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Anthropogenic Pedofeature in Andosols in Santome Shinden, One of the Representative Sites of the Satoyama Environment in Japan

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Abstract

Santome Shinden, a representative site of the Satoyama landscape in Japan, has its origins in 1696 when the common land of wild grass on the Musashino plateau was developed into a strip-shaped land division, which consists of residential area, upland field, and secondary forest. We investigated soils with different land use over 300 years; they are under the secondary forest, and in the upland field where fallen leaves compost derived from secondary forest has been applied continuously for about 300 years since the development. The measured exchangeable cation values suggested that the nutrients in the secondary forest were taken out to the field as fallen leaves. On the surface layer of the upland field soil, characteristic granules of dark brown coated peds (DBC peds) were developed strongly. However, on the surface layer of the secondary forest soil, the DBC peds were not found. Electron probe micro analyzer analysis showed that the outside (dark brown part) of the DBC peds, which was observed only in the upland fields was rich in carbon. The dark brown coated pedofeature was suggested to have an anthropogenic effect due to the long-term application of fallen leaves compost. The anthropogenic activities, which were fallen leaves compost application and cultivation for about 300 years, were thought to affect the soil micromorphology. Therefore, the peds newly found in the Santome shinden field were considered to be a soil microstructure that symbolizes anthropogenic activities.

Keywords

Anthropogenic Pedofeature, Fallen Leaves Compost, Long-Term Cultivation, Satoyama, Soil Micromorphology

1. Introduction

In Santome Shinden area, it has been more than 300 years since a different land use started in 1696 as upland field and deciduous secondary forest [1]. The area was reclaimed from common land of wild grass to form mosaic-like landscapes, comprising of human residential area, upland field, and secondary forest. These still remain in modern times; therefore, the Santome Shinden area has been considered to be a typical example of an area showing a Satoyama landscape on a plateau [2]. Santome Shinden has been approved as a historic site by Saitama prefecture, Japan, because of its high landscape and historical value [3]. In addition, it has been certified as an important Satochi-Satoyama from the perspective of biodiversity conservation by the Ministry of the Environment in Japan [4]. The Satoyama landscape is a traditional Japanese rural land-use system, which represents a balanced relationship between human beings and nature [5].

Santome Shinden has been a settlement centered on upland farming with sweet potato as the main crop. During the middle of the Edo period in Japan (*i.e.*, 1694-1696), about 1350 ha of common land of wilderness was developed by the lord of the Kawagoe domain [1]. According to the "History of Miyoshi Town [6]", sweet potato cultivation expanded and became popular in response to the consumption demand in Edo, and then distribution with Edo became more important. Today, Miyoshi Town which includes a part of Santome Shinden, supplies vegetables to Tokyo [7], but in the Santome shinden area sweet potato is still traditionally cultivated using fallen leaves compost. And the farming in the area called "the farming method in Musashino with composted fallen leaves" has been authorized as the Japanese Nationally Important Agricultural Heritage Systems by the Ministry of Agriculture, Forestry and Fisheries in Japan [8].

So far many studies have been reported on the Santome Shinden from the aspect of historical geography, landscape evaluation, and ecological planning; however, few studies have been conducted on its soil aspect. Information on soil micromorphology under a typical Satoyama environment has also been limited.

Many findings have been published on the effect of continuous use of organic matter on the physicochemical properties of soil [9] [10] [11] [12] [13], however, knowledge on those from the viewpoint of soil micromorphology has been restricted.

The soil is vital for the production of food and other biomass and serves as a physical and chemical environment for mankind [14]. Soil micromorphology acts as an integrating tool in all soil disciplines [15]; thus, soil micromorphological approaches have been considered to be one of the important approaches in examining long-term effects to the soil. There are studies on soil micromorphology including Andosols in Japan [16] [17], but micromorphological studies on long-term effects of organic matter in Andosols are limited [18] [19] [20].

In addition, there have been a few studies on fallen leaves compost. These include studies from the perspective of the utilization of familiar materials [21], the chemical and biological changes due to differences in composting years in relation to Satoyama conservation activities [22], and the application of a paddy [23].

We will clarify the characteristics of the soil in the upland field and secondary forest, which were developed in 1696 from the same common land of wild grass. And the surveyed upland field has been farmed for over 300 years by application of fallen leaves compost from a nearby secondary forest. To achieve the purpose, we investigated mainly from a soil micromorphological point of view, which reflects the long-term characteristics of the soils.

2. Materials and Method

2.1. Site Descriptions and Field Management

The survey site was Santome Shinden mainly in Miyoshi town and Tokorozawa city, Saitama prefecture, adjacent to the north of Tokyo. This is located on the Musashino plateau, which is covered with volcanic ash [24]. The average precipitation and average annual temperature in this area are 1530 mm and 14.6˚C, respectively [25]. The soil distributed in this area is Melanic Silandic Andosols [26].

In the Kanto-Koshin district (including Santome Shinden) where is widely covered with volcanic ash, it has been reported that wind erosion occurs due to strong winds and dryness from winter to spring [27]. According to data from the Tokorozawa Meteorological Station [28] near to Santome Shinden, approximately 73% of the days with a maximum wind speed of 10 $m \cdot s^{-1}$ or higher occur in the winter to spring period (December to April) in 2017 to 2021. Field use in Santome shinden area is mainly for sweet potato (*Ipomoea batatas*) from spring to autumn, and the fields are bare from winter to spring. Therefore, wind erosion in upland fields in Santome shinden area is estimated from winter to spring.

Santome shinden area is characterized by a strip-shaped land allocation, which is distributed among farmers as shown in **Figure 1** [29]. Its approximate width, depth, and total area per farm was 73 m, 683 m, and about 5.0 ha, respectively [1]. It is known for its unique regular land allocation, which is composed of a residential area, upland field that is behind the residential area, and secondary forest that is used for collecting fallen leaves in the farthest part of the residential area [29]. Farming in this land allocation was based on the use of fallen leaves as compost from the secondary forest, which is dominated by Konara oaks (*Quercus serrata*) *[30]*. Some farmers in Santome Shinden have been cultivating sweet potato for about 300 years using the fallen leaves compost which is prepared according to the knowledge of each farmer. Such land allocation and farming still remain (**Figure 2**).

In this study, soil sampling was carried out in the upland fields (35˚49'58"N, 139˚29'53"E) and the secondary forest (35˚49'49"N, 139˚29'39"E) of the farmer. The land has been cultivated for 13 generations since the Santome Shinden reclamation. For generations the land is used to cultivate sweet potato and leaves from the secondary forest is used as compost by the farmer. According to the

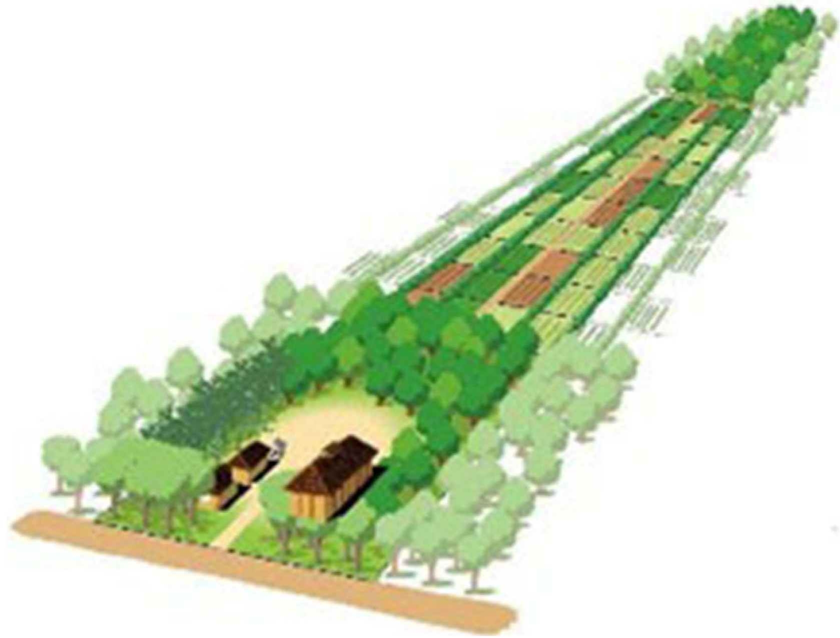
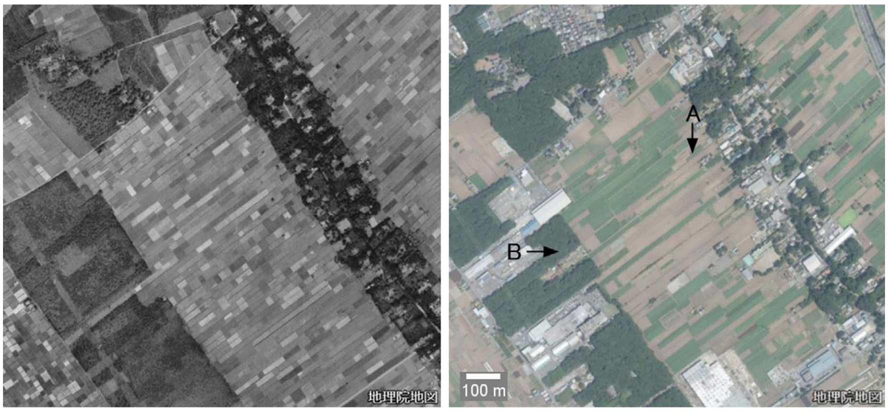


Figure 1. Schematic diagram of a land allocation per farm in Santome Shinden according to the website of the Miyoshi town, Saitama, Japan: From the front (road), residential area surrounded by woods, upland field, and secondary forest are arranged.



(a) (b)

Figure 2. Satoyama landscape in the Santome Shinden. The photos on the left (a) and right (b) were taken in 1947 and 2019, respectively according to the website of the Geographical Survey Institute, Japan. The land allocation of villages, upland fields, and secondary forests on both sides of the road still exist. The arrows added by the authors in the photo on the right (b) indicate the survey sites: A; STM1 and B; STM2.

hearing from the farmer, approximately 3 - 5 $t \cdot ha^{-1}$ of fallen leaves compost (analysis by the authors; C:N ratio 19.1; total carbon 345.6 $g \cdot kg^{-1}$; and total nitrogen 18.1 $g \cdot kg^{-1}$) was applied to the field to a depth of approximately 30 cm using a rotary tiller for cultivating sweet potato every year. In recent decades, the farmer has been making fallen leaves compost by adding rice bran to fallen leaves. And the farmer said that only fallen leaves compost was used for sweet potato cultivation because it was preferable for sweet potato cultivation not to have a lot of nutrients.

2.2. Soil Samples Collection and Physicochemical Properties

Soil surveys were conducted according to the Handbook for Soil Survey by the Japanese Society of Pedology [31]. Soil hardness value was measured by using Soil Hardness Tester (DIK 5553, Daiki Rika Kogyo Co. Ltd., Konosu, Japan), which has penetrating cone of 25˚20' in apex angle and 18 mm in base diameter. We collected and analyzed soil samples in the secondary forest and upland field where farming using fallen leaves compost have been done for about 300 years. Collected soil samples from each horizon were air dried and passed through 2 mm and 0.5 mm sieves prior to chemical analysis. Undisturbed soil core samples were also collected using a 100-mL steel corer (5 cm in diameter) at depths of 0 - 5, 30 - 35, and 45 - 50 cm to check the physical properties and prepare soil thin sections.

Physical properties of soil including bulk density, three-phase ratio, and saturated hydraulic conductivity were analyzed in triplicate according to the Method of Soil Environmental Analysis by the Committee of Soil Environmental Analysis [32].

Soil chemical properties were determined based on the Method of Soil Environmental Analysis by the Committee of Soil Environmental Analysis [32]. Organic carbon content (OC) and total nitrogen (TN) were measured using a NC analyzer (SUMIGRAPH NC-22F, SCAS, Osaka, Japan). Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were determined in solution by flame atomic absorption spectrometry (AA6650, Shimadzu, Kyoto, Japan). Available phosphate (P) was measured by Bray No. 2 method using ultraviolet and visible spectrophotometry (UV-1280, Shimadzu, Kyoto, Japan).

2.3. Preparation and Analysis of Soil Thin Sections

100 mL of collected undisturbed soil core samples were used to prepare the soil thin sections according to Nagatsuka and Tamura [33]. They were freeze dried in the laboratory and then impregnated with a polyester resin [mixed polyester resin A: polyester resin B (Maruto Instrument Co., Ltd.) = 8:2 at 1000 mL with 10 mL of benzoyl peroxide for embedding]. The samples hardened by the resin were cut using a cutting machine (MC-32, Maruto Instrument Co., Ltd., Tokyo). In the initial polishing, the samples were ground using abrasive C3000 from Maruto and then bonded onto a glass slide (5 cm × 5 cm) with an epoxy resin. The resulting samples were cut to reduce the thickness and ground to a thickness of approximately 30 μm. They were polished manually and consecutively using abrasive C400 and C3000 from Maruto.

We described the soil micromorphology according to the Handbook for Soil Thin Section Description [34] with experiments that were conducted using a polarizing microscope (BH-2, Olympus Corporation, Tokyo). The size threshold between coarse and fine materials (C/F concept) was 10 μm. The C/F concept and abundance of voids were obtained under plane-polarized light (PPL).

Optical microscopy images of soil thin sections were used for Image analysis.

The color images were converted into black and white binarized images for quantification of porosity using open source software Image J (National Institute of Health, USA; https://imagej.nih.gov/ij/). In the calculation of porosity abundance, 10 images per sample were analyzed using image J.

The composition of the coatings was measured with EPMA (JXA-8530F, JEOL Ltd., Tokyo) at the Open Facility Network Office within the Research Facility Center for Science and Technology at the University of Tsukuba.

3. Results and Discussion

3.1. Soil Profile Morphology and Physicochemical Properties

The soil profile descriptions in Santome Shinden are summarized in **Table 1**. In the surface layer (0 - 16 cm) of the upland field (STM 1), a fine granular structure (1 - 2 mm) was developed strongly and the color was dark brown (10YR3/3). Meanwhile, in the surface layer (10 - 22 cm) of the secondary forest (STM 2), a crumb structure (1 - 5 mm) was developed strongly and the color was black (10YR2/1). The particles with the characteristics that the dark brown materials surround the B-horizon-like brown particles were observed in Ap1 and Ap2 horizons in STM 1.

Soil hardness values of Ap1 and Ap2 horizons in STM 1 were 0.022 and 0.041 MPa, respectively, suggesting that the materials were very loose. At the AB horizon (30 - 43 cm) in STM 1, the soil hardness value increased abruptly to 0.433 MPa, suggesting plow pan. Up to the AB horizon, very fine roots were mainly observed; however, few roots were observed below the Bw1 horizon, which showed a brown color (7.5YR3/4).

In STM 2, a blackish layer developed up to 50 cm and showed the formation of a thick A horizon. In A1 and A2 horizons, a crumb structure was developed strongly. Many very fine and medium roots were observed in A1 horizon. Meanwhile, very fine and fine roots were observed commonly in the A2 to A4 horizons. Soil hardness values were 0.154 - 0.279 and 0.503 MPa in A and B horizons, respectively. No sudden change in the values was observed in STM2.

The A horizon of the soil in the upland field was 0 - 30 cm. Meanwhile, A horizon of the soil under the secondary forest was as thick as 50 cm. On the same topographical surface and soil parent material, it was observed that the thickness of A horizon is different at the two sites with different land use for over 300 years. And ‘effective soil depth (ESD)’ that has a low soil hardness value (<0.718 - 0.982 MPa) is important in crop production due to the restriction of growth of fine roots by high soil hardness value [35]. Although STM 2 is under secondary forest, ESD values in STM 1 and STM 2 were 43 and 100+, respectively. From the data, it was thought that surface soil layers were effectively used in STM 1 of cultivated land with a plow pan.

The three-phase ratio of solid/liquid/gas phases on the surface layer of STM 1 was approximately 2:3:5 (see **Table 2**). In the lower layer of STM 1, the proportion of the gas and liquid phases decreased and increased, respectively. The bulk

Table 1. Soil profile descriptions in Santome Shinden.

Land use	Horizon	Depth (cm)	Color	Texture	Structure[a]	Soil hardness (MPa)	Roots[b]
Upland field	Ap1	0 - 16	10YR3/3	LiC	GR/3, CR/2	0.022	VF/c
(STM 1)	Ap2	16 - 30	7.5YR2/3	LiC	GR/3	0.041	VF/c, F/f
	AB	30 - 43	7.5YR3/3	HC	SB/2	0.433	VF/c, F/f
	Bw1	43 - 70	7.5YR3/4	HC	MA	0.943	VF/f, F/f
	Bw2	70 - 90	7.5YR3/4	HC	MA	1.118	VF/f, F/f
	2B	90 - 100+	10YR3/4	HC	MA	0.943	VF/vf
Secondary	Oie	+1 - 0					
forest	A1	0 - 10	7.5YR2/2	LiC	CR/3	0.154	VF/m, F/c, M/f
(STM 2)	A2	10 - 22	10YR2/1	LiC	CR/3	0.279	VF/c, F/c
	A3	22 - 38	10YR1.7/1	HC	CR/2	0.241	VF/c, F/c
	A4	38 - 50	7.5YR2/2	HC	SB/2	0.279	VF/c, F/c
	Bw1	50 - 72	7.5YR2/3	HC	SB/2	0.503	VF/f, F/f
	Bw2	72 - 100+	7.5YR3/4	HC	SB/2	0.503	VF/vf, F/vf

[a]Type (CR, crumb; GR, granular; MA, massive; SB, subangular blocky)/Grade (1: weak, 2: moderate, 3: strong); [b]Type (CR, crumb; GR, granular; MA, massive; SB, subangular blocky)/Grade (1: weak, 2: moderate, 3: strong).

Table 2. Soil chemical properties in Santome Shinden.

Land use	Depth (cm)	Bulk density ($Mg \cdot m^{-3}$)	Three phase distribution (%)			Porosity (%)
			Solid	Liquid	Gaseous	
Upland field (STM 1)	0 - 5	0.55	18.4	28.9	52.7	81.6
	30 - 35	0.66	22.7	46.3	31.0	77.3
	45 - 50	0.48	15.7	54.7	29.6	84.3
Secondary forest (STM 2)	0 - 5	0.44	16.5	32.8	50.7	83.5
	30 - 35	0.46	15.7	38.6	45.7	84.3
	45 - 50	0.46	14.1	46.0	39.9	85.9

density in STM 1 was generally higher than that in STM 2. In particular, the bulk density was higher in the middle layer (30 - 35 cm) than surface layer (0 - 5 cm). The increase and decrease in solid phase ratio and porosity, respectively suggested the possibility of being trampled by cultivation. The bulk density of the soil under the secondary forest was approximately 0.45.

The soil chemical properties in Santome Shinden are summarized in **Table 3**. The organic carbons in the surface horizon in Ap1 of STM1 and in A1 of STM2 were 36.0 $g \cdot kg^{-1}$ and 90.4 $g \cdot kg^{-1}$, respectively. Rumpel and Kögel-Knabner [36] mentioned that organic C input into subsoils occurs in dissolved form (DOC) following preferential flow pathways, as aboveground or root litter and exudates along root channels and/or through bioturbation. In STM 2, very fine and fine

Table 3. Soil chemical properties in Santome Shinden

Land use	Horizon	Depth (cm)	OC ($g\cdot kg^{-1}$)	TC ($g\cdot kg^{-1}$)	C/N	pH		CEC ($cmol_c\cdot kg^{-1}$)	Exchangeable cation ($cmol_c\cdot kg^{-1}$)				Base satu. (%)	Available P (mg $P_2O_5\cdot kg^{-1}$)	P absorption ($mg\cdot 100g^{-1}$)
						H_2O	KCl		Ca	Mg	K	Na			
Upland field (STM 1)	Ap1	0 - 16	36.0	3.0	12.1	6.4	5.8	34.6	19.9	5.4	0.7	0.1	75.0	441	2191
	Ap2	16 - 30	35.9	3.0	12.0	6.2	5.7	33.0	19.8	5.4	0.4	0.1	78.1	386	2233
	AB	30 - 43	28.5	2.2	12.9	6.1	5.7	27.5	15.5	4.1	0.1	0.1	71.9	105	2429
	Bw1	43 - 70	18.2	1.4	13.5	6.4	5.7	29.1	7.1	1.5	0.1	0.1	30.1	8	2490
	Bw2	70 - 90	17.0	1.3	13.2	6.4	5.8	22.3	7.8	1.5	0.2	0.1	43.1	6	2502
	2B	90 - 100+	27.1	1.8	14.7	6.5	5.8	33.6	10.3	1.3	0.3	0.1	35.5	7	2532
Secondary forest (STM2)	Oie	+1 - 0													
	A1	0 - 10	90.4	7.4	12.3	5.1	4.3	38.5	1.1	0.5	0.4	0.1	5.5	63	2356
	A2	10 - 22	60.7	3.9	15.7	5.0	4.5	43.0	0.2	0.1	0.1	0.1	1.4	27	2468
	A3	22 - 38	62.6	4.0	15.7	5.2	4.6	27.2	0.8	0.3	0.1	0.1	4.6	15	2479
	A4	38 - 50	48.3	3.3	14.5	5.4	4.8	28.9	0.9	0.6	0.1	0.1	6.2	6	2497
	Bw1	50 - 72	33.3	2.5	13.4	5.5	5.1	22.0	0.6	0.5	0.1	0.1	5.1	3	2400
	Bw2	72 - 100+	21.4	1.9	11.2	5.5	5.1	28.9	0.6	0.5	0.1	0.1	4.1	3	2415

roots were observed up to 100 cm (**Table 1**), suggesting that OC was due to root system activity to the deep horizon. In the secondary forest of Santome Shinden, fallen leaves are collected, and organic matter has been added because the organic matter has been provided continuously from undergrowth and the residue of fallen leaves. On the other hand, in cultivated land, the influence of severe wind erosion [37] is suggested by the seasonal wind (so called karakkaze), which blows at a wind speed of >10 $m\cdot s^{-1}$ on the bare cultivated land with no crops from winter to early spring.

The pH (H_2O) in STM 2 was 5.1 - 5.5; however, the measured pH of 6.1 - 6.5 in STM 1 was higher. This tendency was similar for pH (KCl). In the surface horizon of STM 1 and STM 2, the exchangeable Ca found was 19.9 and 1.1 $cmol_c\cdot kg^{-1}$, respectively. The exchangeable Mg found was 0.5 and 5.4 $cmol_c\cdot kg^{-1}$, respectively. Overall, the exchangeable base was very low in STM 2. The base saturation values were 5.5% and 75.0% in the surface horizon of STM 1 and STM 2, respectively. From the data of these pH, exchangeable cation and base saturation values, it was thought that the nutrients in the secondary forest were taken to the field as compost of fallen leaves. The phosphate absorption coefficients were higher than 1500 $mg\cdot 100g^{-1}$ in both STM 1 and STM 2, indicating the large amount of specific phosphate sorption that is peculiar to Andosols. The available phosphorus values were low in both the lower layer of STM 1 and STM 2, but in the surface layer of STM 1 it was shown that available phosphorus was enriched. It was indicated that available phosphorus accumulated in the surface layer due to fertilization.

Prior to the reclamation of the Santome Shinden area, historical documents [1] described the area was used as a common land of wild grass. The land after reclamation has been used for approximately 300 years, which resulted in changes in soil morphology and physicochemical properties. In STM2, characteristic properties of Andosols such as low bulk density and low base saturation values were indicated. However, increase of values in base saturation, available phosphorus and bulk density in the surface layer of STM 1 were shown, suggesting the effect of long-term plowing of fallen leaves compost. In particular, on the surface layer of the upland field where the fallen leaves compost has been used continuously, particles coated by dark brown materials were observed. Thus, we conducted a micromorphological study to consider the anthropogenic effect of long-term application of fallen leaves compost.

3.2. Soil Micromorphology

In the surface layer (0 - 5 cm) of STM 1 and STM 2, granules of dark brown coated (DBC) peds (**Figure 3(a)**) and crumbs and granules peds (**Figure 3(b)**) were strongly developed, respectively. The DBC peds were observed only in the upland field and not observed in the secondary forest. Approximately 30% - 40% of the granules peds were observed as DBC peds, although this is semi-quantitative, depending on the position of the sliced section and the polishing conditions. Strongly developed granules with coating pedofeature were observed in STM 1 rather than in STM 2.

STM 1 (0 - 5 cm) was dominated by the granular microstructure with a diameter of 0.1 - 3.0 mm rather than a crumb microstructure. It also showed an open porphyric C/F relative distribution. In STM 1 (30 - 35 cm), the structures were different between the upper and lower parts of the soil thin section, showing a plow pan, which was verified by an interview with a farmer who stated that cultivation was about 30 cm (**Figure 3(c)**). In the upper part of the soil thin section, granules were predominant. Meanwhile, in the lower part of it, a compact structure including micro-aggregates that consisted of fine fractions and voids such as vugh/channel among aggregates with sizes of 0.5 - 8.0 mm. Partially accommodated subangular blocky peds dominated the STM 1 (45 - 50 cm), which showed a close porphyric C/F relative distribution (**Figure 3(e)**).

Crumbs dominated the layer of STM 2 (0 - 5 cm). Granules and subangular blocky peds were also observed STM 2 (0 - 5 cm), which showed a close porphyric C/F relative distribution. In STM 2 (30 - 35 cm), crumbs and granules were observed, showing an open porphyric C/F relative distribution. Similar to STM 1 (45 - 50 cm), STM 2 (45 - 50 cm) showed a close porphyric C/F relative distribution, which was dominated by subangular blocky peds (**Figure 3(f)**). Similar soil microstructures were observed in the 45 - 50 cm layer of both STM 1 and STM 2.

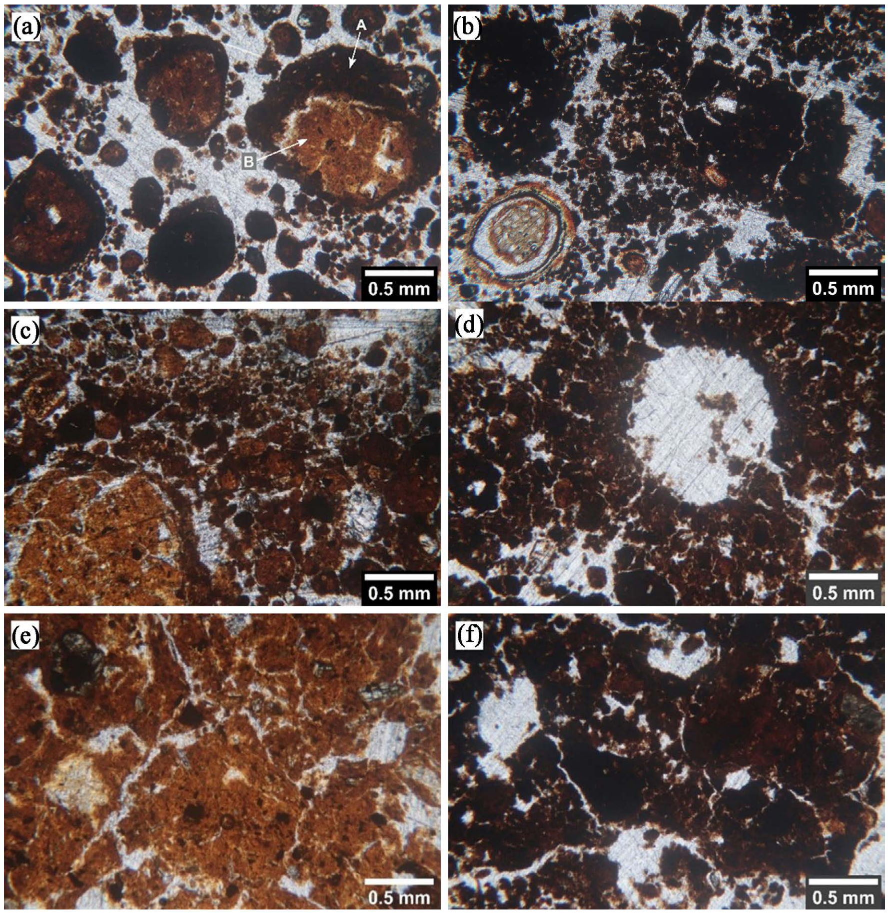


Figure 3. Soil microstructures of STM 1 and STM 2 with plain polarized light (PPL). (a) A particle with an organic coating pedofeature in STM 1 (0 - 5 cm). "A" and "B" shows soil material of A horizon and B horizon, respectively. (b) Crumbs, granules, and plant residues in STM 2 (0 - 5 cm). (c) Near the plow pan. Granular structure is predominant in the upper part. Granular microstructure with coalescent granular aggregates is predominant in the lower part of STM 1 (30 - 35 cm). (d) A microstructure with a trace of root in STM 2 (45 - 50 cm). (e) Partially accommodated subangular blocky peds in STM 1 (45 - 50 cm). (f) Accommodated subangular blocky peds in STM 2 (45 - 50 cm).

In terms of basic organic components and pedofeatures, the existence of DBC peds and particles with dark brown coating pedofeature were noted in STM 1 (0 - 5 cm) and upper part of STM 1 (30 - 35 cm). This pedofeature was observed only in the upland field soil (STM 1) but not in the secondary forest soil (STM 2). Plant residues and black punctuations were found in all horizons of STM 1. In STM 2, light yellow to brown plant residues with sizes of 0.5 - 2.0 mm were distributed randomly. In STM 2 (0 - 5 cm), round or elliptical and pale red intact excrements pedofeatures with a size of 50 - 100 μm were observed. These pedofeatures also existed as infilling within the crumb. Pedofeature of loose discontinuous infillings were observed in STM 2 (45 - 50 cm).

STM 1 (0 - 5 cm) showed a larger void abundance than STM 2 (0 - 5 cm) (**Table 4**). The surface layer (0 - 5 cm) soil of STM1 had significantly more porosities compared with that of STM2, however the middle layer (30 - 35 cm) soil

Table 4. Micromorphplogy of the soil thin sections.

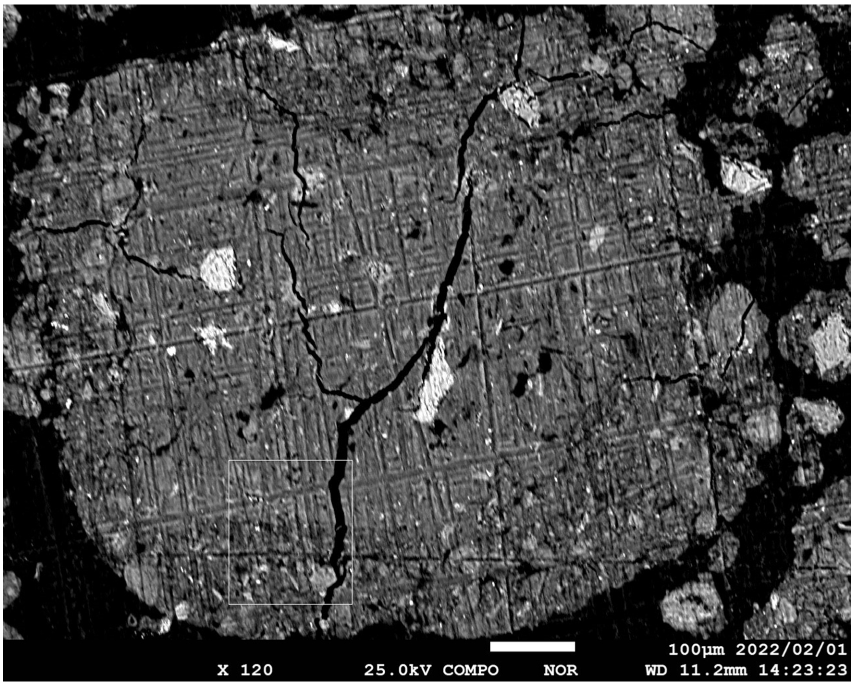
Land use	Depth (cm)	Dominant micro-structure†	Related Dis-tributions‡	Aggregation			Voids		
				Peds§	Grade of pedality¶	Size (mm)	Type††	Abundance‡‡	
Upland Field (STM1)	0 - 5	Gr, Cr	Po	Gr	S	0.1 - 3.0	Cdp	36.9**	(±5.09)
	30 - 35	Gr, Cr	Po/En	Gr	S	0.05 - 7.0	Cdp, Ch	18.8***	(±8.36)
	45 - 50	Sb	Pc	Sb	S	0.1 - 2.0	Cdp, Pl, Vu	16.3	(±2.75)
Secondary Forest (STM2)	0 - 5	Cr, Sb	Pc	Cr, Sb	S, M-S	0.1 - 5.0	Cdp, Pl, Ch	29.3**	(±6.01)
	30 - 35	Cr, Gr	Po	Gr, Cr	S, S	0.01 - 2.0	Cdp	33.2***	(±5.33)
	45 - 50	Sb	Pc	Sb, Cr	S-M, M-S	0.1 - 3.0	Cdp, Pl, Vu	16.9	(±5.46)

†Gr: Granular structure, Cr: Crumb structure, Sb: Subangular blocky structure; ‡Po: open Porphyric, En: Enauric, Mo: Monic; §Gr: Granules, Cr: Crumbs, Sb: Subangular blocky peds; ¶S: Strongly, M: Moderately; ††Cdp: compound packing, Vu: vughs, Ch: channels, Pl: planes; ‡‡Significant differences between STM1 and STM2 for 0 - 5 cm and 30 - 35 cm at $p < 0.01$(**) and $p < 0.001$(***).

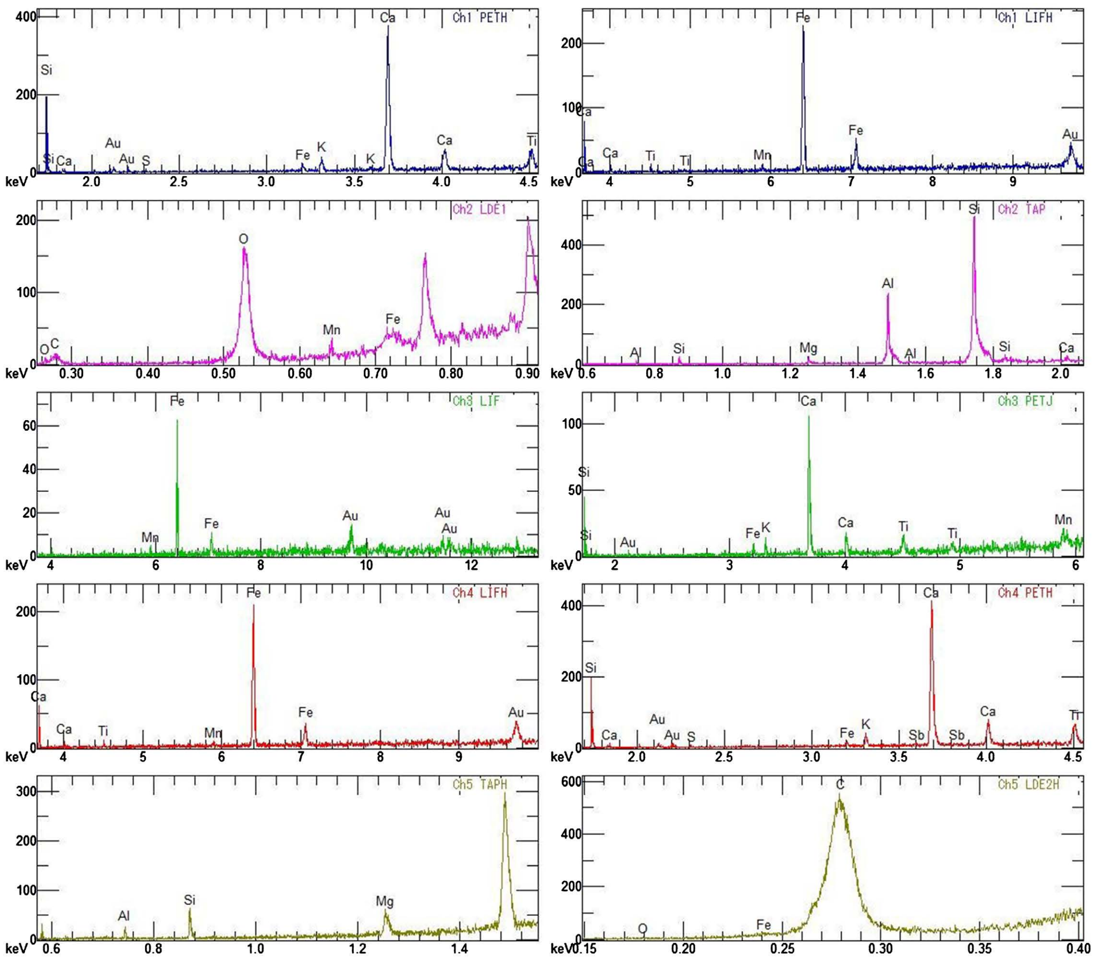
of STM1 had significantly less porosities compared with that of STM2. It was thought that the reduction of porosity in STM1 was due to the compaction by cultivation. But the lower layer (45 - 50 cm) soil between STM1 and STM2 had almost same value of void abundance and not significantly difference.

In STM 1 (0 - 5 cm), which is the surface layer of the field, compound packing voids between single grains and aggregates were dominant. In the lower layer of STM 1 (45 - 50 cm), compound packing voids such as those due to plant root traces were prominent. In addition, accommodated planar voids among subangular blocky structures were also found. In the surface layer of the secondary forest (STM 2), complex packing voids by plant root traces were prominent. Planar voids that divided subangular blocky structures were also observed. In the lower layers of the secondary forest (STM 2), compound packing voids such as by plant root traces (**Figure 3(d)**) were observed along with planar voids, which divided the subangular blocky structures.

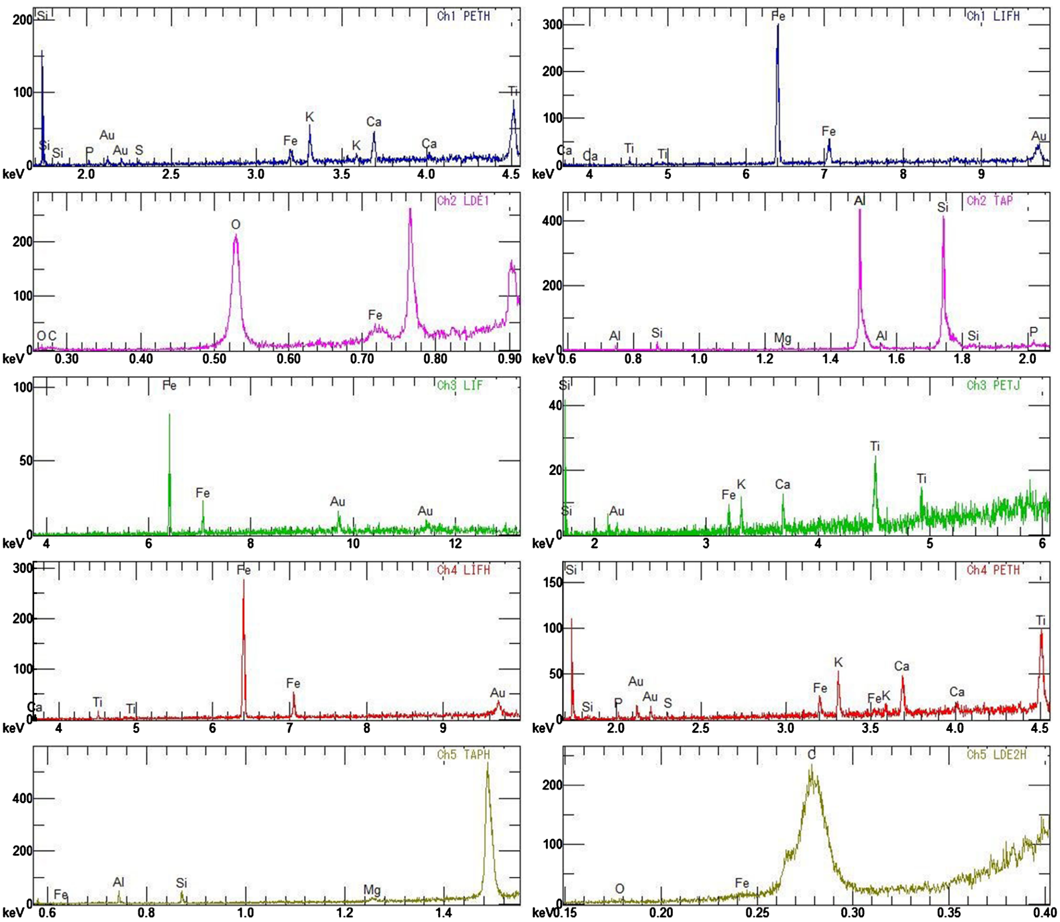
SEM image of DBC peds is shown in **Figure 4(a)**. Dark-colored and light-colored parts were found on the outside and inside of the particle, respectively. In the outside of the DBC peds (**Figure 4(b)**), clear peaks for Ca, Mg, and Mn were found. Meanwhile, in the inside of the DBC peds (**Figure 4(c)**), clear peaks for Al and Ti were observed. In STM 1, fallen leaves compost was prepared by mixing rice bran and fallen leaves. Since Mn is distributed unevenly in rice bran [38], the detected Mn may be derived from the rice bran component that attached during the preparation of the compost. The elemental mapping of DBC peds (**Figure 4(d)**) indicated that C was more abundant on the outside (lower half in the image) than inside (upper half in the image). In addition, O and Al were more abundant on the inside than outside. The inside of the DBC peds (brown part) was relatively rich in Al and Ti; thus it is rich in minerals. Meanwhile, the outside of the DBC peds (dark brown material-covered part) was rich in C. The DBC peds were considered to be the particles with more organic


100μm 2022/02/01
X 120
25.0kV COMPO
NOR
WD 11.2mm 14:23:23

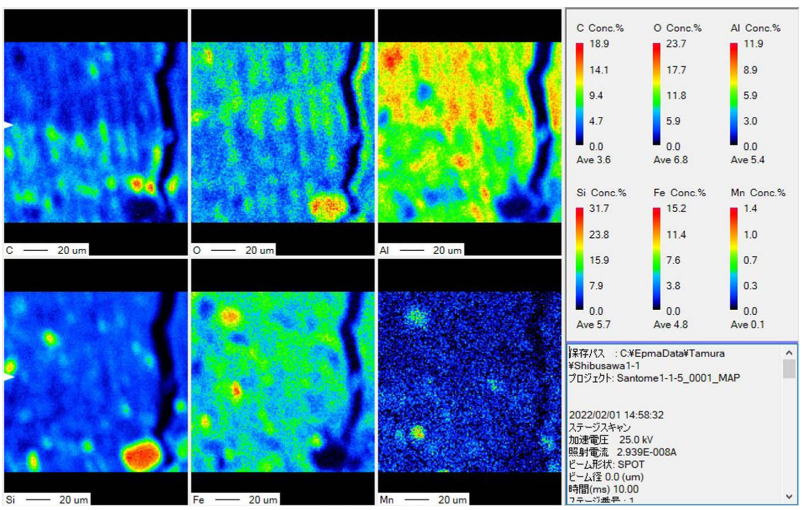
(a)


Ch1 PETH
Ch1 LIFH
Ch2 LDE1
Ch2 TAP
Ch3 LIF
Ch3 PETJ
Ch4 LIFH
Ch4 PETH
Ch5 TAPH
Ch5 LDE2H
keV

(b)



(c)



(d)

Figure 4. (a) Representative SEM image of DBC peds. The white squares indicate the elementary mapping area; (b) Analyzed charts of EPMA (outside the DBC peds). The vertical axis represents X-ray Intensity (Counts) and the horizontal axis represents Energy (keV). Clear peaks of Ca, Mg, and Mn were detected; (c) Analyzed charts of EPMA (inside the DBC peds). The vertical axis represents X-ray Intensity (Counts) and the horizontal axis represents Energy (keV). Clear peaks of Al and Ti were observed; (d) Elemental mapping of DBC peds. The white arrow on the leftmost side indicates the boundary between the outside of the particle (lower side; dark brown material covered part) and the inside of it (upper side; brown part).

material (as in A horizon), which coated the particles with more minerals (as in B horizon).

3.3. DBC Peds in Other Soils

In Andosols, coatings and internal hypocoatings of micromass have been observed on the surface and inside of pumice fragments [39]. Clay coatings appear with increased weathering [40]. And the coatings in Andosols have been reported in Italy [40], Iceland [39], and central Mexico [41]. Granular microstructures have been found to be an important characteristic of Andosols in Japan [42]. STM 2 (0 - 5 cm), the secondary forest soil was found to resemble the Italian Andosols from Tenerife [40] in terms of the observed granular and irregular blocky microstructures. There have been researches such as the above on the micromorphology of Andosols. However, the microstructures on the granular peds with the dark brown substance coating in STM 1 (0 - 5 cm) are new in Andosols; thus, the formation of DBC peds was not due solely to the effect of the parent material.

If DBC peds were formed by the accumulation of organic matter, these peds may be found in Chernozems, which contain a large amount of organic matter that is accumulated under natural grassland vegetation. Chernozems are distributed under steppe vegetation and their principal soil-forming processes include humus accumulation, soil-aggregation and distribution of carbonates [43]. For example, in Chernozems beside the Azov Sea in Russia, a large part of their humus horizons was typically dark gray color due to the groundmass and moderately separated granular structure. Meanwhile, their horizon B is dark brown loam and calcareous with a crumby structure [44]. We have not found reports on DBC peds found in Chernozems, which are typical natural grassland soil with microstructures that were formed over a long period of time. This suggests other effects aside from the cumulative effect of plant materials under natural grassland vegetation. In addition, regarding grassland vegetation, there are no confirmed reports of such DBC peds in the Aso region where grassland is maintained in Japan [45].

In purely natural conditions, soils are formed by soil-forming factors; however, human activities such as cultivation, harvesting of grasses, grazing, and firing field affect the pedogenesis process, resulting in the formation of anthropogenic soil [43]. Anthrosols are soils that are formed through long-term human activities such as addition of organic materials or household wastes and irrigation or cultivation [46]. Pedologist and archaeologist have studied the anthropogenic activity and soil formation from the plaggen soil in Europe [47] to the Amazonian dark earth [48] [49]. Anthrosols are thought to be the result of the continuous application of organic matters, which form layer A. However, the microstructures on the granular peds with a dark brown substance coating, which were observed in STM 1 (0 - 5 cm), are not yet reported in Anthrosols. It seemed that the DBC ped was not formed only by human activities.

3.4. Anthropogenic Pedofeature in the Upland Field of Andosols in Santome Shinden

Since the reclamation in 1696, the application of fallen leaves compost and cultivation have been carried out continuously in the upland fields of Santome Shinden; therefore, the area in the upland fields of Santome Shinden is a very anthropogenic environment. On the other hand, the forest in Santome Shinden is a secondary forest though, the introduction pathway for carbon is via biological circulation in the ecosystem. We confirmed that the soil microstructures under the secondary forest and those formed by anthropogenic effects such as continuous use of fallen leaves compost and cultivation in the upland field are completely different. It was thought that the continuous anthropogenic effects make the soil structure special, and the newly confirmed DBC peds in Andosols in the fields of Santome shinden might be a soil microstructure that symbolizes anthropogenic activities.

In the upland field of Andosols at the Ibaraki Agricultural Center in Japan, the examination of continuous organic matter application for 20 years from 1984 was conducted in 6 test plots (*i.e.*, wheat straw, rice straw compost, sawdust cow dung compost, sludge compost, dried pig dung, and chemical fertilizer as a control) [50]. As a result of verification of the examination by the authors, it was newly confirmed that DBC-like peds existed only in the wheat straw and rice straw compost plots. The DBC-like peds were found only in the plant organic material plots, suggesting the effect of continuous use of plant organic material and long-term cultivation in the formation of the peds.

Regarding the coating structure, a "snowball" structure with very well-developed coatings enveloping a quartz grain have been reported in Devensian sediments found in South England [51]. The authors pointed out that the laminated structures were formed from both water- and wind-deposited sheets, which suggested a vegetation-free surface (bare ground) and sequence of soil disruptions. These can be reflected from the seasonal climatic variation with the accumulation of silts on the sticky and damp surfaces during winters and the sands that formed by sheet flow during the early active layer season of spring and early summer. It was suggested that seasonal climatic variations such as wind and water environment affect the structure of soil. These seasonal climatic variations have something in common with Santome Shinden specifically during the period of bare land and wind erosion. In the fields of Santome Shinden, there are no crops from late autumn to early spring; thus, the land is bare. In particular, during the strong wind season from winter to spring, there are many windy days with winds of $\geq 10\ ms^{-1}$. These seasonal climatic variations might influence the formation of DBC peds

In the early stages of reclamation, grassland vegetation disappeared to develop upland field; therefore, the land became bare and the wind erosion progressed. In the fields, it is necessary to input organic materials for farming. Farmers aim to secure nutrients by applying fallen leaves compost, which are derived from the secondary forest. However, there are no crops from late autumn to spring;

thus, light particles in Andosols are eroded by dry strong winds. From spring to autumn, fallen leaves compost is applied and cultivated, and then crops are grown and harvested. The result of this cycle of natural and anthropogenic environments is the Satoyama landscape in Santome Shinden. Thus, its symbolic existence is considered as the anthropogenic pedofeatur.

4. Conclusions

The characteristic DBC peds were considered due to the anthropogenic effects of continuous use of plant organic matter and cultivation in the field of Andosols in Santome shinden. According to the results of our study and data from literature, it was suggested that the anthropogenic effects were thought to be reflected in the micromorphological properties of the soil in Santome shinden.

The above considerations are related to soil micromorphological characteristics in the upland field and secondary forest soils in Santome shinden, one of the representative sites of the Satoyama environment in Japan. It is necessary to proceed with further study on formation of DBC peds and further survey in other area to examine the soil under the Satoyama environment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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