東北大学機関リポジトリ

TOUR

Tohoku University Repository

Use of Soil Database for Pedological Research as Exemplified by Volcanic Ash Soils

Use of Soil Database for Pedological Research as Exemplified by Volcanic Ash Soils

Masami NANZYO[1]*, Tadashi TAKAHASHI[1] and Hitoshi KANNO[1]

[1]Graduate School of Agricultural Science, Tohoku University, Sendai, 981-8555, Japan
e-mail: nanzyo@bios.tohoku.ac.jp

Abstract

A soil database is a digital storehouse of soil information, and it is expected to be useful for many purposes. Several examples of using soil databases for pedological studies on volcanic ash soils were introduced. The soil databases we used are, the soil database of Ando soils in Japan (ASJ), the Tohoku University world Andosol database (TUWAD), the soil data of cultivated soils in Japan collected during 1959-1978 (DBOD), data for soil monoliths in National Institute of Agro-Environmental Sciences used for determination of elemental concentration (DSMN) and water quality data for rivers in Japan (WQRJ). These data sets have been stored as spreadsheet files, and it is easy to use them. TUWAD was used to examine criteria to define andic and vitric properties of the World Reference Base for soil resources. The DBOD was used for elucidating the involvement of exchangeable Ca and Mg in the phosphate sorption coefficient. The ASJ was used to illustrate the depletion of Si, Ca and Na, and enrichment of Al, Fe and other immobile minor elements during Andosol formation. These results were confirmed using DSMN. As shown in these examples, the soil databases are useful for testing soil classification criteria, examining the relationship between new experimental results and previously reported data, etc. It is desirable to construct a soil database that covers wide regions and research areas in the future.

Introduction

1. Advantages of using soil databases for pedological studies

Hardware and software for computers are available to manage the huge amount of soil data. Soil databases are digital storehouses of soil information, and they are promising tools for further developing pedological studies. Because soil properties change with time due not only to natural processes but also to human activities, soil databases also have historical aspects. We introduce several examples in which we have used soil databases for pedological and pedochemical studies. The examples are (i) discussion on factors affecting the relationship between oxalate extraction and phosphate (P) retention to define andic and vitric properties in the World Reference Base for soil resources (WRB, IUSS Working Group WRB, 2006), (ii) enrichment and depletion of elements during Andosol formation from tephra.

In the course of these studies, we constructed small databases in two cases (Nanzyo and Shoji, 1992; 1993; Shoji et al., 1996). In other cases, we used databases made by Japanese soil scientists due to the courtesy of their authors, and we added some experimental data to other existing databases using kindly distributed soil samples. Soil databases are useful for testing new ideas quickly, analyzing the relationship between new experimental data and previously reported data.

We use the words "volcanic ash soils", "Andosols" or "Andisols". The word "volcanic ash soils" is any soil derived from volcanic ash as a major parent material. Andosols and Andisols are the soils that meet or are estimated to meet the requirements defined in the WRB system and USDA Soil Taxonomy (Soil Survey Staff, 2006), respectively. We use these words depending on the individual topic and the cited literature. Although "Andosols" is used in the classification of Japanese cultivated soils, it is specified when necessary. Because we use volcanic ash in a broad sense here, it has the same meaning as tephra.

2. Databases used for the exemplifying studies

The databases mentioned below are listed in Table 1. The database for Ando soils in Japan (ASJ) was made by the Kurobokudo co-operative research group and compiled as a book by Wada (1986). ASJ includes profile description, chemical, physical and mineralogical data for volcanic ash soils in Japan. The database by Oda et al. (1987) (DBOD) includes many data selected from all over Japanese cultivated soils. The data were collected during the period of the soil fertility survey project supported by the ministry of Agriculture, Forestry and Fishery between 1959 and 1978. Soil characterization data were collected using surface and subsurface horizon soils of paddy fields, upland fields and orchards. TUWAD (Shoji et al., 1996) was constructed adding data for volcanic ash soils in the world, provided by H. Eswaran of the USDA, to ASJ and the Andisol TU database that was used to show chemical and physical characterization data for volcanic ash soils from the northern part of the circum-pacific volcanic zone by Shoji et al. (1993). We used the data for soil monoliths in the National Institute of Agro-Environmental Sciences (DSMN, Nakai et al., 2006) adding the concentrations of 57 elements (Yamasaki et al., 2001). We also used data on water quality of rivers (Kobayashi, 1971) to discuss the depletion of some elements from volcanic ash soils. The water quality data were collected during the old days between 1942 and 1959. The water samples were taken more than several times a year in each river at the boundary between mountains and the river plain in order to minimize human impact, and the mean values were reported.

Classification of volcanic ash soils

Following the activities of the International Committee on Andisols (ICOMAND) (Eswaran and Beinroth, 2000), the Andisol order was added to the USDA-Soil Taxonomy. During the course of the ICOMAND activities, they frequently used the soil database of the USDA to discuss criteria for Andisol classification (personal communication from a previous ICOMAND member). This fact suggests the usefulness of the soil database. The USDA-Soil Taxonomy is the soil classification system of the USA, although soils throughout the world are considered in it. On the other hand, WRB has been developed since 1980's inheriting soil classification system of FAO. The WRB was constructed to correlate classification systems of many countries in the world. Andosols are one of the members of 32 reference soil groups of the WRB.

1. Possible reasons for plot scattering between oxalate-extractable $Al_o + Fe_o/2$ and P retention

The requirements for andic properties of WRB (IUSS working group WRB, 2006) include five

Table 1. Databases used for the exemplifying studies

Databases	Locations of pedons	Number of pedons*	Number of horizons*	References
Ando soils in Japan (ASJ)	Japan	25	157	Wada (1986)
Database by Oda et al. (DBOD)	Cutivated lands in Japan	3343	6686	Oda et al. (1987)
Tohoku University World Andisol Database (TUWAD)	Volcanic areas in the world	260	1463	Shoji et al. (1996), Shoji et al. (1993), Wada (1986)
Data for soil monoliths in NIAES (DSMN)	Japan	78	514	Nakai et al. (2006), Yamasaki et al. (2001)
Water quality data for rivers in Japan (WQRJ)	Japan (1942-1959)	(218 rivers)	-	Kobayashi (1971)

*: The numbers show totals, and the data were further selected according to the individual purpose.

items, (i) $Al_o + Fe_o/2 \geqq 20$ g kg^{-1}, (ii) P retention percentage $\geqq 85$ %, (iii) bulk density $\geqq 0.9$ Mg m^{-3} (iv) $C_p/OC<0.5$ or $C_f/C_p<0.5$ if occurring under tephric material that meets the requirements of an albic horizon, and (v) OC<25% by mass, where C_p and C_f are pyrophosphate-extractable C and fulvic acid C, respectively. $Al_o + Fe_o/2$ of 4 g kg^{-1} or more and a P retention percentage of 25 % or more are used to define the vitric properties. Although simple requirements are desirable, a combination of three or more criteria is used for the andic and vitric properties. Among these properties, $Al_o + Fe_o/2$ and P retention are chemical properties, and there is a correlation between these two. However, it is also true that there is considerable scattering as shown in Fig. 1 (Shoji et al., 1996; Takahashi et al., 2004). Wide scattering between these two is the reason for using both of these criteria. Factors affecting the scattering in the relationship between $Al_o + Fe_o/2$ and P retention are magnetite, forms of active Al, forms of active Fe, etc.

Magnetite included in fresh tephra in various amounts is partly soluble in the oxalate solution. However, the P sorption of magnetite is small. Thus, oxalate-extractable Fe is overestimated by partial dissolution of magnetite. The P retention percentage is needed to properly evaluate the content of active Fe in an Andosol. The effect of magnetite dissolution is significant in the region near the lower limit of the vitric property (Shoji et al., 1987).

Chemical forms of active Al also affect the relationship between $Al_o+Fe_o/2$ and P retention. Although aluminum is extractable in oxalate solution from all of allophane, imogolite and Al-humus, the reactivity of these materials with P is different. Nonallophanic Andosols sorb more P than allophanic Andosols when they are compared at the same $Al_o+Fe_o/2$ value (Fig. 2). As a major form of active Al in nonallophanic Andosols is Al-humus, it is more reactive with P than allophane and imogolite. The major forms of active Al in allophanic Andosols are allophane and imogolite. According to Henmi et al. (1982) who used pure allophane and pure imoglite, allophane is more reative with P than imogolite. The reactivity of active Al with P decreases in the order of Al-humus complex > Al-rich allophane > Si-rich allophane > imogolite. Hence, nonallophanic Andisols are more reactive with P than allophanic Andosols.

Mineralogical difference in iron minerals is also responsible for the plot scattering between $Al_o+Fe_o/2$

and P retention. Goethite and haematite are not extractable with oxalate solution, although these minerals sorb P. Thus, it is expected that soils with high goethite and haematite show higher P retention than those with an average content of these minerals. Soils with high $CaCO_3$ or $MgCO_3$ content may show higher P retention than those expected from the relationship between $Al_o+Fe_o/2$ and P retention, although Andosols containing a high amount of carbonates are rare.

The above-mentioned reasons are included in the plot scattering between $Al_o+Fe_o/2$ and P retention. The criteria for andic and vitric properties are set at the center of the plot scattering (Fig. 1). Thus, $Al_o+Fe_o/2$ and the P retention percentage are mutually complementary in evaluating the amount of active Al
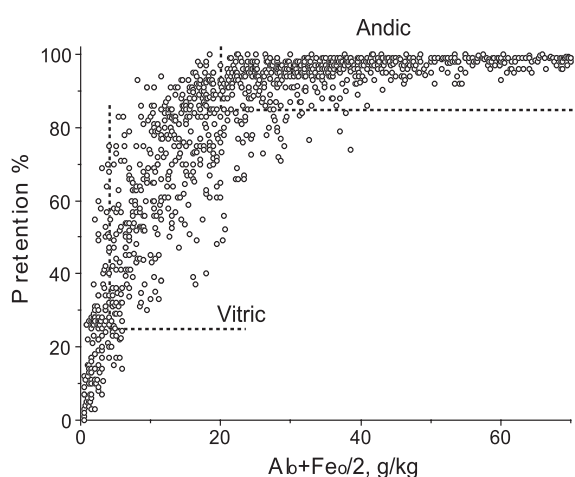

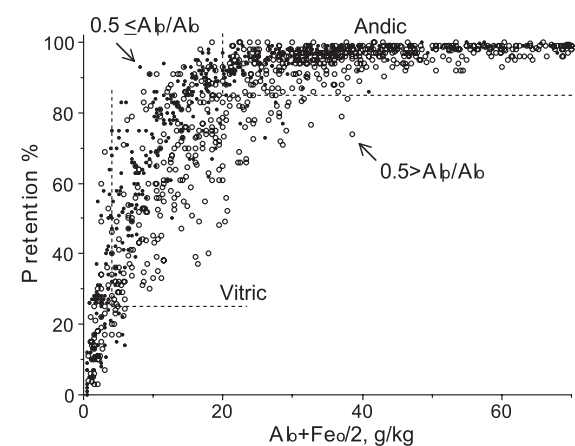**Fig. 1.** Relationship between $Al_o + Fe_o/2$ and P retention of Andisols (TUWAD).

Fig. 2. Relationship between $Al_o+Fe_o/2$ and P retention percentage of allophanic (open circles) and nonallophanic (small closed circles) Andisols (TUWAD).

and Fe in soil classification systems.

2. Subdivisions of WRB Andosols

The WRB system has a subdivision of Andosols into silandic (allophanic) and aluandic (nonallophanic). The Alic subgroups, the equivalent members of aluandic Andosols were also included in some of the Andisols great groups in the USDA Soil Taxonomy. The frequency of allophanic Andosols evaluated by Al_p/Al_o values is higher than that of nonallophanic Andosols in TUWAD (Fig. 3). Accordingly, the area ratio of allophanic and nonallophanic Andosols was reported to be 3:7 in the Japanese cultivated soils by Saigusa and Matsuyama (1998) who analyzed soil samples collected at a high density per unit area. The allophanic Andosols are distributed in the areas covered by relatively new (younger than 10 ka) and abundant volcanic ashes in Japan. ASJ and TUWAD (Fig. 3) show the number of observations and the relationships between data only, and the number of observations in these databases is not directly related to the area of individual soil distribution. On the other hand, each sampling site in DBOD has an area datum.

3. Characterization of volcanic ash soils in Japan

The DBOD is useful for describing the properties of 16 soil great groups in Japanese cultivated lands. The 16 soil great groups were used in the 2nd approximation of soil classification, although 24 soil great groups are used after the publication of the 3rd approximation in 1995 (Cultivated Soil Classification Committee, 1995). Andosols or Kurobokudo in Japanese show unique chemical properties such as high P sorption coefficient (PSC), high organic carbon (OC) content, high C/N ratio, and unique physical properties such as low bulk density and low solid phase ratio (Oda et al., 1987; Iimura, 1988). In the 3rd approximation to classify the Japanese cultivated soils, a PSC of 15 g P_2O_5 kg^{-1} or more is used to key out Andosol groups. Fig. 4 shows the frequency distribution of the PSC of Andosols and other soils according to the 2nd approximation system. The PSC of Andosols is significantly higher than those of other soils. However, some of the non-Andosols also show a higher PSC than 15 g P_2O_5 kg^{-1}.
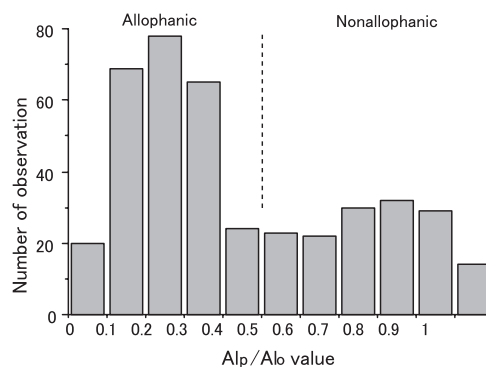

Fig. 3. Frequency distribution of the ratio of pyrophosphate to oxalate extractable Al (Al_p/Al_o) in A horizons with $Al_o + Fe_o/2$ of 1.2% or more (TUWAD).
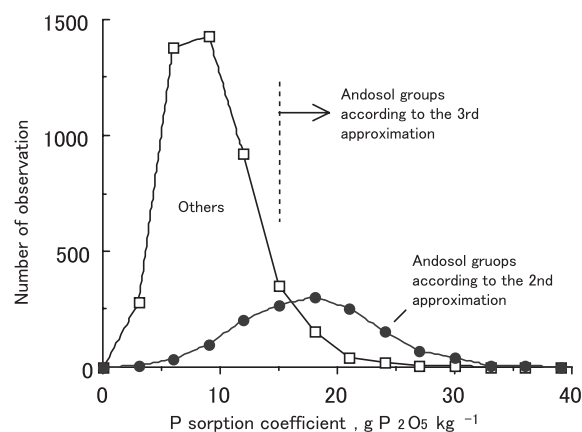

Fig. 4. Frequency distribution of the P sorption coefficient according to DBOD. Three soil great groups, Andosols, Aquic Andosols and Gleyic Andosols, are grouped into the Andosol groups. The plot at 15 g P_2O_5 kg^{-1}, for example, shows the number of observations for $12 < PSC \leqq 15$ g P_2O_5 kg^{-1}.

4. Involvement of exchangeable cations as well as active Al and Fe in PSC at pH 7

The phosphate sorption coefficient is determined using 2.5 % (0.07 mol P L^{-1}) ammonium phosphate at pH 7 and at a solution: soil ratio of 2:1. Using this sorption procedure, exchangeable Ca and Mg also react with P as well as active Al and Fe as schematically shown in Fig. 5. Crystalline P sorption products are $CaHPO_4 \cdot 2H_2O$ (DCPD) and $NH_4MgPO_4 \cdot 6H_2O$ (MAP). These phosphates are detectable by X-ray diffraction in the smectic soils after P sorption determination (Fig. 6). These reactions are most evident in the neutral smectic soils, as exemplified by Gley soils, with high exchangeable Ca and Mg. These reaction products were further confirmed when the so-
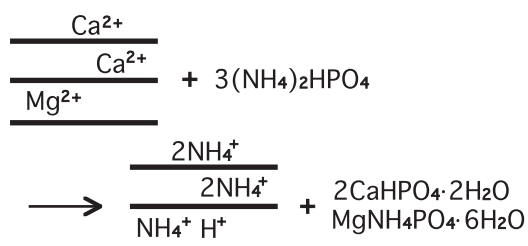
Fig. 5. Schematic representation of forming DCPD and MAP from exchangeable Ca and Mg during P sorption coefficient determination of soils.
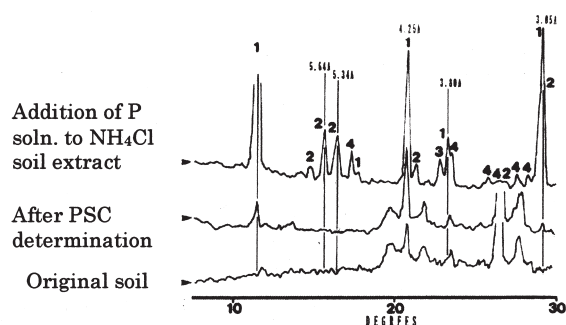

Fig. 6. XRD patterns of a smectic soil in relation to PSC determination. 1: DCPD, 2: MAP, 3: NH_4Cl, 4: $(NH_4)_2HPO_4$. DCPD and MAP precipitated in the reaction between added P and Ca and Mg extracted from the soil.
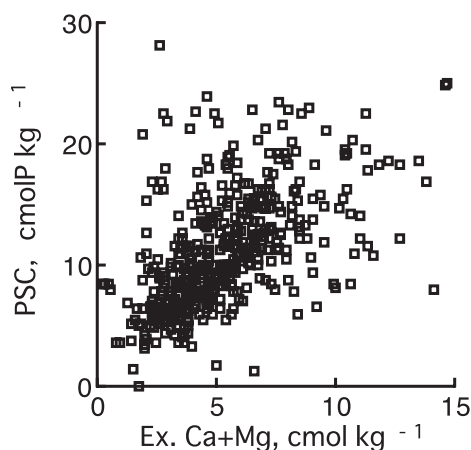

Fig. 7. Relationship between exchangeable Ca + Mg and PSC of Gley soils.

lution separated from an NH_4Cl soil suspension was reacted with P solution as shown in the uppermost XRD pattern in Fig. 6 (Nanzyo et al., 1991).

Using DBOD, a high correlation was found between the PSC of Gley soils and exchangeable Ca + Mg as shown in Fig. 7 (Nanzyo et al., 1992). After subtraction of exchangeable Ca + Mg from the PSC of the Gley soils on a molar basis, the correlation between PSC and exchangeable Ca + Mg disappears

(Fig. 8). Similar results were also obtained for Gray lowland soils (Fig. 9), brown lowland soils, etc. In contrast, the contribution of exchangeable Ca + Mg to PSC of Andosols (Fig. 10) is not significant. The possible reasons are that P is preferentially sorbed by abundant active Al and Fe and that the amount of remaining P in the solution is small. Further, exchangeable Ca and Mg may be strongly sorbed by the increased negatively charged sites of Andosols with P sorption.

Subtracting exchangeable Ca + Mg from the PSC of soils other than Andosols, most of the PSC values of those soils are less than 15 g P_2O_5 kg^{-1}. Thus, Andosols are more clearly separated if the effect of exchangeable Ca + Mg is removed from the PSC of soils other than Andosols as shown in Fig. 11. Further improvement in the PSC was suggested by Nanzyo et al. (1998). As expected from Fig. 1, a single solution method to determine the PSC is not sufficient to cover a wide range of active Al and Fe contents. Fig. 1 shows that the P retention percentage is close to 100 % for the soils with a high Al_o and $Fe_o/2$ content, indicating that the amount of P added is not enough for these soils. The same is also true for the PSC. Nanzyo et al. (1998) proposed a two-solution method with an acetate buffer solution to cover a variety of soils. Because plants can use DCPD and MAP, the above-mentioned properties should be considered in the management of cultivated soils.

Genesis of volcanic ash soils

Volcanic ash is the major parent material of volcanic ash soils, although various amounts of additives are included in the volcanic ash soils. Volcanic ash is intermittently supplied in the volcanic zones of the world and the time zero of soil formation is reset when a new deposit of volcanic ash is provided. Looking at different places, there are volcanic ash soils of different development stages, providing us a kinetic viewpoint for soil formation (Shoji et al., 1993).

In the middle latitude areas, volcanic ash is frequently conveyed to the eastern side of a volcano due to prevailing strong westerly wind when the volcanic eruption is explosive. A highly explosive eruption mostly produces rhyolitic to andesitic tephra. The particle size of the deposit is reduced with the distance from the source volcano and the elapse of time during the ash fall, although the chemical composi-
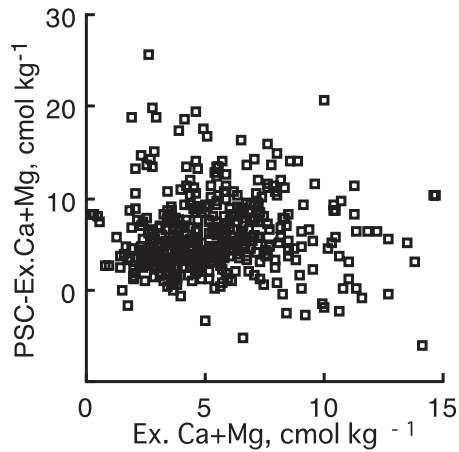
Fig. 8. Relationship between exchangeable Ca+Mg and PSC from which exchangeable Ca+ Mg was subtracted on a molar basis.
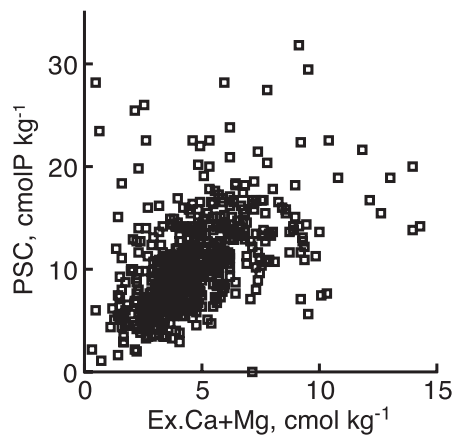

Fig. 9. Relationship between exchangeable Ca + Mg and PSC of Gray lowland soils.
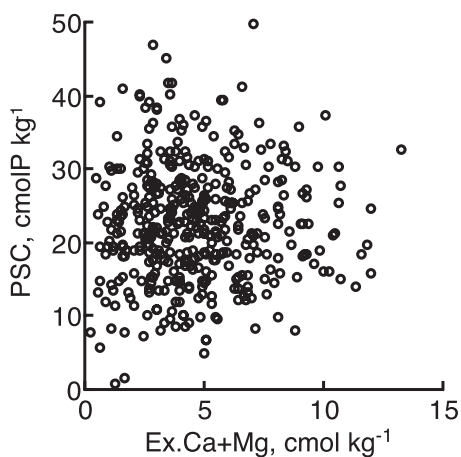

Fig. 10. Relationship between exchangeable Ca + Mg and PSC of Andosols.
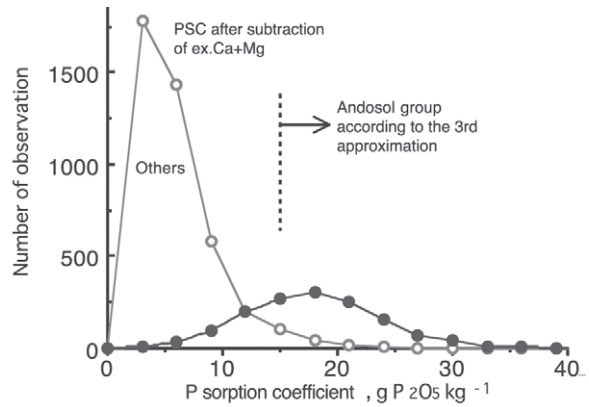

Fig. 11. Frequency distribution of P sorption coefficients according to DBOD. Three great soil groups, Andosols, Aquic Andosols and Gleyic Andosols, are grouped into the Andosol group. For others, ex. Ca+Mg was subtracted from PSC on a molar basis. The plot at 15 g P_2O_5 kg^{-1}, for example, shows the number of observations for $12 < PSC \leqq 15$ g P_2O_5 kg^{-1}.

tion of volcanic glass is relatively similar. Because volcanic glass is dominant in most tephra, the chemical composition of these tephra is somewhat similar. Although mineral separation may take place with the distance from a source volcano, it may not be very pronounced as long as volcanic glass is predominant in the tephra. An example of Tarumae-a (Ta-a) tephra containing a large amount of crystalline particles is an exceptional case because the heavy mineral content steeply decreases with the distance from Mt. Tarumae and the chemical composition of Ta-a also changes accordingly (Mizuno et al., 2008). During the dormant period of a volcano, soil formation proceeds from the surface of the ash deposit depending on the factors of soil formation. The characteristic and major soil formation process of Andosols is *in situ* accumulation of active Al and Fe. Chemical forms of active Al are allophane, imgolite and Al-humus, and that of active Fe is ferrihydrite in many cases. A large amount of humus is accumulated in the A horizons. Halloysite, pedogenic opal and other secondary materials are also formed depending on the soil formation factors. In this section, we describe the effect of climate on Andosol formation, and then we focus on changes in the chemical composition of volcanic ash during the Andosol formation.

1. Enrichment of immobile elements during Andosol formation

Because the elemental composition of fresh volcanic ash (Si-rich) is greatly different from those of the secondary materials (Al- or Fe-rich) in Andosols, the concentrations of many elements are affected during this process depending on the properties of the elements. Using the data for ASJ and stored soil samples, we examined how the rock type of the volcanic ash and its weight loss during the soil formation process affect the changes in the element concentrations of Andosols (Nanzyo et al., 2007). The ASJ has information on the estimated rock-type of parent volcanic ash. A total of 95 samples of different rock types from 18 pedons of allophanic Andosols in Japan and their total concentrations of 54 elements were selected for this analysis. The principal component analysis of the concentrations of 54 elements suggested that the degree of weathering and the rock types of the parent volcanic ash are the important factors in the variation of the element concentrations in Andosols.

Relatively strong correlations between the element concentrations and Si_o, Al_o and Fe_o as well as other weathering indices were found in the andesitic 24 samples. These andesitic samples were used for detailed analysis. This rock-type group tended to show less elemental variation possibly due to the definition having a narrower SiO_2 concentration range than others.

Our preliminary study showed that the concentrations of many elements including Al, Fe increased with Si_o, Al_o and Fe_o (Nanzyo et al., 2002) indicating that these elements are enriched during Andosol formation. It was estimated that the reason for the increase in the concentrations of immobile elements was weight loss during Andosol formation. Changes in the concentrations of 54 elements were then plotted against (W_p/W_s-1) (Fig. 12), where W_p and W_s are the weight of the parent volcanic ash and the weight of the present soil sample, respectively. At time zero of soil formation, W_p was equal to W_s, and then $W_p/W_s-1 = 0$. When $W_p = 2W_s$, $W_p/W_s-1 = 1$. Assuming that volcanic glass quantitatively weathered to form Al_o and that the average Al content of volcanic glass in the andesitic volcanic ash is 69.6 g kg^{-1} (Kobayashi et al., 1976), W_p/W_s was calculated as follows on an ignition residue basis:

$$W_p/W_s = OIIR + Al_o/69.6 \qquad (1)$$

The background for using the equation (1) is schematically shown in Fig. 13.
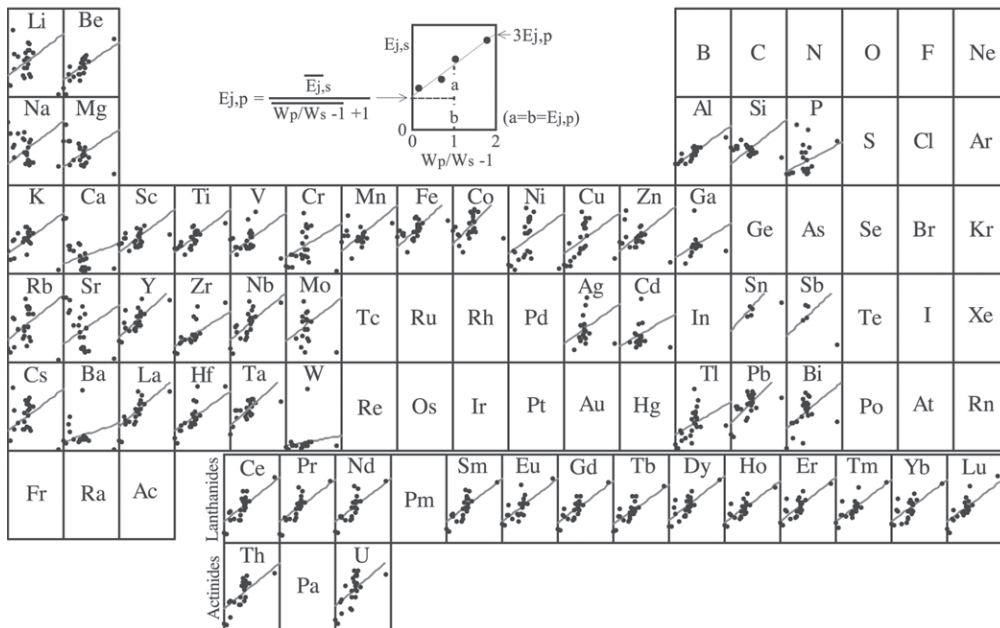
In Fig. 12, the ideal changes in concentration of im-

Fig. 12. Changes in element concentrations ($E_{j,p}$ and $E_{j,s}$ where p and s refer to parent tephra and an Andosol sample, respectively) with Andosol formation. All horizontal axes are the same W_p/W_s-1. The scale of the vertical axes is different depending on each element.
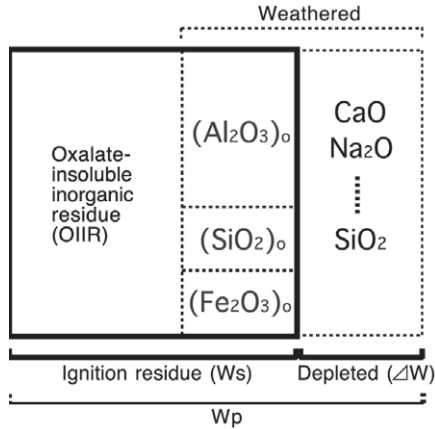
Fig. 13. Schematic representation of the relationship between the ignition residue of the soil sample (W_s) and the weight of the parent material (W_p). Oxalate-extractable Al, Si and Fe are shown in the oxide forms. Delta W ($\triangle W$) is the weight loss during weathering of the parent material and is nearly equal to the summation of the weight of depleted CaO, Na$_2$O and SiO$_2$.

mobile elements are also shown as a solid line. The use of the solid lines in this figure is based on the open-system mass transport that yields the chemical gains and losses of elements in a soil sample compared with the parent material according to Brimhall et al. (1991) and Nieuwenhuyse and van Breemen (1997). In their fundamental equation, three variables of volume, bulk density and element concentration (E in g or mg kg^{-1}) were used. We simplified their equation multiplying the volume by the bulk density to give the equation (Kurtz et al., 2000):

$$W_p E_{j,p} + m_{j,flux} = W_s E_{j,s} \qquad (2)$$

where p, s and $m_{j,flux}$ refer to the parent tephra, an Andosol sample and the overall mass flux of the element j into or out of the system, respectively. If an element j is immobile during Andosol development, $m_{j,flux} = 0$. The equation (2) is further simplified into the equation:

$$E_{j,s} = (W_p/W_s)E_{j,p} \qquad (3)$$

Because W_p/W_s is calculated using the equation (1), the solid lines in Fig. 12 can be drawn so as to pass through the average concentration $E_{j,s}$ and the average weight change W_p/W_s. If an element is immobile during Andosol formation, its concentration is plotted along this line of each element. The theoretical $E_{j,p}$

can also be calculated using $E_{j,s}$ and W_p/W_s so long as an element is immobile.

In Fig. 12, we used W_p/W_s-1 rather than W_p/W_s so that the plots can appear near the vertical axis, converting the equation (3):

$$E_{j,s} = (W_p/W_s - 1 + 1) E_{j,p} = (W_p/W_s - 1) E_{j,p} + E_{j,p} \qquad (4)$$

Among 54 elements, at least 27 (Be, Al, Ti, Fe, Y, Zr, Nb, La, Ce, Pr, Nd, Sm,, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Tl, Pb, Th and U) were enriched in the Andosols, and the increases in these concentrations were related to the total weight loss due to the soil formation processes. These results were confirmed using DSMN that would be reported elsewhere. Although the 24 andesitic samples include A, Bw and C horizon soils, there is no difference among them as shown in Fig. 14. In this way, the concentrations of many elements in Andosols are higher than those in other soils in Japan (Takeda et al., 2005).

2. Depletion of mobile elements during Andosolization

Silicon, Al, Fe, Ca, Mg, Na, K, Ti, Mn and P are the major elements of inorganic soil constituents. The loss of major elements is responsible for the weight loss of Andosols during the formation process. Among these major elements, the concentrations of Si, Ca and Na clearly decrease with the weight loss as shown in Fig. 12. However, the slope of the decrease in the element concentration is steeper for Ca and Na than that for Si (Fig. 15). One of the possible reasons is that Ca and Na are not the major constituents of Andosolization products but that Si is the structural constituent of allophane and imogolite. Other reasons are that Si can be sorbed by ferrihydrite and contribute to retaining its low crystallinity in Andosols and that Si is also partly retained in Andosols as pedogenic opals or plant opals.

The losses of major elements can be related to the weight loss of Andosols during their formation. Fig. 13 is also a simple model for the relationship between the weight loss ($\triangle W$) and the decreases in Si, Ca and Na concentrations (oxide forms). On an ignition residue basis,

$$\triangle W = \triangle SiO_2 + \triangle CaO + \triangle Na_2O \qquad (5)$$
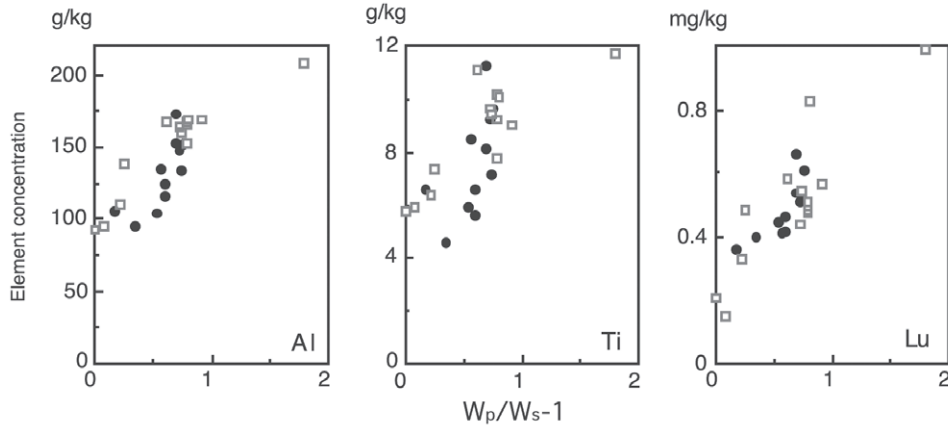
Considering the unit weight of the parent volcanic

Fig. 14. Changes in element concentrations of Al, Ti, and Lu in Andosols with a decrease in weight. This figure is basically the same as Fig. 14 except that the element concentration is plotted using different symbols for A (●) horizons, and Bw and C (□) horizons.

The W_p/W_s-1 was used as the horizontal axis and $E_{j,s}$, the vertical axis. $E_{j,s}$ is then the intercept and also the slope of the solid lines in Fig. 12. If a parent tephra has a higher $E_{j,p}$ than average, the plot of $E_{j,s}$ appears over the solid line and if it has a lower $E_{j,p}$, below the solid line. If different $E_{j,p}$ values of the elements are scaled similarly, the slopes of their $E_{j,s}$ plots are also similar as shown in Fig. 12.
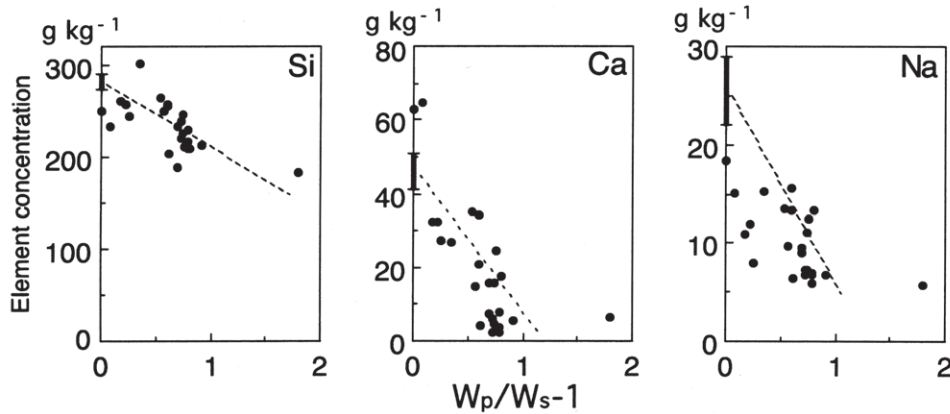

Fig. 15. Decreases in the concentration of major elements (Si, Ca and Na) in andesitic Andosols with weight loss. The thick vertical bars on the y axes shows the ranges of Si, Ca and Na concentration in the fresh volcanic ashes reported by Kobayashi et al. (1976).

ash W_p, (5) should be divided by W_p. Then,

$$\triangle W/ W_p = (\triangle SiO_2 + \triangle CaO + \triangle Na_2O)/W_p \tag{6}$$

Regarding individual elements,

$$\triangle SiO_2/W_p = (SiO_{2p}-SiO_{2s})/W_p = SiO_{2p}/W_p - SiO_{2s}/W_p = SiO_{2p}/W_p - (SiO_{2s}/W_s)(W_s/W_p) \tag{7}$$

Similarly,

$$\triangle CaO/W_p = (CaO_p - CaO_s)/W_p = CaO_p/W_p -$$

$$(CaO_s/W_s)(W_s/W_p) \tag{8}$$

$$\triangle Na_2O/W_p = (Na_2O_p - Na_2O_s)/W_p = Na_2O_p/W_p - (Na_2O_s/W_s)(W_s/W_p) \tag{9}$$

In (7), (8) and (9), SiO_{2p}/W_p, CaO_p/W_p, and Na_2O_p/W_p are the average values of fresh volcanic ashes, SiO_{2s}/W_s, CaO_s/W_s, and Na_2O_s/W_s are the individual values of soil samples, and W_s/W_p can be obtained from (1). We are then able to examine the validity of (6). The left side of (6) can be calculated using the following equation:
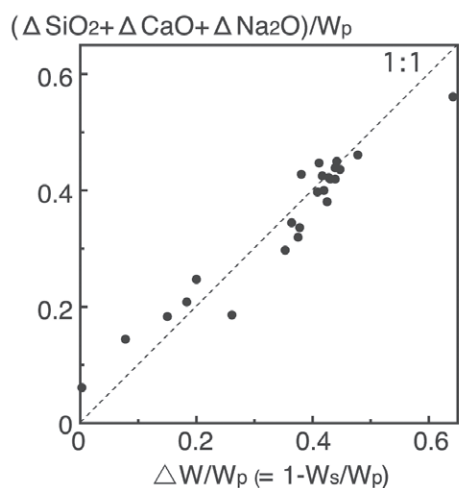
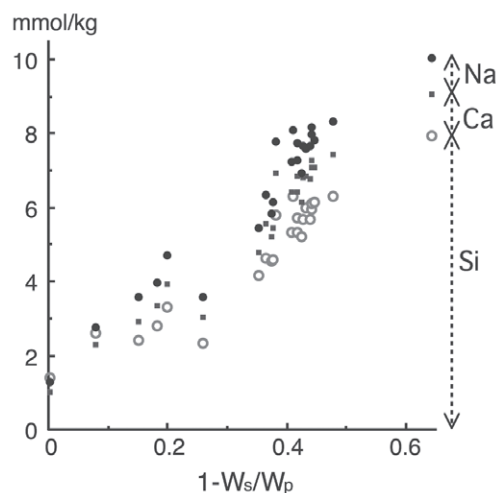**Fig. 16a.** Relationship between the weight loss and the summation of the decreases in SiO_2, CaO and Na_2O.

Fig. 16b. Breakdown of the weight loss into the individual loss of Si ($\circ$), Ca ($\blacksquare$) and Na ($\bullet$) on a molar basis.

Table 2. Comparison of selected atomic ratios between the depleted elements from Andosols and the dissolved elements in the river water.

	Atomic raitos		
	Si/Na	Si/Ca	Na/Ca
Depleted from Andosols	6.33a***	4.56a	0.72b
River water in the Andosol areas*	1.70b	2.61b	1.74a
River water in areas other than Andosols**	1.00d	1.24d	1.41a
All river water tested	1.24c	1.71c	1.52a

*: Rivers showing SiO_2 concentration of 20 mg kg^{-1} or more were included in the Andosol areas.

**: Rivers showing SiO_2 concentration of less than 20 mg kg^{-1}.

***: Different letters show significant difference according to Schefe's test at p=0.05.

$$\triangle W/ W_p = (W_p - W_s)/W_p = 1 - W_s/W_p \qquad (10)$$

Results are shown in Fig. 16a. This figure shows that estimation of the weight loss from the summation of $\triangle SiO_2$, $\triangle CaO$ and $\triangle Na_2O$ is identical to that estimated from Al_o formation. Conversion to molar basis and breakdown to Si, Ca and Na (Fig. 16b) indicate that the contribution of Si loss to the weight loss is much larger than that of Ca or Na loss.

It has been repeatedly stated that the Si concentration of river water is high in a volcanic area. We can understand this statement from Kobayshi (1971) who showed a close relationship between the areas of high SiO_2 concentration in the river water (WQRJ) and the allophanic Andosol areas (Saigusa and Matsuyama, 1998).

Sodium and Ca, released during Andosol formation (Fig. 15), are introduced at least partly into river water. Accordingly, the Na concentration in the river water of a volcanic area tends to be higher than those in other areas, but the Ca concentration is not different between the volcanic areas and other areas. The atomic ratios of Si/Na and Si/Ca were significantly higher in the lost fraction from volcanic ash during Andosol formation than those in the river water (Table 2). If the amount of Si in the river water is comparable to or slightly lower than that leached into the water from Andosols, the amounts of Na and Ca are higher in the river water than those expected from leaching during Andosols formation. These results suggest that other effects on the Na and Ca concentrations of the river water are greater than those from Andosol formation.

Concluding remarks

Soil databases for research purposes are constructed

according to the individual research topic. We have exemplified databases used for pedological studies on volcanic ash soils. The size of the database may be small in many cases, and the database may not necessarily be suitable for other purposes. Research studies are like living things. It is not easy to forecast the new research needs of other researchers. Thus, although researchers can utilize existing databases, they may improve them or construct new databases depending on their purposes. Even if the databases for research purposes are small and specialized, they may still be useful for creating a collection of databases by receiving offers from researchers and distributing them to new users, although it may not be so easy to follow the various changes like the version of software or operating systems. It is useful to store soil samples to distribute for research purposes, although the amount of the samples may not be infinite. The soil monolith museum in NIAES already has that kind of function.

Understanding the relationships between many individual soil data is improving, for example, as pedo-transfer functions. They are useful in outlining the relationships between different data. However, if one needs information at a specific site, a direct survey is still important. In that case, the databases can play a role in providing preliminary information. Although it was beyond our reach to handle soil maps here, the combination of soil data and soil maps in various forms is useful for a broad range of users.

Further recent readings on volcanic ash soils have been edited and published by Buurman and Regalado (2007), Arnalds et al. (2006), Takesako (2006), Dahlgren et al. (2004), Arnalds et al. (2004), Bartoli et al. (2003), Matsumoto (2002), Harsh et al. (2002), Chen (2000), Ping (2000), and others.

Acknowledgement

References

Arnalds, O. and K. Stahr (Guest Editors) (2004) Catena, 56(1-3): 1-264.

Arnalds, O., G, Stoops, P. Buurman, F. Bartoli, H. Oskarsson and E. Garcia Rodgja (Editors) (2006) Soils of Volcanic Regions of Europe, Springer, New York.

Bartoli, F., P. Buurman, B. Delvaux and M. Madeira. (Guest Editors) (2003) Geoderma, 117(3-4): 183-375.

Buurman, P. and C. Regalado (Guest Editors) (2007) European Journal of Soil Science, 58: 355-515.

Brimhall, G. H., O. A. Chadwick, C. J. Lewis, W. Compston, I. S. Williams, K. J. Danti, W. E. Dietrich, M. E. Power, D. Hendricks and J. Bratt (1991) Deformational mass transport and invasive processes in soil evolution. Science, 255: 695-702.

Chen, Z.-S. (2000) Andisols of Taiwan: Soil Properties, Mineralogy, Genesis and Classification.

Cultivated Soil Classification Committee (1995) Classification of cultivated soils in Japan, Third Approximation. Miscellaneous Publication for National Institite for Agro-Environental Sciences, No. 17. The National Institute of Agro-Environmental Sciences, Kannondai, Tsukuba, Ibaraki 305, Japan

Dahlgren, R. A., M. Saigusa, and F. C. Ugolini (2004) The nature, properties and management of volcanic soils. Advances in Agronomy, 82: 113-182.

Eswaran, H. and R. Beinroth (2000) Evolution of their classification and nomenclature. Soil Survey Horizons 41: 104-110.

IUSS Working Group WRB (2006) World Reference Base for Soil Resources 2006. A framework for international classification, correlation and communication. World Soil Resources Report, No. 103. FAO, Rome. pp.128.

Harsh, J., J. Chorover and E. Nizeyimana (2002) Allophane and Imogolite. In: J. B. Dixon and D.

G. Schulze (Editors), Soil Mineralogy with Environmental Applications, pp.291-322. SSSA, Inc., Madison, Wisconsin, USA.

Henmi, T., M. Nakai, T. Nakata, and N. Yoshinaga (1982) Removal of phosphorus by utilizing clays of volcanic ash soil and weathered pumice, Memoirs of the colledge of Agriculture, Ehime University, pp.17-24.

Iimura, K. (1988) Management of upland Andisols in Japan. In: Kinloch, D. I., Shoji, S., Beinroth, F. H. and Eswaran, H. Proceedings of the Ninth International Soil Classification Workshop, Japan, 20 July to 1 August, 1987. Publ. by Japanese Committee for the 9th International Soil Classification Workshop, for the Soil Management Support Services, Washington D.C., USA. pp.258-275.

Kobayashi, J. (1971) A checkup of river water. Iwanami Shinsho 777, Iwanami Shoten, Publishers, Tokyo (in Japanese).

Kobayashi, S., S. Shoji, I. Yamada and J. Masui (1976) Chemical and mineralogical studies on volcanic ashes. III. Some mineralogical and chemical properties of volcanic glasses with special reference to the rock types of volcanic ashes. Soil Science and Plant Nutrition, 22: 7-13.

Kurtz, A. C., L. A. Derry, M. J. Alfano and O. A. Chadwick (2000) Refractory element mobility in volcanic soils. Geology 28: 683-686.

Matsumoto, S. (Editor) (2002) Volcanic ashes and their soils, Global Environmental Research, 6: 1-135.

Mizuno, N., Y. Amano, T. Mizuno and M. Nanzyo. (2008) Changes in the heavy minerals content and element concentration of Tarumae-a tephra with distance from the source volcano, Soil Science and Plant Nutrition, 54: 839-845.

Nakai, M., H. Obara and K. Togami (2006) Catalog and data of soil monoliths in NIAES, Miscellaneous Publication of National Institute for Agro-Environmental Sciences, No.29 (in Japanese).

Nanzyo, M., S. Yamasaki and T, Honna (2002) Changes in content of trace and ultratrace elements with an increase in noncrystalline materials in volcanic ash soils of Japan, Clay Science, 12: 25-32.

Nanzyo, M., S. Yamasaki, T. Honna, I. Yamada, S. Shoji and T. Takahashi (2007) Changes in element concentrations during Andosol formation on tephra in Japan. European Journal of Soil Science, 58: 465-477.

Nanzyo, M. and S. Shoji (1992) Properties of Andisols from the northern part of circum-pacific volcanic zone. I. Physical properties based on Andisols TU database. Pedologist, 36: 34-43 (in Japanese with English abstract).

Nanzyo, M. and S. Shoji (1993) Properties of Andisols from the northern part of circum-pacific volcanic zone. II. Chemical properties based on Andisols TU database. Pedologist, 37: 87-95 (in Japanese with English abstract).

Nanzyo, M., T. Y. Uhm and S. Shoji (1992) Effect of exchangeable cations on the phosphate sorption coefficient of the cultivated soils. Japanese Journal of Soil Science and Plant Nutrition, 63: 559-565 (in Japanese with English abstract).

Nanzyo, M., T. Makino, S. Shoji, and T. Takahashi (1991) Role of exchangeable cations in the measurement of phosphate sorption coefficient of smectic soils. Study on Hachirougata reclaimed soils. Japanese Journal of Soil Science and Plant Nutrition, 62: 41-48 (in Japanese with English abstract).

Nanzyo, M., Y. Nakamaru, T. Ito, and S. Yamasaki (1998) Relationship between forms of active aluminum and iron, and phosphate retention capacity free from precipitation of Ca and Mg phosphate. Japanese Journal of Soil Science and Plant Nutrition, 69: 144-149 (in Japanese with English abstract).

Nieuwenhuyse, A. and N. Van Breemen (1997) Quantitative aspects of weathering and neoformation in selected Costa Rican volcanic soils. Soil Science Society of America Journal, 61, 1450-1458

Oda, K., E. Miwa and A. Iwamaoto (1987) Compact data base for soil analysis data in Japan. Japanese Journal of Soil Science and Plant Nutrition, 58: 112-131 (in Japansese).

Pariftt, R. L. and J. M. Kimble (1989) Conditions for formation of allophane in soils. Soil Science Society of America Journal, 53: 971-977.

Ping, C. L. (2000) Volcanic soils. In: H. Sigurdsson (Ed-in-chief), Encyclopedia of Volcanoes pp.1259-1270. Academic Press, San Diego-San Francisco-New York-Boston-London-Sydney-Toronto.

Ping, C. L., S. Shoji, T. Ito, T. Takahashi and J. P. Moore (1989) Characteristics and classification of volcanic ash derived soils in Alaska. Soil Science, 148: 8-28.

Saigusa, M. and N. Matsuyama (1998) Distribution of allophanic Andosols and Non allophanic Andosols in Japan, Tohoku Journal of Agriculture Research, 48: 75-83.

Shoji, S., T. Ito and M. Saigusa (1987) Andisol Entisol transition problem. Pedologist 31: 171-175.

Shoji, S., M. Nanzyo and R. A. Dahlgren (1993) Volcanic Ash Soils -Genesis, Properties and Utilization, Developments in Soil Science 21. Elsevier, pp.1-288.

Shoji, S., M. Nanzyo, R. A. Dahlgren and P. Quantin (1996) Evaluation and proposed revisions of criteria for andosols in the world reference base for soil resources. Soil Science, 161: 604-615.

Shoji, S., M. Nanzyo, S. Shirato and T. Ito (1993) Chemical kinetics of weathering in young Andisols from northeastern Japan using soil age normalized to 10^0C. Soil Science, 155: 53-60.

Soil Survey Staff (2006) Keys to Soil Taxonomy, 10th ed. USDA-NRCS.

Takahashi, T., M. Nanzyo and S. Shoji (2004) Proposed revisions to the diagnostic criteria for andic and vitric horizons and qualifiers of Andosols in the World Reference Base for Soil Resources. Soil Science and Plant Nutrition, 50: 431-437.

Takeda, A., M. Nanzyo and M. Nakai (2005) Major and trace element concentrations in soils of Japan. In: Eds. M. Nakai and M. Nanzyo, Heavy Metals in Soil Environments, pp.141-157, Hakuyusha Co. LTD., Tokyo (in Japansese).

Takesako, H. (Editor) (2006) Proceedings, International Symposium on Volcanic-Ash Soils and Field Workshop in the Mt. Fuji Area. Co-sponsored by Institute of Science and Technology, Meiji University, and Japanese Society of Pedology, Ikuta Campus, Meiji University, 17-19 March, 2006, pp.94.

Wada, K. (Editor) (1986) Ando soils in Japan, Kyushu University Press, Fukuoka, Japan.

Wada, K. (1980) Mineralogical characteristics of Andisols. In: B. K. G. Theng (Editor), Soils with Variable Charge, New Zealand Society of Soil Science, Lower Hutt. pp.87-107.

Yamasaki, S., A. Takeda, M. Nanzyo, I. Taniyama and M. Nakai (2001) Background levels of trace and ultra-trace elements in soils of Japan. Soil Science and Plant Nutrition, 47: 755-765.

Yonebayashi, K. and T. Hattori (1988) Chemical and biological studies on environmental humic acids, I. Composition of elemental and functional groups of humic acid. Soil Science and Plant Nutrition, 34: 571-584.