6	6.7	SCL
	B6	0–20	18.6	19.7	56.5	5.2	SCL

¹⁾ CL: clay loam; SCL: sandy clay loam.

generally higher for the former soils than for the latter soils. However, the CEC was in the almost similar level between the soils of the two regions.

Particle-size distribution

Table 2 shows the particle-size distribution of soils in the tea garden, which is the result of single measurement. The clay, silt, fine sand, and coarse sand contents were in a relatively narrow variation and ranged from 17.6 to 22.7%, 23.9 to 29.2%, 45.0 to 52.8%, and 3.1 to 5.7%, respectively, in the soils of Laoshan, Qingdao. The soil texture according to the IUSS system was all assigned to clay loam. In the soils of Dahainanchun, Jimo, the clay, silt, fine sand, and coarse sand contents were also in a relatively narrow variation and ranged from 16.1 to 18.6%, 17.6 to 19.7%, 56.5 to 59.6%, and 5.2 to 6.7%, respectively. The soil texture was assigned to sandy clay loam for all the soils.

The clay and silt contents were somewhat higher while the fine and coarse sands contents were lower for the soils of the Laoshan region than for the soils of the Dahainanchun region. However, soils are distributed in the mountainous area in the Laoshan region and in the plain area in the Dahainanchun region.

Mineral identification and estimation

Because the clay fraction of all 12 soils showed similar XRD patterns, the patterns of sample A1 are reproduced in Fig. 1 as a representative. Peaks appeared at 1.43, 1.00, 0.715, 0.496, 0.425, 0.357, 0.332, and 0.319 nm in the Mg-saturated and air-dried specimen. The peak at 1.43 nm shifted to 1.00 nm by K-saturation and air-drying and did not change by glycerol-solvation, and was assigned to vermiculite. The peaks at 1.00, 0.496 and 0.332 nm are due to the presence of mica. The peaks at 0.425 and 0.332 nm and at around 0.32 nm were ascribed to the presence of quartz and feldspars, respectively. The peaks at 0.715 and 0.357 nm remained after heating of the K-saturated clay at 550°C, though the peak intensities were somewhat reduced, and were iden-

tified as an indication of serpentine. However, some possibility of insufficient heating to decompose lattice-structure of kaolinite is remaining, because serpentine usually show a little greater d -spacing.

The relative mineral contents in the clay fraction were semi-quantitatively estimated based on the peak intensities of the respective minerals. In this estimation, the peak intensity was first obtained by multiplication of the peak height by the peak width at half height. The peak intensity was then converted into the mineral content with use of conversion factors shown in Table 3, which was prepared by referring to Islam and Lotse (1986) and Han and Egashira (1999). The intensity of respective peaks was represented with alphabets of "a" through "f", shown in the following table, and calculated as described in the above.

Treatment	Peak	Intensity
Mg-saturation and glycerol-solvation	1.43 nm	a
	1.00 nm	b
	0.715 nm	c
	0.425 nm	d
	0.319 nm	e
K-saturation and heating at 550°C	1.00 nm	f

The mass of mica, vermiculite, serpentine, quartz and feldspars was expressed as W_{Mc} , W_{Vt} , W_{Sp} , W_{Qr} and W_{Fd} , respectively, and equated with the peak intensity as follows.

$$a = 1.5W_{Vt}$$

$$b = W_{Mc}$$

$$f = W_{Mc} + W_{Vt}$$

$$c = 2W_{Sp}$$

$$d = W_{Qr}/3$$

$$e = W_{Fd}$$

The intensity "f" was normalized by taking the ratio of the intensity of the 0.715-nm peak in the K-saturated and air-dried specimen to that in the Mg-saturated and air-dried specimen. The mass of each mineral was obtained by solving the equations and added in the following equation: $R \times [W_{Mc} + W_{Vt} + W_{Sp} + W_{Qr} + W_{Fd}] = 100$. After solution of the equation the mass of each mineral was multiplied by "R" to get the relative mineral contents in the clay fraction. The XRD performance and mineralogical calculation was made in single.

Table 3. Relative intensity for XRD peaks of minerals having equal mass

Mineral ¹⁾	Treatment	
	Mg, glycerol	K, 550°C
Mc	1.00 nm 1	1.00 nm 1
Vt	1.43 nm 1.5	1.00 nm 1
Sp	0.715 nm 2	
Qr	0.425 nm 1/3	
Fd	0.319 nm 1	

¹⁾ Abbreviations: Mc, mica; Vt, vermiculite; Sp, serpentine; Qr, quartz; Fd, feldspars.

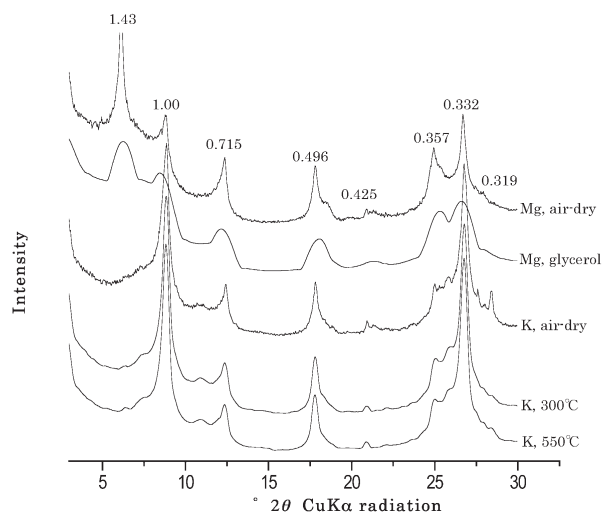


Fig. 1. X-ray diffraction patterns of the clay fraction of sample A1. Spacing is in nm.

Table 4. Approximate relative mineral contents (%) in the clay fraction of soils in the tea garden

Region/City	Sample No	Minerals ¹⁾				
		Mc	Vt	Sp	Qr	Fd
Laoshan/ Qingdao	A1	15	49	25	11	0
	A2	17	48	24	11	0
	A3	16	49	24	11	0
	A4	14	49	25	12	0
	A5	15	47	24	13	1
	A6	15	48	25	12	0
Dahainanchun/ Jimo	B1	21	44	25	10	0
	B2	24	42	23	11	0
	B3	22	43	23	11	1
	B4	20	44	24	12	0
	B5	23	42	24	11	0
	B6	22	43	23	12	0

¹⁾ Abbreviations: Mc, mica; Vt, vermiculite; Sp, serpentine; Qr, quartz; Fd, feldspars.

Mineralogical composition in the clay fraction

Approximate relative mineral contents in the clay fraction of soils in the tea garden are given in Table 4. Vermiculite was a predominant mineral with the content of 42 to 49%. The mica and serpentine contents were also high with ranges of 14 to 24% and 23 to 25%, respectively, and the quartz content was in a range of 11 to 13%. The feldspars content was less than 1%. The mineralogical composition in the clay fraction was similar among the soils in each region.

The vermiculite content was higher for the soils of Laoshan, Qingdao (47 to 49%) than for the soils of Dahainanchun, Jimo (42 to 44%), while the mica content was lower for the former (14 to 17%) than for the latter (20 to 24%). The contents of serpentine (24 to 25% and 23 to 25%) and quartz (11 to 13% and 10 to 12%) were in the same level between the soils of the two regions.

DISCUSSION

Soils collected from tea gardens in Shandong Province, China contained mica, vermiculite, serpentine and quartz in the clay fraction in common. Among them, vermiculite was predominant followed by mica and serpentine and then by quartz. Vermiculite is characterized by the high CEC, and its predominance contributes to increase of the soil CEC. Meanwhile, vermiculite fixes K^+ and NH_4^+ in its interlayer supplied as fertilizers. Mica shows some CEC. It was di-octahedral, and release of K^+ from the interlayer to soil might not be so in a high extent. Serpentine (or kaolinite) is less and quartz not at all active in those functions.

Similarity of soils in the clay mineralogical composition with a mineralogical suite of mica, vermiculite, serpentine and quartz suggests a possibility of the contribution of eolian dust to soil formation in an extensive area of Shandong Province. Inoue and Naruse (1987) reported kaolinite, illite, vermiculite, montmorillonite, quartz, and calcite as dominant minerals of eolian dust collected in Japan and transported from China and Mongolia by

prevailing wind. Minerals detected in soils from tea gardens in Shandong Province are involved in this mineral suite except serpentine. Shandong Province is close geographically to Northeast China, and it can be understood that soils in Shandong Province have been suffered from eolian dust, like upland soils in Northeast China.

Similarity in the clay and organic matter contents of soil and in the mineralogical composition of the clay fraction was observed among the soils in each of the Laoshan and Dahainanchun regions. The CEC was also in a similar level among the soils. These features permit to work out common guidelines for the appropriate plant-nutrient management practice in the tea cultivation throughout the region.

Egashira *et al.* (2000) studied on the chemical fertility of upland soils in Northeast China, where soils originated from eolian dust transported from inland China. The soils showed the similar mineralogical suite in the clay fraction and were composed mainly of mica, the 2:1-type mixed-layer minerals and quartz (Han and Egashira, 1999), where the 2:1-type mixed-layer minerals existed instead of vermiculite in the soils of Shandong Province. The clay content was almost over 25% and was found to be a factor which most strongly controls or affects how to make plant-nutrient management practice of soils, through its greater contribution to the natural soil fertility or plant-nutrient retention capacity.

In soils from the tea garden in Shandong Province, the CEC as an index of the plant-nutrient retention capacity hardly varied with soils. It made difficult to find out which factors most strongly control or affect how to make plant-nutrient management practice of soils. However, contribution of organic matter is expected to be relatively increased, because the clay content was around or below 20%. The CEC of 18 to 19 $cmol_c kg^{-1}$ was estimated to be in a middle level of the plant-nutrient retention capacity of soils (Egashira *et al.*, 2000). It may not need large application of organic residues and so frequent split-dressing of chemical fertilizers.

CONCLUSIONS

The mineralogical composition in the clay fraction with a mineralogical suite of vermiculite, mica, serpentine and quartz was similar among the soils in each of the Laoshan and Dahainanchun regions, Shanong Province. This, along with the similarity in the clay content, enables to work out common guidelines throughout the region for the appropriate plant–nutrient management practice to keep sustainable tea production.

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