Journal of
Integrated Field Science

Vol. 2

March. 2005

Field Science Center
Graduate School of Agricultural Science
Tohoku University

Journal of Integrated Field Science (JIFS)

Office : Integrated Field Science Center,
Graduate School of Agricultural Science,
Tohoku University,
232−3, Yomogida, Ooguchi, Naruko,
Tamatsukuri, Miyagi, 989−6711, Japan

Contents

Special Review on New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems

Review

Original Paper

JIFS, 2 : 1 − 4 (2005) Special review

Unique Properties of Volcanic Ash Soils and Perspectives on their Applications

Masami NANZYO

Graduate School of Agricultural Science, Tohoku University
1-1 Tsutsumidori-Amamiyamachi, Aobaku, Sendai, 981-8555, Japan

Key words : andisol, andosol, soil taxonomy, utilization, volcanic ash soil

Soils are natural products on the land surface of the earth. They are made from a variety of parent materials including rocks, minerals, organisms and so on. Properties of the soils are, in general, dependent on climate, topography, periods of soil formation, and biological activities as well as parent materials (Jenny, 1941). Among these factors, effects of climate are approximately represented using precipitation and temperature on the analogy of those for vegetation (Brady and Weil, 1996). Cryoturbation and permafrost, leaching, clay translocation, and salinization may be intensified to the different directions as schematically shown in the precipitation−temperature diagram (Fig. 1). Biological production is high in the middle or higher precipitation and temperature ranges and humus accumulation is high under moisture−rich conditions. Alternate dry and moist enhance physical action of clays such as alternate shrinkage and swelling, and/or dispersion, eluviation and illuviation. These processes were positioned in the semi−dry regions of Fig. 1. Fig. 1 may be further extended for the distribution of 12 soil orders of the United States Department of Agriculture (USDA)−Soil Taxonomy as shown in Fig. 2. Occurrence of many soil orders such as Gelisols, Spodosols, Oxisols, Vertisols, Aridisols Mollisols and so on are strongly dependent on climatic conditions. In contrast, Entisols occur under any climate although they do not have permafrost. Inceptisols occur in any region except for aridic soil moisture regime by definition (Soil Survey Staff, 1999).

Andisols occur in the wide range of climate as reflected in the suborder members of Gelands, Cryands, Torrands, Xerands, Ustands and Udands. They cover dry to moist and cold to hot climatic regimes. This is due to the fact that Andisols are highly parent material−specific soils. And the definition of Andisols cover wide range of young to matured ones (Soil Survey Staff, 1999). Since the Andisol order was incorporated in the Keys to Soil Taxonomy in 1990, many monograophs and review papers (Van Wambeke, 1992; Shoji et al., 1993; Buol et all, 1997; Kimble et al., 2000, Ping, 2000; Harsh et al., 2002; Lowe et al., 2002; Dahlgren et al., 2004) and special issues (Matsumoto, 2002; Bartoli et al., 2003; Arnalds and Stahr, 2004; Oskarsson and Arnalds, 2004) were published.

Young volcanic ash soils are characterized by abundant volcanic glass that are colored or noncolored. Various kinds of soils can be formed from the volcanic ash depending on the individual set of soil forming factors at different sites (Shoji et al., 1993). Among these soils, Andisols or Andosols show unique properties mostly due to abundant noncrystalline materials such as allophane, imogolite, Al−humus complexes, ferrihydrite and so on. Highly porous structures made of aggregated

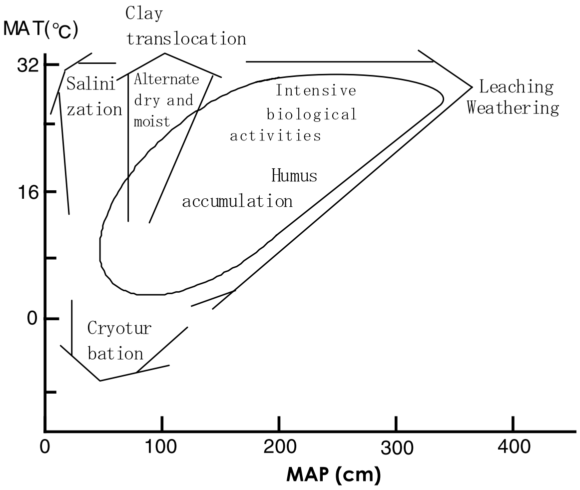


Figure 1. Schematic diagram showing relationship between soil formation processes and climatic factors.

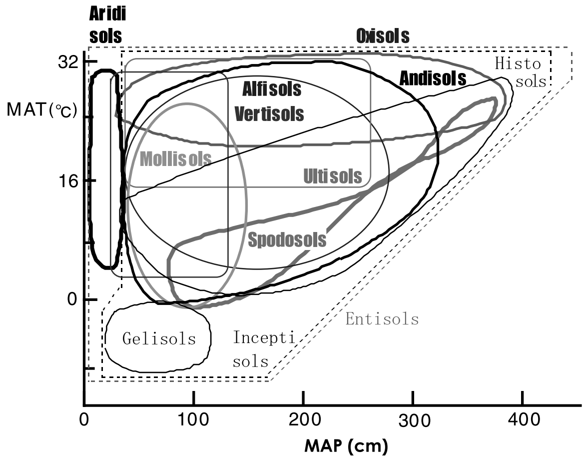


Figure 2. Schematic diagram showing relationship between soil orders of US Soil Taxonomy and climatic factors.

noncrystalline Andisols materials have a light fluffy nature, accommodating large amounts of both plant-available and hygroscopic water. They show many other unique physical properties different from other soils. Moreover, Andisols have unique chemical properties, including Al-rich elemental composition, large amount of humus accumulation in A horizons, variable charge characteristics, high phosphate retention capacity, high affinity for multi-valent cations, high KCl-extractable and water-soluble Al in nonallophanic Andisols at an acidic to weakly acidic pH range.

Some of these unique properties were not necessarily suitable for agricultural production in Japan. However, most of the problematic properties were improved now. Phosphate deficiency was amended by heavy application of phosphate fertilizers. Controlled release fertilizers are very effective to avoid rapid leaching of inorganic nitrogen under humid climate, that is one aspect of the variable charge characteristics. Al-toxicity was amended with liming. Deficiency of Cu and Zn was also amended by application of fertilizers containing these elements. Thus, Andisosl are now used for upland crop production and orchards.

Physical properties of Andisols are advantageous for these agricultural uses due to deep rooting zone, high air and water holding capacity, gradual water stress to enhance sugar content of some crops when the soil is dried (Shoji et al., 1993).

During Andisol formation, huge amount of Si is released to the downward ecosystems (Fig. 3). The SiO_2 concentration in the river water from the volcanic ash areas are as high as several tens mg L^{-1} that is about triplicate of those in other river waters. The river water high in Si is beneficial to rice plants and many other crops when the water is directly used for irrigation.

Allophanic and nonallophanic Andisols show contrasting effects on the behavior of KCl-extractable and water soluble Al. These forms of Al are toxic to many sensitive crops (Saigusa et al., 1980), but show a suppressive effect against potato scab (Mizuno et al., 1998) and bean root rot (Furuya et al., 1999). Content of these forms of Al is high in nonallophanic Andisols and low in

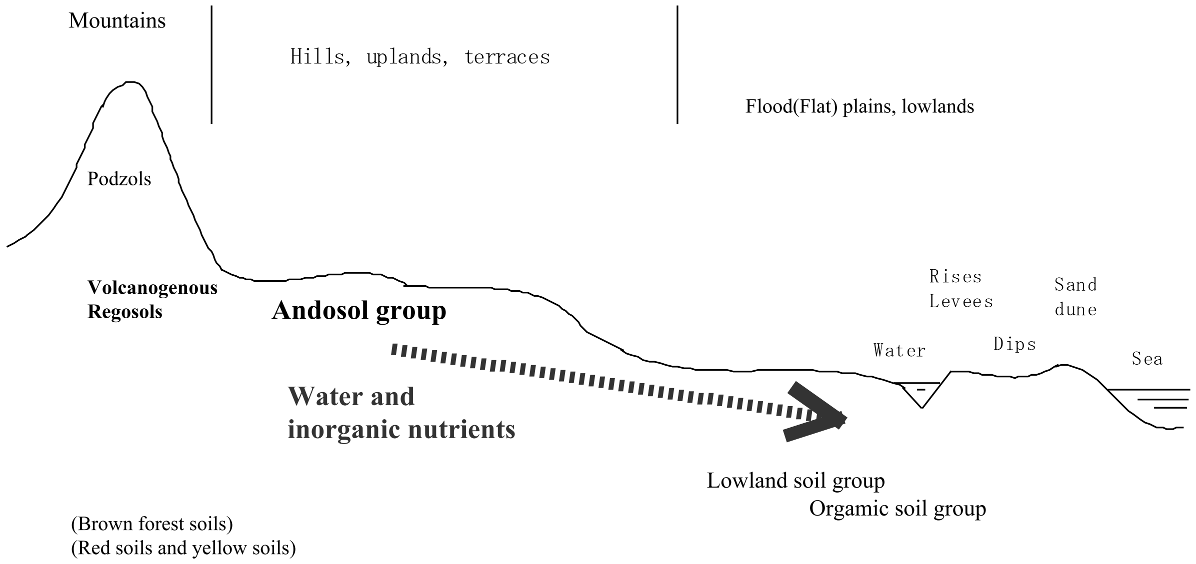


Figure 3. Contribution of volcanic ash soils to the downstream ecosystems. Names of soils and soil groups are represented by the classificatioin of cultivated soils in Japan (3rd revision, 1995).

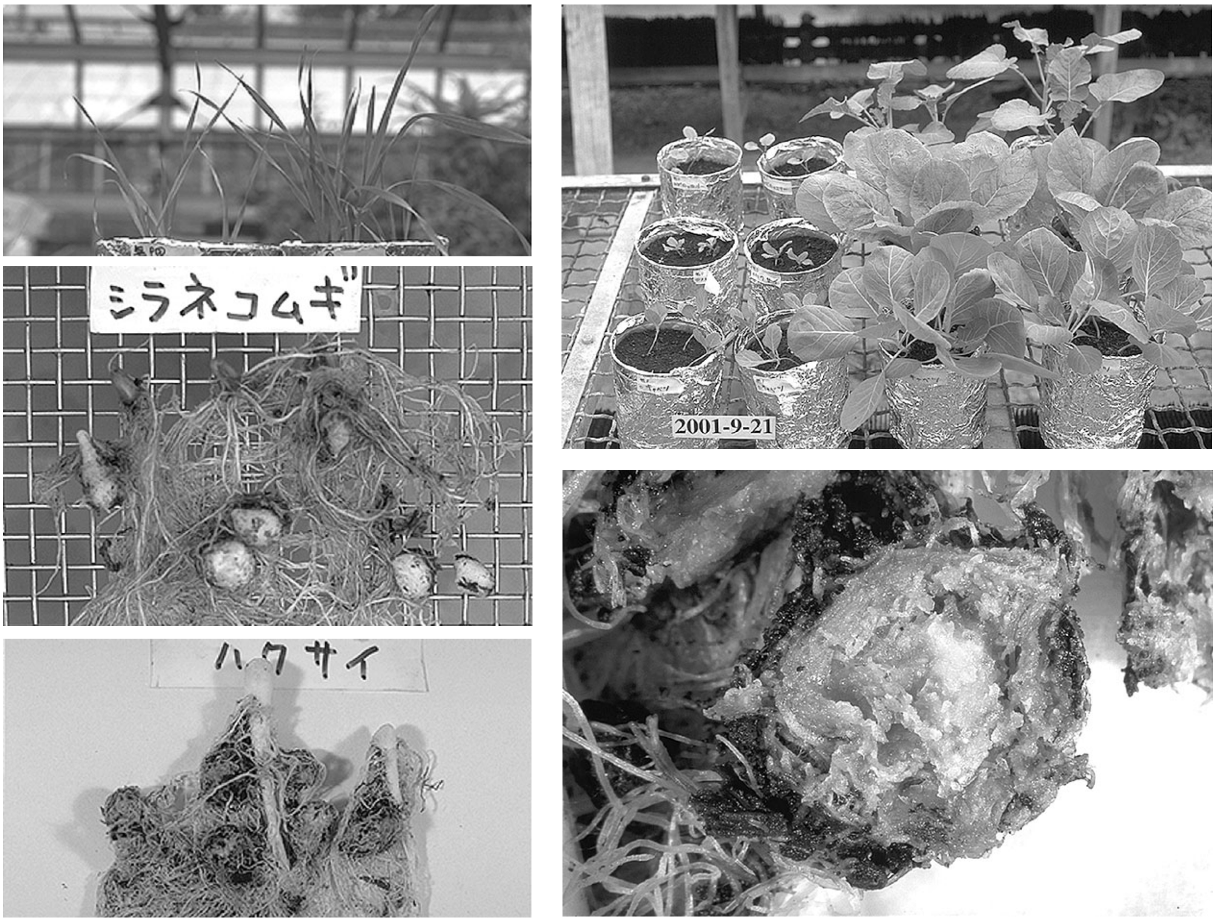


Figure 4. The upper left photo shows wheat growth with and without DCPD gel beads (P fertilizer). Growth improvement for wheat is not so much and contact between wheat roots and the DCPD gel beads was insufficient (middle left). In contrast, cabbage, Chinese cabbage and bloccoli, Brassica plants, showed conspicuous growth improvement with the DCPD gel beads (upper right). Chinese cabbage roots completely covered the surface of the DCPD gel beads (lower left) and there was no soil between the roots and the DCPD gel beads (cross section, lower right).

allophonic Andisols. High Al concentration of 0.3 mg L^{-1} or more in the water extract is considered to provide resistance to potato scab. Although water−extractable Al is negatively correlated with soil pH values, soils with low to high levels of water−extactable Al are included between pH(H$_2$O) levels of 5 and 6. The important factors affecting water extactable Al levels in this pH region were organic C content and Sio. The soils showing high water−extactable Al levels, contained a larger amount of organic C and a smaller amount of Sio than those with low water−extractable Al levels.

Under P deficient conditions in an uncultivated Andisols, Brassica roots show P−foraging root growth (Nanzyo et al., 2002; 2004). The thin lateral roots of Brassica pekinensis, L., completely encircled DCPD gel beads (a Ca−alginate gel in which a CaHPO$_4$.2H$_2$O powder was suspended) and no soil are remained between the roots and the DCPD gel beads. This morphological plasticity of Brassica roots is suitable for improving the P recovery rate because the soil, a few mm thick, with a high P retention capacity between plant roots and P fertilizer reduces the recovery rate of P fertilizers by crops in a P−deficient soils. P−preferential root proliferation was also observed for Fagoppyrum esculentum Moench.

Allophanic clays adsorbed tobacco mosaic virus because adsorption of the virus was not observed after removal of allophonic clays with acid−oxalate treatment. Forms of active Al in Andisols may affect the behavior of the virus. Although the virus was not adsorbed by an A horizon soil of a nonallophanic Andisol, the virus ceased multiplication suggesting the soil had an anti−virus effect (Toriyama et al., 1995).

References

Arnalds, O., and K. Stahr (Eds). 2004. Volcanic Soil Resources : Occurrence, Development and Properties, Catena 56 (Special Issues 1−3) : 1−224.

Bartoli, F., P. Buurman, B. Delvaux, and M. Madeira (Eds). 2003. Volcanic soils : properties and processes as a function of soil genesis and land use, Geoderma, 117 (Special issue 3−4) : 183−375

Brady, N.C., and R.R. Weil. 1996. The Nature and Properties of Soils, 11th ed., p.46. Prentice Hall, New Jersey, USA.

Buol, S.W., F.D. Hole, R.J. McCracken and R.J. Southard. 1997. Andisols : Soils with andic soil properties, *In : Soil Genesis and Classification* (4th ed.), Iowa State University Press, pp.249−257.

Dahlgren, R.A., M. Saigusa and F.C. Ugolini. 2003. The nature, properties and management of volcanic soils. Adv. Agron., 82 : 113−182.

Furuya, H., T. Takahashi and T. Matsumoto. 1999. Suppression of *Fusarium solani* f. sp. *phaseoli* on bean by aluminum in acid soils. *Phytopathology*, 89 : 47−52.

Harsh, J., J. Chorover and E. Nizeyimana. 2002. Allophane and Imogolite, In : J.B. Dixon and D.G. Schulze, eds., *Soil Mineralogy with Environmental Applications*, Soil Science Society of America Inc., Madison, Wisconsin, USA. pp.291−322.

Kimble, J.M., C.L. Ping, M.E. Sumner and L.P. Wilding. 2000. Andisols. In : M. E. Sumner, ed.−in−chief, Handbook of Soil Science, CRC Press, New York, pp.E−209−E−224.

Mizuno, N., H. Yoshida, M. Nanzyo and T. Tadano. 1998, Chemical characterization of conducive and suppressive soils for potato scab in *Hokkaido, Japan. Soil Science* and Plant Nutrition, 44 : 289−295.

Nanzyo, M., Y. Shibata, and N. Wada. 2002. Complete Contact of *Brassica* roots with Phosphates in a Phosphorus−Deficient Soil, *Soil Sci. Plant Nutr.* 48(6) : 847−853

Nanzyo, M., N. Wada, and H. Kanno. 2004. Phosphorus foraging root development of *Brassica rapa* nothovar. grown in a phosphorus−deficient nonallophanic Andisol Plant Soil, 265 : 325−333.

Jenny, H. 1941. Factors of Soil Formation. McGraw−Hill Book Company, Inc., New York and London.

Matsumoto, S. (Eds−in−Chief). 2002. Volcanic Ashes and Their Soils. Global Environmental Research, 6 (2) 1−135.

Oskarsson, H., and O. Arnalds. 2004. Volcanic Soil Resources in Europe, COST Action 622 final meeting, Abstracts. Rala Report no. 214, Agricultural Research Institute, Reykjavik, Iceland, 1−124.

Ping, C−L. 2000. Volcanic soils. In : H. Sigurdsson, ed−in−chief, *Encyclopedia of Volcanoes*, Academic Press, New York, pp.1259−1270.

Saigusa, M., S. Shoji, and T. Takahashi. 1980. Plant root growth in acid Andosols from northeastern Japan, II. Exchange acidity Y1 as a realistic measure of aluminum toxicity potential. *Soil Science*, 130 : 242−250.

Shoji, S., T. Ito, and M. Saigusa. 1984. Properties of nonallophanic Andosols from Japan. Soil Sci. 140 : 264−277.

Soil Survey Staff. 1999. Soil Taxonomy – A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nd Ed., p. 489. United States Department of Agriculture, Natural Resources Conservation Services, Agriculture Handbook No. 436.

Toriyama, S., I. Okabe, M. Nanzyo, M. Mitsuchi and M. Kameya. 1995. Effects of amorphous clay minerals (allophane) in the adsorption of tobacco mosaic virus by soils. *The Bulletin of the National Institute of Agro−Environmental Scineces*, 12 : 75−86.

Early Stage Transformation of 2 : 1 Layer Silicates in Pyroclastic Deposits from the 1980 Eruption of Mt. St. Helens

Randy A. DAHLGREN

Dept. of Land, Air and Water Resources,
University of California, Davis, CA 95616 USA

Key words : allophane, noncrystalline materials, pedogenesis,
smectite, volcanic ash, volcanic soils, weathering

Abstract

Chemical weathering and pedogenesis are especially rapid in volcanic materials due to their glassy nature, fine particle size, and high porosity and permeability. Early stage mineralogical transformations (0 −10 yr) in pyroclastic deposits from the 1980 eruptions of Mt. St. Helens were examined in a cryic−udic climatic regime of western Washington. Chemical weathering in pyroclastic flow deposits near the volcano was strongly affected by acidic precipitation (pH=3.6 to 5.2) originating from sulfuric acid emanating from the vent and by the microtopography that displayed an undulating surface with about 30 cm of relief. Weathering was more intense in depressions because they collected more water than adjacent mounds. Detrital 2 : 1 layer silicate minerals present in the original deposits of the depressions were degraded within five years to poorly crystalline kaolin and noncrystalline hydroxy−Al polymers and aluminosilicates. In the mound landscape position, there was no apparent alteration of the detrital 2 : 1 layer silicates. In forested areas receiving airfall tephra, weathering reactions were driven by carbonic acid originating from CO_2 diffusion from the buried soil. Aluminum released by weathering was preferentially retained as Al−humus complexes and hydroxy−Al interlayers of 2 : 1 layer silicates, which inhibited early formation of allophanic materials. We conclude that 2 : 1 layer silicates in pyroclastic deposits can be rapidly transformed with the resulting weathering products controlled by the dominant proton donor.

Introduction

The 1980 eruptions of Mt. St. Helens in western Washington State, USA provided an excellent opportunity to examine early stage weathering and mineralogical transformations in pyroclastic materials. Layer silicate minerals of the 2 : 1 type are often found in soils derived from pyroclastic materials. Their occurrence in young volcanic materials is variously ascribed to in situ pedogenic origin, eolian addition, or inheritance from hydrothermally altered materials in the parent material. The authigenic formation of 2 : 1 layer silicates in volcanic soils has long been a topic of debate (Shoji et al., 1993). Authigenic formation of 2 : 1 layer silicates has been identified as the initial crystalline weathering product in seasonally dry environments (Glassmann and Simonson, 1985; Quantin, 1992). Inheritance of 2 : 1 layer silicates has been documented in several pyroclastic materials (Kondo et al, 1979; Pevear et al., 1982; LaManna and Ugolini, 1987; Jongmans et al., 1994). Isotopic evidence has also demonstrated the importance of eolian transport as a major source of 2 : 1 layer silicates in areas such as Japan, Canary Islands, Tanzania and Hawaii (e.g., Dymond et al., 1974, Inoue, 1981; Inoue and Naruse, 1987, Mizota et al., 1988; Mizota and Matsuhisa, 1995). While formation of 2 : 1 layer silicates in volcanic materials in the udic soil moisture regime cannot be ruled out, current evidence suggests that eolian deposition is the major source of 2 : 1 layer silicates, with lesser amounts inherited from the pyroclastic deposits.

The primary objective of this study was to examine early stage (0 to 10 yr) weathering and mineralogical transformations of 2 : 1 layer silicates present in pyroclastic deposits from the 1980 eruptions of Mt. St. Helens. Smectite (saponite) and trioctahedral vermiculite were identified in pyroclastic flows near the volcano and in airfall tephra distributed across a wide area (Pevear et al., 1982; LaManna and Ugolini, 1987). These layer silicate minerals were formed by hydrothermal alteration of the volcanic cone prior to the eruption and deposited with the pyroclastic materials. Mineralogical transformations are compared in two contrasting environments : (i) a barren pyroclastic flow deposit near the volcano and (ii) at a site that received simulated airfall tephra in a subalpine forest ecosystem.

Study Areas and Methods

Mt. St. Helens

Several pedons were sampled on a pyroclastic flow located on the northeastern flank of Mt. St. Helens (see Nuhn, 1987 for details). The materials were about 5 yr old at the time of sampling. The elevation of sample sites ranged between 1060 and 1080 m. Mean annual air temperature is 5.6° C and annual precipitation averages about 225 cm with only 14 cm falling between June and August (Franklin and Dyreness, 1988). The depth of the pyroclastic deposits ranges from a few meters to greater than 40 m (Rowley et al., 1981). The study sites had no vegetation. Microtopography, consisting of mounds about 30 cm above the depressions and spaced between 2 and 3 m apart, has played an important role in the early stages of weathering.

Subalpine forest site

Weathering and mineralogical transformations in airfall tephra were simulated at the Findley Lake Research Area located in the central Cascade Mountains east of Seattle, Washington. The site is located at an elevation of 1150 m. Mean annual air temperature is 5.5° C and annual precipitation averages about 230 cm with only 10% occurring during the summer (N.O.A.A. 1985–1986). Vegetation is dominated by a mature coniferous forest dominated by Pacific silver fir (*Abies amabilis*, Dougl.–Forbes) with mountain hemlock (*Tsuga mertensiana*, Bong.–Carr) as an associated species. The dominant soils at the study site are classified as Andic Cryohumods.

The Findley Lake Research Area did not receive any airfall tephra from the 1980 eruptions of Mt. St. Helens. Previously unleached tephra was collected from airport runways at Yakami, Washington, a distance (130 km) approximately equal to the distance between Mt. St. Helens and the Findley Lake Research Area. Tephra was applied to the soil surface in 2 x 2 m plots at depths of either 5 or 15 cm. Soil solutions were collected continuously for 4 yr to follow solute leaching from the added tephra. After 10 yr, solid–phase samples were collected from the tephra plots and changes in tephra properties were compared to a subsample of the unweathered tephra. Detailed descriptions of the study site, experimental design and methodologies have been previously published (Dahlgren and Ugolini, 1989; Dahlgren et al., 1997, 1999).

Pyroclastic materials

The pyroclastic materials at both sites were of dacitic composition and consisted of newly crystallized materials along with lithic components derived from the hydrothermally altered cone (Korosec et al., 1980; Pevear et al., 1982). The magmatic materials were dominated by vesicular glass and plagioclase (andesine) with lower concentrations of hypersthene, hornblende, opaque minerals and biotite (Koresec et al, 1980; Fruchter et al, 1980). The older lithic fraction was dominated by plagioclase, but also contained minor amounts of smectite (saponite), trioctahedral vermiculite, cristobalite, tridymite and quartz (Ames, 1980; Pevear et al., 1982; LaManna and Ugolini, 1987). The pyroclastic materials at both sites had a loamy sand texture with 3 to 6% clay.

Analytical methods

The air–dried, less than 2–mm fraction was used for the following analyses. Soil pH was determined in distilled–deionized water (1 : 1 soil : solution) following a 15–min equilibration period. Particle–size analysis was determined by dry sieving and the pipette method using no pretreatments other than dispersion with sodium hexametaphosphate (Gee and Bauder, 1986). Cation exchange capacity and exchangeable cations were determined by 1 M NH_4Cl at ambient soil pH (Soil Survey Staff, 1984). Phosphate retention was determined using the method of Blakemore et al. (1981). Selective dissolution was performed by the following treatments : (i) sodium pyrophosphate (Al_p), one 16–hr extraction (McKeague, 1967) and (ii) acid ammonium oxalate (Al_{ox}, Fe_{ox}, Si_{ox}), one 4–hr extraction at pH=3 in the dark (McKeague, 1976). Iron, Al and Si in all extracts were measured by inductively coupled plasma (ICP) spectroscopy.

The clay–size fraction (<2 μm) was isolated by sedimentation following particle–size analysis and desalted by dialysis against deionized water. Additionally, subsamples from the forested site were pretreated with citrate-dithionite prior to the separation of the clay-size fraction (Holmgren, 1967). X-ray diffraction was performed on oriented samples using standard methods (Whittig and Allardice, 1986).

Results and Discussion

Pyroclastic flow deposits near Mt. St. Helens

Soil acidification rapidly occurred (<5 yr) in the pyroclastic flow deposits near Mt. St. Helens (Fig. 1). Soils in the mound component of the landscape were acidified in the upper 10 cm with near neutral pH values throughout the lower portion of the profile (Nuhn, 1987). In contrast, soils in the depressions were more strongly acidified with pH values of 5 or less throughout the upper 15 cm. Base saturation showed a similar trend with lower values throughout the upper 40 cm of soils in depressions as compared to the mounds.In the immediate vicinity of Mt. St. Helens, the pH of precipitation ranged from 3.6 to 5.2 in the six years following the 1980 eruption with the acidity originating primarily from sulfuric acid (Nuhn, 1987). Emission of sulfur dioxide (SO_2) averaged more than 1000 Mg d^{-1} following the 1980 eruption (Casadevall et al., 1983) providing a considerable proton load from atmospheric deposition. The acidity originating from the precipitation was largely consumed by weathering reactions in the upper 5 cm of the mound soils (Nuhn, 1987). In contrast, acidification and weathering was more intense in the depressions because they collected more water than adjacent mounds. Surface runoff from mounds to depressions was promoted by formation of a crust on the barren surfaces. Below the zone of intense soil acidification by strong acid (H_2SO_4), carbonic acid became the dominant proton donor (Nuhn, 1987).

In the immediate surface layer (1-3 cm) of the mounds, there was an apparent depletion of 2 : 1 layer silicates in samples collected in 1983 and thereafter (LaManna and Ugolini, 1987). This layer corresponds with the zone of most intense acidification (pH=5) in the mound soils. Detrital 2 : 1 layer silicate minerals in the upper 26 cm of soils in the depressions were largely degraded within five years to poorly crystalline kaolin and noncrystalline materials (Fig. 2) (Nuhn, 1987; Ugolini et al., 1991). Below the surface layers (upper 10 cm) that have received recent eolian materials with 2 : 1 layer silicates, the soil layers display a weathering progression with depth. The 26-55 cm layer has experienced only weak acidification and the unaltered 2 : 1 layer silicates are the dominant clay mineral. The 14-26 cm layer represents a zone with moderate acidification and displays a large decrease in 2 : 1 layer silicates and the formation of a kaolin mineral (0.74 nm). The kaolin mineral did not expand with formamide treatment indicating that the phase was more similar to kaolinite than halloysite. The 10-14 cm layer represents the zone of most intense acidification and weathering within the profile. In this zone the 2 : 1 layer silicates are largely degraded and only a very weak and broad kaolin (0.74 nm) peak was observed. This suggests that crystalline clay minerals were largely unstable in this zone of intense soil acidification by sulfuric acid.

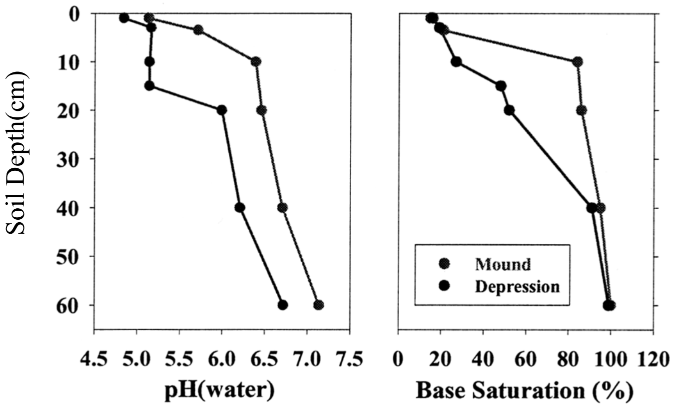


Figure 1. Soil pH(H_2O) and base saturation of soil profiles from the mound and depression microtopographic positions five years after emplacement of the 1980 Mt. St. Helens pyroclastic flow.

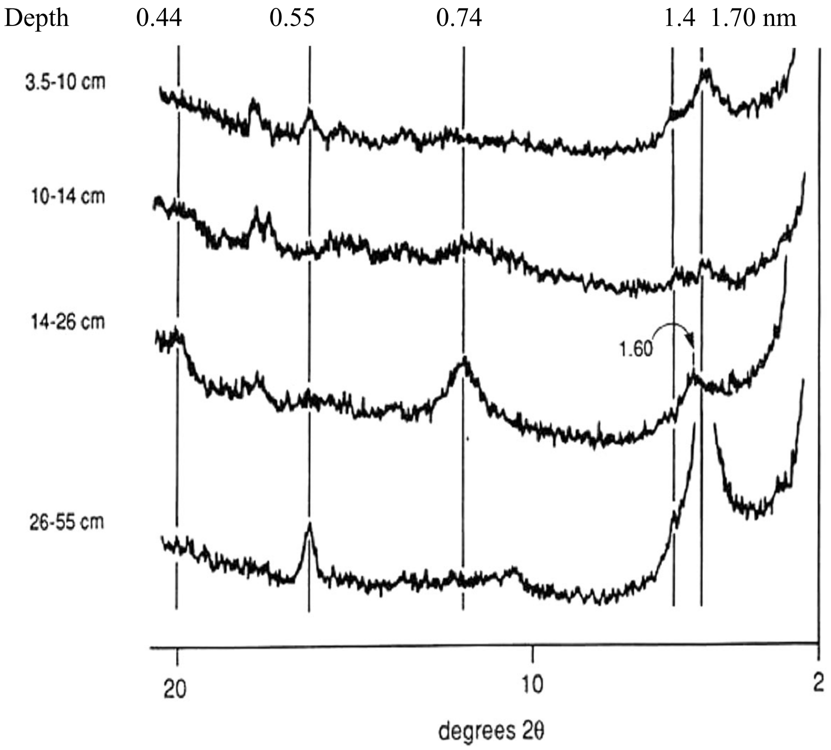


Figure 2. X-ray diffractograms (Mg-glycol treatment) for the clay-size fraction from the depression microtopographic position five years after emplacement of the 1980 Mt. St. Helens pyroclastic flow.

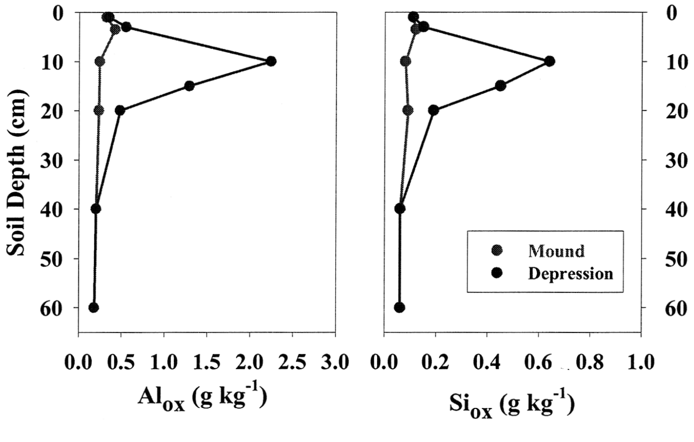


Figure 3. Oxalate extractable Al and Si concentrations of soil profiles from the mound and depression microtopographic positions five years after emplacement of the 1980 Mt. St. Helens pyroclastic flow.

Oxalate extractable Al and Si were distinctly elevated in the 10−14 cm layer suggesting that an allophanic material may be forming in the zone of strongest acidification (Fig. 3). The Al : Si atomic ratio of the oxalate extractable fraction ranged from 2.9 to 3.5, which is appreciably greater than maximum values of 2.0 for Al−rich allophane and imogolite. This suggest that in addition to Al extracted from allophanic materials, the oxalate extractable fraction may contain Al extracted from a noncrystalline hydroxy−Al polymer phase or hydroxy−Al polymers from the interlayer position of 2 : 1 layer silicates (when present).

Airfall tephra simulation in subalpine forest ecosystem

The initial stages of weathering and mineralogical transformations in airfall tephra were simulated by adding previously unweathered tephra to the soil surface of Spodosols (Dahlgren and Ugolini, 1989).

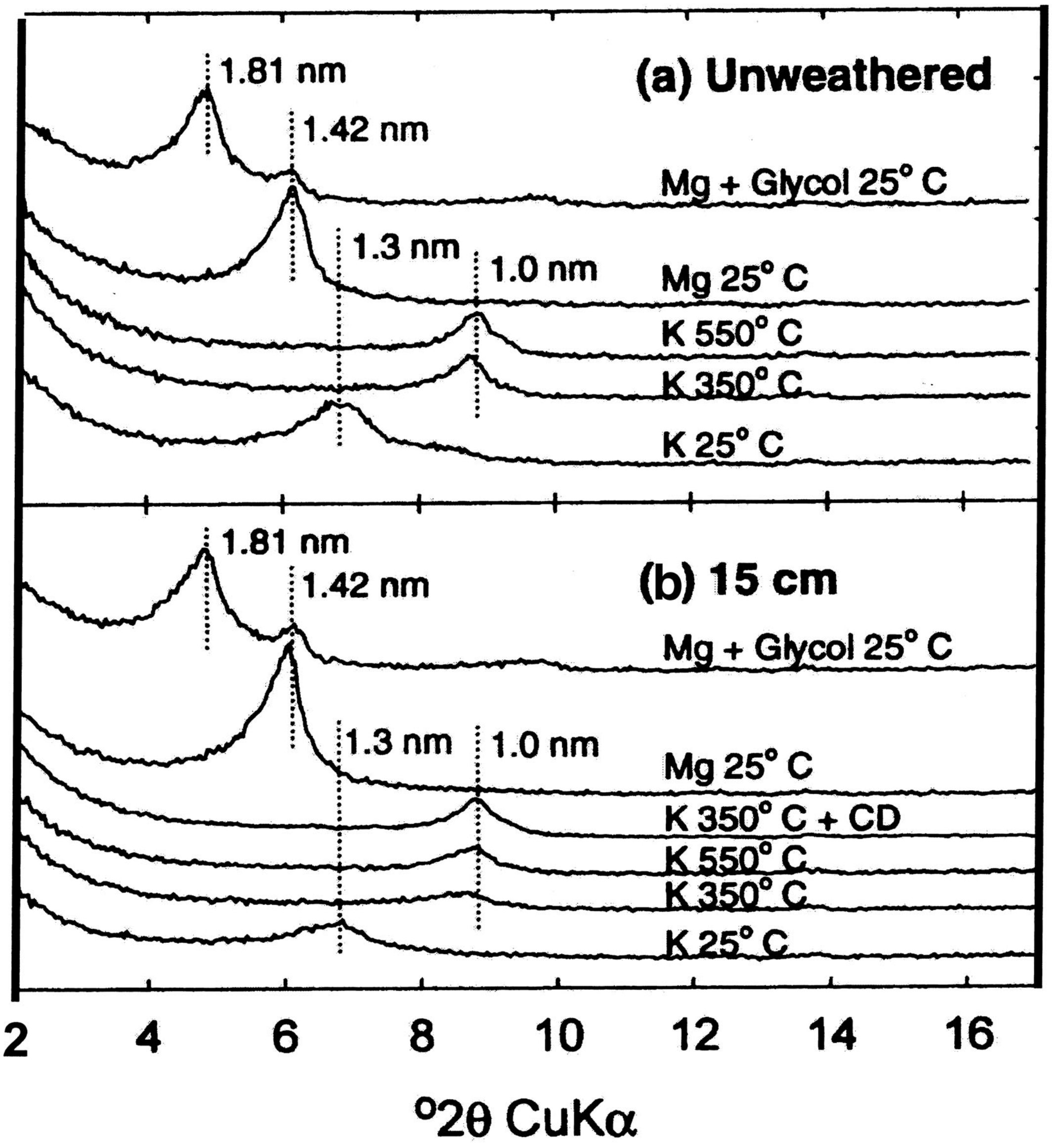


Figure 4. X–ray diffractograms for the clay–size fraction of (a) unweathered and (b) weathered (10 yr) airfall tephra added to the surface of a Spodosol in a subalpine forest ecosystem. Treatment designations refer to temperature pretreatment, K and Mg saturation, glycol solvation, and pretreatment of clays with citrate–dithionite (CD).

Table 1. Selected solid-phase characterization for unweathered tephra and tephra weathered for 10 yr in a subalpine forest ecosystem.

	Unweathered tephra	Weathered tephra
pH(H_2O)	6.3*	5.2*
Pyrophosphate extractable Al (g kg^{-1})	0.1*	0.3*
Oxalate extractable Al (g kg^{-1})	0.2*	0.5*
Oxalate extractable Fe (g kg^{-1})	2.0*	2.8*
Oxalate extractable Si (g kg^{-1})	0.1	0.1
Phosphate retention (%)	1*	7*

*Means are significantly different at ($P<0.05$)

The primary proton donor in the tephra layer was carbonic acid with a minor contribution from organic acids originating from leaching of the tree canopy and the incipient litter layer accumulating at the surface of the tephra layer (Dahlgren et al., 1999). Solution leached from the tephra layer indicated incongruent dissolution resulting in formation of a cation-depleted, silica-rich leached layer on the glass and mineral surfaces. Due to the near neutral pH values and low concentrations of complexing organic ligands, Al and Fe were relatively insoluble and accumulated in the tephra layer. Field weathering rates during the first four years ranged between 10^{-18} and 10^{-17} mol cm^{-2} s^{-1} for sodium, calcium and silicon (Dahlgren et al., 1999). While these rates are 1-3 orders of magnitude less than those determined for glass and plagioclase minerals in laboratory dissolution experiments, they are remarkably high given that soil temperatures were near 0^{o} C for nearly six months of the year when a snowpack persists (cryic soil temperature regime).

The majority of the carbonic acid (CO_2) promoting weathering reactions in the tephra layer originates from upward transport of CO_2 from the organic-rich soil horizons of the buried soil. Elevated concentrations of CO_2 beneath the tephra layer originate from biological respiration (roots and microbes) and from protonation of HCO_3^- leaching from the overlying tephra layer. Cations released by weathering in the tephra layer (pH=6-7) leach downward with bicarbonate to the acidic organic horizons (pH=4) where H_2CO_3 reequilibrates with the high pCO_2. At pH 4, H_2CO_3 decomposes to CO_2 and H_2O and the gaseous CO_2 diffuses upwards to take part in another cycle of weathering and transport. This example of weathering in surface deposits of airfall tephra demonstrates a unique weathering pathway in which the buried organic-rich soil pumps protons upward to the tephra layer that acts as an alkaline trap for CO_2. Thus, the overall process of tephra weathering appears to be controlled by solute/gas transport of the carbonate system (CO_2- H_2CO_3-HCO_3^-).

Solid-phase samples were collected from the added tephra layer after 10 yr in the weathering environment. By this time, a litter layer (Oi) ranging from 2 to 3 cm had accumulated on the surface of the tephra. Tephra pH decreased from 6.3 to 5.2 after 10 yr (Table 1). There were small increases in Al_p, Al_{ox} and Fe_{ox}. There was no detectable change in Si_{ox} concentrations. Phosphate retention increased from 1 to 7% and was probably related to the increase in active Al and Fe (Al_{ox} + Fe_{ox}).

There was no apparent degradation of the inherited 2 : 1 layer silicates in the tephra layer following 10 yr of weathering in the subalpine forest ecosystem. The mineralogy was dominated by smectite as indicated by the shift of the 1.4 nm peak to about 1.8 nm following glycol treatment of the Mg-saturated sample (Fig. 4). The small 1.4 nm peak that remains following glycol treatment collapses upon K saturation indicating the presence of vermiculite. The K-saturated clays in the unweathered tephra collapsed to a relatively sharp and symmetrical peak centered around 1.0 nm on heating to 350^{o} C. Further heating to 550^{o} C resulted in no apparent change compared with the 350^{o} C heat treatment. In contrast, clays that experienced 10 yr of weathering collapsed to a diminished peak near 1.0 nm that displays a broad shoulder toward high d-spacings after heating to 350^{o} C. With further heating to 550^{o} C, the peak became sharper and more symmetrical, similar to the clays in the unweathered tephra. Samples pretreated with citrate-dithionite to remove (or partially remove) hydroxy-Al interlayers (Barnhisel and Bertsch, 1989) collapsed to a sharp, symmetrical peak at 1.0 nm upon heating to 350^{o} C, similar to the clays from the unweathered tephra. This response is consistent with the presence of hydroxy-Al polymers in the 2 : 1 layer silicate clays.

Aluminum released by weathering in the tephra layer is preferentially retained as Al-humus complexes (Al_p) and hydroxy-Al interlayers in 2 : 1 layer silicates inhibiting the formation of allophane and imogolite (anti-allophanic effect). The lack of an increase in Si_{ox} concentrations and no detectable allophane or imogolite by transmission electron microcopy suggest that no appreciable formation of allophanic materials has occurred in the first 10 yr of weathering in this subalpine forest ecosystem.

Transformation of the inherited 2 : 1 layer silicates was shown to be a function of the weathering environment. In the pyroclastic flows surrounding Mt. St. Helens, strong acid deposition resulting from SO_2 emission from the volcanic vent results in rapid soil acidification that destroys 2 : 1 layer silicate minerals. The weathering scenario indicated by mineralogical transformations with depth suggests the following weathering pathway with increasing acidification and weathering intensity : 2 : 1 layer silicate → kaolin → noncrystalline materials (possibly allophanic materials and hydroxy-Al polymers). In contrast, the carbonic acid weathering regime dominating in the tephra layers applied to Spodosols created a less intensive weathering regime in which the Al released by weathering was incorporated into hydroxy-Al interlayers of 2 : 1 layer silicates and Al-humus complexes. As an organic layer accumulates on the surface of the tephra layer, we expect that the carbonic acid weathering regime will be replaced with an organic acid weathering regime that promotes leaching of Al from the tephra layer.

Acknowledgements : I am grateful for the mineralogical investigations conducted by Bill Nuhn and John LaManna on the Mt. St. Helens pyroclastic flow. I am indebted to F.C. Ugolini who was the research team leader for pedological studies on volcanic materials following the 1980 eruptions of Mt. St. Helens. I also thank R.S. Sletten, D. Marrett and M.G. Stoner for their valuable assistance in the field and lab.

References

Ames, L.L. 1980. Preliminary mineralogical investigation of collected ash samples from the May 18, 1980 Mt. St. Helens eruption. Pacific Northwest Laboratory, Richland, WA.

Barnhisel, R.I., and P.M. Bertsch. 1989. Chlorites and hydroxy-interlayered vermiculite and smectite. *In* Minerals in Soil Environments, 2nd ed. (J.B. Dixon and S.B. Weed (Eds.) pp. 729-788. SSSA Book Ser. no. 1. SSSA, Madison, WI

Blakemore, L.C., P.L. Searle, and B.K. Daly. 1981. Soil Bureau laboratory methods : A. Methods for chemical analysis of soils. Sci. Rep. 10A. N.Z. Soil Bureau, Lower Hutt.

Casadevall, T., W. Rose, T. Gerlach, L.P. Greenland, J. Ewert, R. Wunderman, and R. Symonds. 1983. Gas emissions and the eruptions of Mount St. Helens through 1982. Science 221 : 1383-1385.

Dahlgren, R.A., and F.C. Ugolini. 1989. Effects of tephra addition on soil processes in Spodosols in the Cascade Range, Washington, U.S.A. Geoderma. 45 : 331-355.

Dahlgren, R.A., J.P. Dragoo, and F.C. Ugolini. 1997. Weathering of Mt. St. Helens tephra under a cryic-udic climatic regime. Soil Sci. Soc. Am. J. 61 : 1519-1525.

Dahlgren, R.A., F.C. Ugolini, and W.H. Casey. 1999. Field weathering rates of Mt. St. Helens tephra. Geochim. Cosmochim. Acta. 63 : 587-598.

Dymond, J., P.E. Biscaye, and R.W. Rex. 1974. Eolian origin of mica in Hawaiian soils. Geol. Soc. Am. Bull. 85 : 37-40.

Franklin, J.F., and C.T. Dyrness. 1988. Natural Vegetation of Oregon and Washington. p. 452. Oregon State University Press, Corvallis, OR.

Fruchter, J.S., D.E. Robertson, J.C. Evans, K.B. Olsen, E.A. Lepel, J.C. Laul, K.H. Abel, R.W. Sanders, P.O. Jackson, N.E. Wogman, R.W. Perkins, H.H. Van Tuyl, R.H. Beauchamp, J.W. Shade, J.L. Daniel, R.L. Erickson, G.A. Semel, R.N. Lee, A.V. Robinson, O.R. Moss, J.K. Briant, and W.C. Cannon. 1980. Mount St. Helens ash from the 1980 eruption : chemical, physical, mineralogical and biological properties. Science. 209 : 116-1125.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. *In* Methods of Soil Analysis. Part 1. 2nd ed. (A. Klute, Ed.). pp. 383-411. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Glassmann, J.R., and G.M. Simonson. 1985. Alteration of basalt in soils of western Oregon. Soil Sci. Soc. Am. J. 49 : 262-273.

Holmgren, G.G.S. 1967. A rapid citrate-dithionite extractable iron procedure. Soil Sci. Soc. Am. Proc. 31 : 210-211.

Inoue, K. 1981. Implications of eolian dusts to 14 minerals in the volcanic ash soils in Japan. Pedologist. 25 : 97-118.

Inoue, K., and T. Naruse. 1987. Physical, chemical and mineralogical characteristics of modern eolian dust in Japan and rate of dust deposition. Soil Sci. Plant Nutr. 33 : 327-345.

Jongmans, A.G., F. van Oort, A. Nieuwenhuyse, P. Buurman, A.M. Jaunet, and J.D.J. van Doesburg. 1994. Inheritance of 2 : 1 phyllosilicates in Costa Rican Andisols. Soil Sci. Soc. Am. J. 58 : 494-501.

Kondo, Y., T. Fujitani, Y. Katsui, and K. Niida. 1979. Nature of the 1977-1978 volcanic ash from Usu volcano, Hokkaido, Japan. Kazan. 24 : 223-238.

Korosec, M.A., J.G. Rigby, and K.L. Stoffel. 1980. The 1980 eruption of Mt. St. Helens, Washington

−Part 1, March 20−May 19, 1980. Wash. Div. Geol. Earth Resources.

LaManna, J.M., and F.C. Ugolini. 1987. Trioctahedral vermiculite in the 1980 pyroclastic flow, Mt. St. Helens, Washington. Soil Sci. 143 : 162−167.

McKeague, J.A. 1967. An evaluation of 0.1 M pyrophosphate and pyrophosphate−dithionite in comparison with oxalate as extractants of accumulation products in podzols and some other soils. Can. J. Soil Sci. 47 : 95−99.

McKeague, J.A. (ed.). 1976. Manual on soil sampling and methods of analysis. Soil Res. Inst., Agriculture Canada, Ottawa.

Mizota, C., and K. Inoue. 1988. Eolian dust contribution to soil development on volcanic ashes in Japan. In Proceedings 9th Int. Soil Classification Workshop Japan (D.I. Kinloch, S. Shoji, F.M. Beinroth, and H. Eswaran, Eds.), pp. 547−557. Japanese Committee for 9th International Soil Classification Workshop and Soil Management Support Services, Washington, DC.

Mizota, C., and Y. Matsuhisa. 1995. Isotopic evidence for the eolian origin of quartz and mica in soils developed on volcanic materials in the Canary Archipelago. Geoderma. 66 : 313−320.

National Oceanic and Atmospheric Administration. 1985−1986. Local climotological data – monthly summary, Stampede Pass, Washington. National Climatic Data Center, Asheville, NC.

Nuhn, W.W. 1987. Soil Genesis on the 1980 Pyroclastic Flow of Mount St. Helens. p. 179. M.S. thesis, College of Forest Resources, University of Washington, Seattle, WA.

Pevear, D.R., D.P. Dethier, and D. Frank. 1982. Clay minerals in the 1980 deposits from Mount St. Helens. Clays Clay Miner. 30 : 241−252.

Quantin, P. 1992. Les Soils de l' Archipel Volcanique des Nouvelles−Hebrides (Vanuatu). p. 498. ORSTOM, Paris.

Rowley, P.D., M.A. Kuntz, and N.S. Macleod. 1981. Pyroclastic−flow deposits. In The 1980 Eruptions of Mount St. Helens, Washington (P.W. Lipman and D.R. Mullineaux, Eds.), pp. 489−512. USGS Prof. Pap. 1250. US. Government Printing Office, Washington, DC.

Shoji, S. M. Nanzyo, and R.A. Dahlgren. 1993. Volcanic Ash Soils – Genesis, Properties and Utilization. p. 288. Elsevier, Amsterdam, the Netherlands.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Surv. Invest. Rep. No. 1. USDA−SCS Agric. Handb. 436. U.S. Gov. Print. Office, Washington, DC.

Ugolini, R.C., R. Dahlgren, J. LaManna, W. Nuhn, and J. Zachara. 1991. Mineralogy and weathering processes in Recent and Holocene tephra deposits of the Pacific Northwest, USA. Geoderma. 51 : 277−299.

Whittig, L.D., and W.R. Allardice. 1986. X−ray diffraction techniques. In Methods of Soil Analysis. Part 1. 2nd ed. (A. Klute, Ed.). pp. 331−362. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

JIFS, 2 : 13 − 18 (2005)

Morphological and Selected Chemical Characteristics of Tephra-derived Soils in Changbai Volcano Area, Northeast China

Hitoshi KANNO [1], Tsuyoshi MIYAMOTO [2], and Masami NANZYO [1]

[1] Graduate School of Agricultural Science, Tohoku University, Japan
[2] Center for Northeast Asian Studies, Tohoku University, Japan

Abstract

The morphological and selected chemical properties of 18 pedons developed in Changbai volcano area, Northeast China were investigated. The parent material of these soils consists of thick and coarse tephra deposits from plinian falls, pyroclastic flows and lahar (mudflow) mainly from the 10th century eruption. Although some buried horizons underlying the thick tephra deposit of the 10th century eruption showed clayey soil texture, these soils are characterized by sandy soil texture, A/C type of soil horizon sequence and low acid oxalate−extractable Al+Fe content. Based on the world reference base for soil resources (WRB : FAO, ISRIC and ISSS, 1998), many horizons met some criteria of vitric horizon, while considerable horizons were tephric soil materials. These suggest that the tephra−derived soils in this area is on a young stage of soil development. The cooler climate condition played a major role in the slow soil development. Furthermore, the parent material consisting of the coarse textured tephras provided by the sequential plinian falls and pyroclastic flows, not fine textured volcanic ash, would affect the slow rate of tephra weathering. The soil genesis of the Changbai volcano area is dependent on the properties of the parent material and different climate conditions with elevation.

Introduction

Changbaishan (Baitoushan), locating on the border between China and North Korea, is one of the famous volcanos in China. Changbaishan, the highest peak at 2,691 m above sea level, consists of accumulated pyroclastic materials. The 10th century eruption of Changbai volcano was one of the largest volcanisms in the last 2000 years (Machida et al., 1990; Miyamoto et al., 2002; Wei et al., 2003; Miyamoto et al., 2004). The ejecta (B−Tm : Baitoushan−Tomakomai ash) is found also in northeast Japan, more than 1,000 km from the source (Machida and Arai, 1992). There are a number of studies on volcanic ash soils in Changbaishan (Zhao, 1988; Xie, 1990; Zhao et al., 1993; Zhao et al., 1997; Zhao et al. 2000). Zhao et al. (1993) reported morphological, chemical and humus properties of 5 pedons developed on volcanic ash under cool temperature conditions in Changbaishan. Although they showed that these pedons were characterized by soil horizon sequences of A/Bw/C or A/C and by bright colors in A horizons, their study area was limited to a part of its mountain area consisting of relatively high elevation (1,030 to 2,300 m above sea level) and the contribution of the 10th century volcanism to the parent material of these soils was not considered so much. The purpose of this study is to describe overview of the morphological and selected chemical characteristics of tephra−derived soils in Changbai volcano and to examine the effects of the eruptive sequence of the 10th century Changbaishan eruption on soil formation in this area.

Materials and Methods

The study area is mainly located on the northeastern slopes of Changbaishan in the eastern part of Jilin province. Soil samples were collected from 18 pedons developed on tephra deposits (Fig. 1). Sampling locations of the pedons were selected covering the extensive Changbai volcano area. Elevation range of the pedons are from 430 to 1,500 m and geographical distribution of them are widely spread, which shows lower height and farther distance from the vent of Changbaishan (summit caldera called "Tianchi" lake). The climate in the area strongly depends on elevation. The mean annual temperature at the elevations of 300 to 600 m, 600 to 1,100 m, 1,100 to 1,700 m, 1,700 to 2,000 m and 2,624 m asl are 2.2 to 4.8, −0.3, −2.9, −4.4 and −7.3 ° C, respectively (Mao, 1989). The mean annual precipitation is about 518 to 857 mm at 300 to 600

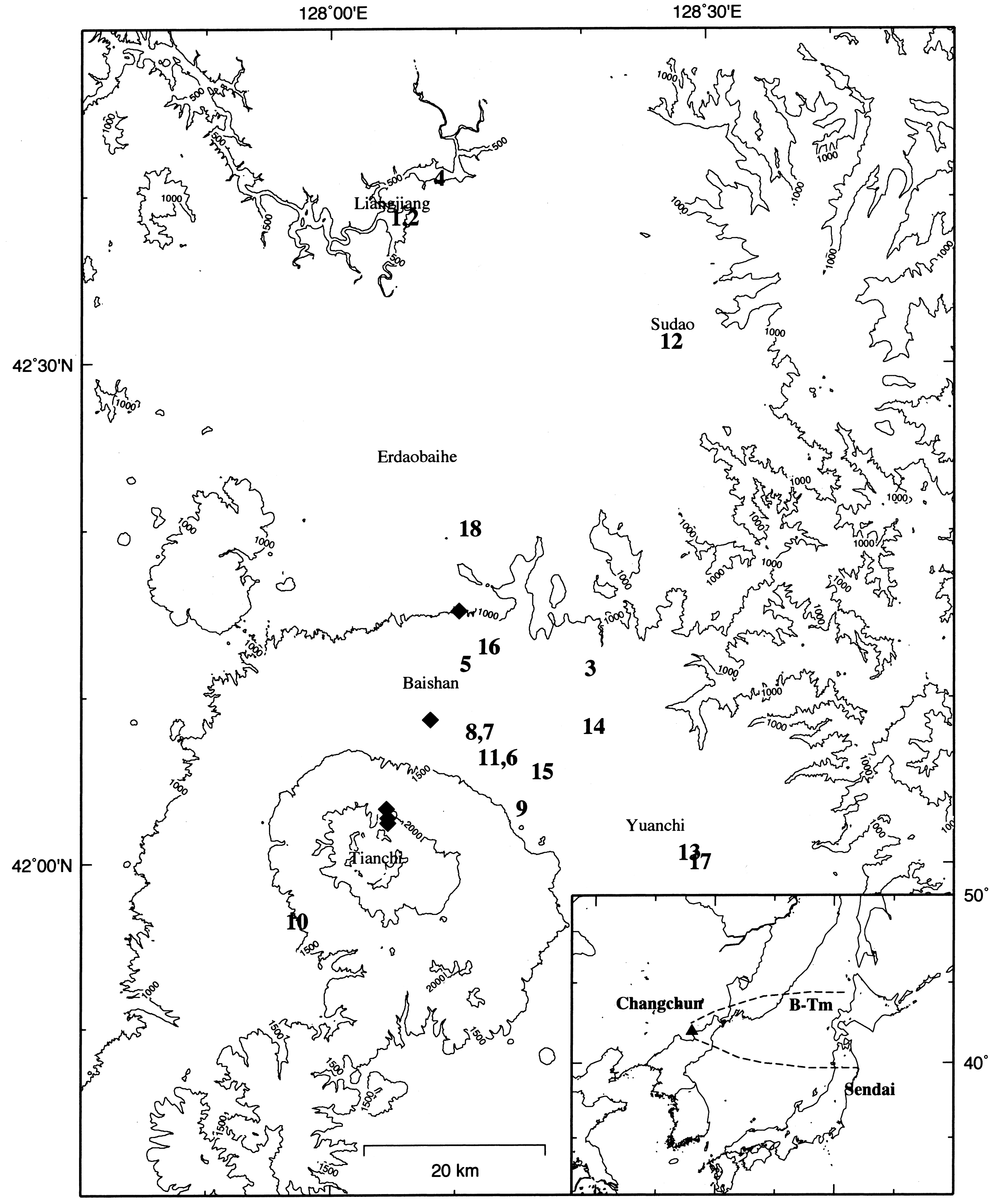


Fig. 1 Geographical locations of the areas surveyed in Changbaishan, northeast China. Number symbols of 1 to 18: location of pedons. ◆: location of pedons described by Zhao et al. (1993). B-Tm: distribution area of Baitoushan-Tomakomai tephra deposited after the eruption of the Changbaishan volcano in 10th century (Machida and Arai, 1992).

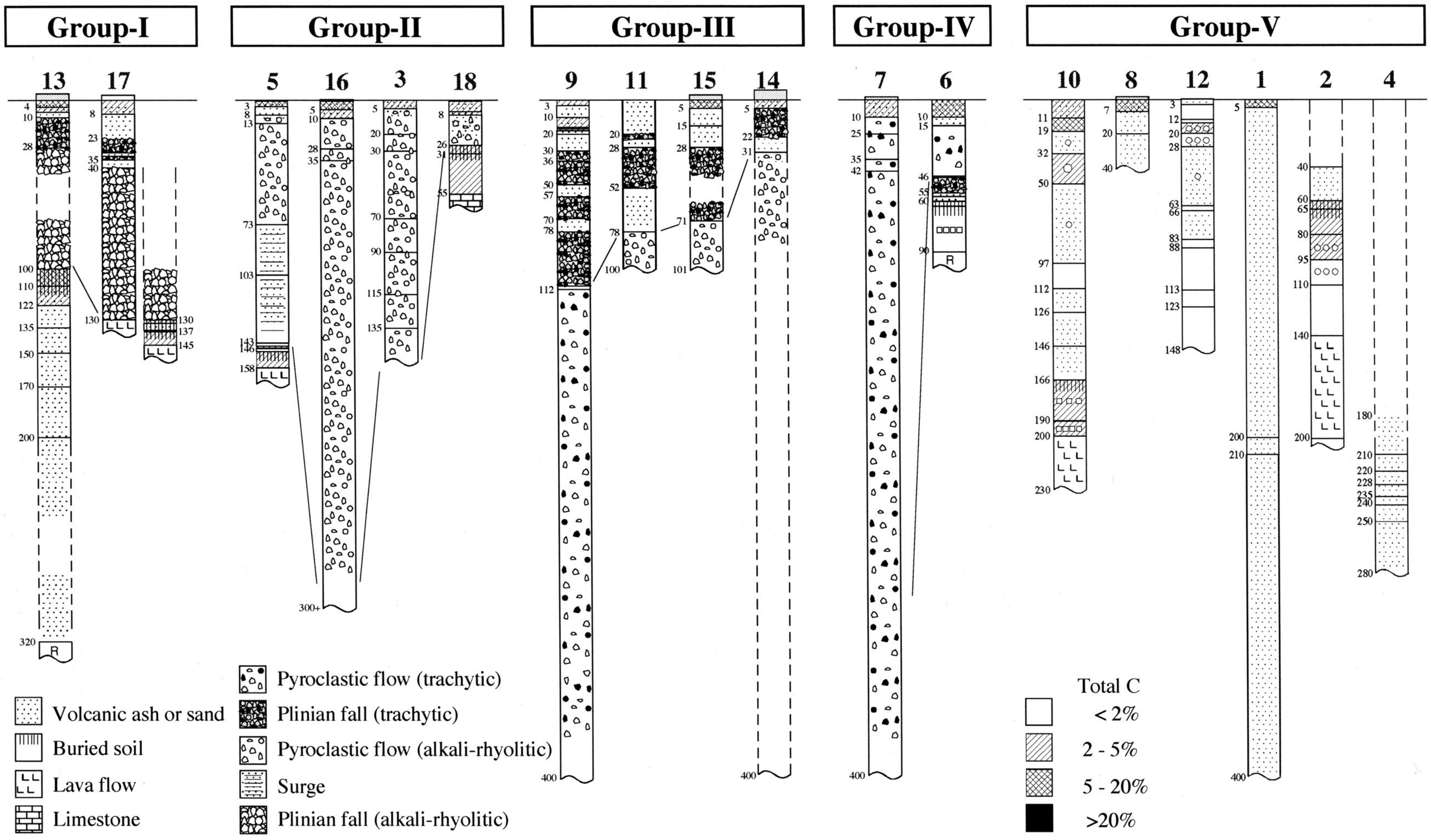


Fig. 2. Profile sections of the tephra−derived soils in Changbai volcano area. The numbers on and beside the sections indicate the sampling sites as described in Fig. 1 and the depth (cm) from the surface, respectively. Group−Ⅰ : soils from trachytic plinian fall over alkali−rhyolitic plinian fall. Group−Ⅱ : soils from alkali−rhyolitic pyroclastic flow. Group−Ⅲ : soils from trachytic plinian fall. Group−Ⅳ : soils from trachytic pyroclastic flow. Group−Ⅴ : soils from lahar deposit.

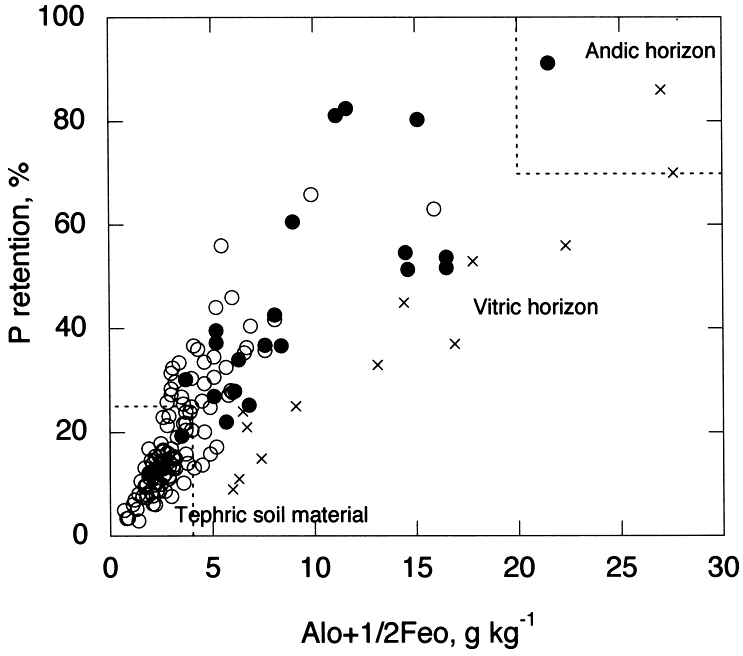


Fig. 3 Relationship between P retention and the amount of acid oxalate-extractable Al plus 1/2 Fe in the Changbaishan soils. Open circles: surface and subsurface horizon (n=111). Closed circles: buried horizon (n=24). ×: data of Changbaisan by Zhao et al. (1993) with the exception of the C horizon soil from the C-2 pedon (n=13). Dashed line show the criteria of andic horizon, vitric horizon and tephric soil material (FAO, ISRIC and ISSS, 1998).

m asl and increases with elevation to about 1,333 mm at 2,624 m asl with maximum values of 1,630 mm in the summit caldera. The vegetation is also related to the elevation. Pedons were sampled and described according to horizonsor layers, air-dried, and passed through a 2-mm sieve. Total carbon (C) was determined by dry combustion. Particle size distribution was measured by the sieving and pipette method. P retention and acid oxalate-extractable Al and Fe content was determined by the method described by Blakemore et al. (1981).

Results and Discussion

Fig. 2 shows the profile sections of the pedons. The Changbaishan soils consist of thick and coarse tephra deposit mainly from 10th century eruption. In some pedons, there were buried horizons covered by the tephra deposit. Sequential eruptions of the 10th century volcanism could be divided into two stages, whose magma composition changed from alkali-rhyolitic to trachytic (Machida et al., 1990; Miyamoto et al., 2002). According to the stratigraphy of the 10th century eruption proposed by Miyamoto el al. (2004), we distinguished five groups of tephra-derived soil by the major parent material as follows : soils from the trachytic plinian fall over the light-colored alkali-rhyolitic plinian fall (group I), the light-colored alkali-rhyolitic pyroclastic flow (group II), the trachytic plinian fall (group III), the dark-colored trachytic pyroclastic flow (group IV) and lahar (mudflow) deposit (group V).

The soils from the plinian fall deposit (Group I and III) were distributed in a specific direction of mountainous area along the main axis of a each eruption. The alkali-rhyolitic pyroclastic flow, called "unit C" by Miyamoto et al. (2004), was provided far and wide at the early stage of 10th century volcanism and covered by the later ejecta. Therefore, the group-II soils were found at a distant foot-slope of Changbaishan. Group-IV soils were found at the restricted area since the trachytic pyroclastic flow, called "unit F", flowed along valleys selectively. The soils from lahar deposit was observed in the both far and near areas of Changbaishan. Around Liangjiang town along the Erdaobaihe river, 70 km north from the summit caldera, we found the soils developed from thick and coarse lahar deposit.

The mountainous soils were characterized by soil horizon sequences of A/C with sandy soil texture reflecting the properties of the parent material (data not shown). These suggest that the tephra−derived soils in this area is at a young stage of soil development (Zhao et al., 1993; Shoji et al., 1993). The soils in a distant area derived from the lahar deposits also showed weak soil development. Some buried horizons underlying the thick tephra deposit of 10th century eruption showed clayey soil texture. Fig. 3 shows the relationship between P retention and the amount of acid oxalate−extractable Al+1/2Fe (Alo+1/2Feo) of the Changbaishan soils including the data of Zhao et al. (1993). The values of Alo+1/2Feo in surface and subsurface horizons tended to be lower than those of buried horizons.

Alo+1/2Feo and P retention of almost all horizons or layers were less than 2% and 70%, respectively (Fig. 3). Based on the world reference base for soil resources (WRB : FAO, ISRIC and ISSS, 1998), many horizons met some criteria of vitric horizon (Alo+1/2Feo > 0.4% or P retention > 25%), while considerable horizons fell within the range of tephric soil material (Alo+1/2Feo < 0.4%). Clay contents of most soil horizons or layers were less than 10%. These features also indicate that the soils in the Changbai volcano area still remain at the young stage of soil development. The relationship between age of volcanic ash soils and their soil development in northeastern Japan indicates that the volcanic ash soils older than 1000 years have a horizon with more than 2.0% and 85% of Alo+1/2Feo and P retention, respectively, as well as humic surface and Bw horizon (Shoji et al., 1993). However, the Changbaishan soils, whose soil age would be more than 1000 years old, show the earliest stage of pedogenesis. The cooler climate condition of this area might be a major factor of the slow soil development. Furthermore, the parent material consisting of the coarse textured tephras provided by the sequential plinian falls and pyroclastic flows, not fine textured volcanic ash, would affect the slow rate of tephra weathering. Further studies to examine the effect of the parent material and local climate on the soil genesis of tephra−derived soils in Changbai volcano area are required.

Acknowledgments : We thank Professors Hiromitsu Taniguchi and Masaru Narisawa (Tohoku University) for their kind encouragement of this study, and Professor Xu Jin (Jilin University, China) and Professor Zheng Yongzhen (Yanbian University, China) for their support of field survey in China. The present work was supported in part by the Grant−in−Aid for Scientific Research (No. 11691003 and No. 13573012) from the Japan Society for the Promotion of Science (JSPS).

References

Blakemore, L. C., P. L. Searle and B. K. Daly. 1981. Methods for chemical analysis of soils. New Zealand Soil Bureau Scientific Report. 10A.

FAO, ISRIC and ISSS. 1998. World reference base for soil resources. World Soil Resources Reports. 84. FAO, Roma.

Machida, H. and F. Arai. 1992. Atras of Tephra in and around Japan. 276 pp. University of Tokyo Press, Tokyo, Japan. (*in Japanese*)

Machida, H., H. Moriwaki and D.C. Zhao. 1990. The recent major eruption of Changbai volcano and its environmental effects. Geographycal Reports of Tokyo Metropolitan University. 25 : 1−20.

Mao, Z. (ed.) 1989. Changbaishan Zhi. 431 pp. Jilin Culture and History Publication, Changchun, China. (*in Chinese*)

Miyamoto, T., M. Nakagawa, T. Nagase, H. Kanno, T. Ohba, S. Kitamura and H. Taniguchi. 2002. Reexamination of explosive eruption history of Baitoushan (Changbaishan) volcano. Northeast Asian Studies. 7 : 93−110, The Center for Northeast Asian Studies, Tohoku Univ., Sendai, Japan. (*in Japanese*)

Miyamoto, T., M. Nakagawa, Y. Tanaka and M. Yoshida. 2004. Eruptive sequence of the 10th century Baitoushan eruption. 10th Century Great Eruption of Baitoushan Volcano, Northeast China, and its Historic Effect (CNEAS Monograph Series) 16 : 15−43, The Center for Northeast Asian Studies, Tohoku Univ., Sendai, Japan. (*in Japanese*)

Shoji, S., M. Nanzyo. R. A. Dahlgren. 1993. Volcanic ash soils −genesis, properties and utilization−. Elsevier Science Publishers, Amsterdam.

Wei, H., R. S. J. Sparks, R. Liu, Q. Fan, Y. Wang, H.

Hong, H. Zhang, H. Chen, C. Jiang, J.Dong, Y. Zheng and Y. Pan. 2003. Three active volcanoes in China and their hazards. J. Asian Earth Sci. 21 : 515–526.

Xie, P. 1990. Mineralogy of volcanic ash soils on nothern slope of Changbai mountain. In Trans. 14th Int. Cong. Soil Sci., Kyoto, Vol. VII, p. 165–170.

Zhao, Q. 1987. Volcanic ash soils in China. In Proc. 9th Int. Soil Classification Workshop, Japan, 1987, p. 446–455, Japanese Committee for the 9th International Soil Classification Workshop, for the Soil Management Support Services, Wasington, D.C.

Zhao, L., K. Fujii and K. Inoue. 2000. Characteristics of volcanic ash soil clay–humus complexes in Changbaishan and Wudalianchi, northeast China. J. Clay Sci. Soc. Jpn. 39 : 157–170. (*in Japanese*)

Zhao, L., M. Satoh and K. Inoue. 1997. Clay mineralogy and pedogenesis of volcanic ash soils influenced by tropospheric eolian dust in Changbaishan, Sanjiaolongwan, and Wudalianchi, northeast China. Soil Sci. Plant Nutr. 43 : 85–98.

Zhao, L., X. Yang and K. Inoue. 1993. Morphological, chemical, and humus characteristics of volcanic ash soils in Changbaishan and Wudalianchi, northeast China. Soil Sci. Plant Nutr. 39 : 339–350.

JIFS, 2 : 19 − 27 (2005)　　Special review

Partial Rejuvenation of the Soil in Intavas Techno Demo Farm, Bukidnon, Mindanao, Philippines by Volcanic Ash Material

C. D. BACATIO[1], H. KUBOTERA[2], M. NANZYO[3] and I. YAMADA[4]

[1] Bureau of Soils and Water Mgt. (BSWM) Dept. of Agriculture, The Philippines
[2] National Agricultural Research Center for Kyushu Okinawa Region, Japan
[3] Tohoku University, Japan and [4] JICA Team, BSWM, Japan

Keywords : Philippine soils, Oxic Dystrudepts, tephra, volcanic glass, halloysite, gibbsite, dark and high humus surface

Abstract

Intavas Techno Demo Farm is situated in high elevation of 1,220 meters above sea level, with cool temperature and without pronounced dry season. The soil has low pH (5.24, average) and medium total carbon (4.3%) in the surface. Phosphorus retention is relatively high (77.5 %, ave.), low cation exchange capacity (12 cmol(+) kg^{-1} ave.) and low base saturation (13 %, ave.). Clay content is 45% (ave.) and bulk density of 1.1 Mg m^{-3} in average.

Micrograph of the thin section of Bw$_1$ horizon reveals that void content is very small (6%). Voids are vughy and are not interconnected. In crossed nicol there were no clay illuviation seen.

Total element analysis revealed that Intavas soils have about 60 % Al_2O_3 but very low in SiO_2, 16.05 % only. This indicates an advanced weathering that Si has been leached out and Al precipitated.

As to the primary minerals, opaque minerals predominate with the presence of hornblende in heavy minerals. For light minerals, weathered particles predominate with the presence of mica, quartz and volcanic glass.

Selective dissolution analysis reveals that Al_o is relatively high as compared to Fe_o and Si_o. However, these elements have the same pattern that irregularly decrease with depth and increase in the buried A horizon. Fe_p is relatively high followed by Al_p that significantly decreases with depth. The data show that amorphous materials are higher in surface and buried A horizons.

Electron micrograph of BA shows no defined form that can be considered as amorphous materials. Bw$_2$ shows angular shapes that correspond to gibbsites and halloysite as indicated by spheroid configurations.

X−ray diffraction pattern exhibits small and weak peak at 7 Å in BA horizon. This peak corresponds to the presence of halloysite. The sharp and strong peaks at 4.8 Å and 4.3 Å in BA and Bw$_2$ horizons correspond to gibbsite.

According to the selective dissolution analysis, electron microscopy and X−ray diffraction analysis, the dominant clay mineral in BA horizon is gibbsite and followed by amorphous material and small amount of halloysite. On the other hand, gibbsite dominate Bw$_2$ horizon followed by halloysite.

Based on the physical, chemical, mineralogical and thin section analyses, the TDF soil can be classified as fine clayey, acid, isothermic, gibbsittic, Oxic Dystrudepts. It can be considered as soil with partial rejuvenation by volcanic ash material. As compared with soils without rejuvenation, this soil has higher total carbon, phosphorus retention, lower bulk density relatively, high amorphous materials in the surface and halloysite in the subsoils.

Introduction

In agricultural lands, considerable areas have been converted to non−agriculture prompting agriculture to shift to sloping to steep marginal areas. To cope up with the increasing population but diminishing land resources for food security, these marginal lands must be surveyed and evaluated. There is a need to understand the characteristics, genesis and classification of these soils in order to obtain basic information for soil utilization and management. Corollary to this, the Bureau of Soils and Water Management (BSWM) of the Department of Agriculture implemented the Environmental and Productivity Management of Marginal Soils in the Philippines (EPMMA) through Technology

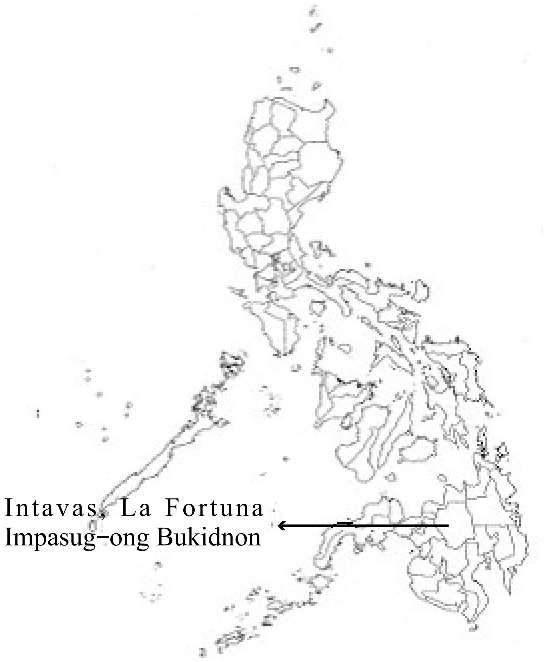
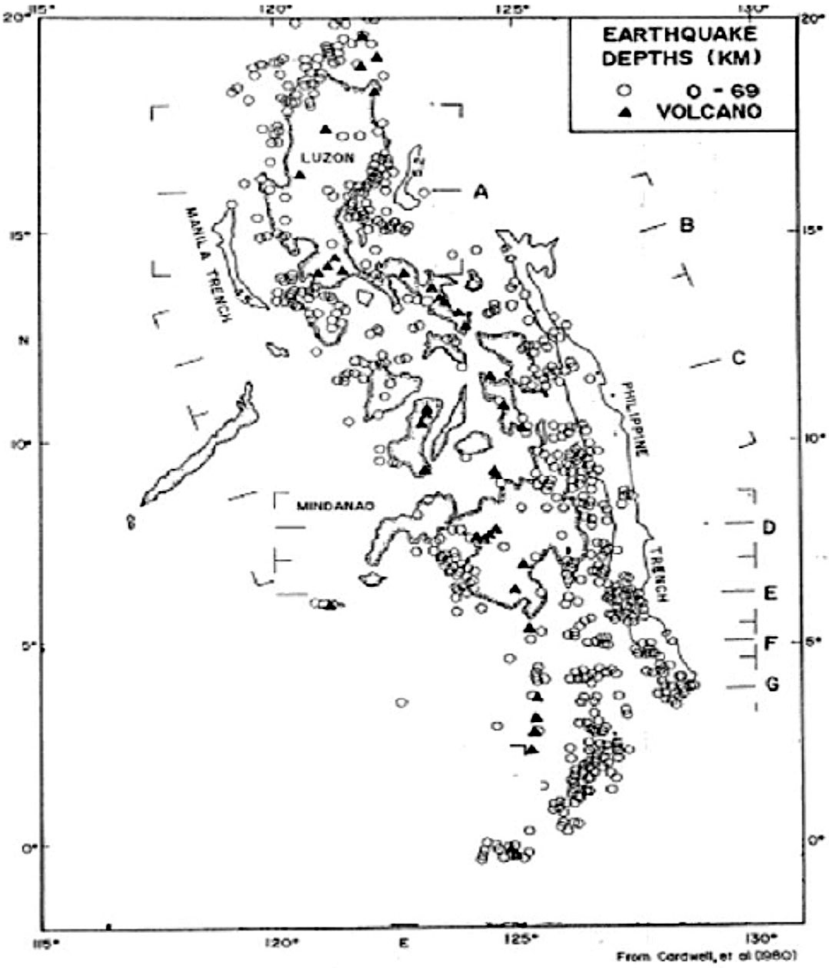

Intavas, La Fortuna
Impasug-ong Bukidnon

Fig. 1. IntavasTechno Demo Site



From Cardwell, et al (1980)

Fig. 2. Distribution of Volcanoes in the Philippines

Demonstration Farms (TDFs). This is a cooperation project between the governments of Japan and the Philippines under the auspices of Japan International Cooperation Agency (JICA) starting February 2000 to January 2005.

The EPMMA TDF sites were selected to represent the pedo-ecological zones where marginal soils are most likely to occur, namely : upland represented by Bulusukan TDF in San Ildefonso, Bulacan, hillyland by Agoho TDF in Sampalok, Tanay, Rizal and highland by Intavas TDF in La Fortuna, Impasug-ong, Bukidnon.

The Intavas TDF soil is characterized by dark and relatively deep surface like volcanic ash soil, but this is classified as Typic Hapludults by profile observation. In this study, the mineralogical, physical and chemical properties of Intavas TDF soil were investigated for an environmentally sound management in the highlands (Fig. 1).

The Philippine Archipelago belongs to the Circum-Pacific Volcanic Zone, otherwise known as "ring of fire". There are about 35 known volcanoes, nine of which are active (Fig. 2). Mariano (1964) and Otsuka (1988) reported that Andepts are present around Mt. Banahaw and the Taal volcano, Mts. Isarog and Mayon in Southern Luzon, some parts of Negros Island in the Visayan Region and in Cotabato plain in Mindanao island. Though there were findings of the wide existence of volcanic soils, only few studies on the physico-chemical and mineralogical properties, genesis and classification had been conducted in Mindanao Islands. Therefore, only a limited data are available.

Materials and Methods

Site characterization

Intavas Techno Demo Farm represents the pedo-ecological zone in the highland in Barangay La Fortuna, Municipality of Impasug-ong, Province of Bukidnon, Mindanao Island (Figure 1) with an elevation of 1,220 meters above sea level. The TDF falls under Type IV climate characterized by evenly distributed rain throughout the year with annual rainfall of 2,590 mm. Parent material is dominantly diorite and formerly vegetated with grasses and shrubs.

Morphological description

The pit profile and auger boring were described using the FAO Manual.

Methods of Analysis

Particle size distribution

Silt and clay were measured by pipette method. Fine (0.2-0.02 mm) and coarse sands (2-0.2mm, International method) were separated by wet sieving method.

Bulk density

100 ml core method was done.

Thin Sections

The core sample from Bw1 horizon of the TDF where the increase in clay was most likely to be found was collected. The sample was impregnated with polyster resin and benzoil peroxide in a vacuum container and heated in an oven until the consolidation was completed. Thin section cutting across the samples was prepared to see the occurrence of translocated or illuviated clay within the profiles in the form of coatings on ped faces or in pores.

pH (H_2O)

The supernatant suspension of a 1 : 2.5 soil liquid mixture of distilled water was immersed by electrode in the upper part of the suspension.

Total Carbon and Total N

N-C elemental analyzer measured total Carbon and Nitrogen of ground 10 to 15 mg samples.

Phosphorus retention

Phosphorus retention was done by Blakemore method.

Exchangeable cations (Ca, Mg. Na and K) and Cation Exchange Capacity (CEC)

Exchangeable cations, base saturation and cation exchange capacity were determined semi-micro Schollenberger method (Kamewada, 1997). Ca and Mg were done by ICP while K and Na were determined by AAS.

Total Elements

Total elemental composition (SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MnO, CaO, MgO, K_2O, Na_2O and P_2O_5) was analyzed by X-ray Fluorescence.

Primary minerals

Light and heavy minerals of 0.1 to 0.2 mm fractions were separated by using heavy solution, TBE with a specific gravity of 2.97. The composition of these heavy and light primary minerals was determined by polarized microscope by counting about 200 particles.

Clay mineralogy

Selective dissolution

Extractable Silicon, Aluminum, and Iron elements were determined by Dithionite− citrate (Blakemore, et.al), Pyrophosphate and Acid oxalate Reagents and Inductively Coupled Plasma− Atomic Emission Spectroscopy (ICP−AES).

Electron Microscopy

Sodium clays of the samples from the BA and Bw2 horizons where decrease and increase of clay occur were analyzed through electron microscopy.

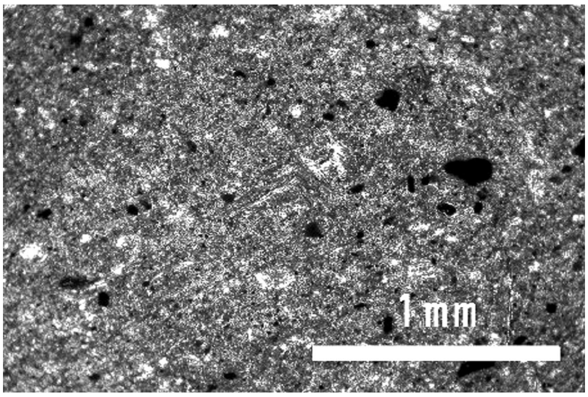
X−ray Diffraction

Clay minerals were determined using a Rigaku Geigerflex with a Cu−K a radiation of 40 and 35mA, with a scan speed of 2^0 min $^{-1}$

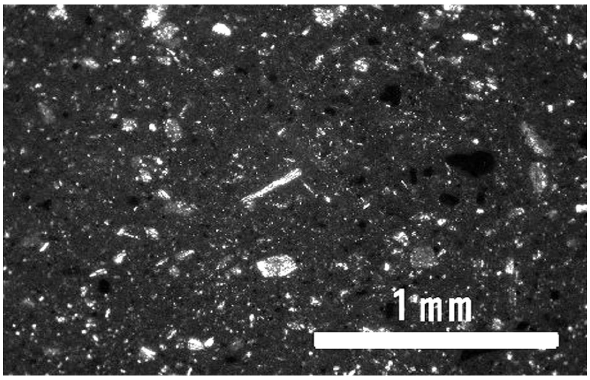
Results and Discussions

Morphological Characteristics of Intavas Profile

Table 1 shows the morphological characteristics of Intavas soil. The description indicates that the profile is very deep, dark surface that becomes lighter in the lower horizons but darker in the last horizon. Texture is fine loamy that is heavier in the fourth and fifth horizons and lighter in the last horizon with soil consistency that is slightly sticky and plastic. The structure is weak all throughout the profile suggesting good root penetration and good tilth. Only few to none moderately weathered gravel sized fragments are present in the first to fifth horizons. However, these gravels increase in the last horizon.



Open Nicol



Closed Nicol

Fig. 3 Micrographs of Thin Section of Bw1 horizon.

Table 1. Morphological Characteristics of Intavas TDF soil (Costelo, et al, 2000).

Horizon Symbol.	Depth (cm)	Description
Ap	0−16	Brownish black (10YR3/2) moist; clay loam; weak fine subangular Blocky and granular structure; slighty sticky, slightly plastic; common fine to very fine and few medium pores; no cutans; few fine slightly weathered gravels (5YR 3/6 in soil and 5YR 4/1 surface) abrupt smooth boundary; Yamaha hardness, 20 mm;
BA	16−37	Yellowish brown (10YR 5/8) moist; clay loam; weak fine subangular blocky structure; slightly sticky; slightly plastic; common fine to very fine pores; no cutans few fine roots; diffuse smooth boundary; Yamaha hardness, 24 mm.
Bw1	37−64	Yellowish brown (10YR 5/8) moist; clay loam, weak medium subangular blocky structure; slightly sticky, slightly plastic, no cutans, common fine to very fine pores; few moderately weathered diffused smooth gravels (2 cm); very few fine roots; boundary; Yamaha hardness 22 mm.
Bw2	64−98	Yellowish brown (10YR 5/6) moist; clay; moderately weak coarse subangular blocky structure; slightly sticky, slightly plastic; no mottles; no cutans; common fine to very fine pores; few moderately weathered gravels (5−6 cm); no roots; diffused smooth boundary; Yamaha hardness, 21 mm.
BC1	98−117	Yellowish brown (10YR 5/6) moist; clay; weak coarse sub angular blocky structure; slightly sticky, slightly plastic, no cutans; common fine to very fine pores; no gravels; no roots; diffused, smooth boundary; Yamaha hardness, 22 mm.
BC2	117−150	Yellowish brown (10YR 5/6) moist, clay loam; weak fine to medium sub angular blocky structure; slightly sticky, slightly plastic, many very fine and few fine pores; no roots; many moderately weathered gravels (9−1cm);Yamanaka hardness, 19mm

Table 2. Physical, Chemical and Extractable Si, Al and Fe and Total Elements

Soil Characteristics	Horizons					
	Ap	BA	Bw1	Bw2	BC1	BC2
1. Particle size distribution (mm)						
2.0 − 0.2	9.8	10.6	7.5	2.2	3.1	6.2
0.2 − 0.02	20.0	29.7	21.2	11.2	16.6	33.9
0.02 − 0.002	29.7	28.6	21.9	22.4	27.5	26.5
<0.002	40.5	31.1	49.4	64.3	52.8	33.4
2. Bulk Density (g/m^3)	0.85	1.18	1.12	1.06	1.18	1.06
3. pH (H_2O)	5.0	5.6	5.4	5.0	4.8	5.4
4. Total Carbon (%)	4.31	1.73	1.09	0.43	0.57	1.27
5. Total Nitrogen (%)	0.35	0.12	0.1	0.06	0.07	0.15
6. Phosphorus retention (%)	78	75	75	67	58	76
7. Exchangeable bases (cmol/kg)						
Ca	1.42	0.19	0.14	0.48	0.31	0.2
Mg	0.1	0.04	0.03	0.06	0.05	0.03
K	0.21	0.05	0.09	0.15	0.17	0.13
Na	0.1	0.04	0.01	0.04	0.04	0.03
8.Cation Exchange Capacity (cmol/kg)	17.3	9.2	7.4	10.2	11.1	9.5
9. Base saturation (%)	11	3	3	7	5	4
10. Extractable Al, Fe & Si (%)						
by Acid Oxalate						
Si	0.28	0.46	0.24	0.07	0.06	0.58
Al	0.98	1	0.52	0.22	0.21	1.02
Fe	0.88	0.7	0.42	0.34	0.41	0.51
by Pyrophosphate						
Si	0.08	0.07	0.03	0.02	0.02	0.04
Al	0.61	0.25	0.19	0.05	0.07	0.15
Fe	1.13	0.46	0.46	0.02	0.09	0.09
11. Total Element(%)						
SiO_2	21.92	11.55	11.43	17.04	17.89	16.2
Al_2O_3	56.35	62.65	62.92	58.01	57.26	58.2
Fe_2O_3	17.87	22.05	22.16	21.86	21.04	21.11
TiO_2	1.99	2.43	2.48	2.39	2.32	2.33
Others (MnO, CaO, MgO, K_2O, Na_2O and P_2O_5)	1.88	1.33	1.02	0.71	1.49	2.16
Sum	100.0	100.0	100.0	100.0	100.0	100.0

Physical and Chemical Characteristics

Table 2 shows that the soil profile described has fine loamy textures in the 1st and 2nd horizons, clayey in the 3rd to 5th horizon and back to fine loamy in the last horizon. Soil reaction ranges from strongly to slightly acidic. Bulk density is relatively low, ranging from 0.85 to 1.18 gm/m^3. Total carbon of the surface horizon is high (4.3%) that irregularly decreases with depth as it increases in the last horizon. Phosphorus retention is relatively high (78%) that irregularly decreases with depth as it increases in the last horizon. Exchangeable bases (Ca, Mg, K and Na) are deficient in all horizons. Cation exchange capacity ranging from 7.4 to 17.3 cmol kg^{-1} is low to very low and so with base saturation ranging from 3 to 11%.

Thin section

The micrographs of Bw1 horizon TDF in Figure 3 show that there is small void content of 6%. Microstructures are vughy and are not interconnected . No clay accumulation can be observed in closed nicol. The climatic condition in Intavas TDF, characterized by rain throughout the year retarded clay illuviation and ped development.

Extractable Si, Al and Fe

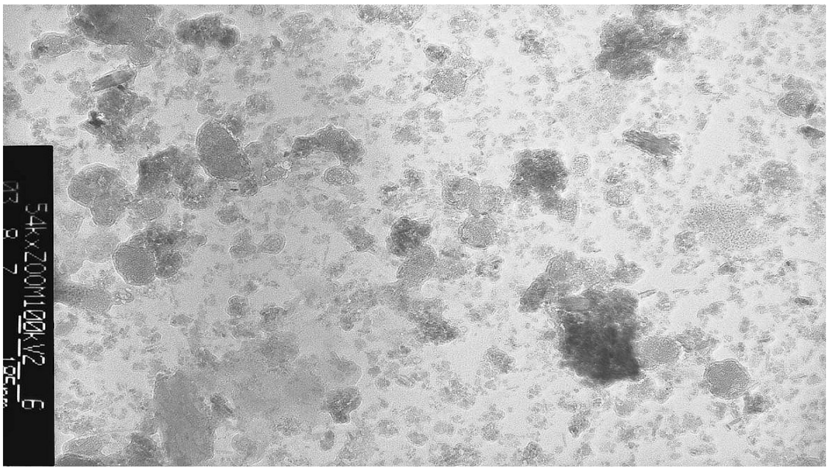
Table 2 shows that Al_o is relatively higher as compared to Fe_o and Si_o. However, these elements have the same pattern that irregularly decrease with depth and increase in the last horizon. Fe_p is relatively high followed by Al_p that irregularly decreases with depth as it also increases in the last

Table 3. Primary Mineral Composition

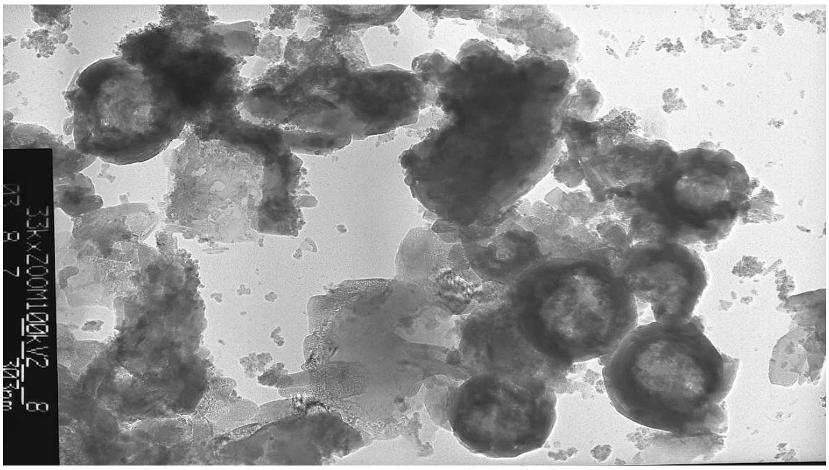
Soil Profile		Heavy minerals (particle %)[1]					Light minerals (particle %)[2]					HM[3]
		Opx	Cpx	Ho	Op	Wp	Fd	Qz	Mica	Vg	Wp	(wt%)
Intavas	Ap	–	1	64	33	1	2	17	3	3	76	16
	BA	–	–	33	66	1	–	1	3	1	95	13
	Bw_1	1	1	13	57	28	2	2	3	1	93	19
	Bw_2	–	–	4	95	2	1	9	3	1	85	30
	BC_1	–	1	13	86	1	–	1	6	2	91	34
	BC_2	–	1	37	60	2	–	6	17	1	76	20

Note :

[1] Opx : orthopyroxene, Cpx : Clinopyroxene, Ho : Hornblende, Op : Opaque mineral, Wp : weathered mineral
[2] Fd : Feldspar, Qz : Quatz, Mica : Mica, Vg : Volcanic glass, Wp : weathered particles
[3] HM : Heavy minerals

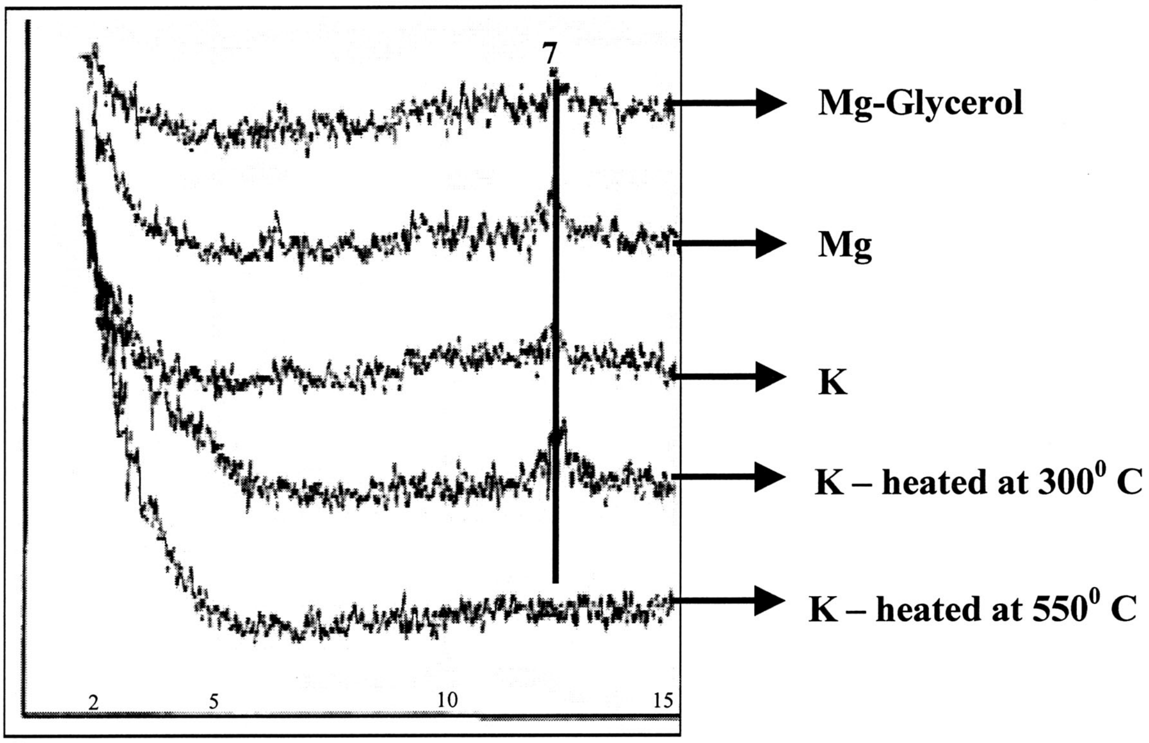


BA Horizon



Bw2 Horizon

Fig. 4 : Electron Micrographs



BA Horizon

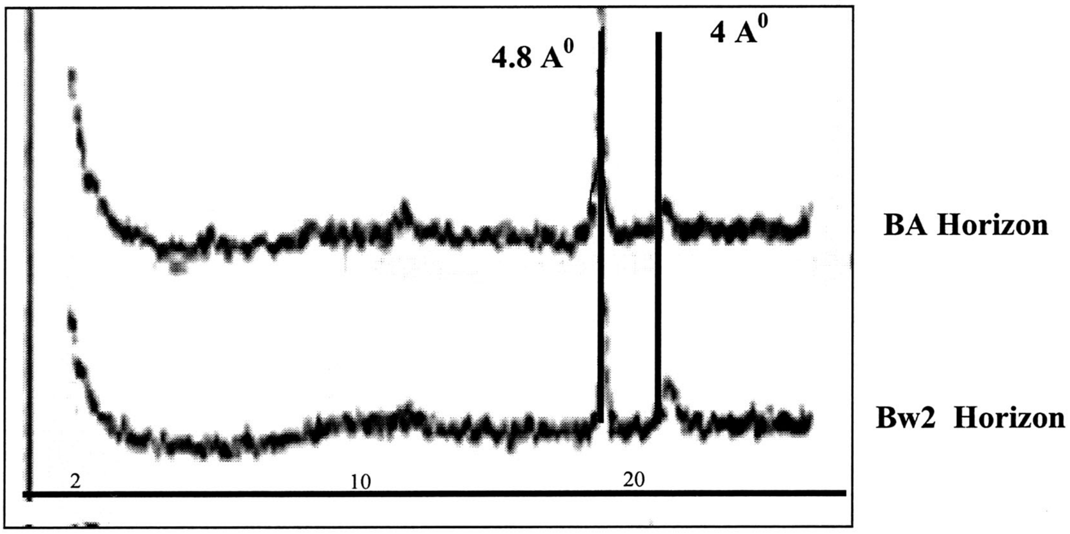


Fig. 5. X−ray Diffractograms

horizon. These data show that amorphous materials are higher in the surface and last horizon suggesting the presence of buried A horizon.

Total elements

As to the total elements (particularly Al_2O_3, and SiO_2), Al_2O_3 is higher (about 60% maximum) than SiO_2 (20% maximum) as shown in Table 2. This indicates that this soil is advanced in weathering that Si had been leached out while Al precipitated.

Primary Minerals

For the heavy minerals, the opaque particles predominate seconded by hornblende followed by pyroxene and weathered particles (Table 3). Weathered particles, small amounts of quartz, mica and volcanic glass composed the light minerals. The presence of small amount of volcanic glass in all horizons shows that Intavas TDF soils are affected by volcanic ash material.

Clay Mineralogy

Figure 4 shows the electron micrographs of BA and Bw_2. BA shows no defined form that can be considered X-ray amorphous while Bw_2 show angular shape that seems to be gibbsites and spheroid configurations indicating the presence of halloysites.

The X-ray diffractogram of BA (Fig. 5) shows small and weak peaks at 7 Å of kaolinite minerals when treated with Mg, Mg-glycerol, K, K-heated at 300 ^{0}C that totally collapsed when heated at 550^{0}C. However, a sharp peak of 4.8 Å can be observed when treated with Mg indicating the dominance of gibbsites both in BA and Bw_2.

Partial Rejuvenation by Volcanic Ash Material

The Intavas soil has unique characteristics like relatively high organic matter in the surface, dark color and relatively high phosphate retention, relatively low bulk density, relatively high amorphous clay in the surface and high halloysite in the subsoils similar to relatively young soils that are affected by volcanic ash. On the other hand, this soil has highly weathered characteristics like high aluminum and very low silica content in major elements and very high gibbsite in clay minerals. These contrasting characteristics are recognized by the partial rejuvenation of the volcanic material into the very old parent material.

Conclusions

Based on the morphological, physical, chemical, thin section and clay minerals, soil of Intavas TDF was classified as fine clayey, acid, isothermic, gibbsitic, Oxic Dystrudepts.

The Intavas TDF soil can be evaluated in terms of its physical and chemical properties. Physically, this soil is suited for root development, good aeration, good tilth and workability that can be attributed to low bulk density and good soil structure. The surface soil and the buried A horizon show the properties of volcanic ash affected materials characterized by dark and high carbon residency. As to the chemical properties, this soil has many limitations, namely : low pH that affect the availability of most plant nutrients; relatively high phosphate retention that causes phosphorus deficiency; low cation exchange capacity and base saturation that both affect the ability to adsorb plant nutrients in ionic forms.

Primary minerals show that this soil is dominated by weathered particles as similar to highly weathered soils. But small amount of volcanic glass, which is highly weatherable primary mineral is found in all horizons. This shows that Intavas soil is affected by volcanic ash material.

The clay mineralogical analysis shows that the dominant clay mineral in BA horizon is gibbsite and followed by amorphous materials and small amount of halloysite and Bw_2 horizon is dominated by gibbsite followed by halloysite.

In comparison to non-rejuvenated soils, Intavas TDF can be considered partially rejuvenated soil by volcanic ash material brought about by medium total carbon, relatively high phosphorus retention, relatively low bulk density and higher acid oxalate and pyrophosphate soluble Al and halloysite clay.

Acknowledgement

My profound gratitude to Japan International Cooperation Agency (JICA) for giving me the opportunity to go on training in Japan as counterpart of the Environmental and Productivity Management of Marginal Soils in the Philippines Cooperation Project. Gratitude is also due to Dr. Rogelio N. Concepcion, Director of the Bureau of Soils and Water Management.

Appreciation is due to the officers and staff of the National Agricultural Research Center for Kyushu Okinawa Region (KONARC), who in one way or the other contributed to the success of the training. I am also indebted to Dr. Toshiro Matsunaga, Chief of Laboratory of Soil Resources and Plant Nutrition and Dr. Shin-Ichiro Wada of Kyushu University, Fukuoka Prefecture for his valuable suggestions.

Efforts from the Farm Manager, Farmer-Cooperators and my colleagues in the Soil Survey Division who conducted the soil investigation of the Techno Demo Farm at Intavas, La Fortuna, Impasug-ong, Bukidnon, Mindanao Island is also highly appreciated.

References

Costelo, O. F., et al, 2000. Detailed Soil Resource Inventory and Evaluation of Environmental and Productivity Management of Marginal Areas in the Philippines Techno Demo Farms, BSWM-JICA.

Kamewada, K. 1997. Soil Exchange Capacity (Semi-Micro Schollenberger Method), Methods of Soil Environment Analysis, Ed. Editorial Committee of Methods of Soil Analysis. Pp. 208-211

Mariano, J A. 1964. Volcanic Ash Soils of the Philippines. In meeting on the Classification and correlation Resources. Report No. 14. FAO Rome, 53-55.

Otsuka, H. et al. 1988. Characteristics and Genesis of Volcanic Ash Soils in the Philippines Technical Bulletin of the Tropical Agricultural Research Center No. 24

JIFS, 2 : 29 − 37 (2005)

Properties and Utilisation of Andisols in Indonesia

D. FIANTIS [1], N. HAKIM [1] and E. Van RANST [2]

[1] Department of Soil Science, Faculty, of Agriculture University of
Andalas Limau Manis PO Box 87 Padang, Indonesia
[2] Laboratory of Soil Science, Department of Geology and Soil Sciecne,
Ghent University, Krijgslaan 281/ S 8, B−9000 Ghent, Belgium.

Abstract

Soils formed on volcanic ash parent materials and classified as Andisols are widespread in the Indonesian archipelago, covering an area about 3 million hectares. Soils are developed from mostly andesitic to basaltic rocks on Upper Pleistocene to Holocene surfaces. Weathering gradually increases downslope and with the prevailing high precipitation and high temperature produces deep soils. The Indonesian Andisols mostly have dark epipedons with high content of organic carbon and low bulk densities (< 0.9 Mg m^{-3}). soil reaction is slightly acid with negative A pH values with CEC ranges from 22 to 30 cmol(+) kg^{-1}. Major minerals in the sand fraction are quartz, plagioclase, hornblende, augite, hypersthene, olivine and volcanic glass. Short−range−order minerals like allophane, imogolite and/or ferrihydrite dominate the clay fraction, whilst halloysite, gibbsite, cristobalite are also detected in lesser amount. The surface charge of Indonesian Andisols containing allophane and imogolite is pH dependent (variable charge) resulting high phosphate fixation. The Langmuir phosphorus sorption maxima ranged from 300 to 2,500 mg P kg^{-1}.

Most of the Indonesian Andisols are among the most productive soils. These soils are intensively cultivated with both annual and perennial of upland crops like tea, coffee, cocoa with quite high productivity. The areas in the vicinity of volcanoes are also well−known as the horticultural centre and support more than 50% of the Indonesian people. The tea and Arabica coffee plantations occupied hundreds hectares of land from lower to medium slopes of volcanoes both in Sutmatra and Java islands while secondary and primary forests formed in the upper slopes of volcano.

Introduction

The Indonesian archipelago consists of a chain of volcanoes, which are relatively young and mostly still active. Volcanoes emit a variety of substances such as lava, pyroclastic materials, ash and gases. These volcanic products are very important parent materials of soils in the vicinity of the volcanoes that rejuvenate mineral contents in the soils. The effect of volcanic ash on soil properties varies according to the age and depth of the ash deposit, land form and lithology.

Information on the nature, genesis and properties of volcanic ash soils in Japan, Hawaii and New Zealand is available. This information has been used to maximize land productivity in those countries. The same cannot be said for the volcanic ash soils of Sumatra and Java, Indonesia. It is clearly shown that our knowledge on the soils of West Sumatra regions and Java is limited. Many issues are unclear with problems unresolved. It is clearly shown that our knowledge on the soils of West Sumatra regions and Java is limited. For instance, it may be possible to describe the fertility of the soil in terms of charge property and/or P−fixation behavior. Accurate and extensive information on these properties are necessary for improving productivity, sustainable utilization and conservation of the soils.

Soils formed on volcanic materials are classified as Andisols regarding these soils meet the andic properties' requirement. Tan (1965) reported that die Parent material from which the Indonesian Andisols developed changes from basic to acid types when moving from east to west in Java and from north west to south east in Sumatra island. Andisols in Indonesia occur within a wide range of altitudes from 100 m above sea level in West Sumatra (Fiantis et al., 2002) to above 900 m upwards in Java island (Subagyo and Buurman, 19$0; Van Ranst, et al., 2002). Nevertheless, the Indonesian Andisols is

Table 1. Selected chemical properties of the soils at Mt. Marapi and Mt. Pasaman, West Sumatra.

Horizon	Depth	pH(H2O)	Org C	clay	Ca	Mg	K
	(cm)		----------------%-------			--cmol(+) kg^{-1} soil-----	
			Profile I Mt. Marapi				
Alp	0-25	5.7	3.32	20	1.16	0.60	0. 12
A12	25-39	5.8	2.73	13	0.80	0.34	0.06
B	39-68	5.9	1.88	16	0.10	0.42	0.04
BC	68-100	6.1	1.63	28	1.00	0.50	0.02
			Profile II Mt. Marapi				
Alp	0-26	5.0	3.91	31	1.18	0.32	0.06
A12	26-39	5.7	2.14	29	1.38	0.38	0.02
B	39-63	6.1	1.34	16	1.62	0.46	0.02
BC	63-85	6.0	1.61	20	2.10	0.68	0.06
			Profile III Mt. Pasaman				
Alp	0-14	5.7	8.74	50	1.86	0.66	0.28
B21	14-33	6.2	5.67	41	1.90	0.50	0.04
B22	33-46	6.3	3.17	51	1.48	0.66	0.04
C	46-85	6.3	0.52	20	1.16	0.68	0.04
			Prone IV Mt. Pasaman				
Alp	0-11	6.0	5.1	59	2.06	1.74	0.16
B21	11-46	5.7	3.64	54	0.28	0.30	0.06
B22	46-68	5.8	1.87	34	0.46	0.52	0.24
C	68-95	6.0	0.23	47	0.66	0.78	0.04

covering an area of approximately 3.831.000 ha (Sukarman, et al., 1997).

Most of the Andisols in Indonesia are utilized for food and industrial estate crop production and support some of the highest population densities in the country especially in central and east Java. They are often considered the most important factor for a successful horticultural and food crop operation and are favored for growing potatoes, cabbages, carrots, onions, maize, green pepper, tomatoes and cut flowers. The best tea and coffee plantations are also found on these soils and the upper part of the volcano slopes are covered with primary and secondary forests of pine trees.

Indonesian Andisols are thought be very productive soils, but many of them are not utilized to their full capacity. These soils have unique and distinct properties; low bulk density, high water retention, high permeability, Stable structure, high amount of ‘active Al and/or Fe’, variable charge and high phosphate fixation (Shoji et al., 1993). Chemical, physical and morphological properties of these soils ate closely related to the nature and behavior of non-crystalline and para-crystalline clay minerals, such as allophane, ferrihydrite and imogolite (Wada, 1 980).

Allophanes are the most reactive components in volcanic ash soil because of their high specific surface area. They strongly retain phosphate and organic matter (Bear, 1967; Wada, 1985; Famer et al., 1991). The availability to plants of soluble phosphorus, applied as fertilizer, is quickly decreased and only 10 % of the applied phosphorus is utilized by most crops (Egawa, 1977). The loss of applied phosphorus and the availability of native phosphates for crops are very important problems related to agricultural practices on these soils.

Chemical md mineralogical properties influence the productivity of Andisols in various ways. Accurate and extensive information on these properties are necessary for improving their productivity, sustainable utilization and conservation. In the tropical regions where low input farming is common and weathering of soil materials is rapid, Andisols are generally evaluated as the most productive soils (Shoji et al., 1993). The high productivity of these Soils is largely due to their rapid release of nutrients. But leaching may occur severely in Andisols,

Table 2. Different forms of iron in the soils from Mt. Marapi and Mt. Pasaman

Horizons	Fed	Feo	Fep	Fet	Ferryhydrite	Feo−Fop	Fed−Feo	Feo/Fed
	−−−−−−−−−−−−−−−−−−−−−−−−−−−− % −−−−−−−−−−−−−−−−−−−−−−−−−−−−−−							
Profile I, Tanjtmg Karang, Mt. Marapi								
Alp	0.80	1.05	0.39	2.24	2	0.60	–	1.31
A12	0.84	1.18	0.15	2.17	2	1.03	–	1.40
B	0.92	1.22	0.08	2.22	2	1.14	–	1.33
C	1.45	1.37	0.05	2.87	2	1.32	0.08	0.94
Profile II, Guguk Batu, Mt. Marapi								
Alp	1.38	1.27	0.21	2.86	2	1.06	0.11	0.92
A12	1.41	1.15	0.08	2.64	2	1.07	0.26	0.82
B	1.18	1.14	0.03	2.35	2	1.11	0.04	0.97
C	1.32	1.45	0.03	2.80	2	1.42	–	1.10
Profile Ill, Banjar Kubu, Mt. Pa3iaman								
Alp	1.59	1.24	0.45	3.28	2	0.79	0.35	0.78
A12	1.89	1.29	0.30	3.63	2	0.99	0.60	0.68
B	2.50	1.97	0.11	4.58	3	1.86	0.53	0.79
C	1.85	I.48	0.02	3.35	3	1.46	0.37	0.80
Profile IV, Pasar Pinagar, Mt. Pasaman								
Alp	1.89	0.71	0.28	2.88	1	0.43	1.10	0.38
B21	2.64	0.99	0.23	3.86	2	0.76	1.65	0.38
B22	2.31	1.50	0.09	4.00	3	1.51	0.71	0.69
C	2.58	1.04	0.03	3.65	2	1.01	1.54	0.40

Fed = Fe is extracted with DCB
Feo = Fe is extracted with amonium oxalate
Fep = Fe is extracted with pyrophosphate

resulting in a rapid depletion of the weatherable mineral reserves in the soil (Van Wambeke, 1 992).

Surface charge characteristics are of fundamental importance in Soil management. It is because the majority of the reactions that control nutrient availability, along with many of the soil physical properties, are dependent upon the physico−chemical processes that occur at the soil particle surface (Uehara and Gillman, 1981). Andisols display typical variable charge contributing from active Al, Si and Fe complexes such as allophane, imogolite, ferrihydrite and metal humus complexes (Uehara and Gillman, 1981; Shoji et al., 1993).

Despite of the extensively use of these soils, highland Andisols both in Java Nan Ranst et al., 2002) and Sumatra Fiantis et al., 2002) have significant fertility problems that are accentuated by agricultural intensification. Furthermore Van Ranst et al. (2002) stated that an understanding of the factors governing soil fertility is prerequisite to determining the feasibility of ameliorating they constrains and increasing soil productivity. The main objective of this paper is to characterize the physico−chemical, mineralogical properties and utilization of Andisols from Sumatra and Java, Indonesia.

2. Physical Environment

As recorded by Van Bemmelen (1970), there are about 177 volcanoes spread over different islands in Indonesia. On the island of Sumatra alone, 52 volcanoes are found along a great volcanic mountain chain known as the BariSan Mountains−Range. Whilst in Java Island there about 35 volcanoes are spread from east to west and the rest of volcanoes are scattered in lesser Sunda islands, Celebes and Moluccas or Banda Arcs.

The main physiographic trendlines of Sumatra are rather simple. Its backbone is formed by the Barisan Range along its western side. The slope towards the Indian Ocean in the western part is generally steep and consequently the West Coast belt is mostly mountainous. The Barisan range is the prominent orographic element of the island and measures about 1,650 km long and about 100 km wide with several summit altitudes above 3,000 m (Van Bemmelen, 1970; Hamilton, 1979).

This mountainous region consists of pre-Tertiary rocks and is topped by Quaternary volcanic rocks. The areas Of the Quaternary are separated in a general way from areas of older volcanic rocks. The pre-Holocene rocks are andesite and dacite and mostly concentrated in the Northwest-central part of Sumatra. Along the Southwest coast, old rocks are surmounted by recent volcanic rocks of the active magma arc (Hamilton, 1 979).

Van Ranst et al. (2002) reported that Java island is characterized by distinct wet and dry seasons. This seasonality is somewhat more pronounced in the east, and locally in the central part, compared with the western part of the island. The Java's Andisols were developed in finely comminuted Quarternary volcanic ash, ranging from basic (calc-alkaline basaltic ash) in East Java to more acid types (basalt-andesitic ash) in Central and andesitic tuffaceous in West Java.

The distribution of volcanoes both in Sumatra and Java is closely related to the tectonic structure of the region. Based on dated eruptions, the active volcanoes can be grouped into three different types as follows (Van Bemmelen, 1970) :

- type A volcanoes ; volcanoes with eruptions or with periods of increased activity later than 1600 AD (Amo Domini);
- type B volcanoes with fumarole or solfatara stages; no magma eruptions after 1600 AD.,
- type C volcanoes; no dated eruptions, but with actual fumarole activity.

3. The Indonesian Andisols Properties

3.1. Sumatra's Andisols

3.1.1. Physico-Chemical properties

The bulk density values of the soils are less than 0.9 Mg m^{-3}, satisfying the andic soil properties requirement. The BD of the A horizons of the southern slope soils of Mt. Marapi ranges from 0.73 to 0.89 Mg m^{-3}, while for the northern slope soils it ranges from o.63 to 0.88 Mg m^{-3}. The bulk density value of the B horizons is slightly lower than those of the surface horizons; the values are 0.58 - 0.86 Mg m^{-3}. Allophane is responsible for the lower bulk density in the B horizons as it is more abundant in B horizons than in the topsoils. Bulk density tends to be lowered also by organic matter.

Total porosity varies from 59 to 74% (w/w). These values are comparable with those of the Andisols from Japan. Young volcanic ash soils have porosity of about 60 %, while the matured soils have porosity up to 80 percent (Shoji and Ono, 1978; Nanzyo et al., 1993a). There is a negative relationship between total porosity add organic carbon. However, total porosity is linearly correlated with allophane content. The high porosity in Andisols is attributable to the allophane structure. Allophanes have hollow spherical aluminosilicates sheets, which create macro, meso and micropores Nanzyo et al., 1993a).

Soil water storage is commonly measured at different moisture tensions, namely pF (potential Force) 1, 2, 2.54 and 4.2. Water storage of soils from Mt. Marapi measured at pF 1 ranges between 54 to 74% w/w or between 25 to 209 mm while soils of Mt. Pasaman have water storage between 53 to 72% w/w or 53 to 162 mm. Statistical analysis indicates that there is no influence of both allophane and organic carbon on gravitational water.

In the A horizons, the available water held between pF 2 and 4.2 varies from 8 to 60 mm (39% w/w) for soils of Mt. Marapi. For the soils from Mt. Pasaman it is 15-48 mm (38% w/w). In the B horizons the variation is narrower and ranges from 20 to 60 mm. Compared to other soils in the tropics sdch as Oxisols, these figures are high (Van Wambeke, 1992) but they are similar to those obtained from Andisols in Japan, Hawaii, Chile, Equador and New Zealand (Wada, 1985).

Selected chemical properties were presented in Table 1. The carbon contents ape quite high in the upper horizons with values increasing with increase elevation in both volcanoes. Available phosphorus contents are quite low as compared to total P. Phosphate retention is very high (> 95 %) in both toposequences; these satisfy the requirements for andic properties. Lower P retention values were observed with decreasing altitude (Fiantis et al., 1998). The high P retention capacity is related to large specific surface areas of these soils (Wada, 1980; Sanyal aLld Datta, 1991). CEC ranges from 22 to 28 cmol(+) kg^{-1} soil in the soils of Mt. Marapi and from 19 to 30 cmol(+) kg^{-1} soil on those of Mt. Pasaman. The pH$_0$ values of the topsoils are lower than those of the subsoils, attributed to higher amount of organic matter in the topsoils.

Comparable results were also found earlier by Tan (1965) for Andisols in North Sumatra and West Java. These soils have a low permanent charge then variable charge soils that have medium to high variable charge show low anion-exchange capacity (AEC) whereas soils with low variable charge tends to have high AEC.

Humus composition in Andisols from North Sumatra dominated by the fulvic acid (up to $l%) whereas humic acid only count l8%. Comparable results were also obtained by Puteri et al. (2003) for Andisols from West Sumatra which have more fulvic acid than humic acid also but with lesser amount of humic acid (<1%).

DCB solution extracted more Fe than acid ammonium oxalate or Na-pyrophosphate (Table 2). The Fe_o/Fe_d ratios of the surface horizons of soils from Mt. Pasaman are lower compared to those of the Mt. Marapi, indicating that iron oxides in soils from Mt. Pasaman are of higher crystallinity. The higher crystallinity and the larger amounts of Fe_d indicate that soils from Mt. Pasaman are more weathered than soils from Mt_ Marapi. This is in agreement with Mizota and Van Reeuwijk (1989) who believed that the Fe_o/Fe_d ratio can be used as an index for the crystallinity or 'age' of iron oxides. Values for young Andisols are > 0.75, whereas the older soils have values<0.75.

The soils from Mt. Maqapi show lower Al_p/Al_o ratios than the soils from Mt. Pasaman (Table 2). This indicates that the soils from Mt. Pasaman are more weathered than the soils from Mt. Marapi. The ratio of Al_p over Al_o also gives some indications about the occurrence of allophane and imogolite. A lower ratio (close to zero) indicates the presence of allophane and imogolite Mizota and Van Reeuwijk, 1989). The allophane content is lower in the topsoil than in the subsoil (Table 2). The lower content of allophane in the topsoil is probably due to the higher content of organic matter in the A horizonn than the underlying B and C horizons. The allophane content of soils from Mt. Pasaman is lower than that of Mt. Marapi. Moisture content also plays an important role in the formation of allophane. Low amounts of annual precipitation that reduce the loss of Si from the soils favor the formation of allophane and imogolite rather than ferrihydrite and/or gibbsite (Parfitt et al., 1988).

3.1.2. Mineralogical Properties

Andisols from Mt. Pasaman have more clay content than Andisols from Mt. Marapi as reported by Fiantis et al. (1998). The clay fraction of soil at Mt. Marapi is largely amorbhous to x-rays (diffused spectrum) as compared to that of Mt. Pasaman which is largely crystalline. The mineralogical composition of the clay fraction of the two soils does not change with depth. The soils are characterized by the presence of cristobalite (0.405 nm), feldspars (0.377, 0.321, 0.315 nm) and halloysite (1.01, 0.405 nm). Opaline silica, which gives a diffuse, broad X-ray spectrum centers at about 0.41 nm, is only observed in profile 1 from Mt. Marapi. This findings is in agreement with the results obtained by Diakite (1992) who found opaline silica accumulating in the surface horizons of Andisols from Mexico. High amounts of opaline silica are also reported present in the Andisols of Japan. A review of literature shows that opaline silica is found more abundantly in younger Andisols (< 500 years) than in older ones (4000-7000 years), also in humus-rich A horizon than in underlying B and C-horizons. Therefore, opaline silica is a product of the early stages of weathering of volcanic ash.

Gibbsite (0.485 nm) is detected in the clay fraction of the soils at Mt. Pasaman, but absent in the soils from Mt. Marapi. Formation of gibbsite in the clay hction of Mt. Pasaman soil is presumably due to high precipitation. Under high precipitation, Si and basic cations are leached out of the profiles, leaving aluminum behind to precipitate as aluminum oxide (Parfitt et a1., 1 988). Weathering of Al-silicates directly to gibbsite or through a 1 : 1 layer is governed by the intensity of leaching which, in turn, is affected by minLal1, temperature, topography, ground water table and time (Hsu, 1989).

Disappearance of the 0.715 and 0.357-nm reflection peaks after heating at 550^0 C is indicative of the occurrence of 1 : 1 layer minerals in the samples. This phenomenon occurred in all the samples. The 1 : 1 layer silicate is found to be halloysite. The presence of halloysite in the samples is confirmed by the strong reflection at 0.445 nm and the collapse of the 1.01 nm reflection to 0.72 nm after heating at 350^0 C (Dixon, 1989). The intensity of the halloysite XRD reflections increases with decreasing altitude of the soil profiles and also with increasing soil depth. This suggests that silica is subjected to leaching from the upper topographic areas and accumulates in the lower zones. This is supported by the study of Mizota and Chapelle (1988) who found that high amounts of halloysite accumulated in the lower parts of Andisols in Rwanda. Silicium with its intermediate solubility can partly be leached out and precipitate in the lower subsoils (Van Ranst, 1995).

Interstratified 1 : 1− 2 : 1 phyllosilicates are observed in the fine and medium clay fraction of the surface horizons (Figure 1C). The presence of shoulder at the low angle side of 0.715 nm after heating at 350^0 C and 550^0 C and shift of this peak towards low angle side after glycolation indicates the presence of interstratifled 1 : 1−2 : 1 layers and swelling properties. Dehydroxylation of the interstratified 1 : 1 layers gives a broad diffraction band between 0.99−1.4 nm (Herbillon et al., 1981). This result is in

agreement with the study of Wada et al. (1987) and Delvaux et al. (1990). Wada et al. (1987) named this mineral as a 'embryomic halloysite', but Parfitt et al. (1988) disagreed and call it as 'a mixed layer of kaolidte/smectite' instead.

3.2. Java's Andiols

3.2.1. Physico−chemical Properties

Utami (1 998) reported that Andisols of Java island are characterized by relatively good physical properties as shown by low bulk density (< 0.90 Mg m^{-3}) and high total porosity indicate that a lwge mount of water can be stored in the soil profiles. Bulk density decreases with decreasing organic matter content but the effect of organic matter on bulk density is less important than that of allophane, DCB−extractable Al and Fe. The amount of available water for plant grow is considered to be equal to the difference between water content at field capacity (0.033 MPa) and at wilting point (1.5MPa). Allophane, DCB and pyrophosphate extractable Al and Fe, ferrihydrite and organic matter content are highly correlated to the water content held at these two suction values.

Van Ranst et al. (2002) summarized that soil acidity (pH) and sum of exchangeable basic cations, sepecially Ca^{2+} of Andisols in Java generally decreased from East to West Java. This trend is attributed to the combined effect of the parent ash, becoming more acid from east to west and the more pronounced seasonality in East Java. The Andisols from East Java are capable of holding far great amount of exchangeable basic cations then the other soils from Central and West Java at natural pH. On the other hand, Andisols in West Java have far greater capacity to retain anions such as NO_3^- and SO_4^{2-} in subsoils (at 50 cm). Thus, these soils are capable of holding a large store of such nutrients in the subsoil. Andisols in West Java showed different behavior which has more humic acid than fu1vic acid with the values of 57% and 43%, respectively (Tan, 1965).

Subagjo and Buurmm (1980) investigated soil catenas on the west and north−east slopes of the Lawu volcano in East Java and found that base saturation in those soils gradually increased dowhill with the lowest value obtain in Andisols compared to Inceptisols or Alfisols. The same trend was also observed for CEC, permanent charge and effective CEC. Whils variable charge of Andisols of Mt. Lawu was the highest one compared to other soils and highly correlated with one or both of organic matter and non−crystalline substances and/or sesquioxides.

3.2.2. Mineralogical Properties

The mineralogical composition of Andisols in Java consist of long−range order crystalline minerals as well as short−order or non−crystalline minerals as it was reported by Utami (1998). Feldspar, cristobalite and pyrophillite are commonly found in all soils. She further grouped Andisols in Java into four types such as smectitic, hal1oysitic, gibbsitic and mixed mineralogies groups. The content of the long−order minerals are in inverse relation with the non−crystalline minerals. In the al1ophanic Andisols, allophane, imogolite and ferrihydrite constitute 30 − 50% of the clay fraction in A horizons, and 30 − 65% in B horizons.

Van Ranst et al. (2002) reported that the weight average contents of Si_o, Al_o, Fe_o.,allophane and ferrihydrite in the fine earth of the upper 100 cm showed clear increase in the pedons from East to West sides of Java. Differences in the amounts of Si_o, Al_o, Fe_o are less marked between the A and B horizons in the pedons of East and Central Java, but clearly increased with depth in pedons of West Java. This indicates that the development of active forms of Al and Fe in weathering of volcanic ash is favored by strongly leaching conditions (Mizota et al., 1 988).

3.3. Utilization of Andisols

Highland Andisols both in North and West Sumatra are utilized for industrial estate and horticulture crop productions. The area of north Sumatra is famous for its Deli−tobacco wrappers and tea plantations and the quality of the tobacco and tea are considered as the best ones in the country (Tan, 1965).

Fiantis et al. (2003) found that Andisols in surrounding Mt. Ta1ang in West Sumatra have Climatic Rating Index of 80 wd high Land Production Potential for horticulture crops such as potato and cabbage. Those areas ate considered as the most productive horticultural region in West Sumatra. Furthermore, they reported that in the lower middle to upper slope of Mt. Talang laid huge tea plantations, cinnamomum trees, robusta and arabica coffee. The production of these estate crops are considered quite high in the province and the quality of this highland tea and coffee are more favored than lowland estate crops.

Similar soil utilization were also reported for Andisols ih Java. In West Java, best horticultural and tea plantation sites are located in the slopes of Mt. Gede and Mt. Pangrango. Andisols in foot slopes of Mt. Merapi and Mt. Merbabu in Central Java are classified also as the most productive region. These two volcanoes are type−A volcano which from time to time intermittently ejected volcanic materials from their caldera into surrounding slopes. Shoji et al. (1993) summarized that the high productivity of Andisols in Central Java related to cumulative deposits of basaltic to andesitic volcanic parent materials, soils have a deep and unrestricted rooting zones, thick humus horizons with large amounts of organic N, relatively abundant of apatite in the parent material and the high content of available water.

Conclusions

Andisols from West Sumatra have lower allophane content in the topsoil than in the subsoil. This is related to higher amount of organic matter in the topsoil. Due to higher rainfall, the soils at Mt. Pasaman are more weathered than those at the Mt.Marapi. This is reflected by lower allophane and higher ferrihydrite contents in the soils at Mt. Pasaman. The clay fraction of West Sumatra's Andisols is composed mainly of halloysite, cristobalite and feldspars. The intensity of halloysite reflections in the B horizons iS more pronounced with decreasing altitude of the soil profile, indicating a downward leaching of Si. Gibbsite is only present in the clay of the soils at Mt. Pasaman, ale opaline silica is only present in the clay of Mt. Marapi soils. Interstratified 1/1−2/1 phyllosilicates are identified in the deferrated clay fraction. In all the soils, the surface horizons have lower pH_o value than the underlying B horizons. The negative variable charge of the soils varies from 6 to 10 cmol kg^{-1} soil, while the negative permanent charge varies from 0.42 to 7.4 cmol(+) kg^{-1} soil. The AEC is higher in the subsoil than in the topsoil, having values ranging from 0.3 to 1. 1 cmol(+) kg^{-1} soil.

Andisols in highlands of Java island, Indonesia have varying chemical compositions. The development of these soils is affected by the parent ash composition and climatic conditions. From East to West Java, pH and exchangeable Ca decrease, whereas allophane and ferrihydrite contents, PZNC, and pH_o, increase. Some of the soils tend to develop a net positive variable charge at $pH < pH_o$; this may affect the soils's productivity. Managing the soils for sustainable crop production should consider the CEC at the natural soil pH, the PZNC, and the pH_o.

Andisols both in in Sumatra and Java high Land Production Potential for horticulture crops such as potato and cabbage, rice, and tea plantation. Those areas are considered as the most productive horticultural region, rice, and tea plantation in country.

Acknowledgement

Gratitude is expressed to the International Foundation for Science (IFS) of Sweden for the financial support of this investigation (grant no : C/2452−1 and C/2452−2) to the first author. The second author is grateful for the travel grant provided by the Organizing committee of the 6th International Symposium on Plant−Soil Interaction at Low pH and the OC of the 2nd workshop of Andisols.

References

Bartoli, F., E. Paterson, R. Philippy, J.J. Demai, and M. Doirisse. l98S. Aggregation in soil with Small amounts of swelling clays. II. Chemistry and surface properties of Na resin stable soil aggregates. J. Soil Sci., 39 : 617−628.

Bartoli, F., G. Burtin, and A.J. Herbillon. 1991.

Disaggregation and clay dispersion of Oxiosls; Na Resin, a recommended Methodology. Geoderma 49 : 301–3 17.

Bear, F. R. 1967. Chemistry of the Soil. Reinhold Publishing Corp. New York. 515p.

Blakemore, L.C., P. L. Scarle, and B. K. Daly. 1987. Soil Bureau Laboratory Methods for chemical analysis of soil. New Zealand Soil Bureau. Soil Rep. 10A. DSIO. New Zea1and.

Delvaux, B., A. J. Herbillon, L. Vilvoye and m. M. Mestdagh. 1990. Surface properties and clay mineralogy of hydrated halloysitic soil clays. II. Evidence for the presence of halloysite/smectite qSm) mixed layer clays. Clay Minerals, 25 : 141–180.

Diakite, L. 1992. Genesis, mineralogy and micromorphology of an Andisol sequence on the NWW slope of Nevado de Toluca Volcano Mexico). Thesis Ph.D.University of Gent. 340p.

Dixon, J. B. 1989. Kaolin and serpentine group minerals. In : J. B. Dixon and S. B. Weed (eds). Minerals in Soil Environment. SSSA. Madison. Pp. 467–525.

Drees L. R., L. P. Wilding, N. E Smeck, and A. I. Senkayi. 19$9. Silica in soils : quartz and disordered silica polymorphs. b : J. B. Dixon and S. B. Weed (eds). Minerals in Soil Environment. SSSA. Madison. pp. 913–973.

Egawa, T. 1977. Properties of soil derived from volcanic ash soils. b K. H. Tan (ed.). 1984. Andosols. Van Nostrand Reinhold Comp. New York. pp. 249–302.

Farmer, V. C., W. J. McHardy, F. Palmieri, A. Violante, and P. Violante. 1991. Syntethic allophanes formed in calcareous environments; Nature, conditions of formation and transformations. SSSA Journal Vol. 55 : 1162–1166.

Fiantis, D., E. Van Ranst, and J. Shamshuddin. 1998. Mineralogical and Charge Properties of Volcanic Ash Soils from West Sumatra, Indonesia. Malaysian J. Soil Sci. 2 : 45–57.

Fiantis, D., J. Shamshuddin, E. Van Ranst, S. Zauyah and I. Fauziah. 2002. Effect of Calcium Silicate and Superphosphate Application on Surface Charge Properties of Volcanic Soils from West Sumatra, Indonesia. Commun. in Soil Sci. and Plant Ana1., 33 (1 1&12), 1887–1900.

Fiantis, D., Nelson, R. Febriamansyah and N. Nazir. 2003. Konsep PengembangaJI Kawasan Sentra Hortikultura. Badan Penelitian dan Pengembangan Propinsi Sumatra Barat. Padang. 103 p.

Gillman, G. P., and D, Jr Abel. 1986. A Summary of surface charge characterisdcs of the major soils of the Tully–Innistail Area, North Queenslands. CSIRO Aust. Div. Soils Div. Rep. No. 85.

Gillman, G. P., and E. A. Sumpter. 1986. ModiflCation of compulsive exchange method for measuring exchange characteristics of soils. Aust. J. Soil Res. 24 : 61–66.

Herbillon, A. J., R. Frankart, and L. Vielvoye. 1981. An occurrence of interstreatified kaolinite–smectite minerals in a red–black soil toposequence. Clay miner., 16 : 195–201.

Hsu, P. H. 1989. Ahminium hydroxides and oxyhydroxides. In : J. B. Dixon and S. B.weed (eds.). Minerals in Soil Environments. SSSA. MLdison. pp.99–134.

Huang, P. M. 1989. Feldspars, olivines, pyroxcnes and amphiboles. b : J. B. Dixon and S. B. Weed (edS.) Minerals in Soil Environments. SSSA. Madison. Pp.975–1039.

Mehra, 0. P., and M. L. Jackson. 1960, Iron oxide removal from soils and clays by a dithiomiteqcitrate system buffered with sodium bicahonate. Clays and Clay Mineral. 7 : 713–727.

Mizota, C., and S. Aomine. 1975. Clay mineralogy of some volcanic ash soils in which cristobalite predominates. Soil Sci. Plant Nutrition, 21 : 327–335.

Mizota, C., and J. Chapelle. 1988. Characterization of some Andepts and Andic soils in Rwanda, Central Africa. Geoderma, 41 : 193–209.

Mizota, C., and L. P. Van Reeuwijk. 1989. Clay mineralogy and chemistry of Soils formed in volcanic material in diverse climatic region. Soil Monograph 2. ISRIC. Wageningen. 185 p.

Parfitt, R. L., and G. J. Churchman. 198S. Clay minerals and humus complexes in five Kenyan soils derived from Volcanic Ash–a discussion. Geoderma 42 : 365–367.

Puteri, L. E., D. Fiantis and 0. Emalinda. 2003. Karakterisasi Asam Humat dan Fulvat serta Koloid Al–Fe pada Horizon Permukaan Tanah Vulkanis Sumatra Barat. Prosiding Kongres Nasional ke qI Himpunan Ilmu Tanah Indonesia di Padang 21–23 Juli 2004, pp. 348–356.

Shoji, S., M. Nanzyo, and R. Dahlgren. 1993.

Volcanic Ash Soils. Elsevier. Amsterdam. 288 p.

Subagyo, H., and P. Buurman. 1980. Soil Catenas on the West and Northeast Slopes of the Lam Volcano, East Java. In Red Soils in Indonesia. P. Buurman 9ed.) Centre Agric. Publ. Doc., Wahemingen, The Netherlands, pp 49–67.

Sukaman, Yusrial, A. Mulyadi, A. Mutt, W. Esdningtyas and N. Rohmah. 1997. Statistik Sumber Daya Lahan / Tanah Indonesia. Pusat Penelitian Tanah Dan Agroklimat. Bogor. 191 p.

Tan, K. H. 1965. The Andosols in Indonesia. Soil Sci. 99 : 375–378.

Tan, K. H. 1996. Soil Sampling, Preparation, and Analysis. Marcell Dekker, Inc. New York. 408p.

Uehara, G., and G. Gillman. 1981. The mineralogy, chemistry, and physics of tropical soils with variable charge clays. Westview Tropical Agriculture Series No. 4. Westview Press, Inc. Colorado. 170 p.

Utami, S. R. 1998. Properties and Rational Management Aspects of Volcanic Ash Soils from Java, Indonesia. Ph. D. Thesis. Ghent University, Belgium. 388 p.

Van Bemmelen, R. W. 1970. The biology of Indonesia, vol. I A. Martinus Nijhoff. The Hague.

Van Ranst, E. 1995. Rational Soil Management in the Humid Tropics. Meded. Zitt. K. Acad overzeese Wet 40(1994–2) : 209–233.

Van Ranst, E., S. R. Utami and J. Shamshuddin. 2002. Andisols on Volcanic Ash from Java Island, Indonesia : Physico–Chemical Properties and Classification. Soil Sci. Vol. 167. No. 1 : 6S–79.

Van Wambeke, A. 1992. Soils of the tropics, properties and appraisal. McGraw–Hill, Inc. New York. 343 p.

Wada, K. 1980. Mineralogical chaJaCteriSdcs ofAndisols. b : B. K. G. Theng (ed). Soils with variable charge. New Zealand Society of Soil Science. Lower Hutt, pp.87–107.

Wada, K. 1985. The Distinctive Properties of Andosols. Adv. in Soil Sci. 2 : 173–228.

Wada, K. 1989. A11ophane and Imogolite. b J.B. Dixon and S.B. Weed (eds) Minerals in Soil Envirorment. 2nd ed. SSSA. Madison. pp 1051–1087.

Wada, K., Y. Kakuto, and F. N, Muchena. 1987. Clay minerals and humus complexes in five Kenyan soils derived from volcanic ash. Geoderma 39 : 307–321.

JIFS, 2 : 39 – 65 (2005) Special review

Andisols of New Zealand and Australia

David J. LOWE and David J. PALMER

Department of Earth Sciences, University of Waikato,
Private Bag 3105, Hamilton, New Zealand

Keywords : Vitrands, Udands, Xerands, short–range–order clays, allophane, ferrihydrite, multisequal soils, North Island, Taupo Volcanic Zone, South Australia, Mount Gambier

ABSTRACT

During the Quaternary, much of central North Island, New Zealand, was repeatedly overwhelmed or modified by emplacement of ignimbrites and especially by multiple rhyolitic and andesitic tephra fallout deposits, and reworked derivatives, that successively mantled landsurfaces forming buried paleosols in multisequal profiles. Relatively thick proximal deposits buried and isolated antecedent soils, forming compound soil profiles, whereas relatively thin tephra fallout at medial and distal sites resulted in composite or aggrading profiles, their character determined by the interplay of upbuilding and topdown pedogenesis. Scoriaceous basaltic tephras erupted in northern North Island were locally distributed. Andisols, of the 'allophanic' type with andic soil properties dominated by short–range–order (SRO) clays rather than Al–humus complexes, cover ~32,100 km^2 and comprise about 12.5% of New Zealand soils. They consist of three groups : (1) 'Entic' Udands or Cryands occur on mainly andesitic eruptives <1000 years old near recently active volcanoes (Tephric Recent Soils in New Zealand Soil Classification; ~1200 km^2, ~0.5%); (2) Vitrands occur in central–eastern North Island on glassy, rhyolitic pumiceous deposits mainly from the Taupo eruption *c.* 232 AD and the Kaharoa eruption *c.* 1314 AD (Pumice Soils; ~17,200 km^2, ~6.5%); and (3) Udands occur typically on composite, multiple tephra deposits of varying ages in Taranaki (mainly andesitic tephras), King Country–western Waikato (mixed andesitic–rhyolitic), eastern Waikato–western Bay of Plenty–Coromandel (mainly rhyolitic), and Auckland–Northland (basaltic), the age span of sola increasing towards distal sites as constituent tephra layers become thinner and shallower (Allophanic Soils; ~13,700 km^2, ~5.5%). Moisture and temperature regimes are mainly udic and mesic, thermic, or cryic. Udands are pre–eminent among New Zealand's most versatile, high–quality soils because they provide valuable soil ecosystem services including sorption, water storage and supply, natural fertility, and foundation support.

Andisols are currently known only in the Mt Gambier area of southeast South Australia, and comprise ~85 km^2 (~ 0.001%) of Australian soils. Intraplate basaltic volcanoes at Mts Gambier and Schank erupted *c.* 5000 years ago and the resultant localised tephras contain both exotic crystalline material, derived from underlying limestone and calcareous dunes, and juvenile basaltic material. Sand fractions at Mt Gambier are dominated by exotic, silicic crystalline material (≥80%) and relatively little glass (<20%) but at Mt Schank unaltered Al–rich glass predominates (≥50%). Vitrixerands and Haploxerands with pHs 6.4–8.0 have been formed under xeric moisture and mesic temperature regimes (Andic, Chernic Tenosols in Australian Soil Classification). The parent mineralogies have influenced clay mineral formation : SRO clays at Mt Schank (up to 20% allophane, 7% ferrihydrite, fine–earth basis) are more abundant than at Mt Gambier (≤12% allophane, 4% ferrihydrite) because the glass at Mt Schank weathers more rapidly than the Al–poor crystalline material at Mt Gambier, releasing Al. Seasonal Si–leaching has also been influential : where leaching is sufficient to remove silica, and $CaCO_3$ content is low (in upper soil horizons at Mt Gambier; in most horizons at Mt Schank), Al–rich allophane has formed; where leaching is weak (intermediate horizons), Si–rich allophane and layer silicate minerals (but not halloysite) have formed; and where leaching barely occurs (in lowest horizons), smectite has formed. The Xerands are versatile soils.

INTRODUCTION

Although making up only about 1.24 million km^2, or approximately 1% of the global land area (Kimble et al., 2000; Takahasi and Shoji, 2002), Andisols have long been regarded as special soils because of their distinctive or unique morphological, mineralogical, physical, and chemical properties and generally high productivity. They were included in Soil Taxonomy in 1990 as the eleventh order (Parfitt and Clayden, 1991) following recommendations of the International Committee on the Classification of Andisols chaired by the late Dr Michael L. Leamy of New Zealand (Parfitt et al., 1988). Since then, numerous excellent reviews of the genesis, nature, and environmental and agricultural significance of Andisols have been published, including those of Shoji et al. (1993a), Kimble et al. (2000), Ping (2000), Nanzyo (2002), Shoji and Takahashi (2002), Takahashi and Shoji (2002), Ugolini and Dahlgren (2002), Dahlgren et al. (2004), and Qafoku et al. (2004).

Andisols (approximately equivalent to Andosols in the World Reference Base for Soil Resources : Spaargaren, 2000) are defined essentially by the presence of andic soil properties, these being attributable to significant amounts of short-range-order (SRO) (i.e. allophane, ferrihydrite) or paracrystalline (i.e. imogolite) minerals or Al-humus complexes (Soil Survey Staff, 1999; Kimble et al., 2000). These and other materials are commonly formed during weathering and mineral transformations of tephra – the unconsolidated, primary pyroclastic products of a volcanic eruption (Lowe and Hunt, 2001) – and other parent materials with a significant content of volcanic glass, the processes being known collectively as andisolization (Shoji et al., 1993b; Lowe, 1995; Ugolini and Dahlgren, 2002). Although volcanic glass is a common component in many Andisols (Lowe and Green, 1992), it is not a requirement of the Andisol order and some soils develop andic properties without the influence of volcanic glass (Soil Survey Staff, 1999). The concept of Andisols includes weakly weathered soils with much volcanic glass as well as more strongly weathered soils dominated by (1) SRO minerals and imogolite, the so-called 'allophanic Andisols', or by (2) Al/Fe-humus complexes, typically with 2 : 1 layer silicates, the so-called 'non-allophanic Andisols' (Dahlgren et al., 2004).

Translocation within Andisols is normally minimal (Soil Survey Staff, 1999; Ugolini and Dahlgren, 2002). However, Bakker et al. (1996) demonstrated that micro-laminated, anisotropic, clay coatings had been illuviated into lower horizons of a Typic Placudand/Vitric Hapludand (Horotiu series) in New Zealand (cf. Jongmans et al., 1994).

In New Zealand, Andisols are found only in the North Island, as described in the next part of this paper, and at around 12.5% (approximately 32,100 km^2) of the total area comprise the third-most extensive soil order in New Zealand after Inceptisols (~47.4%) and Spodosols (~13.2%) (Lowe et al., 2000a; Table 1). However, significant areas of soils containing Al-rich allophane are recognised in extensive upland or 'high country' regions of inland South Island (Parfitt and Webb, 1984; Parfitt, 1990a). They are mainly Andic Dystrudepts in Soil Taxonomy (Soil Survey Staff, 1999) and Allophanic Brown Soils in the New Zealand Soil Classification (NZSC) (Hewitt, 1998). An 'Andisol-like' soil (Venlaw series : Wallace et al., 2000), dominated by Al-humus complexes, has been reported in southern South Island (Saigusa and Matsuyama, 2004; R.L. Parfitt pers. comm., 2004) and warrants further investigation.

Soils formed either from very young, little-weathered tephra deposits or from older, strongly-weathered tephra and other volcanic deposits, but lacking sufficient andic properties to qualify as Andisols, also occur in New Zealand (Gibbs, 1968; Hewitt, 1998; Molloy and Christie, 1998). Such volcanogenic soils are mostly Entisols or Ultisols, respectively, but Oxisols and other orders (rare) occur as well (Hewitt, 1995, 1998; Rijkse and Hewitt, 1995; Bakker et al., 1996; Lowe et al., 2001).

In Australia, Andisols have been identified only in the southeastern part of South Australia (Lowe et al., 1996; Table 1), and these are described later in this paper.

VOLCANISM AND TEPHRA DISTRIBUTION IN NORTH ISLAND

Because New Zealand bisects an obliquely convergent plate boundary, tectonism and volcanism, together with Quaternary environmental change, have been the dominant influences on its soil pattern (Molloy and Christie, 1998; Lowe et al., 2000a).

Volcanism in the North Island since *c.* 2.5 million years ago can be classed into three main types (Fig. 1), each generating characteristic pyroclastic products from which Andisols have been formed.

(1) Intraplate basaltic volcanic fields, largely monogenetic, have erupted locally distributed basaltic (scoriaceous) tephra-fall deposits in northern North Island.

(2) Subduction-related volcanic centres, forming andesitic stratovolcanoes, especially Egmont/Taranaki and Tongariro, Ngauruhoe, and Ruapehu volcanoes, have erupted local to widespread but generally thin andesitic tephra-fall deposits very frequently, and localised pyroclastic density current or flow deposits (including block-and-ash flow deposits).

(3) Crustal-derived and explosive rhyolite volcanic centres include the large, active Taupo and Okataina calderas in the central part of the Taupo Volcanic Zone from which voluminous pyroclastic density current or flow deposits (ignimbrites) and widespread silicic tephra-fall deposits have been erupted moderately frequently to infrequently. Another type of rhyolite has been erupted from the offshore peralkaline Tuhua caldera volcano (Fig. 1) (Froggatt and Lowe, 1990; Houghton et al., 1992; Wilson et al., 1995; Shane, 2000).

Thus most parts of the central North Island landscape especially have been repeatedly overwhelmed or modified by the catastrophic emplacement of ignimbrites and the widespread fall of numerous rhyolitic and andesitic tephra deposits, and reworked derivatives that include volcanogenic alluvium, colluvium, and subsurface tephric loess (Cowie and Milne, 1973; Pullar and Birrell, 1973; Soil Bureau Staff, 1973; McCraw, 1975). The tephra-fall deposits have successively mantled rolling and flattish landsurfaces forming multisequal soils comprising repetitions of soil horizons and buried paleosols within the vertical profile. Similarly layered soils comprising multiple sequences of buried horizons and tephra deposits are recognised in other volcanic terrains (e.g. Ping et al., 1988; Shoji et al., 1993c; Kimble et al., 2000).

Relatively thick proximal deposits have buried and isolated antecedent soils, forming compound soil profiles (e.g. see Fig. 5 below), whereas fallout at medial/distal sites of relatively thin, multiple tephra deposits from successive eruptions has resulted in composite or aggrading (accretionary) profiles, the ensuing soil character being determined by the interplay of upbuilding and topdown pedogenesis (Hill, 1999; Hill et al., 1999; Lowe, 2000) (e.g. see Fig. 6 below). Soils on such aggrading landscapes have undergone 'developmental upbuilding' (progressive pedogensis) if the rate of addition of tephras allowed assimilation of the deposits and profile deepening, or 'retardant upbuilding' (regressive pedogenesis) if the rates were so rapid that horizonation was prevented (Johnson and Watson-Stegner, 1987; Lowe, 2000). In upbuilding soils, each increment of soil below the A horizon has experienced processes that are characteristic of all horizons above it (Almond and Tonkin, 1999).

Many of the major tephra deposits in the North Island, mainly rhyolitic, have been dated and mapped (Froggatt and Lowe, 1990), thereby providing time-stratigraphic frameworks for studies on soils, paleosols, and paleoclimates (e.g. Parfitt et al., 1983; Alloway et al., 1992; Bakker et al., 1996; Cronin et al., 1996; Newnham et al., 1999; Lowe et al., 2001), on their rates of weathering and clay mineralogy (Neall, 1977; Lowe, 1986; Hodder et al., 1990, 1996; Parfitt, 1990a; Lowe and Percival, 1993), and on the interaction of volcanism with humans in antiquity (Lowe et al., 2000b, 2002).

DISTRIBUTION AND CHARACTER OF ANDISOLS IN NORTH ISLAND

Most North Island Andisols have developed under udic moisture regimes (some are perudic, e.g. in elevated parts of Mt Egmont/Taranaki region) and thermic, mesic, or cryic temperature regimes. Isofrigid temperature regimes were reported by Suryaningtyas (1998). The Andisols may be classed into three main groups of increasing age (Table 1; Fig. 2).

(1) Weakly developed or 'Entic' Cryands or Udands, typically integrading to Vitrandic Cryorthents/Udorthents, occur adjacent to Egmont volcano and Tongariro Volcanic Centre on very weakly weathered, coarse-grained, glassy andesitic tephras <1000 years old (zone 1a, Fig. 3), near Mt Tarawera in the Okataina Volcanic Centre on basaltic scoria and fine-grained hydrothermally altered rhyolite and sediment from the 1886 AD Tarawera eruption (zone 1b), and on basaltic ashfall on Motutapu Island from the Rangitoto eruption

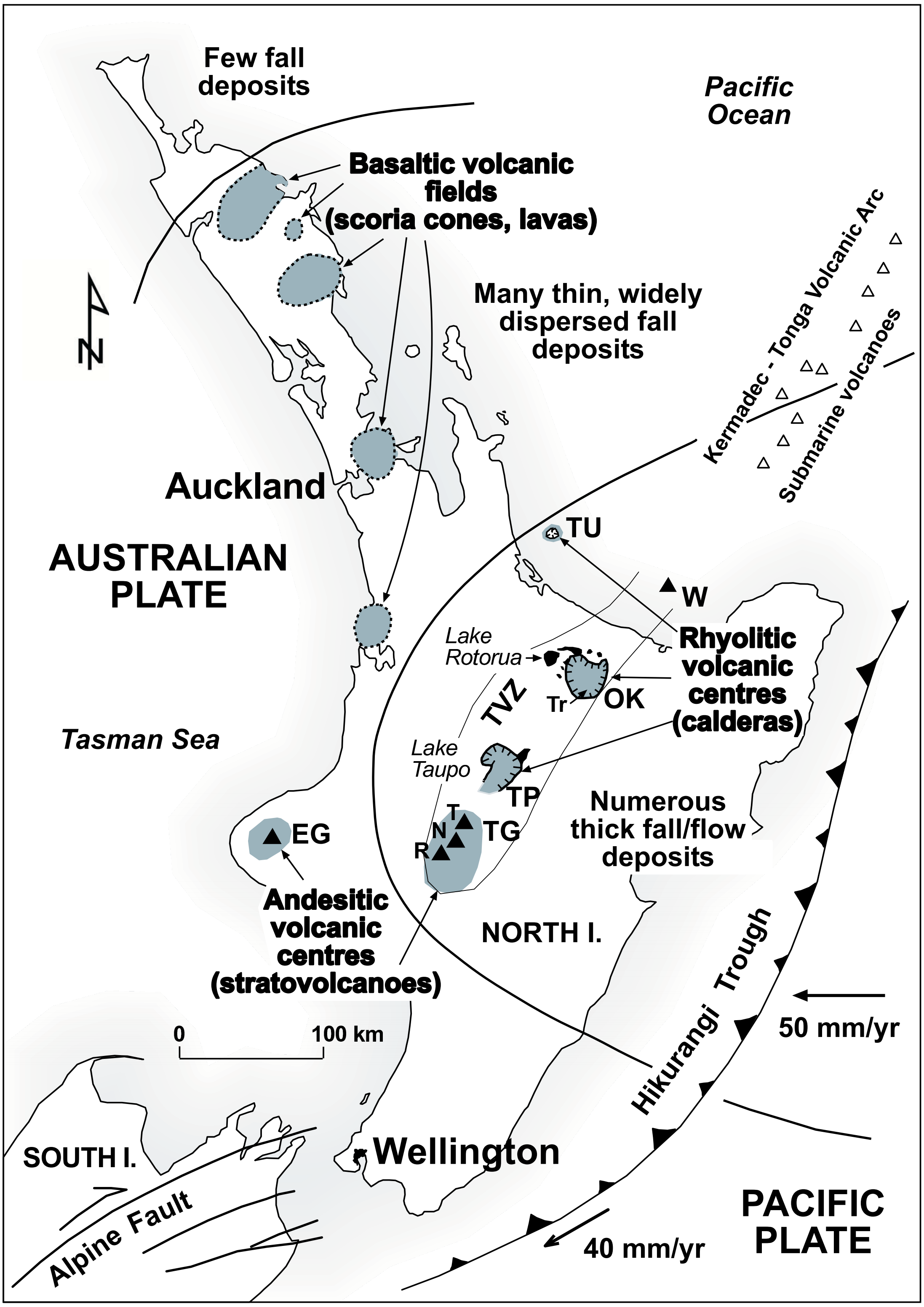


Fig. 1. Plate tectonic setting and the main volcanic centres that have erupted Andisol−forming tephra deposits, and the general dispersal of tephra in North Island (after Shane, 2000; Lowe et al., 2002). EG, Egmont volcano (also known as Mt Taranaki); TG, Tongariro Volcanic Centre (T, Tongariro volcano; N, Ngauruhoe volcano ['Mt Doom']; R, Ruapehu volcano); TP, Taupo Volcanic Centre; OK, Okataina Volcanic Centre (Tr, Mt Tarawera); TU, Tuhua Volcanic Centre (Mayor Island); W, Whakaari (White Island); TVZ, Taupo Volcanic Zone. Distribution of submarine volcanoes after Wright et al. (2004).

near Auckland *c.* 1400 AD (zone 1c). These soils are classed mainly as Tephric Recent Soils in NZSC (Clayden et al., 1997; Hewitt, 1998).

(2) Vitrands (also Vitriaquands and Vitricryands) occur in central-eastern North Island on weakly weathered, relatively coarse textured, glassy and pumiceous rhyolitic deposits (zone 2) derived from the Taupo eruption in *c.* 232 AD ± 15 and the Kaharoa eruption in *c.* 1314 AD ± 12 (Fig. 4). Small areas of Vitrands in eastern North Island were also formed on rhyolitic pumiceous deposits from the Waimihia eruption (from Taupo caldera) *c.* 3500 calendar years ago.

All these Vitrands are classed as Pumice Soils in NZSC and an example is shown in Fig. 5. This Humic Udivitrand has been formed on a layer of Taupo Ignimbrite about 80 cm thick that was emplaced instantaneously as a single unit around 1770 years ago. At higher elevations and with increasing leaching and podzolization, soils on similar materials grade to Andic Haplohumods (Parfitt and Saigusa, 1985; Molloy and Christie, 1998; Palmer et al., in press).

(3) Udands (also Aquands and Cryands) occur largely as multisequal soils on composite, weakly to moderately weathered, relatively fine textured, multiple tephra deposits of varying ages derived from eruptions from either the andesitic or rhyolitic volcanic centres (Fig. 1), typically both (Fig. 3), hence are time transgressive. The Udands occur in the Taranaki-Ruapehu region (comprising mainly andesitic tephras, zone 3), King Country-western Waikato (mixed andesitic-rhyolitic, zone 4), eastern Waikato-western Bay of Plenty-Coromandel Peninsula (mainly rhyolitic, zone 5), and Auckland-Northland (basaltic, zone 6), the age span of sola increasing towards distal sites as constituent tephra layers become thinner and shallower and increasingly intermixed with one another (Fig. 3).

All these Udands are grouped as Allophanic Soils in NZSC. An example is given in Fig. 6, which shows a Typic Hapludand formed on a composite of multiple, pedogenically intermixed and moderately weathered, thin tephras that have accumulated since about 26,500 years ago (this arbitrary 'starting' point is marked stratigraphically by Kawakawa Tephra, also known as Oruanui or Aokautere tephra : Froggatt and Lowe, 1990). Individual tephra layers preserved in nearby 20,000 year-old lakes (see inset) allow likely constituent parent tephras in the upper soil profile, each a few millimetres to centimetres thick, to be identified (Lowe, 1988, 2000; Selby and Lowe, 1992). At this site in the southern part of zone 5 (Fig. 3), most of the tephra layers are rhyolitic (~94%) but very thin andesitic tephras, identified on the basis of mineralogical and geochemical analyses of the soil materials and the tephras in the lake cores (Lowe, 1986, 1988), are also present (~6%). The rate of tephra accumulation since Kawakawa Tephra was deposited has been about 50 mm ka^{-1}, sufficiently slow for andisolization to take place concomitantly with upbuilding (and about the same rate as quartzofeldspathic loess accumulation in Westland, New Zealand : Almond and Tonkin, 1999). Earlier episodes of tephra and loess deposition and generally slower soil formation are evident below Kawakawa Tephra, and these lower horizons are typically halloysitic rather than allophanic because of resilication at depth or because of drier and colder climatic conditions, or both (Parfitt et al., 1983; Lowe, 1986; Singleton et al., 1989; Dahlgren et al., 1993; Lowe and Percival, 1993).

On a global basis, Vitrands (30.8%) and Udands (30.6%) are the two most common Andisol suborders, followed by Cryands (28.0%) (Wilding, 2000). These suborders similarly predominate in North Island : Vitrands ≥Udands >>Cryands, Aquands.

In contrast to Japan and some other long-settled volcanic countries (e.g. Ecuador), epipedons on Andisols in North Island generally do not meet thickness or other requirements for melanic horizons in Soil Taxonomy because New Zealand's Polynesian settlement history, and thus change from forest cover to fern and tussock grassland and scrub, dates from only *c.* 1250–1300 AD (Newnham et al., 1998; Hogg et al., 2003; Table 1). However, some A horizons, typically ≤20 cm thick and under bracken fern and native grasses or scrub, are black or very dark, have high organic carbon contents, and contain type-A humic acids that are characteristic of melanic horizons (Birrell et al., 1971; Birrell and Pullar, 1973; Hosono et al., 1991; Sase and Hosono, 1996; see also Nanzyo et al., 1993).

Utilization and management

High-quality, versatile soils are of very limited extent in New Zealand (~5.4% : Singleton, 1999)

Table 1. Classes, general features and approximate extent of Andisols in New Zealand and Australia (Japan and Iceland for comparison)

Andisol suborder (± great group)	National soil classification[h]	General parent material composition	Vegetation	Climate[m]	Area[n] km^2	Area[n] %
	New Zealand					
‘Entic’Udands/Cryands[a]	Tephric Recent Soils	Andesitic	Dense podocarp–	Ud, Me–Cr	1,200	0.5
Vitrands[b]	Pumice Soils	Rhyolitic	broadleaf forest	Ud, Me–Cr	17,200	6.5
Udands[c]	Allophanic Soils	Andesitic to rhyolitic[i]	(bracken, grass/ shrubland)[k]	Ud, Me–Th	13,700	5.5
Total New Zealand[d]					32,100	12.5
As global percentage of Andisols						~2.7
	Australia					
Xerands[e]	Andic, Chernic Tenosols	Basaltic[j]	Dense to semi–	Xe, Me	85	0.001
Total Australia			open woodland & grassland/shrubs[l]		85	0.001
As global percentage of Andisols						~0.007
Japan						
Total Japan[f]					69,000	18.0
As global percentage of Andisols						~5.8
Iceland						
Total Iceland[g]					80,000	80
As global percentage of Andisols						~6.7

[a] Weakly developed Udands or Cryands usually marginal to Orthents.

[b] Includes small areas of Vitriaquands and Vitricryands as well as Udivitrands.

[c] Mainly Hapludands but Hydrudands also occur (Suryaningtyas, 1998). Includes small areas of Aquands (Epi/Endoaquands) and Cryands (Haplocryands).

[d] Areas estimated using Parfitt et al. (1988), Rijkse and Hewitt (1995), Hewitt (1998), and Kirkpatrick (1999, p.11).

Table 1 contd

[e] Approximate area estimated from ~50-cm isopach in Fig. 7, which is based on Blackburn (1959), Hutton et al. (1959), Sheard (1986, 1990), and field work; small areas of soils with andic properties, and possibly Andisols, occur in the 'Newer Volcanics' province of western Victoria (e.g. Tower Hill, Mt Eccles, Red Rock, or Mt Porndon volcanic complexes) (Hamblin and Greenland, 1972; Lowe et al., 1996).

[f] Includes Hapludands, Udivitrands, Melanudands, Fulvudands, Hydrudands; area is maximum estimate (Otawa, 1986; Takahashi and Shoji, 2002).

[g] Mainly Vitricryands; area is maximum estimate (Arnalds and Kimble, 2001).

[h] From New Zealand Soil Classification (Hewitt, 1998) and Australian Soil Classification (Isbell, 2002).

[i] Small local areas of Udands are formed also in free-draining scoriaceous basaltic tephra deposits in northern North Island (Fig. 3).

[j] Eruptions also incorporated exotic calcareous and siliceous material (see text) (after Lowe et al., 1996). The eruptions *c.* 5000 years ago were evidently recorded in Aboriginal oral tradition (Sheard, 1990).

[k] Most soils developed under dense native forest but repeated burning by early Polynesians (Maori) in parts of North Island from *c.* 1250–1300 AD resulted in many being developed under bracken fern, shrubland and native grasses (McGlone, 1989; Newnham et al., 1998; McGlone and Wilmshurst, 1999; Hogg et al., 2003). Many of the soils have been under introduced grasses (together with bracken and scrub) since European settlement from the mid-1800s.

[l] European accounts from the early–mid-1800s described the volcanic soils beyond the craters generally as heavily timbered with dense to semi-open woodland and some open grassy meadows with ferns, whereas the crater interiors were sparsely treed with grasses and shrub cover on the steeper slopes (M.J. Sheard, pers. comm. 2004; see also Dodson, 1975). Plants fossilized by the volcanic ash include common tree or shrub species and grasses (Sheard, 1978, 1983). The impact of Aboriginal 'fire-stick' burning after the eruptions was probably limited to understorey firing in cooler times to avoid deforestation (M.J. Sheard, pers. comm., 2004). The area has been under introduced grasses and bracken fern since extensive European clearance from the mid-1800s (Blackburn, 1959).

[m] Soil moisture and temperature regimes from Soil Survey Staff (1999): Ud, udic; Xe, xeric; Me, mesic; Cr, cryic; Th, thermic; local aquic moisture regimes and conditions gave rise to Aquands and Vitriaquands in New Zealand.

[n] Globally, Andisols cover about 1.24 million km^2 (Soil Survey Staff, 1999; Kimble et al., 2000), around 0.84% of the world's land surface (Takahashi and Shoji, 2002).

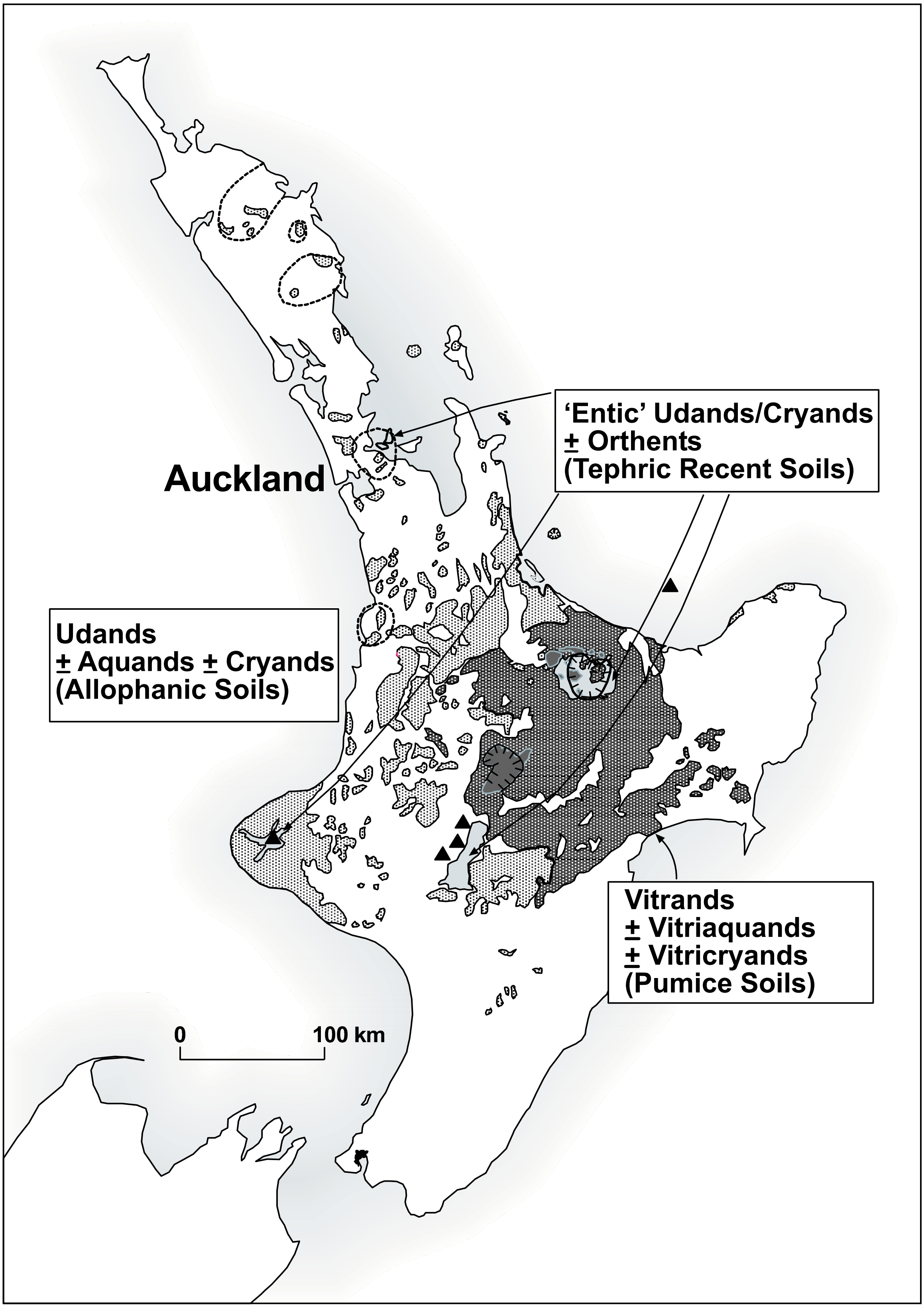


Fig. 2. Distribution of three main groupings of Andisols in North Island (after Kirkpatrick, 1999, based on Rijkse and Hewitt, 1995). Classifications according to NZSC are given in parentheses (Hewitt, 1998).

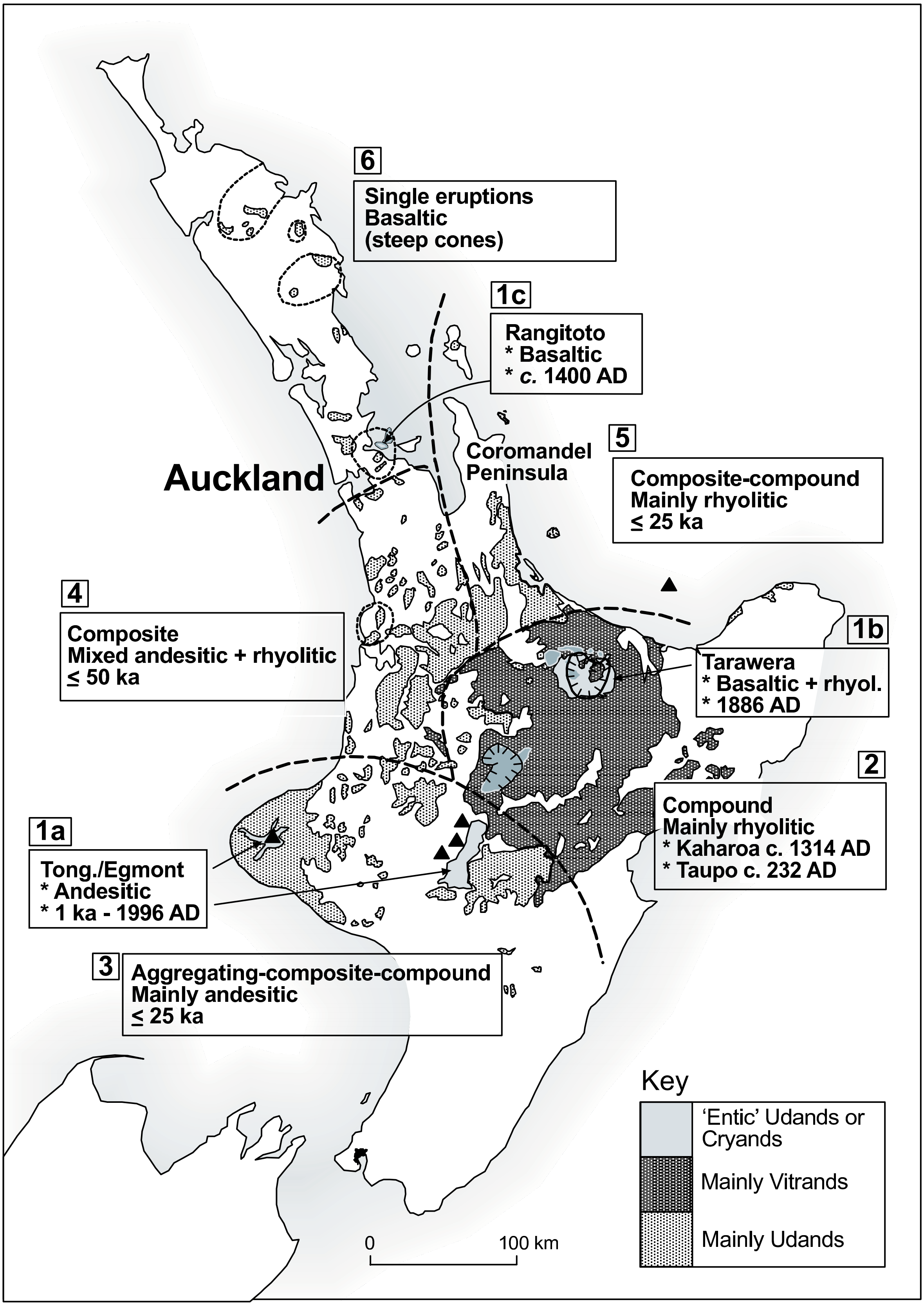


Fig. 3. Generalised subdivisions of the main groupings of Andisols in North Island into six zones according to their multisequal soil character (soil stratigraphy), the primary composition(s) of component tephras, and approximate ages of the soil profiles (ka, thousands of years).

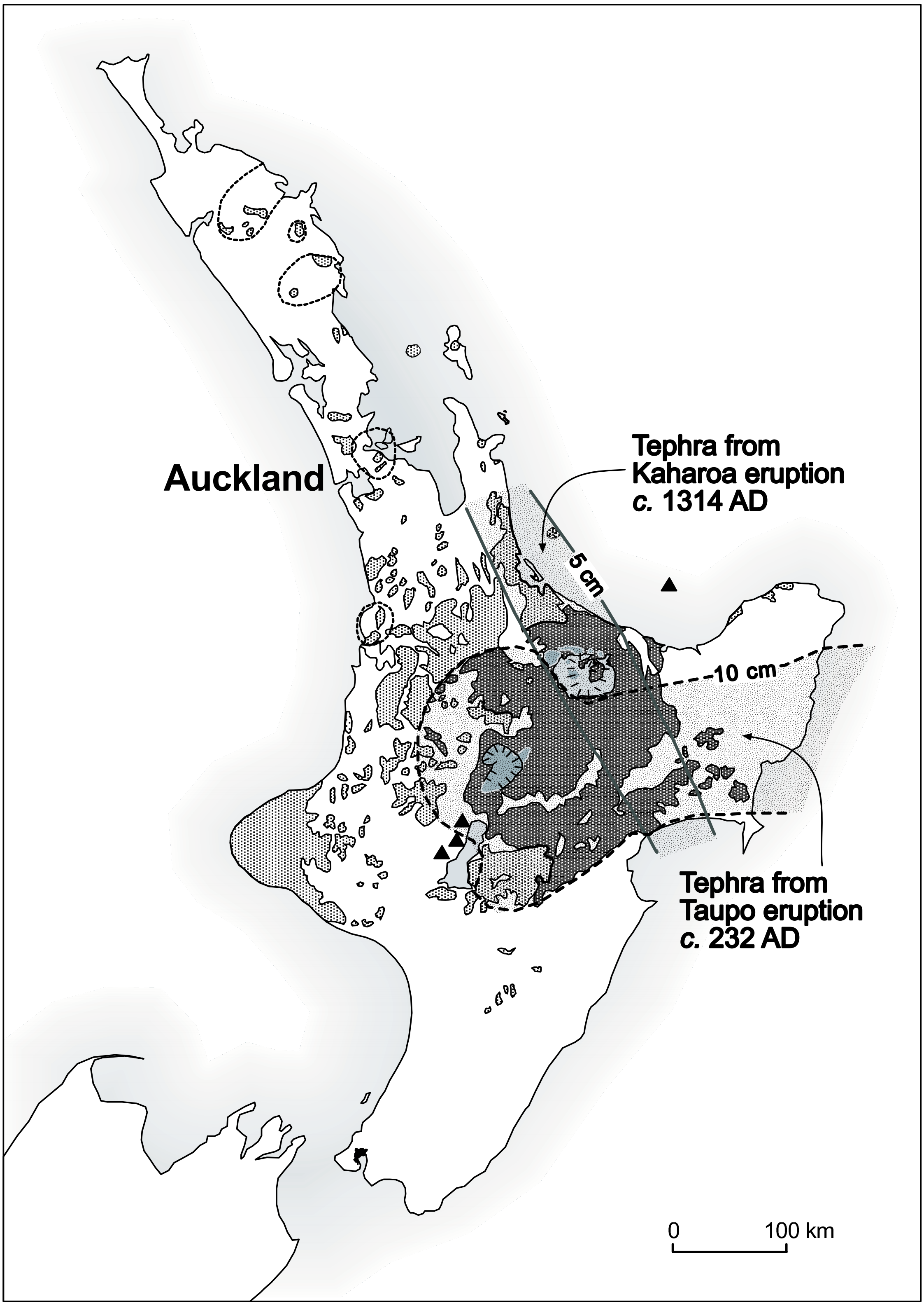


Fig. 4. Approximate single isopach distributions of tephra deposited from the two most recent rhyolitic eruptions in North Island: the Taupo eruption *c.* 232 AD ± 15 from Taupo Volcanic Centre (after Wilson and Walker, 1985; Sparks et al., 1995; Lowe and de Lange, 2000), and the Kaharoa eruption *c.* 1314 AD ± 12 from Mt Tarawera in Okataina Volcanic Centre (after Lowe et al., 1998; Hogg et al., 2003). Key for shading as in Fig. 3.

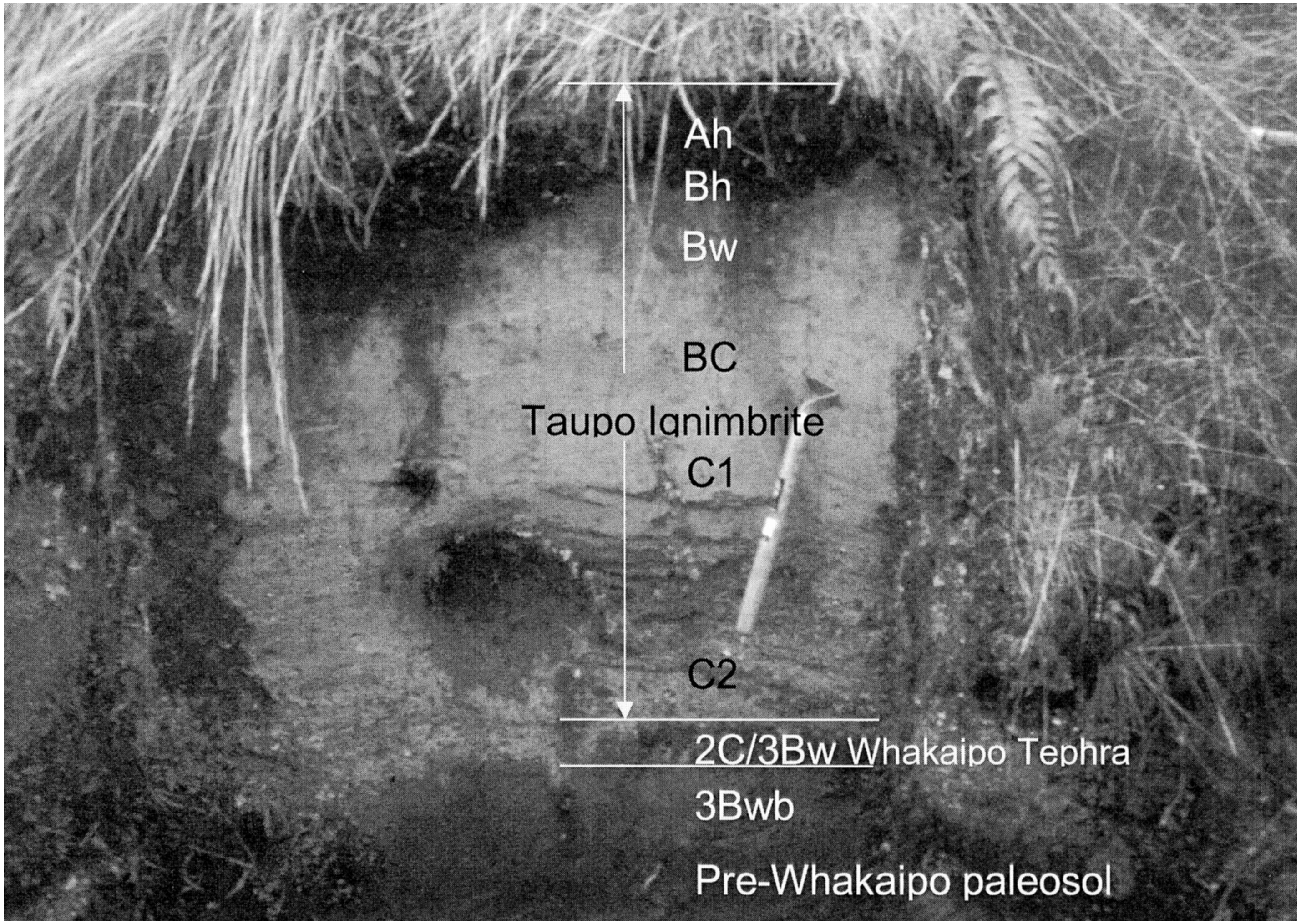


Fig. 5. Humic Udivitrand developed on Taupo Ignimbrite (unconsolidated pyroclastic density current deposit from phase Y6 of Taupo eruption *c.* 232 AD), on Mamaku Plateau east of Tokoroa (New Zealand Map Series 260 grid reference U16/745313). In NZSC, this soil is a Podzolic Orthic Pumice Soil (Hewitt, 1998), a member of the Oruanui series (Rijkse, 1979; Hill, 1999). Whakaipo Tephra (Unit V) was erupted from Taupo Volcanic Centre *c.* 2800 years ago (Wilson, 1993). Horizonation is based on Schoeneberger et al. (2002). Photo: D.J. Lowe.

Fig. 6. Typic Hapludand developed on a composite of multiple tephras overlying Okareka Tephra (*c.* 22,500 years old, Newham et al., 2003) and earlier eruptives and tephra loess deposits and associated paleosols, near Putaruru (T15/575498) in southeastern Waikato region. Kawakawa Tephra (from Taupo VC) is *c.* 26,500 years old (Wilson, 2001), Rotoehu Ash (from Okataina VC) is *c.* 55,000 years old (Newnham et al., 2004). In NZSC, the modern soil is a Typic Orthic Allophanic Soil (Hewitt, 1998), a member of the Tirau series (McLeod, 1992). Horizonation is based on Schoeneberger et al. (2002). Inset shows Holocene tephra layers preserved in organic lake sediment (after Lowe, 1988). Main photo: D. J. Lowe

and Andisols, covering ~29% of the North Island, are pre-eminent among them, especially Udands, because of important soil ecosystem services they provide including sorption, water storage and supply, natural fertility (with regular maintenance dressings of potassic superphosphate and other fertilisers), and foundation support (Leamy et al., 1980; Hewitt, 2001).

The Vitrands (Pumice Soils in NZSC) are extremely deficient in phosphorus, potassium, sulphur, nitrogen and magnesium and typically deficient also in micronutrients such as cobalt (especially), selenium, copper, boron, iodine and molybdenum (Cornforth, 1998; Hewitt, 1998; Molloy and Christie, 1998). Because of their coarse textures and low strength, they tend to be easily depleted of nutrients, readily eroded, and droughty (Gibbs, 1968; Selby and Hosking, 1973). On the credit side, however, shifting nutrient balances by fertilizer management of Vitrands is much easier than in other soils of greater weathering and clay content, and they respond well to fertilizer inputs (Gibbs et al., 1968; Molloy and Christie, 1998). Occasional 'dustings' by andesitic tephra fallout from eruptions of volcanoes in the Tongariro Volcanic Centre have generally added small but beneficial amounts of nutrients to Vitrands (and some Udands), such as from the 1995-1996 eruptions of Mt Ruapheu that added between 30–1500 kg ha^{-1} sulphur, as well as small quantities of selenium, potassium and magnesium, to substantial land areas (Cronin et al., 1998). The young age of the Vitrands also means that soil nutrients are potentially available from ongoing weathering by carbonic acid of the easily-weatherable fine pumice fragments in the parent material (Bakker et al., 1996; Dahlgren et al., 2004; Zabowski et al., in press).

Vitrands are generally well suited to deep-rooting plants such as lucerne (alfalfa) and exotic pine plantations, which are dominated by *Pinus radiata* in central North Island (Molloy and Christie, 1998; Palmer et al., in press), and also for forest farming (Tustin et al., 1979). Except where subsoils are compact, trees are usually able to develop extensive, deep root systems very rapidly and hence tap and exploit reserves of nutrients and moisture in buried soils (Gibbs, 1970; Knight and Will, 1970; Will, 1974). In addition, the very fine vesicularity of the pumice particles in the Vitrands confers a high water storage capacity (20–30% of soil volume) yet the soils are highly porous, drain readily, and have good infiltration characteristics (Jackson, 1974; Molloy and Christie, 1998). Edaphic factors relating to plantation forestry on Vitrands have been the focus of considerable study (e.g. Madgwick et al., 1990; Beets et al., 2004), and research into sustainable forest practices has increased markedly since the Resource Management Act was enacted in 1991 and New Zealand became a signatory to the Montreal Process (e.g. Murphy et al., 1997; Richardson et al., 1999; Simcock et al., 2003; Oliver et al., 2004; Palmer et al., in press).

The Udands (Allophanic Soils in NZSC), like their counterparts beyond New Zealand, are generally of high value for food production because they are deep and have outstanding physical properties including free drainage and high porosity and hence good aeration, high friability and good tilth, low bulk densities, stable aggregates, and high plant-available moisture retention (Gibbs et al., 1968; Soil Bureau Staff, 1968; Fletcher and Jessen, 1982; Allbrook, 1983; Molloy and Christie, 1998). These features thus provide a high rate of seedling emergence, excellent rooting characteristics, and strong resistance to drought stress (Dahlgren et al., 2004), ideal for plant production and grazing in udic climates because the upper soil profiles are not sticky and when moist absorb large amounts of water without swelling (Gibbs et al., 1968). On the other hand, the Udands have high maintenance requirement for phosphorus, potassium and magnesium for dairying, and they respond to regular additions of these and also to lime where pHs are <5.5 (Gibbs et al., 1968; Cornforth, 1998; Hewitt, 1998). Sulphur retention is also high (Cornforth, 1998) and cobalt is marginally deficient in more strongly leached Udands (Hewitt, 1998). However, the Udands are unmatched with regard to versatility for pasture growth (16-18 tonnes dry matter/ha in the Taranaki and Waikato regions), cropping (maize in thermic parts of the Waikato region), horticulture (including nurseries, kiwifruit, tamarillos, berry fruit, pip and stone fruit, citrus, asparagus, feijoas, and avocados, especially in the Bay of Plenty and in Northland for warmth-requiring crops), and sports fields (Molloy and Christie, 1998). Although under growing pressure from much more intense cropping and grazing, North Island Udands are proving to be remarkably resilient soils (e.g. Cotching et al., 1979; Magesan et al., 1999; Shepherd et al., 2001; Parfitt et al., 2002), but in some cases properties have deteriorated as a consequence of such intensification (e.g. Singleton and Addison, 1999). Udands and some Vitrands are being used successfully for effluent (wastewater) irrigation and the disposal of biosolids (Cameron et al., 1997; Degens et al, 2000; Speir, 2002; Magesan and Wang, 2003; Barton et. al., 2005), and they are proving to be generally effective at pesticide sorption (Baskaran et al., 1996).

HOLOCENE VOLCANISM AND ANDISOLS IN SOUTHEAST SOUTH AUSTRALIA

Origin, age and composition of Holocene volcanoes and eruptives

The volcanoes of southeast South Australia form the western extension of the Newer Volcanics Province of western Victoria (Sheard and Nicholls, 1989) and comprise two distinct groups : a northern Pleistocene group in the Mount Burr range (not considered further) and a southern Holocene group of two isolated basaltic eruption centres at Mounts Gambier and Schank (Fig. 7; Sheard, 1978, 1983, 1990, 1992). About 10 km apart, Mounts Gambier and Schank are both aged about 5000 years old on the basis of a combination of radiocarbon, thermoluminescence and palaeomagnetic dating, and are the youngest volcanoes on the Australian mainland (Barton and McElhinny, 1980; Barbetti and Sheard, 1981; Smith and Prescott, 1987; Sheard, 1990). Leaney et al. (1995) suggested that the Mount Gambier complex was considerably older, at least 28,000 years old, but this older age has been disputed (M.J. Sheard, pers. comm. 2004).

Mounts Gambier and Schank comprise unusual complex maar and cone structures built over eruptive fissures and, strongly influenced by the presence of abundant groundwater, erupted mainly tephra including scoria, lapilli and ash that was dispersed to a thickness of about 5 cm or less at around 10−12 km from source (Fig. 7; Hutton et al., 1959; Hutton, 1974); lava is less common and rarely soil−forming.

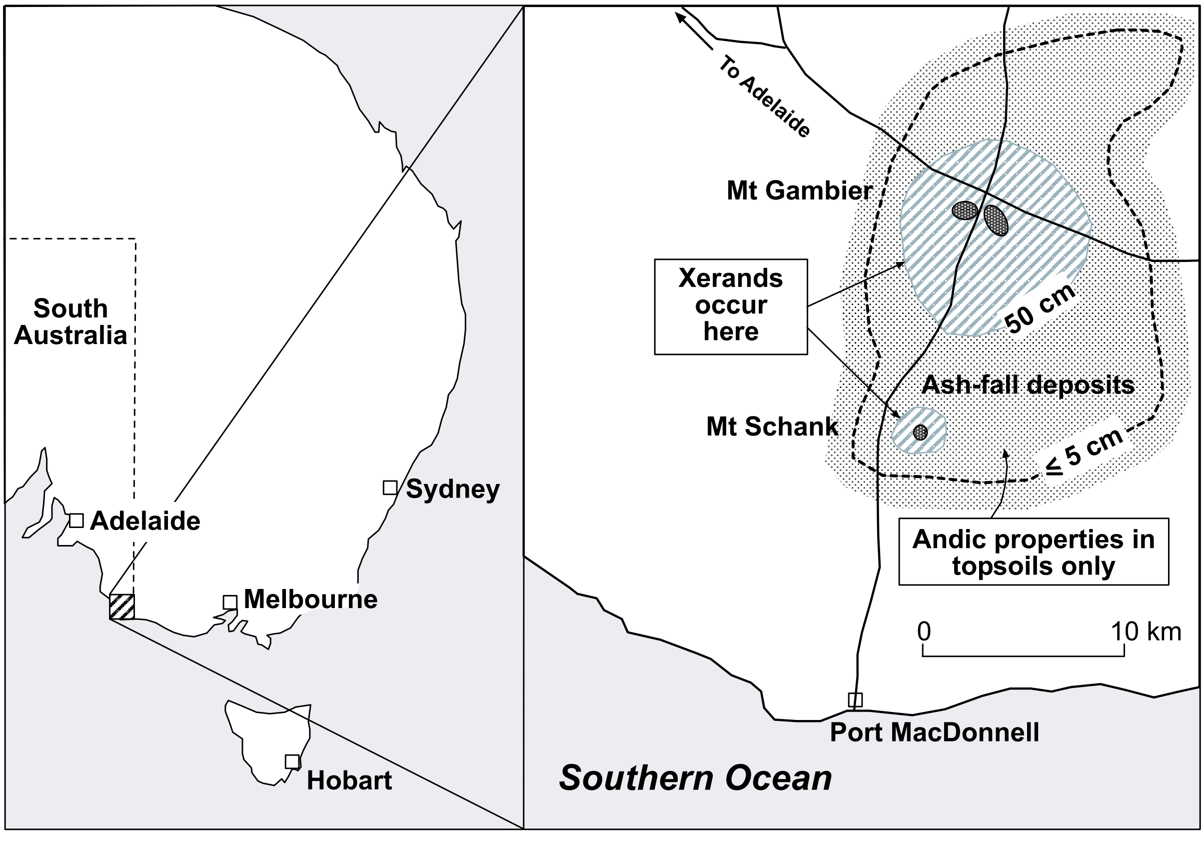


Fig. 7. Location of Mts Gambier and Schank in southeastern South Australia and generalised distribution of ash−fallout from these volcanoes and associated soils with andic properties.

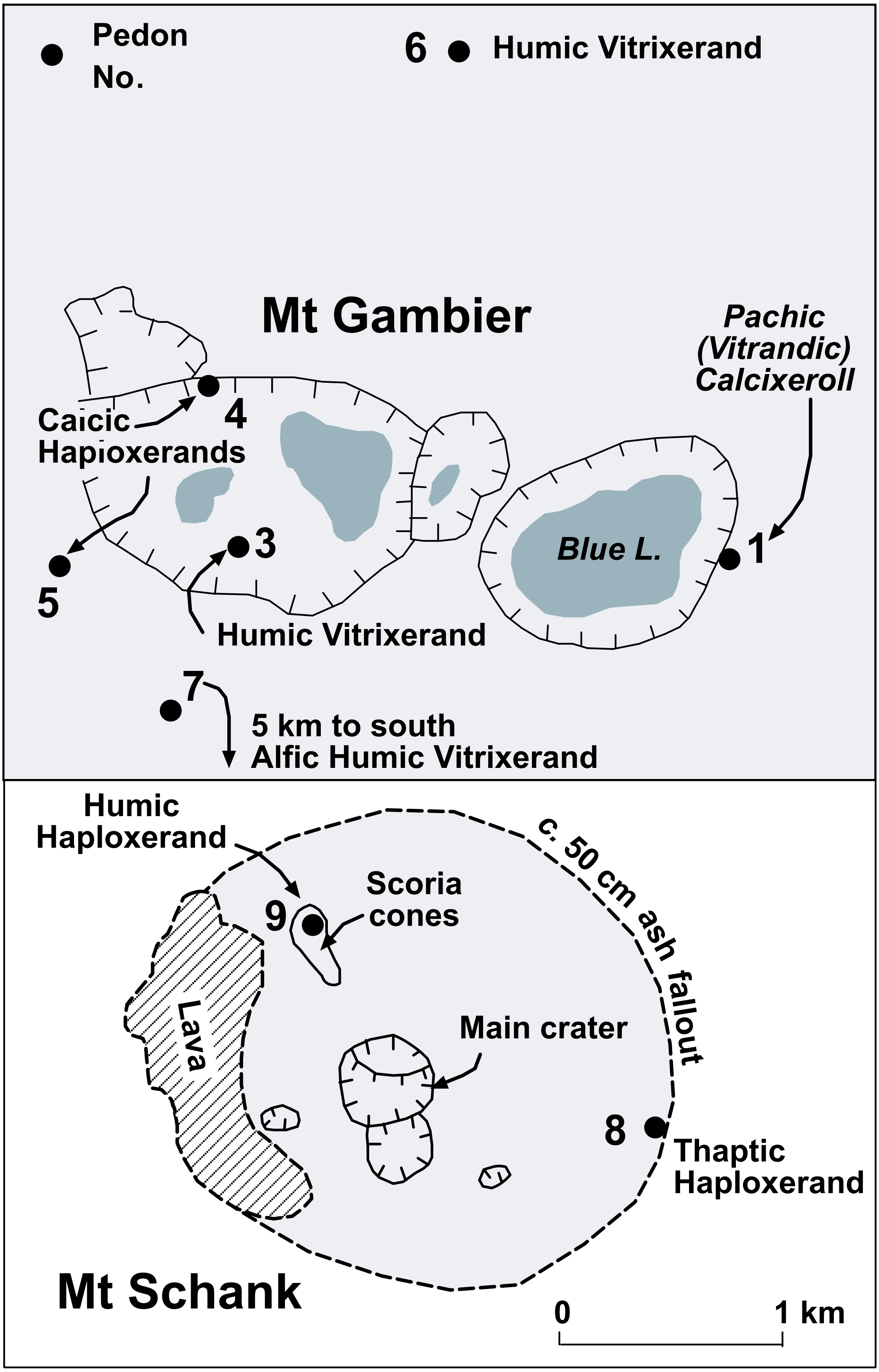


Fig. 8. Locations of pedons studied at Mts Gambier and Schank and subgroup classifications (Soil Survey Staff, 1999). In upper panel, Mt Gambier township lies mainly on the northern slopes of the cones/crater features, and ashfall thickness is ≥~50 cm throughout. Grey areas represent crater lakes.

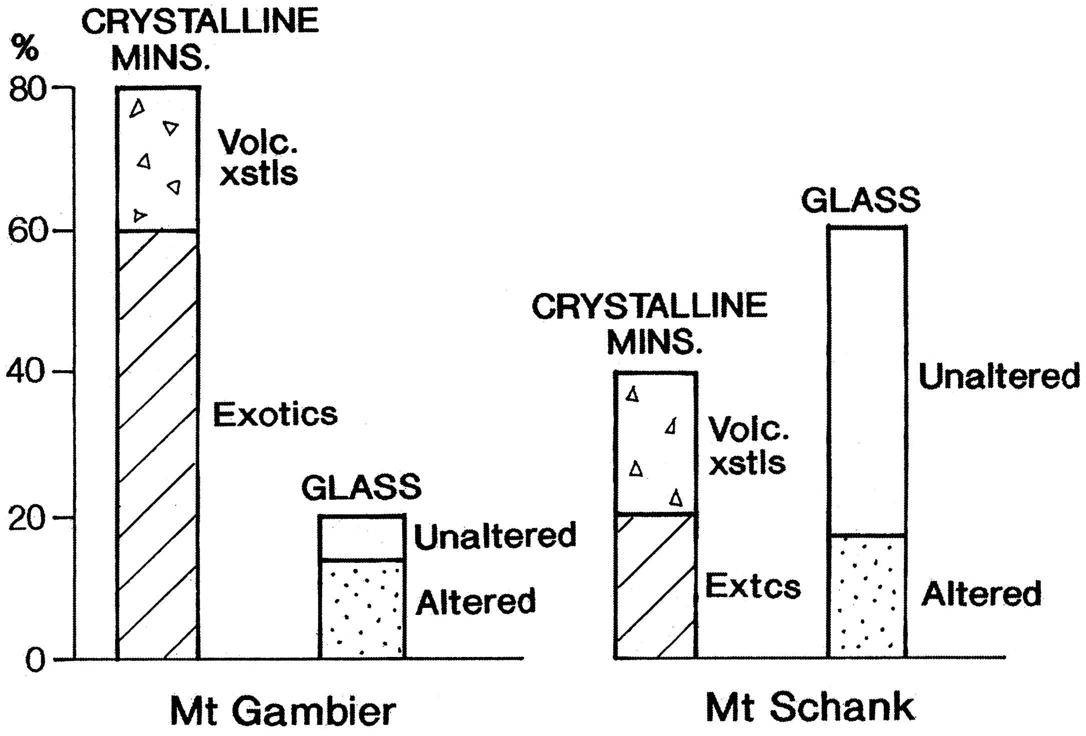


Fig. 9. Mineralogy of sand fractions of tephra–derived soils in the Mt Gambier region, showing contrast between Mt Gambier and Mt Schank. Juvenile volcanic crystals include olivine, labradorite, titanaugite, and Fe–Ti oxides; exotic minerals include quartz, chert, sponge spicules. After Sheard et al. (1993) and Lowe et al. (1996).

Both volcanic complexes stratigraphically overlie consolidated, calcareous aeolian sands (Bridgewater Formation) and Oligocene–Miocene limestone (Gambier Limestone) (Sheard, 1986, 1990, 1992), and therefore the resultant pyroclastic deposits, and hence soils, may contain large proportions (up to 60%, see below) of exotic, non–volcanic material including limestone fragments as well as basaltic material (Lowe et al., 1996).

Five pedons were studied by Lowe (1992) and Lowe et al. (1996) at Mount Gambier, two at Mount Schank, and one mid–way (pedon 7) between the two centres (Fig. 8). Sand fractions of the Mount Gambier soils, acid–treated to remove $CaCO_3$ and analysed using optical mineralogy and an electron microprobe, are dominated by crystalline minerals (≥80%) including substantial exotic, silicic minerals (quartz, chert, sponge spicules), magma–derived crystals of forsteritic olivine, labradorite, titanaugite, and Fe–Ti oxides, and little volcanic glass (<20%), most of which is altered (Fig. 9). In contrast, the acid–treated sand fractions of the Mt Schank soils contain abundant glass (≥50%), most of which is unaltered, fewer exotic minerals (quartz, sponge spicules), and magma–derived crystals of titanaugite, olivine, labradorite, and Fe–Ti oxides (Fig. 9). The volcanic glass shards from Mts Gambier and Schank are basaltic (mean SiO_2 content = 48–50%) and Al–rich (mean Al_2O_3 = 16.3%), the two centres being indistinguishable on the basis of glass major oxide compositions (Sheard et al., 1993).

Soil physical and chemical properties and clay mineralogy

Profile morphologies of the pedons at four of the sites are illustrated in Fig. 10. At sites close to source, the soils are developed entirely within pyroclastic eruptives from Mt Gambier or Mt Schank (e.g. Fig. 10A, B) but at the more distant sites (pedons 7 and 8) the ashfall of ~60 cm thickness has buried and isolated the pre–existing soils, forming compound, multisequal soil profiles containing buried paleosols (Fig. 10C, D).

The soils were formed under xeric moisture and

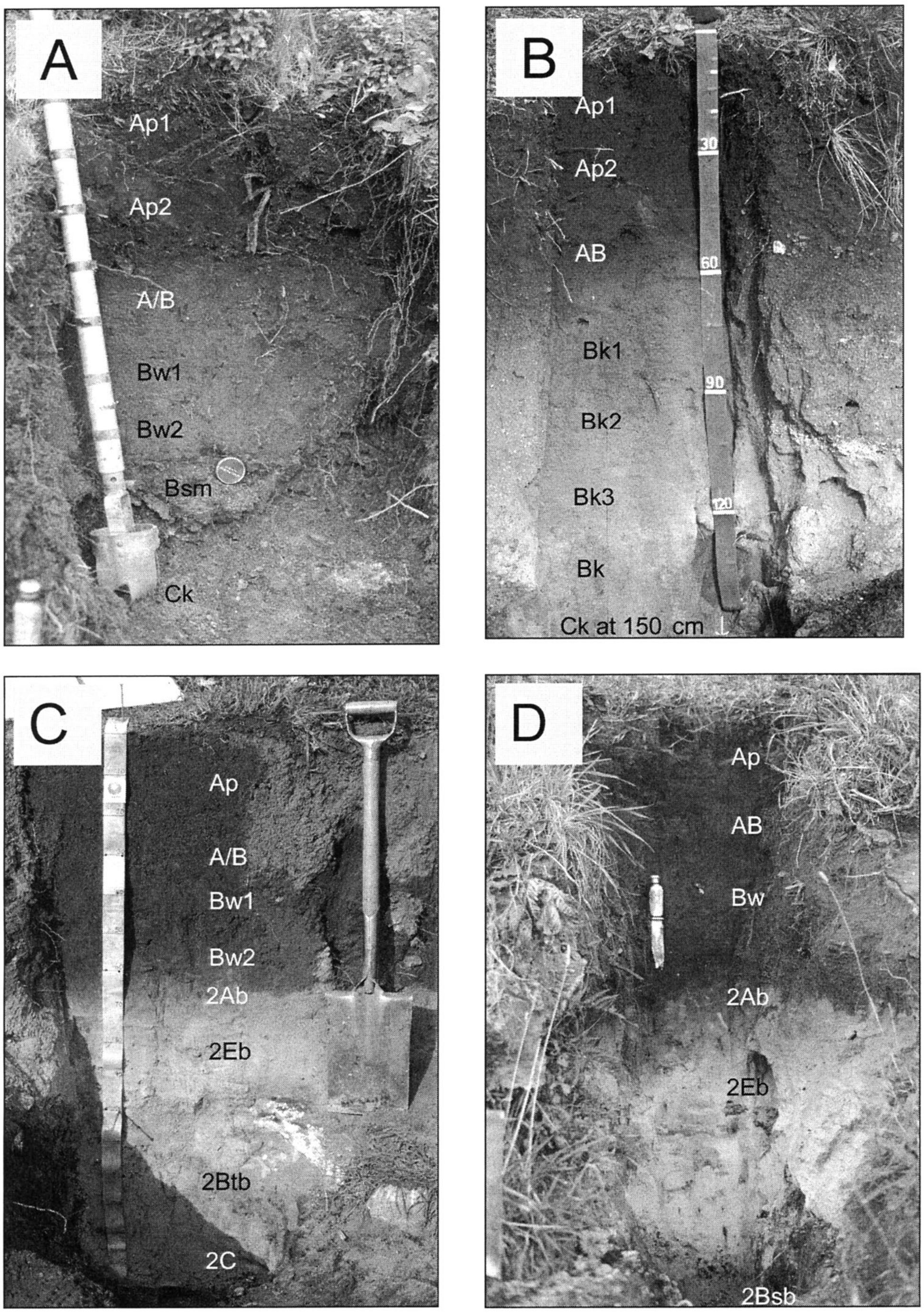


Fig.10. Profiles of four Xerands in the Mt Gambier region at sites indicated in Fig. 8. Soils and locations are described in Lowe (1992). Horizonation is based on Schoeneberger et al. (2002). All photographs by D.J. Lowe.

A. Humic Vitrixerand at site 3 (Brownes Lake; see also McKenzie et al., 2004, p.346) developed in coarse, basaltic lava spatter and ashfall deposits. In the Australian Soil Classification, this soil is a Humose, Andic, Chernic Tenosol (Isbell, 2002). Marks on auger at 10–cm intervals.

B. Calcic Haploxerand at site 4 (Potters Point) developed in fine basaltic lava spatter (above ~65 cm) over basaltic ash and lapilli fall deposits. In ASC, this soil is a Humose–Calcareous, Andic, Chernic Tenosol. Scale in cm.

C. Alfic Humic Vitrixerand at site 7 (Louden Hill Quarry) developed in basaltic ashfall deposits overlying a buried soil on aeolian sand. In ASC, this soil is a Melanic, Andic, Chernic Tenosol *on* Bleached, Dystrophic, Yellow Chromosol. Scale in cm.

D. Thaptic Haploxerand at site 8 (Laslett Rd) developed on basaltic ashfall deposits overlying a buried soil on aeolian sand. In ASC, this soil is a Humose, Andic, Chernic Tenosol *on* Fragic, Sesquic, Aeric Podosol. Knife is 25 cm long.

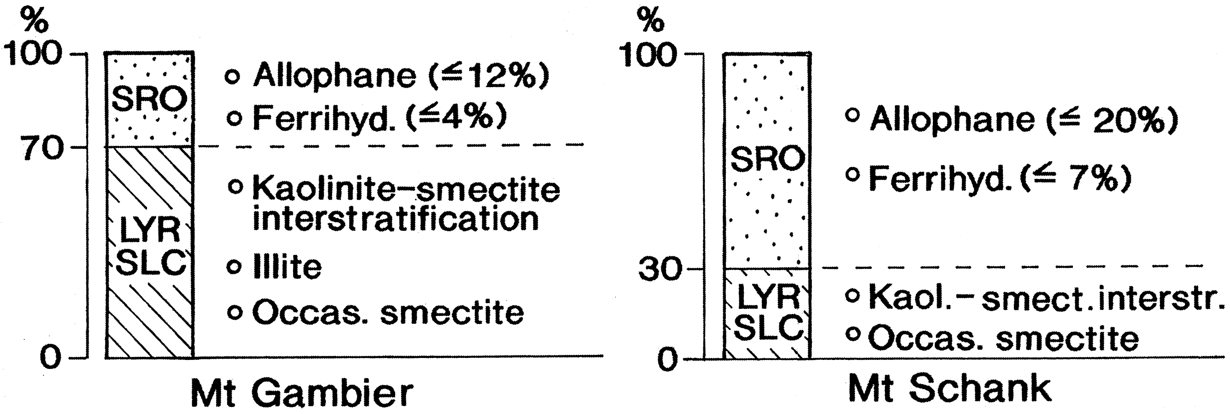


Fig. 11. General distribution of clays (percentages on fine–earth basis) in profiles in the Mt Gambier region, contrasting the differences between Mt Gambier and Mt Schank (after Lowe et al., 1996; see also Churchman, 2000). SRO = short–range–order clays, LYR SLC = layer silicate clays.

mesic temperature regimes characterised by moist (drizzly), cool winters and very warm, dry summers (Table 1). Although the annual rainfall at Mt Gambier is around 700 mm, water balance studies show that usually about 280 mm of water drains through upper soil profiles over a period of three to ten weeks in winter and early spring (Allison and Hughes, 1978).

At both Mts Gambier and Schank, the soils are generally weakly weathered and have deep, black to dark brown, very friable, polyhedral or apedal earthy A horizons with gritty silt loam textures (mean <2 μm–clay contents = 11–22%) and a mean of 5.5 ± 1.0 % organic carbon (range 3.7–6.9%). Subsoils comprise mainly brown or yellowish to greyish–brown, friable Bw horizons with textures of loamy sands or sandy or silt loams (mean <2 μm–clay contents = 2–15%), usually with gravel (e.g. Fig 10B). Visible or HCl–reactive accumulations of $CaCO_3$, up to 38 wt%, are common at Mt Gambier, forming Bk and Ck horizons (e.g. Fig. 10A, B). The soils to 60 cm depth have generally low bulk densities (mean = 0.84 ± 0.13 Mg m^{-3}, range 0.68–1.17 Mg m^{-3}), high acid–oxalate extractable Al_{ox} and Fe_{ox} (both 4%) if $CaCO_3$ is low and vice versa, P retentions that exceed 50% (highest when Al_{ox} is high), 1.5 MPa water from 7 to 26%, and pH_{water} values from 6.4 to 8.0 (Lowe et al., 1996).

Clay fractions (<2 μm) at Mt Gambier are dominated by layer silicate minerals including kaolinite interstratified with smectite, illite and sometimes discrete smectite (Churchman and Lowe, 1993; Lowe et al., 1996). No halloysite was detected by the formamide expansion test (Churchman et al., 1984). Substantial allophane (up to ~12% on a fine–earth basis, FEB) and ferrihydrite (up to ~4%, FEB) occur in some horizons (Fig. 11).

Clay fractions of the soils at Mt Schank contain substantial allophane (up to ~20%, FEB) and ferrihydrite (up to 17%, FEB) in most horizons, with some layer silicates (not illite) found in the lowest horizons (Fig. 11). The greater abundance of SRO minerals at Mt Schank than at Mt Gambier may reflect the contrast in proportions of glassy and xenolithic materials making up the parent materials (Fig. 9), with the abundant basaltic glass at Mt Schank weathering more readily to release Al (Churchman and Lowe, 1993; Lowe et al., 1996).

For each of the pedons, the ratio of Al to Si of the allophane (Al_{ox}–Al_{py}/Si_{ox}) tends to diminish with increasing depth (Churchman and Lowe, 1993; Churchman, 2000). It averages~1.8 in upper horizons, dropping to 1.5 and then 1.2 in intermediate horizons; there is little or no allophane in lowermost horizons that are usually calcareous. These trends imply that 'imogolite–like'Al–rich allophane is forming in the upper horizons whereas 'halloysite–like' Si–rich allophane is forming at intermediate depths lower in the profiles, consistent with a general Si–leaching model (Parfitt et al., 1983; Lowe, 1986, 1995). It was suggested by Lowe et al. (1996) that the formation of the Al–rich allophane in the upper horizons was probably the result of frequent seasonal leaching (consistent with low $CaCO_3$ content) during winter or early spring when rainfall is highest and evapotranspiration lowest. The drainage of ~280 mm of water through the upper profile each year on average matches or just exceeds the threshold of about 250 mm needed for Al−rich allophane to form, based on New Zealand models (Parfitt et al., 1984; Lowe, 1995; Churchman, 2000). In contrast, the formation of the Si−rich allophane in the intermediate horizons is probably the result of weaker leaching, the net rainfall being insufficient to penetrate to such depths very often because only about 100 mm of water drains through the intermediate horizons each year at Mt Gambier (Allison and Hughes, 1982), and thus silica levels remain relatively high. The silicic components derived from the limestones have provided an additional potential source of silica (Fig. 9). The lack of allophane, together with the presence of smectite, in the lowest horizons is consistent with minimal leaching or possibly silica accumulation, or both. The absence of halloysite is surprising because previous work on soils formed in dry (or calcareous) regimes suggested that this was likely to be the main clay mineral formed (e.g. Mizota and van Reeuwijk, 1989; Parfitt, 1990b; Takahashi et al., 1993; Silber et al., 1994; Qafuka et al., 2004).

Thus clay mineral formation, especially allophane, is affected partly by leaching and partly by the parent material composition. The Mt Gambier sand fractions are dominated by exotic, silicic crystalline minerals and the clays comprise mainly layer silicates with some allophane in upper horizons, whereas the Mt Schank clay fractions are dominated by Al−rich basaltic glass and the clays consist of mainly allophane with minor layer silicates.

Classification

Most of the pedons studied at Mts Gambier and Schank are Vitrixerands or Haploxerands (Figs. 8, 10), all but one qualifying by exceeding required glass contents >5% to >12% (Soil Survey Staff, 1999). Pedon 1 failed because it contained too little glass (>21% glass required), and instead is a Pachic Calcixeroll. This subgroup keys out just before Vitrandic Calcixerolls. An alternative classification – 'Vitrandic Pachic' Calcixeroll – would encapsulate both the thick mollic epipedon and (weak) andic properties of the soil (Lowe et al., 1992; Fitzpatrick et al., 1992).

Xerands, making up only 3.5% of the Andisols (Wilding, 2000), are comparatively rare on a global basis because andisolization processes that form SRO clays (or Al/Fe−humus complexes), and hence andic soil properties, tend to be favoured by strong leaching in cool, udic moisture regimes (Mizota and van Reeuwijk, 1989; Parfitt and Kimble, 1989; Parfitt, 1990b; Kimble et al., 2000; Dahlgren et al., 2004). Moreover, the South Australian Xerands have evidently formed quite rapidly, in only 5000 years, assuming the ages for the volcanoes are accurate. They are the only Andisols currently identified in Australia, but small patches of soils with andic properties probably occur on younger volcanoes in the Newer Volcanics Province in western Victoria such as at the Tower Hill volcanic complex, and possibly elsewhere (Table 1).

In the Australian Soil Classification (Isbell, 2002), the pedons are all classed as Andic, Chernic Tenosols, this great group being erected specifically by the late Ray F. Isbell to accommodate the Xerands first identifed at Mts Gambier and Schank by Lowe et al. (1992) (Isbell et al., 1997). Most of the characteristic thick topsoils, which gave rise to their classification previously as Chernozems (e.g. Blackburn, 1959; Stace et al., 1968), qualify in Isbell (2002) as Humose horizons (e.g. Fig. 10A, B, D) but pedon 7, with less organic carbon, has a Melanic horizon[1] (Fig. 10C).

Why do the Xerands around Mts Gambier and Schank tend to have such thick A horizons? One suggestion is that Aboriginal 'fire−stick' farming (see Mckenzie et al., 2004, p.112), although probably limited to understorey burning in cooler times to avoid deforestation (M.J. Sheard, pers. comm. 2004), has led to partial 'melanisation' of the ash−derived soils in areas where semi−open woodland and open grassy meadows with ferns prevailed (Table 1). Alternatively, the Al−rich nature of the readily weatherable basaltic glass at Mt Schank may have helped stabilise humus accumulation via Al−humus complexing in addition to forming allophane.

Utilization and management

The Xerands in the Mt Gambier region are regarded as valuable, versatile soils that have been used for agriculture (dairying) and horticulture (especially vegetables chiefly potatoes, onions, and also cut flowers) since the 1850s. They are essentially

---

[1] Note : The Melanic horizon of Isbell (2002) differs from that of Soil Survey Staff (1999).

free of micro-element deficiencies and have relatively high levels of P, N, K, and S (Blackburn, 1959; Hutton, 1974). However, extended periods of cutting lucerne hay have resulted in the development of potassium deficiency where the volcanic-ash derived soils are shallow (less than ~50 cm thick) over limestone or calcareous aeolian sand. Although naturally high in total phosphorus, a small response was obtained to this element at such sites (R. Merry, pers. comm. 2004). Some soils near Mt Schank have been used for effluent irrigation.

ACKNOWLEDGEMENTS

DJL is very grateful to Professor Masahiko Saigusa and Professor Masami Nanzyo (Tohoku University), and others, for their hospitality and for financial support that enabled him to attend both the 2nd International Andisol Workshop and the 6th International Symposium on 'Plant-Soil Interactions at Low pH' in Sendai, Japan, in August 2004. We are also grateful to Professor Nanzyo for edditing the paper and to the following for their invaluable support or for providing information on soils or mineralogy relevant to New Zealand or Australia : Drs Allan Hewitt, Roger Parfitt, and Hugh Wilde (Landcare Research, New Zealand), Dr Reece Hill (Environment Waikato), Associate Professor Roger Briggs (University of Waikato), and Dr Paul Froggatt (Victoria University of Wellington); Dr Rob Fitzpatrick, Richard Merry, Clive Kirkby and Adrian Beech (CSIRO, Adelaide); Dr Jock Churchman (University of Adelaide); Dr Malcom Sheard (Primary Industries and Resources, South Australia) who also commented on the manuscript; Professor Wayne Hudnall (Texas Tech University); and the late Ray Isbell (CSIRO, Canberra). Professors Hiroshi Takesako and Hiroko Obanai (Meiji University) are thanked for their support and hospitality. Mr George N. Lasleft (Adelaide) is especially thanked for providing information about farming in the Mt Gambier region in the 1920s-1940s.

REFERENCES

Allbrook, R.F. 1983. Some physical properties of allophane soils from the North Island, New Zealand. New Zealand Journal of Science 26 : 481-492.

Allison, G.B., and M.W. Hughes. 1978. The use of environmental chloride and tritium to estimate total recharge to an unconfined aquifer. Australian Journal of Soil Research 16 : 181-195.

Alloway, B.V., M.S. McGlone, V.E. Neall, and C.G. Vucetich. 1992. The role of Egmont-sourced tephra in evaluating the paleoclimatic correspondence between the bio- and soil-stratigraphic records of central Taranaki, New Zealand. Quaternary International 13-14 : 187-194.

Almond, P.C., and P.J. Tonkin. 1999. Pedogenesis by upbuilding in an extreme leaching and weathering environment, and slow loess accretion, south Westland, New Zealand. Geoderma 92 : 1-36.

Arnalds, O., and J. Kimble. 2001. Andisols of deserts in Iceland. Soil Science Society of America Journal 65 : 1778-1786.

Bakker, L., D.J. Lowe, and A.G. Jongmans. 1996. A micromorphological study of pedogenic processes in an evolutionary soil sequence formed on Late Quaternary rhyolitic tephra deposits, North Island, New Zealand. Quaternary International 34-36 : 249-261.

Barbetti, M., and M.J. Sheard. 1981. Palaeomagnetic results from Mounts Gambier and Schank, South Australia. Journal of the Geological Society of Australia 28 : 385-394.

Barton, C.E., and M.W. McElhinny. 1980. Ages and ashes in lake floor sediment cores from Valley Lake, Mt Gambier, South Australia. Transactions of the Royal Society of South Australia 104 : 161-165.

Barton, L., L.A. Schipper, G.F. Barkle, M. McLead, T.W. Speir, M.D. Taylor, A.C. McGill, A.P. van Schaik, N.B. Fitzgerald, and S.P. Pandey. 2005. Land application of domestic effluent on to four soil types. Journal of Environmental Quality 34 : 635-643.

Baskaran, S., N.S. Bolan, A. Rahman, and R.W. Tilman. 1996. Pesticide sorption by allophanic and non-allophanic soils of New Zealand. New Zealand Journal of Agricultural research 39 : 297-310.

Beets, P.N., G.R. Oliver, M.O. Kimberley, S.H. Pearce, and B. Rodgers. 2004. Genetic and soil factors associated with variation in visual magnesium deficiency symptoms in *Pinus radiata*. Forest Ecology and Management 189 : 263-279.

Birrell, K.S., and Pullar, W.A. 1973. Weathering of paleosols in Holocene and late Pleistocene tephras in central North Island, New Zealand. New Zealand Journal of Geology and Geophysics 16 : 687–702.

Birrell, K.S., W.A. Pullar, and J.C. Heine. 1971. Pedological, chemical, and physical properties of organic horizons of paleosols underlying the Tarawera Formation. New Zealand Journal of Science 14 : 187–218.

Blackburn, G. 1959. The soils of County Grey, South Australia. CSIRO Soils and Land Use Series 33. 51p.

Cameron, K.C., Di, H.J., and McLaren, R.G. 1997. Is soil an appropriate dumping ground for our wastes? Australian Journal of Soil Research 35 : 995–1035.

Churchman, G.J. 2000. The alteration and formation of soil minerals by weathering. In : Sumner, M.E. (ed–in–chief) Handbook of Soil Science. CRC Press, Baca Baton : F3–76.

Churchman, G.J., and D.J. Lowe. 1993. Poorly crystalline clay minerals in soils from Holocene basaltic tephra in a calcareous environment and xeric moisture regime in South Australia. Abstracts, 10th International Clay Conference, Adelaide : P–30.

Churchman, G.J., J.S. Whitton, G.G.C. Claridge, and B.K.G. Theng. 1984. Intercalation method using formamide for differentiating halloysite from kaolinite. Clays and Clay Minerals 32 : 241–248.

Clayden, B., A.E. Hewitt, M. McLeod, W. Rijkse, H. Wallace, and R.H. Wilde. 1997. North Island soil surveys : classification of named soils by subgroups of the New Zealand Soil Classification. Landcare Research, Lincoln. 149p.

Cornforth, A. 1998. Practical Soil Management. Lincoln University Press, Whitireia Publishing, and Daphne Brasell Associates, Canterbury. 248p.

Cotching, W.E., R.F. Allbrook, and H.S. Gibbs. 1979. Influence of maize cropping on the soil structure of two soils in the Waikato district, New Zealand. New Zealand Journal of Agricultural Research 22 : 431–438.

Cowie, J.D., and J.D.G. Milne. 1973. Maps and sections showing the distribution and stratigraphy of North Island loess and associated cover deposits, New Zealand. New Zealand Soil Survey Report 6.

Cronin, S.J., V.E. Neall, and A.S. Palmer. 1996. Investigation of an aggrading paleosol developed into andesitic ring–plain deposits, Ruapehu volcano, New Zealand. Geoderma 69 : 119–135.

Cronin, S.J., M.J. Hedley, V.E. Neall, R.G. Smith. 1998. Agronomic impact of tephra fallout from the 1995 and 1996 Ruapehu Volcano eruptions, New Zealand. Environmental Geology 34 : 21–30.

Dahlgren, R., S. Shoji, and M. Nanzyo. 1993. Mineralogical characteristics of volcanic ash soils. Developments in Soil Science 21 : 101–143.

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

Degens, B.P., L.A. Schipper, J.J. Claydon, J.M. Russell, and G.W. Yeates. 2000. Irrigation of an allophanic soil with dairy factory efluent for 22 years : responses of nutrient storage and soil biota. Australian Journal of Soil Research 38 : 25–35.

Dodson, J.R. 1975. The pre–settlement vegetation of the Mt Gambier area, South Australia. Transactions of the Royal Society of South Australia 99 : 89–92.

Fitzpatrick, R.W., W.H. Hudnall, D.J. Lowe, D.J. Maschmedt, and R.H. Merry. 1992. Proposed changes in the classification of Histosols, Alfisols, Andisols, Aridisols, Inceptisols, Mollisols, Entisols, and Spodosols in South Australia. CSIRO Division of Soils Technical Report 51/1992. 17p.

Fletcher, J.R., and M.R. Jessen. 1982. Land use capability of yellow–brown loams. In : Neall, V.E. (ed) Soil Groups of New Zaland. Part 6 Yellow–brown Loams. New Zealand Society of Soil Science, Lower Hutt : 96–101.

Froggatt, P.C., and D.J. Lowe. 1990. A review of late Quaternary silicic and some other tephra formations from New Zealand : their stratigraphy, nomenclature, distribution, volume, and age. New Zealand Journal of Geology and Geophysics 33 : 89–109.

Gibbs, H.S. 1968. Volcanic–ash soils of New Zealand. New Zealand Department of Scientific and Industrial Research Information Series 65. 39p.

Gibbs, H.S. 1970. Nature of paleosols in New Zealand, and their classification. In : Yaalon, D.H. (ed) Paleopedology – Origin, Nature, and Dating of Paleosols. ISSS and Israel University Press, Jerusalem : 229−244.

Gibbs, H.S., J.D. Cowie, and W.A. Pullar. 1968. Soils of North Island. New Zealand Soil Bureau Bulletin 26(1) : 48−67.

Hamblin, A.P., and D.J. Greenland. 1972. Mineralogy of soils from the Holocene volcanic area of southern Australia. Australian Journal of Soil Research 10 : 61−79.

Hewitt, A.E. 1995. Soil map of the South Island, New Zealand Soil Classification 1 : 1,000,000 scale. Manaaki Whenua, Landcare Research, Lincoln, New Zealand.

Hewitt, A.E. 1998. New Zealand Soil Classification, 2nd edition. Landcare Research Science Series 1. 133p.

Hewitt, A.E. 2001. New Zealand soils in volcanic materials. Abstract in ‘Volcanic Soils : Properties, Processes and Land Use’. International Workshop of COST Action 622, Soil Resources of European Volcanic Systems, Ponta Delgarda, Azores Portugal, October 2001.

Hill, R. B. 1999. Applying a land systems approach to describe and partition soil and forest variability, southern Mamaku Plateau, part of Kinleith Forest, New Zealand. Unpublished Ph.D. thesis, Lincoln University, Canterbury, New Zealand.

Hill, R.B., P.J. Tonkin, and P.C. Almond. 1999. A revised stratigraphic interpretation of the geomorphology and late Quaternary erosion history of the southern Mamaku Plateau. Geological Society of New Zealand Miscellaneous Publication 107A : 64.

Hodder, A.P.W., B.E. Green, and D.J. Lowe. 1990. A two−stage model for the formation of clay minerals from tephra−derived volcanic glass. Clay Minerals 25 : 313−327.

Hodder, A.P.W., T.R. Naish, and D.J. Lowe. 1996. Towards an understanding of thermodynamic and kinetic controls on the formation of clay minerals from volcanic glass under various environmental conditions. In : Pandalai, S.G. (ed) Recent Research Developments in Chemical Geology. Research Signpost, Trivandrum, India : 1−11.

Hogg, A.G., T.F.G. Higham, D.J. Lowe, J. Palmer, P. Reimer, and R.M. Newnham. 2003. A wiggle−match date for Polynesian settlement of New Zealand. Antiquity 77, 116−125.

Hosono, M., Y. Oba, T. Sase, T. Utsugawa, and K. Aoki. 1991. Holocene volcanic ash soils at Waimangu Road tephra section, North Island, New Zealand : soil−forming vegetation relationships. Quaternary Research (Tokyo) 30 : 91−101.

Houghton, B.F., S.D. Weaver, C.J.N. Wilson, and M.A. Lanphere. 1992. Evolution of a Quaternary peralkaline volcano : Mayor Island, New Zealand. Journal of Volcanology and Geothermal Research 51 : 217−236.

Hutton, J.T., G. Blackburn, and A.R.P. Clarke. 1959. Identification of volcanic ash in soils near Mount Gambier, South Australia. Transactions of the Royal Society of South Australia 82 : 93−98.

Hutton, J.T. 1974. Chemical characterization and weathering changes in Holocene volcanic ash in soils near Mount Gambier, South Australia. Transactions of the Royal Society of South Australia 98 : 179−184.

Isbell, R.F. 2002. The Australian Soil Classification, Revised edition. Australian Soil and Land Survey Series 4. CSIRO Publishing, Melbourne. 152p.

Isbell, R.F., W.S. McDonald, and L.J. Ashton. 1997. Concepts and rationale of the Australian Soil Classification. ACLEP, CSIRO Land and Water, Canberra. 152p.

Jackson, R.J. 1974. Physical properties. In : Read, N.E. (ed) Soil Groups of New Zealand. Part 1 Yellow−brown Pumice Soils. New Zealand Society of Soil Science, Lower Hutt : 97−102.

Jongmans, A.G., F. Van Oort, P. Buurman, A.M. Jaunet, and J.D.J. van Doesburg. 1994. Morphology, chemistry and mineralogy of isotropic aluminosilicate coatings in a Guadaloupe Andisol. Soil Science Society of America Journal 58 : 501−507.

Johnson, D.L., and D. Watson−Stegner. 1987. Evolution model of pedogenesis. Soil Science 143 : 349−366.

Kimble, J.M., C.−L. Ping, M.E. Sumner, and L.P. Wilding. 2000. Andisols. In : Sumner, M.E. (ed−in−chief) Handbook of Soil Science. CRC Press, Baca Baton : E209−224.

Kirkpatrick, R. 1999. Bateman Contemporary Atlas New Zealand. David Bateman, Auckland. 160p.

Knight, P.J., and G.M. Will. 1970. An appraisal of nutrient supplies available for tree growth in a pumice soil. Earth Science Journal 4 : 1−16.

Leamy, M.L., G.D. Smith, F. Colmet−Daage, and M. Otawa. 1980. The morphological characteristics of Andisols. In : Theng, B.K.G. (ed) Soils With Variable Charge. New Zealand Society of Soil Science, Lower Hutt : 17−34.

Leaney, F.W.J., G.B. Allison, J.C. Dighton, and S. Trumbore. 1995. The age and hydrological history of Blue Lake, South Australia. Palaeogeography, Palaeoclimatology, Palaeoecology 118 : 111−130.

Lowe, D.J. 1986. Controls on the rates of weathering and clay mineral genesis in airfall tephras : a review and New Zealand case study. In : Colman, S.M., and D.P. Dethier (eds) Rates of Chemical Weathering of Rocks and Minerals. Academic Press, Orlando : 265−330.

Lowe, D.J. 1988. Stratigraphy, age, composition, and correlation of late Quaternary tephras interbedded with organic sediments in Waikato lakes, North Island, New Zealand. New Zealand Journal of Geology and Geophysics 31 : 125−165.

Lowe, D.J. 1992. Profile descriptions of Quaternary basaltic volcanogenic soils of the Mount Gambier area, southeast South Australia. CSIRO Division of Soils Technical Report 9/1992. 26p.

Lowe, D.J. 1995. Teaching clays : from ashes to allophane. In : Churchman, G.J., R.W. Fitzpatrick, and R.A. Eggleton (eds) Clays : Controlling the Environment. Proceedings 10th International Clay Conference, Adelaide (1993). CSIRO Publishing, Melbourne : 19−23.

Lowe, D.J. 2000. Upbuilding pedogenesis in multisequal tephra−derived soils in the Waikato region. Proceedings, Australian and New Zealand 2nd Joint Soils Conference, Lincoln University. New Zealand Society of Soil Science 2 : 183−184.

Lowe, D.J., and W.P. de Lange. 2000. Volcano−meteorological tsunamis, the *c.* AD 200 Taupo eruption (New Zealand) and the possibility of a global tsunami. The Holocene 10 : 401−407.

Lowe, D.J., and B.E. Green. 1992. A hydrofluoric acid dissolution method for determining volcanic glass content of tephra−derived soils (Andisols). Australian Journal of Soil Research 30 : 573−581.

Lowe, D.J., and J.B. Hunt. 2001. A summary of terminology used in tephra−related studies. In : Juvigné, E.T., and J.−P. Raynal (eds) Tephras : Chronology, Archaeology. Les Dossiers de l'Archeo−Logis 1 : 17−22.

Lowe, D.J., and H.J. Percival. 1993. Clay mineralogy of tephras and associated paleosols and soils, and hydrothermal deposits, North Island. Guidebook for New Zealand Pre−Conference Field Trip F1, 10th International Clay Conference, Adelaide. 110 p.

Lowe, D.J, R.H. Merry, W.H. Hudnall, and R.W. Fitzpatrick. 1992. Proposed changes to Soil Taxonomy : IV. Andisols. Abstracts, Australian Society of Soil Science 4th National Soils Confererence, Adelaide : 7.

Lowe, D.J., G.J. Churchman, R.H. Merry, R.W. Fitzpatrick, M.J. Sheard, and W.H. Hudnall. 1996. Holocene basaltic volcanogenic soils of the Mt Gambier area, South Australia, are unusual globally : what do they tell us? Proceedings of ASSS and NZSSS National Soils Conference, University of Melbourne 2 : 153−154.

Lowe, D.J., B.G. McFadgen, T.F.G. Higham, A.G. Hogg, P.C. Froggatt, and I.A. Nairn. 1998. Radiocarbon age of the Kaharoa Tephra, a key marker for late−Holocene stratigraphy and archaeology in New Zealand. The Holocene 8 : 487−495.

Lowe, D.J., R.M. Newnham, and J.D. McCraw. 2000a. Quaternary environmental change in New Zealand and its effects on the soil pattern. Proceedings, Australian and New Zealand 2nd Joint Soils Conference, Lincoln University. New Zealand Society of Soil Science 3 : 117−118.

Lowe, D.J., R.M. Newnham, B.G. McFadgen, and T.F.G. Higham. 2000b. Tephras and New Zealand archaeology. Journal of Archaeological Science 27 : 859−870.

Lowe, D.J., M.J. Tippett, P.J.J. Kamp, I.J. Liddell, R.M. Briggs,and J.L. Horrocks. 2001. Ages on weathered Plio−Pleistocene tephra sequences, western North Island, New Zealand. In : Juvigné, E.T., and J.−P. Raynal (eds) Tephras : Chronology, Archaeology. Les Dossiers de l'Archeo−Logis 1 : 45−60.

Lowe, D.J., R.M. Newnham, and J.D. McCraw. 2002. Volcanism and early Maori society in New Zealand. In : Torrence, R., and J. Grattan (eds) Natural Disasters and Cultural Change. Routledge, London : 126−161.

Madgwick, H.A.I., G.R. Oliver, and A.T. Lowe. 1990. Boron, copper, manganese and zinc nutrition of *Pinus radiata* plantations. Forest Ecology and Management 37 : 37−48.

Magesan, G.N., and H. Wang. 2003. Application of municipal and industrial residuals in New Zealand forests : an overview. Australian Journal of Soil Research 41 : 557–569.

Magesan, G.N., J.C. Williamson, G.P. Sparling, L.A. Schipper, and A.R. Lloyd–Jones. 1999. Hydraulic conductivity in soils irrigated with wastewater of differing strengths : field and laboratory studies. Australian Journal of Soil Research 37 : 391–402.

McCraw, J.D. 1975. Airfall deposits of New Zealand. Royal Society of New Zealand Bulletin 13 : 35–44.

McGlone, M.S. 1989. The Polynesian settlement of New Zealand in relation to environmental and biotic changes. New Zealand Journal of Ecology (Supplement) 12 : 115–129.

McGlone, M.S., and J.M. Wilmshurst. 1999. Dating initial Maori environmental impact in New Zealand. Quaternary International 59 : 5–16.

McKenzie, N., D. Jacquier, R. Isbell, and K. Browne. 2004. Australian Soils and Landscapes : An Illustrated Compendium. CSIRO Publishing, Melbourne. 416p.

McLeod, M. 1992. Soils of part northern Matamata County, North Island, New Zealand. Department of Scientific and Industrial Research Land Resources Science Report 18.

Mizota, C., and L.P. van Reeuwijk. 1989. Clay mineralogy and chemistry of soils formed in volcanic materials in diverse climatic regions. International Soil Reference and Information Centre Soil Monograph 2. 185p.

Molloy, L., and Q.R. Christie. 1998. Soils in the New Zealand Landscape, 2nd edition. New Zealand Society of Soil Science, Lincoln. 253p.

Murphy, G., J.G. Firth, and M.F. Skinner. 1997. Soil disturbance effect of *Pinus radiata* growth during the first 11 years. New Zealand Forestry 42 : 27–30.

Nanzyo, M., Dahlgren, R., and S. Shoji. 1993. Chemical characterisitcs of volcanic ash soils. Developments in Soil Science 21 : 145–187.

Nanzyo, M. 2002. Unique properties of volcanic ash soils. Global Environmental Research 6 : 99–112.

Neall, V.E. 1977. Genesis and weathering of Andosols in Taranaki. Soil Science 123 : 400–408.

Newnham, R.M., D.J.Lowe, M.S. McGlone, J.M. Wilmshurst, and T.F.G. Higham. 1998. The Kaharoa Tephra as a critical datum for earliest human impact in northern New Zealand. Journal of Archaeological Science 25 : 533–544.

Newnham, R.M., D.J. Lowe, and P.W. Williams. 1999. Quaternary environmental change in New Zealand : a review. Progress in Physical Geography 23 : 567–610.

Newnham, R.M., D.N. Eden, D.J. Lowe, and C.H. Hendy. 2003. Rerewhakaaitu Tephra, a land–sea marker for the Last Termination in New Zealand, with implications for global climate change. Quaternary Science Reviews 22 : 289–308.

Newnham, R.M., D.J. Lowe, J.D. Green, G.M. Turner, M.A. Harper, M.S. McGlone, S.L. Stout, S. Horie, and P.C. Froggatt. 2004. A discontinuous ca. 80 ka record of Late Quaternary environmental change from Lake Omapere, Northland, New Zealand. Palaeogeography, Palaeoclimatology, Palaeoecology 207 : 165–198.

Oliver, G.R., P.N. Beets, L.G. Garrett, S.H. Pearce, M.O. Kimberley, J.B. Ford–Robertson, and K.A. Robertson. 2004. Variations in soil carbon in pine plantations and implications for managment in New Zealand monitoring soil carbon stocks in relation to land–use change and forest sites. Forest Ecology and Management 203 : 283–295.

Otawa, M. 1986. Morphology and classification. In : Wada, K. (ed) Ando Soils in Japan. Kyushu University Press, Hakozaki : 3–20.

Palmer, D.J., D.J. Lowe, T.W. Payn, B.K. Höck, C.D.A. McLay, and M.O. Kimberley. in press. Soil and foliar phosphorus as indicators of sustainability for *Pinus radiata* plantation forestry in New Zealand. Forest Ecology and Management.

Parfitt, R.L. 1990a. Allophane in New Zealand–a review. Australian Journal of Soil Research 28 : 343–360.

Parfitt, R.L. 1990b. Soils formed in tephra in different climatic regions. Transactions 14th Congress, International Society of Soil Science, Kyoto 7 : 134–139.

Parfitt, R.L., and B. Clayden. 1991. Andisols – the development of a new order in Soil Taxonomy. Geoderma 49 : 181–198.

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

Parfitt, R.L., and T.H. Webb. 1984. Allophane in some South Island yellow–brown shallow and stony soils and high country and upland yellow–brown earths. New Zealand Journal of Science 27 : 37–40.

Parfitt, R.L., and M. Saigusa. 1985. Allophane and humus-aluminium in Spodosols and Andepts formed from the same volcanic ash beds in New Zealand. Soil Science 139 : 149-155.

Parfitt, R.L., M. Russell, and G.E. Orbell. 1983. Weathering sequence of soils from volcanic ash involving allophane and halloysite, New Zealand. Geoderma 29 : 41-57.

Parfitt, R.L., M. Saigusa, and J.D. Cowie. 1984. Allophane and halloysite formation in a volcanic ash bed under different moisture conditions. Soil Science 138 : 360-364.

Parfitt, R.L., C.W. Childs, B. Clayden, M.L. Leamy, and D.I. Kinloch (compilers). 1988. International Committee on the Classification of Andisols (ICOMAND) Circular Letter No. 10. 80p.

Parfitt, R.L., A. Parshotam, and G.J. Salt. 2002. Carbon turnover in two soils with contrasting mineralogy under long-term maize and pasture. Australian Journal of Soil Research 40 : 127-136.

Ping, C.-L. 2000. Volcanic soils. In : Sigurdsson, H. (ed-in-chief) Encyclopaedia of Volcanoes. Academic Press, San Diego : 1259-1270.

Ping, C.-L., S.Shoji, and T. Ito. 1988. The properties and classification of three volcanic ash-derived soils in Alaska. Soil Science 148 : 8-28.

Pullar, W.A., and K.S. Birrell. 1973. Age and distribution of late Quaternary pyroclastic and associated cover deposits of the Rotorua and Taupo area, North Island, New Zealand. New Zealand Soil Survey Report 1.

Qafoku, N.P., E. Van Ranst, A. Noble, and G. Baert. 2004. Variable charge soils : their mineralogy, chemistry and management. Advances in Agronomy 84 : 159-215.

Richardson, B., M.F. Skinner, and G. West. 1999. The role of forest productivity in defining the sustainability of plantation forestry in New Zealand. Forest Ecology and Management 122 : 125-137.

Rijske, W. 1979. Soils of Rotorua Lakes district, North Island, New Zealand. New Zealand Soil Survey Report 43.

Rijske, W.C., and A.E. Hewitt. 1995. Soil map of the North Island, New Zealand Soil Classification 1 : 1,000,000 scale. Manaaki Whenua, Landcare Research, Lincoln, New Zealand.

Saigusa, M., and N. Matsuyama. 2004. Distribution and agronomic aspects of non-allophanic Andisols. Proceedings 6th International Symposium on Plant-Soil Interactions at Low pH, Sendai. Japanese Society of Soil Science and Plant Nutrition : 334-335.

Sase, T., and M. Hosono. 1996. Vegetation histories of Holocene volcanic ash soils in Japan and New Zealand - relationship between genesis of melanic volcanic ash soils and human impact. Earth Science (Chikyu Kagaku) 50 : 466-482.

Shane, P.A.R. 2000. Tephrochronology : a New Zealand case study. Earth-Science Reviews 49 : 223-259.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., Broderson, W.D. (editors) 2002. Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Selby, M.J., and P.J. Hosking. 1973. The erodibility of pumice soils of the North Island, New Zealand. Journal of Hydrology (New Zealand) 12, 32-56.

Selby, M.J. and D.J. Lowe. 1992. The middle Waikato Basin and hills. In : Soons, J.M., and M.J. Selby (eds) Landforms of New Zealand, 2nd edition. Longman Paul, Auckland : 233-255.

Sheard, M.J. 1978. Geological history of the Mount Gambier volcanic complex, southeast South Australia. Transactions of the Royal Society of South Australia 102 : 125-139.

Sheard, M.J. 1983. Volcanoes. In : Tyler, M.J., Twidale, C.R., Ling, J.K., and Holmes, J.W. (eds) The Natural History of the South East. Royal Society of South Australia, Adelaide : 7-14.

Sheard, M.J. 1986. Some volcanological observations at Mount Schank, southeast South Australia. Geological Survey of South Australia, Quarterly Geological Notes 100 : 14-20.

Sheard, M.J. 1990. A guide to Quaternary volcanoes in the Lower South-east of South Australia. Mines and Energy Review, South Australia 157 : 40-50.

Sheard, M.J. 1992. Volcanoes of the Mount Gambier area. South Australian Department of Mines and Energy Information Sheet 19.

Sheard, M.J., and I.A. Nicholls. 1989. Mt Gambier Sub-province. In : Johnson, R.W. (ed) Intraplate Volcanism in Eastern Australia and New Zealand. Australian Academy of Science and Cambridge University Press, Sydney : 141-142.

Sheard, M.J., D.J. Lowe, and P.C. Froggatt 1993. Mineralogy of pyroclastic and lava deposits of Holocene basaltic volcanoes of Mts Gambier and Schank, South Australia. Abstracts, IAVCEI International Volcanological Congress, Canberra : 98.

Shepherd, T.G., S. Saggar, R.H. Newman, C.W. Ross, and J.L. Dando. 2001. Tillage-induced changes to soil structure and organic carbon fractions in New Zealand soils. Australian Journal of Soil Research 39 : 465–489.

Shoji, S., and T. Takahashi. 2002. Environmental and agricultural significance of volcanic ash soils. Global Environmental Research 6 : 113–135.

Shoji, S., M. Nanzyo, and R. Dahlgren. 1993a. Volcanic Ash Soils : Genesis, Properties and Utilization. Developments in Soil Science 21. Elsevier, Amsterdam. 288p.

Shoji, S., R. Dahlgren, and M. Nanzyo. 1993b. Genesis of volcanic ash soils. Developments in Soil Science 21 : 37–71.

Shoji, S., R. Dahlgren, and M. Nanzyo. 1993c. Morphology of volcanic ash soils. Developments in Soil Science 21 : 7–35.

Shoji, S., M. Nanzyo, and R. Dahlgren. 1993d. Productivity and utilization of volcanic ash soils. Developments in Soil Science 21 : 209–251.

Silber, A., B. Bar-Yosef, A. Singer, and Y. Chen. 1994. Mineralogical and chemical composition of three tuffs from northern Israel. Geoderma 63 : 123–144.

Simcock, R., R. Parfitt, R. Schuster, and M. Skinner. 2003. Which soils are vulnerable to growth-limiting compaction? Results from 24 field trials. Proceedings, 10th North American Forest Soils Conference, Sault Saint Marie, Ontario, Canada 3 : 8–10.

Singleton, P.L. 1999. High quality soils. New Zealand Soil News 47 : 143–146.

Singleton, P.L., and B. Addison. 1999. Effects of cattle treading on physical properties of three soils used for dairy farming in the Waikato, North Island, New Zealand. Australian Journal of Soil Research 37 : 891–902.

Singleton, P.L., M. McLeod, and H.J. Percival. 1989. Allophane and halloysite content and soil solution silicon in soils from rhyolitic volcanic material, New Zealand. Australian Journal of Soil Research 27 : 67–77.

Smith, B.W., and J.R. Prescott. 1987. Thermoluminescence dating of the eruption at Mt Schank, South Australia. Australian Journal of Earth Sciences 34 : 335–342.

Soil Bureau Staff. 1968. Soils of New Zealand, Part 2. New Zealand Soil Bureau Bulletin 26(2) : 7–218.

Soil Bureau Staff. 1973. Map of parent rocks of New Zealand soils 1 : 1,000,000. New Zealand Soil Survey Report 5.

Soil Survey Staff. 1999. Soil Taxonomy, 2nd edition. USDA Natural Resources Conservation Service Agriculture Handbook 436. 869 p.

Spaargaren, O.C. 2000. Other systems of soil classification. In : Sumner, M.E. (ed-in-chief) Handbook of Soil Science. CRC Press, Baca Baton : E137–174.

Sparks, R.J., W.H. Melhuish, J.W.A. McKee, J. Ogden, and J.G. Palmer. 1995. ^{14}C calibration in the Southern Hemisphere and the date of the last Taupo eruption : evidence from tree-ring sequences. Radiocarbon 37 : 155–163.

Speir, T.W. 2002. Soil biochemical properties as indices of performance and sustainability of effluent irrigation systems in New Zealand–a review. Journal of the Royal Society of New Zealand 32 : 535–553.

Stace, H.C.T., G.D. Hubble, R. Brewer, K.H. Northcote, J.R. Sleeman, M.J. Mulcahy, and E.G. Hallsworth. 1968. A Handbook of Australian Soils. Rellim Technical Publications, Adelaide.

Suryaningtyas, D. 1998. Characterisation of volcanic-ash derived soils of southern area of Mount Ruapehu, North Island, New Zealand. Unpublished M.App.Sci. thesis, Massey University, Palmerston North, New Zealand.

Takahashi, T., and S. Shoji. 2002. Distribution and classification of volcanic ash soils. Global Environmental Research 6 : 83–97.

Takahashi, T., R. Dahlgren, and P. van Susteren. 1993. Clay mineralogy and chemistry of soils formed in volcanic materials in the xeric moisture regime of northern California. Geoderma 59 : 131–150.

Tustin, J.R., R.L. Knowles, and B.K. Klomp. 1979. Forest farming : multiple land-use production systems in New Zealand. Forest Ecology and Management 2 : 169–189.

Ugolini, F.C., and Dahlgren, R.A. 2002. Soil development in volcanic ash. Global Environmental Research 6 : 69–81.

Wallace, H.J., S.J. Burgham, A.E. Hewitt, P.D.

McIntosh, and T.H. Webb. 2000. South Island soil surveys : classification of named soils by subgroups of the New Zealand Soil Classification. Landcare Research, Lincoln. 145p.

Wilding, L.P. 2000. General characteristics of soil orders and global distributions. In : Sumner, M.E. (ed-in-chief) Handbook of Soil Science. CRC Press, Baca Baton : E175-183.

Will, G.M. 1974. Forestry. In : Read, N.E. (ed) Soil Groups of New Zealand. Part 1 Yellow-brown Pumice Soils. New Zealand Society of Soil Science, Lower Hutt : 181-183.

Wilson, C.J.N. 1993. Stratigraphy, chronology, styles and dynamics of late Quaternary eruptions from Taupo volcano, New Zealand. Philosopical Transactions of the Royal Society London A343 : 205-306.

Wilson, C.J.N. 2001. The 26.5 ka Oruanui eruption, New Zealand : an introduction and overview. Journal of Volcanology and Geothermal Research 112 : 133-174.

Wilson, C.J.N., and G.P.L. Walker. 1985. The Taupo eruption, New Zealand I. General aspects. Philosophical Transactions of the Royal Sociey London A314 : 199-228.

Wilson, C.J.N., B.F. Houghton, M.O. McWilliams, M.A. Lanphere, S.D. Weaver, and R.M. Briggs. 1995. Volcanic and structural evolution of Taupo Volcanic Zone, New Zealand : a review. Journal of Volcanology and Geothermal Research 68 : 1-28.

Wright, I.C., R.D. Garlick, A. Rowden, and E. Mackay. 2004. New Zealand's Undersea Volcanoes. National Institute of Water and Atmospheric Research Chart Miscellaneous Series 81.

Zabowski, D., M.F. Skinner, and T.W. Payn. in press. Nutrient release by weathering : implications for sustainable harvesting of radiata pine from six New Zealand soils. New Zealand Journal of Forestry Science.

Modifying A Soil Carbon Turnover Model Considering Unique Properties of Andisols

Yasuhito SHIRATO and Ichiro TANIYAMA

National Institute for Agro-Environmental Sciences
Kan-non-dai 3-1-3, Tsukuba, Ibaraki 305-8604, Japan

Key words : Al-humus complex, carbon sequestration, RothC, soil organic matter, volcanic ash soils

We modified the Rothamsted carbon model (RothC, Coleman and Jenkinson 1996), which is one of leading soil organic matter turnover models in the world, to adopt it to Andisols, because it could simulate the changes in soil organic carbon (SOC) adequately in non-volcanic soils in Japan (Fig. 1, Shirato and Taniyama 2003) while it could not simulate well in Andisols (thin line in Fig. 2). Among several options to modify the model, we decided to change the decomposition rate constant of the humus (HUM) pool, which is one of five SOC pools that the RothC contains, because the presence of Al- or Fe- humus complexes in Andisols gives HUM strong stability (Shirato et al. 2004). In addition, the inert organic matter (IOM) pool was set at zero, because the soil did not contain carbon when it was formed from fresh volcanic ash. H(f) was defined as the factor required to divide the decomposition rate constant of the HUM pool so that the modeled SOC level matched the measured level. H(f) was calculated for 32 Japanese Andisols, and the relationships between H(f) and soil properties such as contents of acid–oxalate-extractable Al, Fe, and Si (Alo, Feo, and Sio) or pyrophosphate-extractable Al (Alp) were analyzed. The equation H(f) = 1.20 + 2.50Alp(%), (r^2=0.52) was selected to divide the decomposition rate constant of HUM. The modified model was tested for four long-term experimental data sets on Andisols under various climatic conditions, soil textures, and management techniques from north to south across Japan. We obtained considerably improved fits between the contents of modeled and measured SOC by using the modified RothC model (thick line in Fig. 2) instead of the original model. Use of this modified model may contribute to the improvement of the performance of existing SOC models in modeling Andisols. It can be used for estimating CO_2 emission from soils, as well as for planning suitable organic matter management in Japanese Andisols.

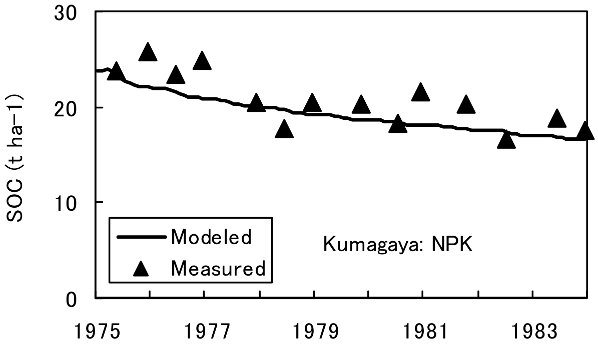


Fig 1. Modeled vs. measured SOC on non-volcanic soils. Example from Gray lowland soils in Kumagaya, Saitama prefecture.

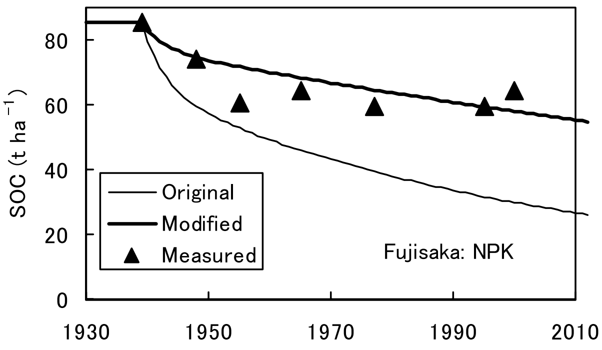


Fig 2. Modeled vs. measured SOC on Andosols by original RothC and modified model. Example from Fujisaka, Aomori prefecture.

References

Coleman, K. and Jenkinson, D.S., 1996. RothC−26.3 −A model for the turnover of carbon in soil. In Evaluation of Soil Organic Matter Models : Using Existing Long−Term Datasets, Ed. DS Powlson, P Smith and JU Smith, p. 237–246, Springer, Berlin

Shirato, Y. and Taniyama, I., 2003. Testing the suitability of the Rothamsted carbon model for long−term experiments on Japanese non−volcanic upland soils. Soil Sci. Plant Nutr. 49 921−925.

Shirato, Y., Hakamata, T. and Taniyama, I., 2004. Modified Rothamsted carbon model for Andosols and its validation : Changing humus decomposition rate constant with pyrophosphate−extractable Al. Soil Sci. Plant Nutr. 50 : 149−158.

Effects of Gypsum on Amelioration of Subsoil Acidity of Andisols

M. TOMA [1], M. SAIGUSA [2], N. QAFOKU [3], and M.E. SUMNER [4]

[1] Experimental Farm, Faculty of Agriculture, Yamaguchi Univ., Japan
[2] Tohoku Univ, Japan [3] PNNL USDOE; [4] Univ. of Georgia, USA

In acid soils such as nonallophanic Andisols, crop production is severely limited because of the presence of chemical barriers such as subsoil Al toxicity and Ca deficiency. These barriers often restrict the root penetration in these subsoils reducing crop yields. However, surface application of lime ($CaCO_3$) is not effective in amelioration of subsoil acidity because of low solubility and slow movement in soil profile. On the other hand, gypsum ($CaSO_4 \cdot 2H_2O$), which has higher solubility, is used as a practical ameliorant for subsoil acidity (Shainberg et al. 1989). In this presentation, the authors summarize the effects of gypsum on amelioration of subsoil acidity of Andisols.

Experiment 1 : The movement of gypsum and the effects on subsoil acidity were evaluated using open end columns 0.45 m long with interior diameter of 0.10m (Saigusa et al. 1996, Toma and Saigusa 1997). According to humus content, two types of Andisols (Andosols) were used as test soils (Table 1). Gypsum were mixed in top 0.15m and 300mm of water were applied. Ca applied as gypsum moved down to both subsoils (Fig. 1), however reduction of exchangeable acidity (y_1) (Fig. 2) and deep root penetrations into subsoils (Fig. 3) were observed only in the low humus soil. These results suggested that gypsum is effective to the soils with low humus content or soils with relatively shallow high humus topsoil.

Experiment 2 : The long term effects of gypsum were evaluated by field experiment using an Ultisol (Toma et al. 1999). The experiment was conducted in Plant Science Farm of The University of Georgia, Oconee County, GA, U.S.A. Gypsum was surface−applied and mixed to a depth of 0.15m. Even 16 years after application, the effects of gypsum were still clearly visible. Exchangeable Ca was higher down the soil profile in the gypsum treatment (Fig. 4). The reduction in exchangeable Al was observed in gypsum treatment to 80 cm depth (Fig. 5). This amelioration of the effects of subsoil acidity was

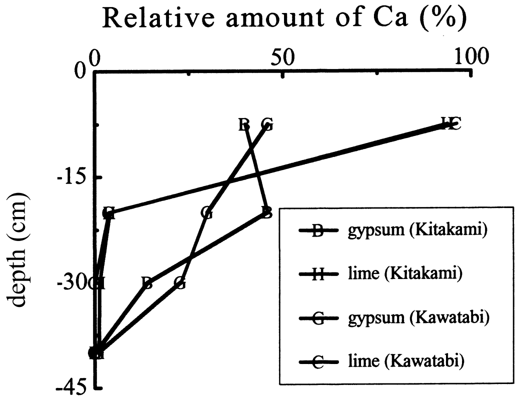


Fig.1. Move of Ca applied as gypsum or lime

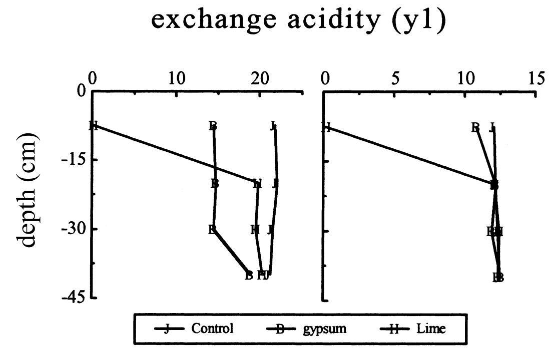


Fig. 2. Profile distribution pattern of exchange acidity (y1)

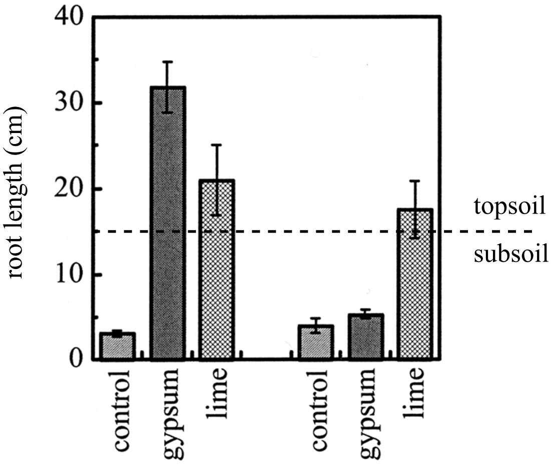


Fig. 3. Effect of gypsum on root elongation of barley

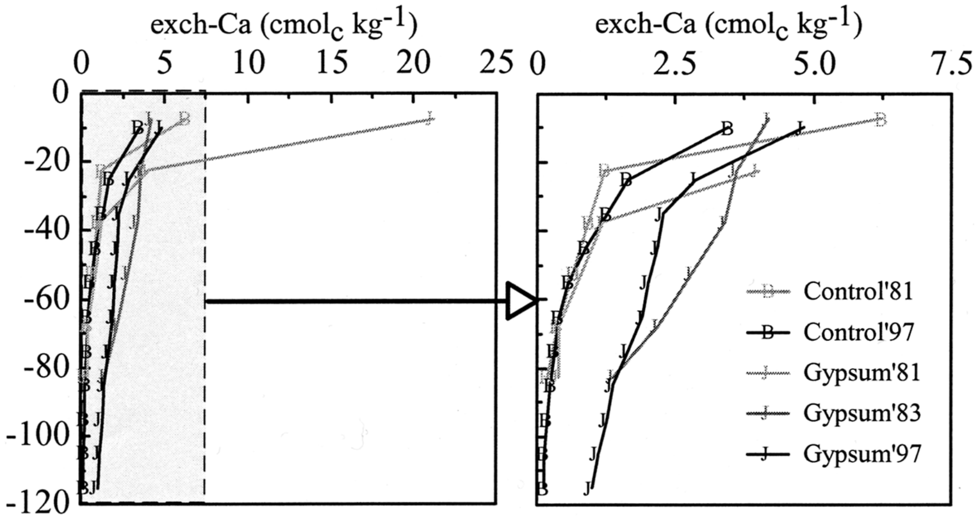


Fig. 4. Change of Exchangeable Ca status with time after gypsum application

Table1. Some properties of test soils for experiment 1

	pH(H_2O)	pH(KCl)	y1	Organic−C	Classification
Kitakami(low humus)	5.4	4.2	19.4	0.59	Fine, mixed, mesic, Andic Dystrochrept
Kawatabi(high humus)	4.9	4.2	11.8	14.52	Medial, Alic Pachic Melanudand

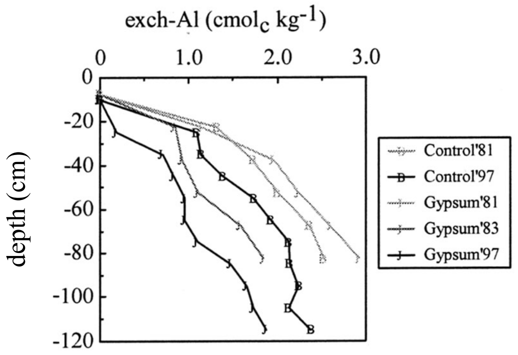


Fig. 5 Changes of exchangeable Al status with time after gypsum application.

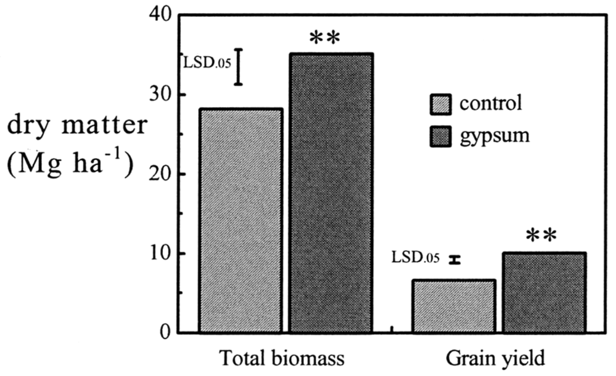


Fig.6 Effect of gypsum applications made 16 years previously on corn yield

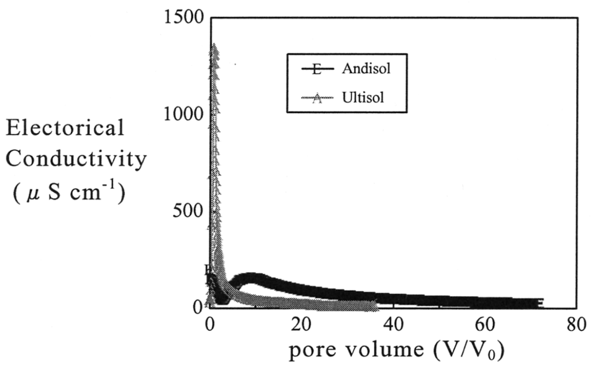


Fig. 7 Electorical conductivity breakthrough curves of leachates

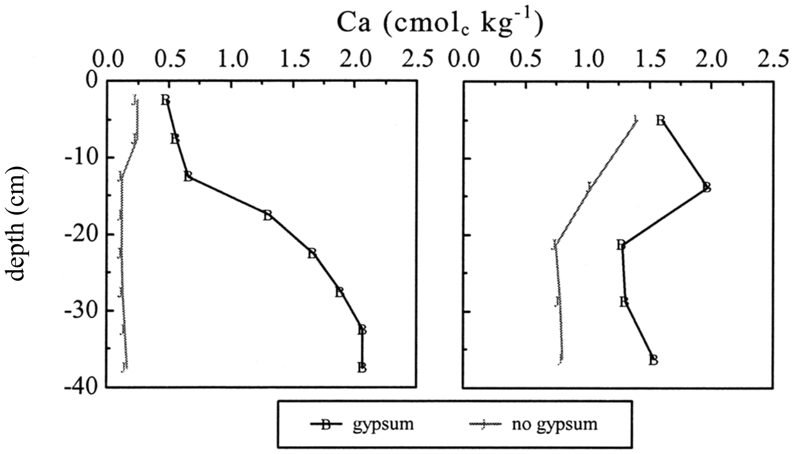


Fig. 8 Distribution of calcium in soil columns at the end of leaching experiment

reflected in improvement of crop yields (Fig. 6).

Experiment 3 : Column experiments were conducted in order to understand better the fate and transport of gypsum in acid soils and to estimate the long term effects of gypsum on subsoil chemical properties. An Andisol from Iwate, Japan and an Ultisol from Georgia, U.S.A. were used as test soils. The columns used were 0.4 m long with an interior diameter of 0.05 m. Gypsum was mixed in top 0.1m and leached with deionized water using a peristaltic pump at a flow rate of 1 mL min^{-1}. About 72 and 36 pore volume of water were leached to reduce the electrical conductivity of effluent below 20 μ S cm^{-1} in Andisol and Ultisol, respectively (Fig. 7). These amounts of water were equal to 22 and 9 years of precipitation. Gypsum applied in the topsoil significantly increased the amount of exchangeable Ca in the subsoil (Fig8) . These results sggested that effects of gypsum appeared to continue for many years.

References

Saigusa, M., M. Toma, and M. Nanzyo. 1996. Alleviation of subsoil acidity in nonallophanic Andosols by phosphogypsum application in topsoil. Soil Sci. Plant Nutri. 42 : 221−227.

Shainberg I. , M. E. Sumner, W. P. Miller, M. P. Farina, M. A. Pavan and M. V. Fey 1989. Use of gypsum on soils : A review. Adv. Soil Sci. 9 : 1−111.

Toma, M. and M. Saigusa. 1997. Effects of phosphogypsum on amelioration of strongly acid nonallophanic Andosols, Plant and Soil 192 : 49−55.

Toma, M. M.E. Sumner, G. Weeks, and M. Saigusa. 1999. Long−term effects of gypsum on crop yield and subsoil chemical properties. Soil Sci. Soc. Am. J. 39 : 891−895.

Phosphorus Dynamics and Bioavailability in Andosols −Estimation of Potential Bioavailable P Transport in Agricultural Runoff of Andosols

T. ITO, N. KIKAWA and M. SAIGUSA

Field Science Center, Graduate School of Agricultural Science, Tohoku University, Japan

Key words : potential bioavailable P loss, surface runoff,
silandic Andosols, aluandic Andosols

Abstracts

In this study, we estimated the potential bioavailable P transport in agricultural runoff of Andosols from the relations between P sorption saturation and anion exchange resin and Mehlich−3 extractable P, with special references to the difference in active Al composition. the P sorption saturation of 10 %, that is optimum P level needed for good crop yields, is critical point of inorganic P for the potential bioavailable P loss in surface runoff from agricultural Andosols with different active Al composition. However, silandic A and B soils showed lower values of Mehlich−3 P than aluandic soils when they had the same P sorption saturation. Mehlich−3 P underestimated the bioavailability of soil P in the silandic soils compared to the aluandic soils. We recommend the use of different critical values of Mehlich−3 P for assessing the upper critical limits for P in aluandic and silandic Andosols.

Introduction

Phosphorus (P) is essential element for plant and animal growth and its application has been conducted to increase crop and animal production. Phosphorus inputs can accelerate eutrophication and increase the biological productivity of surface waters. Eutrophication restricts water use for fisheries, recreation, industry and drinking due to the increase of undesirable aquatic biota, in some case toxic species of blue−green algae, and due to oxygen shortages generated by their death and decomposition. Although nitrogen and carbon are also essential to the increase of aquatic life, most concern has focused on P inputs, because of the difficulty in controlling the inputs of nitrogen and carbon and atmospheric nitrogen fixation by some blue−green algae. Therefore, P is often the limiting element for the growth of aquatic biota and its control has the greatest significance in reducing the accelerated eutrophication of fresh waters (Sharpley and Rekolainen, 1997).

The world P resources of high quality is decreasing, while agricultural lands are gathering concern as major non−point P sources for the water bodies (Sharpley et al., 1999). Therefore, there is a growing need for accurate recommendation of P fertilizer and animal manure to establish agronomically, economically and environmentally sound agricultural systems. The P input from agricultural lands to surface waters occurs in the ways of surface runoff (sediment−bound and dissolved forms) and subsurface flow. Dissolved P in surface runoff is most available for aquatic biota and also a part of soil particulate−bound P is available for fresh water algae. These bioavailable P in surface runoff is estimated by traditional soil P tests and P−sink approaches. One of the former methods is Mehlich−3 soil P test, which is adopted by several states in USA to set upper critical limits for P in soils (Sharpley et al., 1999). Pote et al (1996) found that the dissolved P concentration of surface runoff was related to Mehlich−3 extractable P content of surface soil. The P−sink approach, such as anion−exchange resin extractable P (AER−P) and P−sorption saturation (%) closely related to dissolved P concentration of surface runoff (Sibbesen and Sharpley, 1997). The P−saturation approach provides a greater degree of flexibility across soil types than soil test P in estimating the potential P loss in surface runoff because it accounts for soil properties affecting P sorption and desorption (Sibbesen and Sharpley, 1997).

Andosols are major soil type of agricultural upland in Japan and have large amounts of active aluminum (Al) and iron (Fe) derived from short−range−order minerals and show a very high P fixation. Two major types of Andosols are recognized, Silandic Andosol in which allophanic clay is predominant, and Aluandic Andosol in which Al-humus complex prevails (Driessen et al. 2001).

In this study, we focused on the estimation of potential bioavailable P transport in agricultural runoff of Andosols with special references to the difference in active Al composition.

Materials and methods

We used 4 high-humic aluandic horizon soils and 8 silandic horizon soils including 4 high-humic soils (silandic A horizon soils) and 4 low-humic soils (silandic B horizon soils). Soil P levels were varied in the range of 0.06 to 1.43 g P kg^{-1} (4 levels in each soil) by adding calcium phosphate to the uncultivated soils and keeping the treated soils for 9 months. Acid oxalate (Blakemore et al., 1981) and pyrophosphate extractable (Wada and Higashi, 1976) Al and Fe were measured and phosphate absorption coefficient was determined by adding 26.8 g P_2O_5 kg^{-1} soil. Total inorganic phosphorus contents were measured by extraction using hot conc. HCl. Soil test P values were determined by Mehlich-3 extractant (Mehlich, 1984) and strongly basic anion exchange resin (AER, Amberlite IRA-900) with resin to soil ratio of 1 : 1 and reaction time of 24h. Phosphorus sorption saturation was calculated by dividing total inorganic P in soils by P sorption capacity (phosphate absorption coefficient) and was expressed by percentage.

Results and discussion

Eight Silandic Andosols had major active aluminum (Al) of allophanic clay according to high amounts of acid oxalate extractable silicon (Sio) and low ratios of Alp (pyrophosphate extractable Al derived from Al-humus complex) to Alo (acid oxalate extractable Al). Four Aluandic Andosols showed low Sio contents and high Alp/Alo ratio, in which Al-humus complex were major active Al. Major form of soil inorganic P was Al-bound P (67-87%) in silandic and aluandic Andosols according to the results of sequential P extraction (data is not shown).

Potential bioavailable P loss in surface runoff from agricultural lands can be estimated by AER-P contents in soils. It is known that heavy P fertilizer application was practiced for newly reclaimed Andosols and the amounts of P equal to ten percent of the phosphate adsorption coefficient of soils was enough to obtain high crop yields for successive croppings in Japan(Yamamoto and Miyasato, 1972).

Table 1. Some properties of Andosols used in this study

Types of soils	Sample names	Total carbon (g/kg)	Alo*1 (g/kg)	Sio*2 (g/kg)	Alp/Alo*3	Phosphate absorption coefficient*4 (g P_2O_5/kg)
Aluandic horizon soils	Mukaiyama A1	172	15	0.9	0.99	22.6
	Mukaiyama A3	177	30	2.4	0.98	26.7
	Kawatabi A	69	16	2.7	0.72	21.3
	Hirosaki A	135	26	6.0	0.65	24.5
Silandic A horizon soils	Takizawa A1	101	44	18.6	0.25	24.1
	Takizawa A2	61	63	31.8	0.14	25.5
	Mouka A	98	51	21.7	0.26	25.7
	Nango A	47	45	19.4	0.15	20.3
Silandic B horizon soils	Takizawa B	18	64	41.9	0.07	23.3
	Mouka B	31	60	34.9	0.10	24.0
	Zao B	24	40	25.3	0.10	20.5
	Tsukuba B	44	54	26.1	0.13	22.7

Alo*1, Sio*2 ; acid oxalate extractable Al, Si

Alp/Alo*3 ; ratio of pyrophosphate extractable Al to acid oxalate extractable Al

Phosphate absorption coefficient*4; sorbed phosphate determined by addition of 26.8 g P_2O_5 kg^{-1} soil

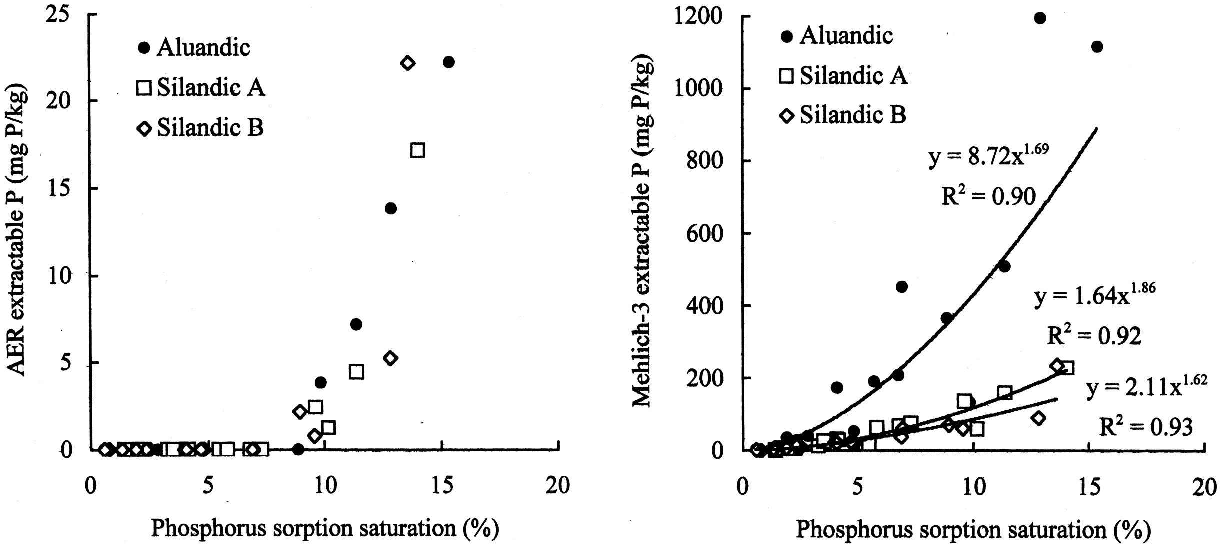


Fig. 1. Relationship between P sorption saturation and AER and Mehlich-3 extractable P contents in soils

According to Fig. 1, AER extractable P in soils showed almost zero when P sorption saturation was less than 10 % and increased sharply above 10 % of P sorption saturation. Relationship between P sorption saturation and AER-P contents can be expressed by the same curve in both of three types of Andosols including 12 soils. The result suggests that the P sorption saturation of 10 %, that is optimum P level needed for good crop yields, is critical point of inorganic P for the potential bioavailable P loss in surface runoff from agricultural Andosols with different active Al composition.

Soil P test value by Mehlich-3 method increase with increase of P sorption saturation (Fig. 1). The Mehlich-3 extractable P contents closely correlated with P sorption saturation in each type of Andosols with exponential curves. The correlations were significantly different between silandic soils and aluandic soils. Silandic A and B soils showed lower values of Mehlich-3 P than aluandic soils when they had the same P sorption saturation. Mehlich-3 P underestimated the bioavailability of soil P in the silandic soils compared to the aluandic soils. The modified Bray-2 P value decreased with the extraction time in allophanic Andosols because the net resorption was occurred during the extraction (Hylander et al., 1999). Mehlich-3 and Bray-2 extractants are strongly acidic solution. It was considered that P sorption during the extraction process happened more intensively in the silandic soils than the aluandic soils under acidic conditions (Mehlich-3 extractant) according to the results of Hylander et al. We recommend the use of different critical values of Mehlich-3 P for assessing the upper critical limits for P in aluandic and silandic Andosols.

References

Blakemore L. C., P. L. seaele and B. K. Daly (1981) Soil Bureau Laboratory Methods : A. Methods for chemical analysis of soils. New Zealand Soil Bureau Sci. Report 10A (revised).

Driessen P., J. Deckers, O. Spaargren and F. Nachtergaele (2001) Lecture notes o the major soils of the world, World Soil Resources Reports 94, FAO, Rome, pp.1-334.

Hylander, L. D., T. Makino and N. Ae (1999) : Bray-2 phosphorus as influence by soil fineness and filtration time. Commun. Soil Sci. Plant Anal., 30 : 947-955

Mehlich A. (1984) Mehlich 3 soil test extractant : A modification of Mehlich 2 extractant, Commun. Soil Sci. Plant Anal., 15 : 1409-1416.

Pote D. H., T. C. Daniel, A. N. Sharpley, P. A. Moore Jr., D. R. Edwards and D. J. Nichols (1996) Relating extractable soil phosphorus to Phosphorus losses in runoff, SSSAJ, 60 : 855-859.

Sharpley A. N., T. D. Daniel, T. Sims, J. Lemunyon, R. Stevens and R. Parry (1999)

Agricultural phosphorus and eutrophication, USDA Agricultural Research Service, ARS-13, pp37

Sharpley A. N. and S. Rekolainen (1997) Phosphorus in agriculture and its environmental implication, In Phosphorus loss from soils to water (eds. H. Tunney, O. T. Carton, P. C. Brookes and A. E. Johnston), CAB INTERNATIONAL, pp. 1−53.

Sibbesen E. and A. N. Sharpley (1997) Setting and justifying upper critical limits for phosphorus in soils, In Phosphorus loss from soils to water (eds. H. Tunney, O. T. Carton, P. C. Brookes and A. E. Johnston), CAB INTERNATIONAL, pp. 151−176.

Wada K. and T. Higashi (1976) The categories of aluminium and iron−humus complexes in Ando soils determined by selective dissolution, J. Soil Sci., 27 : 357−368.

Yamamoto, T. and S. Miyasato (1972) : Studies on soil productivity of upland fields− Heavy application of phosphate mixture in Iwate volcanic ash soil. Bull. Nat. Agric. Exp. Sta., 42 : 53−92.

JIFS, 2 : 77 − 82 (2005) Special review

Aluminum Dynamics in Nonallophanic Andosols from Northeastern Japan

Tadashi TAKAHASHI and Masami NANZYO

Graduate School of Agricultural Science, Tohoku University,
1−1, Tsutsumidori Amamiya−mach, Aoba−ku, Sendai, 981−8555 Japan

Key words : aluminum–humus complexes, aluminum release rate, aluminum solubility, aluminum toxicity, exchangeable aluminum, liming.

Abstract

We studied Al dynamics in nonallophanic Andosols from northeastern Japan by determination of Al solubility and Al release rates, selective dissolution analyses of active Al fractions, and examination of liming effect on the active Al. Aluminum solubility of the nonallophanic Andosols was lower than that of gibbsite in the lower pH range and showed oversaturation in the higher pH range, indicating that the Al solubility was controlled by Al−humus complexes. There was a close relationship between Al saturation (KCl−extractable Al / effective CEC) and the amount of pyrophosphate extractable Al, indicating that exchangeable Al is equilibrated with organically complexed Al. Liming ($CaCO_3$ treatment) largely reduced the amount of organically complexed Al (pyrophosphate− and $CuCl_2$−extractable Al), confirming that a portion of Al−humus complexes are labile.

Introduction

The processes regulating aluminum solubility and release/retention kinetics play a major role in determining the productivity of acid soils. Dissolved Al in soil solutions has been recognized to be a limiting factor for plant root growth. The exchangeable Al fraction, such as 1 M KCl−extractable Al, has also been found to be toxic to plant roots due to its presumed rapid release kinetics to the soil solution (Saigusa et al., 1980). Therefore, information on the factors controlling the concentrations of aqueous Al is critical for elucidating the potential toxicity of Al in soils.

Andosols are divided into two major groups on the basis of their colloidal compositions : "allophanic" Andosols dominated by allophanic clay materials and "nonallophanic" Andosols dominated by Al − humus complexes and 2 : 1 type aluminosilicates. Both groups of Andosols show unique properties characteristic of volcanic ash derived soils, such as high reactivity with phosphate and fluoride ions and a low bulk density. However, there are large differences in soil acidity and Al toxicity between the two groups of Andosols. Allophanic Andosols are moderate to slightly acid even when the base saturation is very low and rarely contain toxic levels of KCl−extractable Al. In contrast, nonallophanic Andosols are strongly acid when the base saturation is low and possess a high KCl−extractable Al (Nanzyo et al. 1993). The origin and status of the toxic Al are not yet clear although the exchangeable Al is assumed to be adsorbed mainly in permanent negative charges of 2 : 1 type minerals.

To clarify Al dynamics in nonallophanic Andosols, we analyzed Al solubility of A horizons of soils from northeastern Japan. Then, we investigated the relationship between 1 M KCl−extractable Al and organically complexed Al that is a major Al pool in nonallophanic Andosols. Finally, we examined the effects of liming ($CaCO_3$ treatment) on Al−humus complexes.

Materials and methods

Soil samples. Soil samples of nonallophanic Andosols were collected from northeastern Japan. Sampling points were distributed in Aomori, Akita, Iwate and Miyagi Prefectures. As comparisons, we used some allophanic Andosols and a Bhs horizon of a Spodosol.

Determinations of active Al pools. Selective dissolution techniques were used to remove operationally defined solid−phase pools of Al : 1) acid ammonium oxalate at pH 3 in the dark (Al_o) (McKeague 1976); 2) sodium pyrophosphate at pH 10 (Al_p) (McKeague 1967); 3) 0.5 M $CuCl_2$ (Al_{Cu}) (Hargrove and Thomas 1981); and 4) 1 M KCl

(Al_{KCl}) (Blakemore et al. 1981).

Aluminum release rates and Al solubility of soils. Rates of Al release from non-treated soil samples and residues obtained from the selective dissolution extraction were determined using a stirred, flow-through reaction vessel with an extracting solution which consists of a 10^{-3} M sodium acetate / acetic acid solution adjusted to pH 3.5. (Takahashi et al. 1995). The reacted solution was continuously injected into an auto-analyzer equipped with the pyrocatechol violet method for determination of monomeric Al.

An equilibrium study was conducted to determine the solubility of Al as a function of pH. A 0.01 M $CaCl_2$ solution was added to soil samples and HCl or NaOH was added to provide a pH range from 3 to 5. After 30 d incubation at 25°C, monomeric Al concentrations in the solution were determined and Al^{3+} activity was estimated.

Comparison between Al saturation and pyrophosphate-extractable Al. Extractable Al (1 M KCl and sodium pyrophosphate (Al_p)) was determined to characterize soil aluminum pools for 25 surface soil samples from Noshiro City, Akita Prefecture. The relationship between Al saturation (KCl-extractable Al / effective CEC) and Al_p was examined.

Liming and analyses of limed soils. Based on the lime requirement with respect to a pH of 6.5, the mixture of soil samples and $CaCO_3$ was incubated at field water capacity for 30 d. After air-drying, the limed and unlimed samples were used for determination of 1 M KCl-extractable Al, Al_p, and so on.

Results and discussion

Solid-phase pools of active Al for representative soil horizon samples (Takahashi et al. 1995).

Table 1 shows the properties of three representative soil horizons : a nonallophanic Andosol A horizon, an allophanic Andosol A horizon, and a Spodosol Bhs horizon. The nonallophanic A horizon (Noshiro) and the spodic Bhs horizon (Hubbard Brook) showed high Al_p/Al_o ratios (0.88 and 0.97, respectively) indicating that Al-humus complexes are dominant form of active Al. In contrast, the allophanic Andosol A horizon (Hiyamizu) showed a lower Al_p/Al_o ratio and a high content of Si_o (acid oxalate-extractable Si) indicating that allophanic materials dominate the active Al fraction.

The amount of 1 M KCl extractable Al, approximating easily exchangeable Al, is high for the nonallophanic A horizon and the spodic Bhs horizon (5.4 and 6.7 $cmol_c\ kg^{-1}$) , whereas the value for the allophanic A horizon was very low (0.4 $cmol_c\ kg^{-1}$).

Aluminum solubility of soils (Takahashi et al. 1995).

It is generally assumed that Al solubility of mineral soils is regulated by a solid $Al(OH)_3$ mineral phase (e.g. gibbsite). However, aqueous Al concentrations in humus-rich soil horizons are considered to be regulated also by humic substances. Although Andosols are included in mineral soils, they have a lot of organic matter especially in A horizons.

Results of Al release rates are shown in Fig. 1. Following the treatment with the pyrophosphate reagent, the Al release rates from the nonallophanic A horizon and the spodic Bhs horizon dropped to very low levels. In contrast, the Al release rates from the allophanic A horizon slightly decreased by the

Table 1. Some properties of the representative soil horizons.

	$pH(H_2O)$	Organic C $g\ kg^{-1}$	KCl-Al $cmol_c\ kg^{-1}$	Al_p $g\ kg^{-1}$	Al_o $g\ kg^{-1}$	Al_p/Al_o	Si_o $g\ kg^{-1}$
Noshiro (nonallophanic)	5.1	41.4	5.4	9.2	10.5	0.88	0.7
Hubbard rook (Spodosol Bhs)	4.7	53.7	6.7	6.5	6.7	0.97	0.4
Hiyamizu (allophanic)	5.4	67.7	0.4	8.3	30.2	0.27	10.9

pyrophosphate treatment. Following acid oxalate treatment, all soils showed virtually no Al release. Therefore, Al released from non-treated soil samples was attributed primarily to the Al-humus complexes for the nonallophanic A horizon and the spodic Bhs horizon. In contrast, Al released from the allophanic A horizon originated largely from allophanic materials.

Figure 2 and Table 2 show pH-pAl relations obtained by the equilibrium study. The dotted line in Fig. 2 indicates the solubility of synthetic gibbsite with a slope of 3.0 and log K^*_{so} of 8.1 for the reaction :

$$Al(OH)_3 + 3\ H^+ = Al^{3+} + 3\ H_2O.$$

The solubility of the allophanic A horizon (Hiyamizu) was nearly identical with that of synthetic gibbsite (Fig. 2 and Table 2). The saturation index (SI) of imogolite for the soil calculated from H^+, Al^{3+} and H_4SiO_4 activities showed +0.4 to +1.0, indicating slight oversaturation with respect to imogolite. Thus, the allophanic Andosol horizon appears to be in near equilibrium with both $Al(OH)_3$ and imogolite. On the other hand, the value of the slope of the solubility line for the nonallophanic A horizons and the spodic Bhs horizon ranged between 2.0-2.4 and was significantly lower than the value of 3.0 of the slope for $Al(OH)_3$ minerals (Table 2). The calculated log K^*_{so} value of these horizons ranged between 3.4-5.2 as compared with the value of 8.1 for the gibbsite (Table 2).

These results obtained from the Al release rates and the solubility experiments strongly suggest that in nonallophanic Andosol A horizons, the Al concentration is controlled by ion exchange reaction of H^+ and Al^{3+} ions on negatively charged sites of humus and that Al solubility is regulated by Al-humus complexes.

Relationship between exchangeable Al and organically complexed Al in A horizons (Takahashi et al. 2003). The above results indicate that organically complexed Al controls Al concentration in soil solution of nonallophanic Andosols. Exchangeable Al estimated by 1 M KCl extraction is thought to be easily released into soil solution. Therefore, exchangeable Al should be related to organically complexed Al. To confirm this

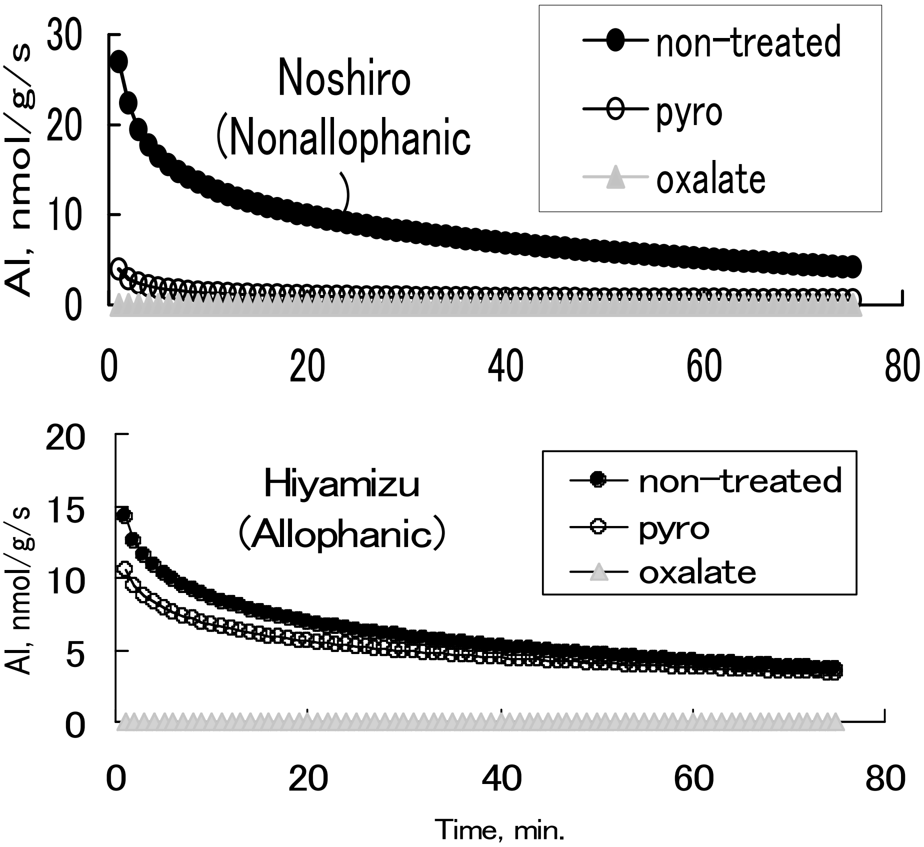


Fig. 1. Aluminum release rate for non-treated, pyrophosphate, and oxalate treated soil samples.

Table 2. Slopes and log K^*_{so} (intercept) values obtained from Al solubility data.

	Nonallophanic			Spodosol	Allophanic
	Mukaiyama	Noshiro	Wakami	Hubbard Brook	Hiyamizu
Slope	2.4	2.2	2.3	2.0	2.9
log K^*_{so}	5.2	4.5	4.8	3.4	7.5

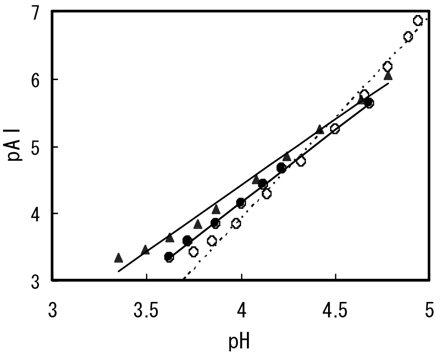


Fig. 2. Plot of equilibrium Al solubility versus pH. The solubility of synthetic gibbsite is indicated by the dotted line for comparison

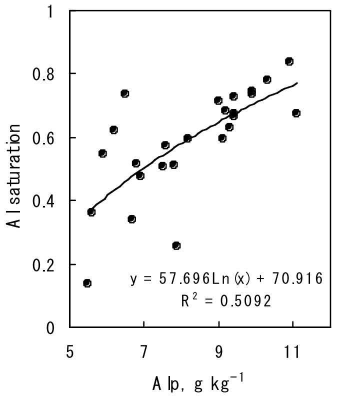


Fig. 3. Relationship between the concentration of pyrophosphate−extractable Al (Al_p) and Al saturation for A horizons of Noshiro soils.

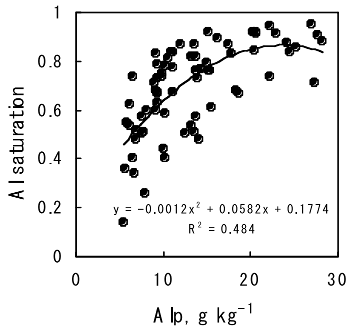


Fig. 4. Relationship between the concentration of pyrophosphate−extractable Al (Al_p) and Al saturation for A horizons of Noshiro soils and those of Shoji et al. (1985).

hypothesis, we investigated the relationship between Al saturation (exchangeable Al / effective CEC) and Al_p contents of nonallophanic Andosol A horizons from Noshiro City, Akita Prefecture.

As shown in Fig. 3, a significant, positive correlation was observed between Al saturation and Al_p content (r = 0.714, $p < 0.001$). Though there was a significant correlation between the two values, the soil pH must have affected the solubility and release/retention of Al. We analyzed a multiple regression of Al saturation on two variables, Al_p and pH(H_2O). Because of the absence of a significant correlation between the Al_p concentration and pH(H_2O) value (r = −0.054), these factors can be used as independent variables. The resultant regression is as follows :

$$\text{Al saturation} = 0.070\times Al_p\ (\text{g kg}^{-1})^{***} - 0.426\times pH(H_2O)^{***} + 2.277$$

R = 0.895, ***Significant at 0.1% level.

Eighty percent of Al saturation can be explained using the regression equation.

Although a significant positive correlation was observed between Al saturation and the Al_p concentration in the soils from Noshiro city, the

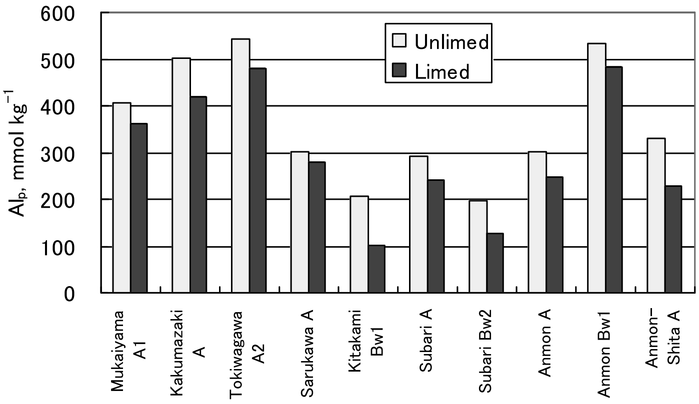


Fig. 5. Amounts of pyrophosphate-extractable Al from unlimed and limed soil samples.

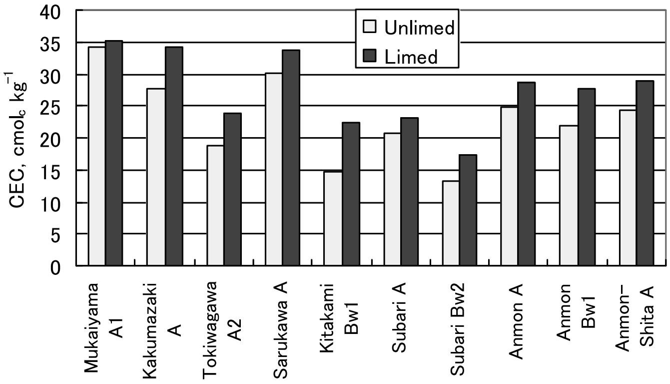


Fig. 6. Cation exchange capacity (CEC) of unlimed and limed soil samples.

concentrations of Al$_p$ were rather low (5.5-11.1 g kg^{-1}). To confirm the relationship for other soils with higher Al-humus contents, the data for the Noshiro soils were combined with the data from the A horizons of a wide range of nonallophanic Andosols in Japan (Shoji et al. 1985). As shown in Fig. 4, a significant relationship was also observed between Al saturation and the Al$_p$ concentration over a wide range of Al$_p$ concentrations from 5 to 28 g kg^{-1} though the parent materials and ages of soils were different. In these soil horizons, aqueous Al is considered to be equilibrated as follows : humus-complexed Al ⇔ aqueous Al ⇔ exchangeable Al.

Effect of liming on organically complexed Al (Takahashi et al. 2004). From the results of the Al solubility and the relationship between exchangeable Al and organically complexed Al, it was indicated that a portion of Al-humus complexes are labile and are easily altered by rather simple chemical treatment such as liming. Because nonallophanic Andosols usually show low pH values and high levels of toxic Al, liming is commonly performed.

Figure 5 shows the pyrophosphate-extractable Al (Al$_p$) of limed and unlimed soil samples. A large decrease of Al$_p$ value with liming was observed (decrease rate of 9-43%), and the decrease is significant ($p < 0.001$) according to the result of the t-test (for paired samples) for the Al$_p$ values of the two groups, unlimed and limed samples. The decrease of Al$_p$ values cannot be explained only by the disappearance of the KCl extractable Al (data not shown). These results strongly indicate that liming reduces significant amounts of organically complexed Al as well as exchangeable Al. As shown in Fig. 6, the increase in the cation exchange capacity (CEC) at pH 7 after liming further suggested that the carboxyl group was partly liberated from Al complexation and became to develop negative charges.

This phenomenon is very important because the dominance of Al-humus complexes is considered to be the essential characteristics for nonallophanic Andosols.

References

Blakemore, L.C., Searle, P.L. and Daly, B.K., 1981. Soil Bureau Laboratory Methods : A. Methods for chemical analysis of soils. New Zealand Soil Bureau Scientific Report, 10A (revised).

Hargrove, W.L. and Thomas, G..W., 1981. Extraction of aluminum from aluminum-organic matter complexes. Soil Sci. Soc. Am. J., 45 : 151-153.

McKeague, J.A., 1967. An evaluation of 0.1 M pyrophosphate and pyrophosphate-dithionite in comparison with oxalate as extractants of the accumulation products in podzols and some other soils. Can. J. Soil Sci., 47 : 95-99.

McKeague, J.A., 1976. Manual on Soil Sampling and Methods of Analysis. Soil Resource Institute, Agriculture Canada, Ottawa.

Nanzyo, M., Dahlgren, R. and Shoji, S., 1993. Chemical characteristics of volcanic ash soils. In : S. Shoji, M. Nanzyo and R.A. Dahlgren (Editors), Volcanic Ash Soils -Genesis, Properties and Utilization. Elsevier, Amsterdam-London-New York-Tokyo, pp.145-187.

Saigusa, M., Shoji, S. and Takahashi, T., 1980. Plant root growth in acid Andosols from northeastern Japan : 2. Exchange acidity Y_1 as a realistic measure of aluminum toxicity potential. Soil Sci., 130 : 242-250.

Shoji, S, Ito, T, Saigusa, M, and Yamada, I., 1985 : Properties of nonallophanic Andosols from Japan. Soil Sci., 140 : 264-277

Takahashi, T., Fukuoka, T. and Dahlgren, R.A., 1995. Aluminum solubility and release rates from soil horizons dominated by aluminum-humus complexes. Soil Sci. Plant Nutr., 41 : 119-131.

Takahashi, T., Sato, T., Sato, A. and Nanzyo, M., 2003. Relationship between 1 M KCl-extractable aluminum and pyrophosphate-extractable aluminum in A horizons of non-allophanic Andosols. Soil Sci. Plant Nutr., 49 : 729-733.

Takahashi, T., Ikeda, Y., Fujita, K. and Nanzyo, M. 2004. Effect of liming on organically complexed aluminum of nonallophanic Andosols from northeastern Japan. Geoderma (in press).

Changes in Elemental Composition with Andosolization

Masami NANZYO and Tadashi TAKAHASHI

Graduate School of Agricultural Science, Tohoku University
1−1 Tsutsumidori−Amamiyamachi, Aobaku, Sendai, 981−8555, Japan

Key words : volcanic ash soil, weathering, trace element, ultratrace element, Andisol

Abstract

A total of 57 elements in volcanic ash soils from 18 pedons distributed in Japan were analyzed and the relationships between noncrystalline material content and that of individual elements were examined. The content of the noncrystalline materials was estimated by using acid−oxalate extraction. Oxalate−extractable Fe (Fe_o) and Al (Al_o) corresponds to Fe in ferrihydrite and Al in allophane−imogolite plus Al complexed with humus, respectively. Silicon and alkaline or alkaline−earth elements such as Na, K, Ca, and Sr tended to decrease during the process of volcanic ash soil formation, i.e., andosolization. In contrast, the contents of Al, Y and the first transition metals tended to increase with the increasing content of noncrystalline materials. The first transition metals showed a high correlation with Feo suggesting their similarity in chemical behavior during andosolization. The lanthanoid elements tended to increase with the increasing Al_o and Fe_o content.

Introduction

A characteristic process of Andosolization is preferential formation of noncrystalline materials such as allophane, imogolite, opaline silica, ferrihydrite, and Al−humus complexes (Kato, 1983; Shoji et al., 1993; Soil Survery Staff, 1999). The Al and Fe in these noncrystalline materials are extractable with acid−oxalate solution (Parfitt and Henmi, 1982; Childs et al., 1990). No significant tanslocation of Al, Fe and dissolved organic carbon take place. These soil components are Al− or Fe−rich materials except the opaline silica that is found in the A horizon of young Andisols. (Shoji et al., 1993) The Si/Al atomic ratio of imogolite is 0.5 and that of allophane in Andisols is mostly around 0.5 according to selective dissolution analyses (Parfitt and Kimble, 1989; Shoji et al., 1993).

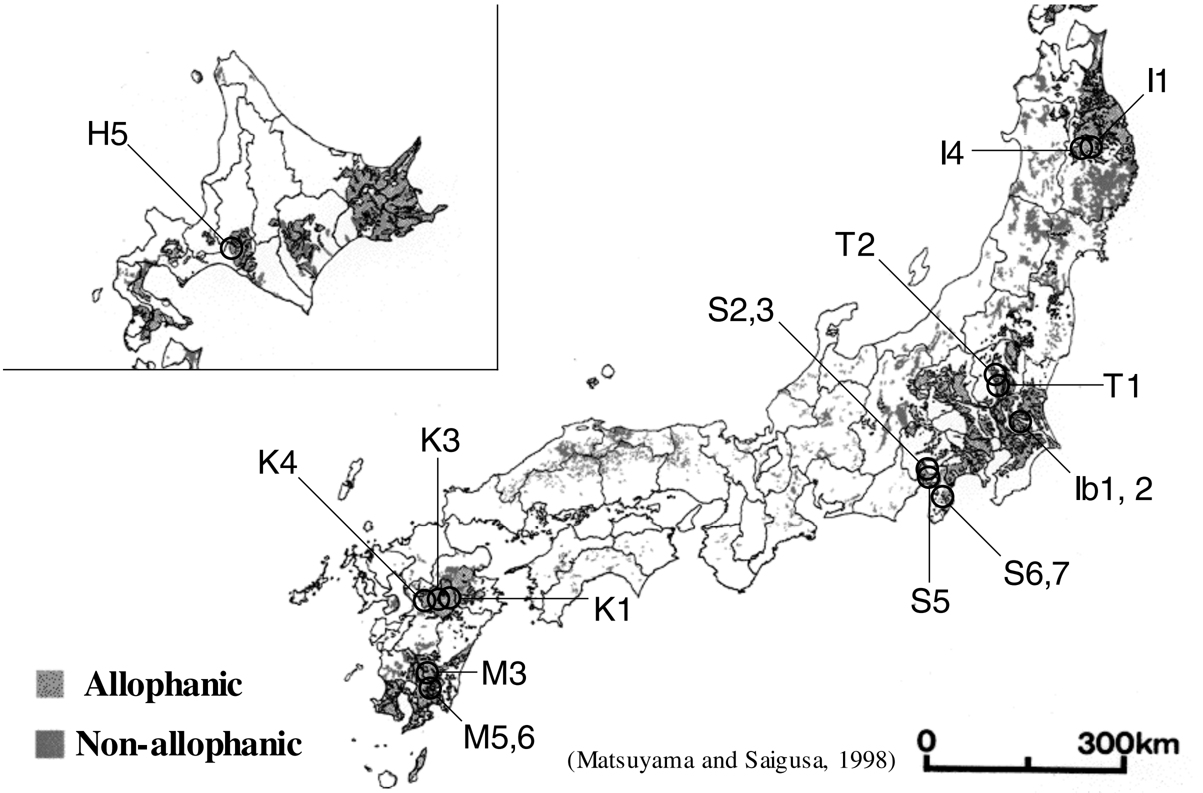
In contrast, the Si/Al ratio of pyroclastic materials and volcanic glasses, major parent materials of Andisols, are 4.8−2.4 and 5.2−2.3, respectively. These materials are rich in Si compared with those of the Al−rich noncrystalline materials mentioned above. Thus, a large amount of Si is removed during Andosolization, and Al and Fe is concentrated in Andisols (Ugolini et al., 1988). It is easily deduced that contents of other elements are also affected during Andosolization.

Although biologically essential or beneficial nutrients and some contaminated elements in soils (Aubert and Pinta, 1977; Kitagishi and Yamane, 1981; Mortvedt et al., 1991; Gobran et al., 2001) were studied previously, researches covering a wide range of elements are in the introductory stage in soil science (Gooddy et al., 1995; Yamasaki, 1996,2000a,b; Yamasaki et al., 2001). The primary objective of this paper is to examine the relationships between their contents and formation of active Al and Fe. Allophane, imogolite and Al−humus are the major forms of active Al and ferrihydrite is the major form of active Fe in the volcanic ash soils used in the present study. Detailed definition of the active Al and Fe was described by Wada (1980).

Materials and Methods

Soil samples

Ninty−five soil samples from 18 pedons in the Hokkaido, Tohoku, Kanto, Chubu and Kyushu districts were used and the locations of the pedons are shown in Figure 1. Soil profile descriptions and the chemical, mineralogical and physical properties of these samples (H5, I1, I4, T1, T2, Ib1, Ib2, S2, S3, S5, S6, S7, K1, K3, K4, M3, M5 and M6) were given elsewhere (Wada, 1986). All the 18 pedons used in the present study were selected from allophanic areas determined by Saigusa and Matsuyama (1998) to minimize the mixing of aeorian dusts (Inoue and



(Matsuyama and Saigusa, 1998)

Figure 1. Locations of 18 pedons.

Mizota, 1988) although some humus-rich horizons are dominated by Al-humus. These samples contain both young and highly weathered volcanic ash soils. The active Al and Fe content of these soil samples were described by nanzyo et al. (2002).

Analytical methods

Air-dried fine earth fractions of the soil samples were finely powdered using an agate mortar. The C and N contents were determined by using the dry combustion method. The Al, Si, K, Ca, Fe, P and Ti contents were analyzed by using a glass-bead X-ray

fluorescence spectrometer. The Na, Mg, Mn, Zn and Cu contents were analyzed by using an atomic absorption spectrometer after HNO_3-$HClO_4$-HF digestion. These analytical results were cited from Wada (1986). After digesting 1 g of the air-dried and finely powdered fine earth fraction with HNO_3-$HClO_4$-HF, the dried residue was dissolved in 1 : 20 (v/v) HNO_3 and the trace and ultratrace elements were determined by the induced coupled plasma-mass spectrometric method (Nanzyo et al., 2002). Acid-oxalate extractable Al, Si and Fe of the fine earth fraction were obtained by using the method of Blakemore et al. (1981).

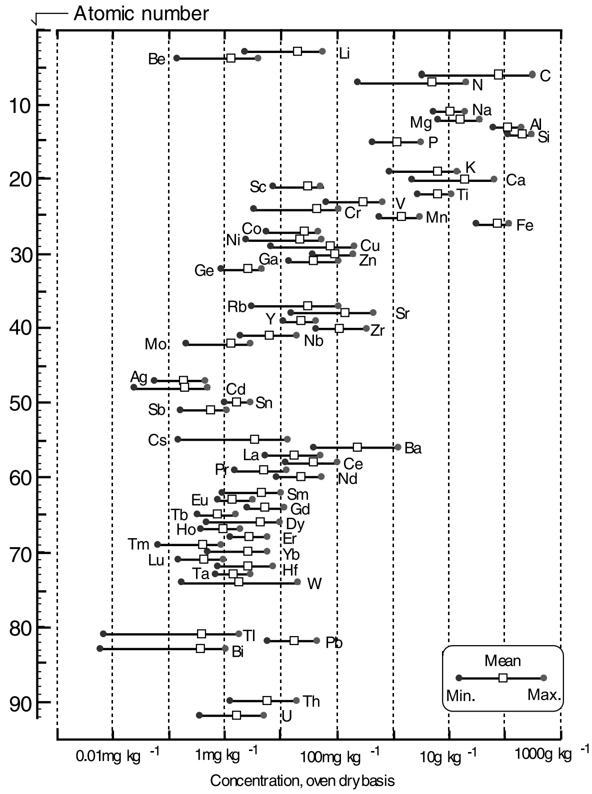


Figure 2. Concentration ranges of major, trace and ultratrace elements in volcanic ash soils of Japan.

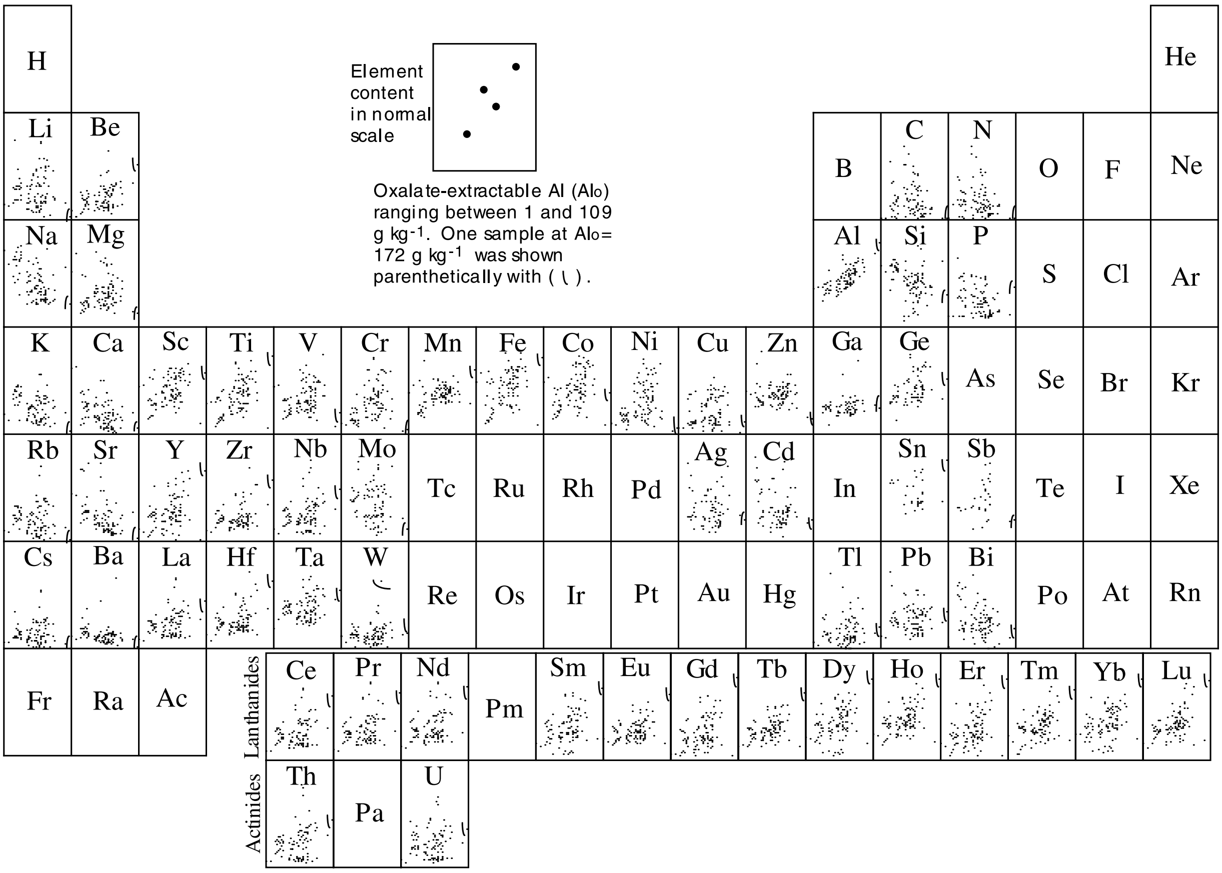


Figure 3. Relationships between content of oxalate-extractable Al (Al_o) and that of major, trace and ultratrace elements in volcanic ash soils of Japan.

Results and Discussion

Total content of elements

The ranges and means of the total element content are shown in Figure 2 on a logarithmic scale. The number of analytical data obtained for Tl and Bi was 92, for Mo 86, for Ga, Ge, Ag and Cd 74, for Sn and Sb 33 due to their low content compared with their background noise and for the other elements 95. The concentration of Cr, Zr, Hf and the heavy rare earth elements might have been somewhat underestimated because minerals containing these elements such as garnet, chromite, magnetite and zircon are highly acid−tolerent (Yamasaki et al., 2001). The obtained element content was highly variable and the values of maxmum/minimum ranged between 2 and 300. The maximum/minimum values for Si, Al and Fe were rather narrow ranging between 2 and 4. The contents of many other elements varied widely and many factors such as weathering, leaching, biological activities, rock types of tephras, human activities are involved in the variation of the element concentration. The mean content of the 12 major elements (C, N, Na, Mg, Al, Si, P, K, Ca, Ti, Mn and Fe) was more than 1 g kg^{-1} and the others were less than these. The Oddo−Harkins' law that the content of the even atomic number elements is greater than those for the neighboring odd atomic number ones was clearly shown for the lanthanoid elements of which the atomic number was from 57 (La) to 71 (Lu). These results were almost within the range reported by Yamasaki et al. (2001) using 514 samples from 78 pedons which covered many soils in Japan. Various correlations, very strong and weak, were observed examining the correlation matrix of 57 elements as reported by Nanzyo et al., (2002).

Relationship between total content of elements and active Al and Fe

Table 1 shows the correlation coefficient between oxalate−extractable soil components [Si (Si_o), Al (Al_o) and Fe (Fe_o)] and total contents of 57 elements. Scatter graphs of 57 elements as a funcitron of Al_o and Fe_o are shown in Figures 3 and 4, respectively. Significant negative correlation was found between

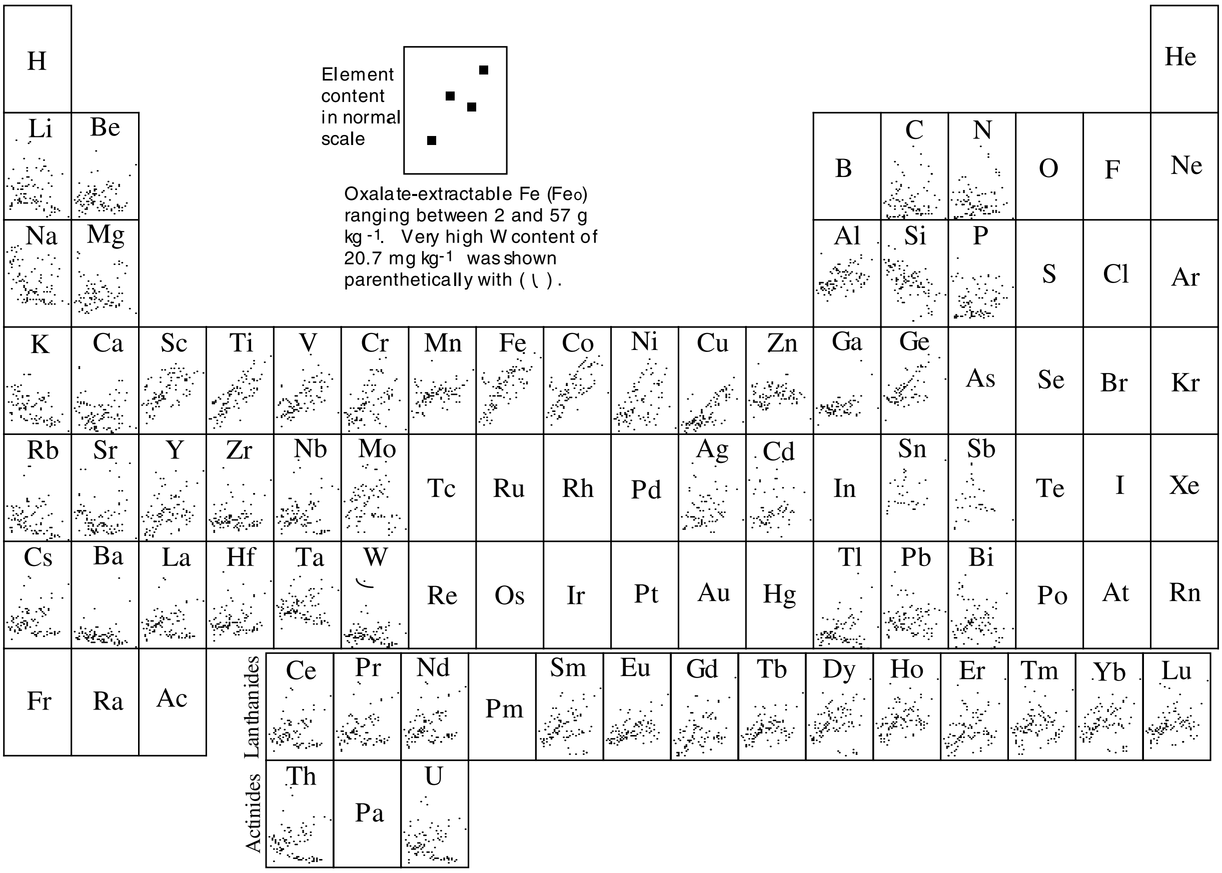


Figure 4. Relationships between content of oxalate-extractable Fe (Fe_o) and that of major, trace and ultratrace elements in volcanic ash soils of Japan.

Si_o and 4 elements (C, N, Na and Sr), between Al_o and 3 elements (Na, Ca and Sr) and between Feo and 3 elements (Na, Si and K) at p=0.1%. These elements are alkali and alkaline−earth elements except C, N and Si. Some other alkali and alkaline−earth elements also tended to show negative correlation with Si_o, Al_o and Fe_o although not as strong. Thus, many alkali and alkaline−earth elements are lost with Andosolization. The relatively strong negative correlation between Si_o and humus content (C and N) can be explained due to inhibition of allophane formation by humus. The strong negative correlation between Fe_o and Si is partly attributable to the properties of parent materials as well as the Andosolization process. Negative correlation between Fe and Si content is basically found in fresh tephras having a wide range of rock types.

Significant positive correlation was found between Sio and 24 elements (Be, Al, Sc, Ti, Mn, Fe, Y, Zr, Nb, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf and Ta), between Alo and 22 elements (Be, Al, Sc, Ti, Fe, Ge, Y, Zr, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Hf), and between Feo and 18 elements (Al, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Ga, Ge, Y, Eu, Gd, Tb, Ho and Er). These elements are concentrated in Andisols during Andosolization. Due to very high correlation between Si_o and Al_o, 21 elements among 23 strongly correlated with Si_o, also showed high correlation with Al_o. Mn and Ta, strongly correlated with Si_o, also showed significant positive correlation with Al_o at p=1%.

Ten elements (Al, Sc, Ti, Fe, Y, Eu, Gd, Tb, Ho and Er) that showed strong correlation with either of Si_o and Al_o also correlated with Fe_o. However, 11 elements (Be, Ce, Pr, Nd, Sm, Dy, Tm, Yb, Lu and Hf) among 21 elements that correlated with both Si_o and Al_o did not correlate very strongly with Fe_o. Other 8 elements (V, Cr, Mn, Co, Ni, Cu, Ga and Ge) correlated strongly with Feo in spite that they did not correlate with either Si_o or Al_o very strongly. All the members of first transition metals from Sc to Cushowed strong correlation with Fe_o, adding Sc, Ti and Fe that correlated also with Si_o and Al_o.

Thus, many trace elements are concentrated in Andisols in spite that these soils are formed with strong leaching possibly due to strong affinity to noncrystalline materials. Rock type of parent tephras also affect the elemental composition of Andisols.

References

Aubert, H. And Pinta, M. 1977. Trace Elements in Soils. Developments in Soil Science 7, Elsevier, Amsterdam, 1−395.

Blakemore, L.C., Searle, P.L. and Daly, B.K. 1981. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 10A. Department of Scientific and Industrial Research, New Zealand.

Childs, C.W., Matsue, N., and Yoshinaga, N. 1990. Ferrihydrite in volcanic ash soils of Japan, Soil Sci. Plant Nutr., 37, 299−311.

Gobran, G.R., Wenzel, W.W. and Lombl E. 2001. Trace elements in the rhizosphere, CRC Press, Boca Raton, USA, 1−321.

Gooddy, D.C., Shand, P., Kinniburgh, D.G., and Van Riemsdijk, W.H. 1995. Field−based partition coefficients for trace elements in soil solutions, Eur. J. Soil Sci., 46, 265−285.

Inoue, K., and Mizota, C. 1988. Eolian origin of 2 : 1 layer silicates and fine quartz in Andosols and red−yellow soils developed on limestones and basalts, J. Clay Sci. Soc. Jpn, 28, 30−47.

Kato, Y. 1983. Mechanism of volcanic ash soil formation. In : Y. Yoshinaga (ed.) Volcanic Ash Soils −Genesis, Properties and Classification, Hakuyuusha, Tokyo, 5−30.

Kitagishi, K. And Yamane, I. 1981. Heavy Metal Pollution in Siols of Japan, Japan Scientific Press, Tokyo, 1−302.

Mortvedt, J.J., Cox, F.R, Shuman, L.M. and Welch, P.M. 1991. Micronutrients in Agriculture 2nd Ed. Soil Sci. Soc. Am., Inc. Madison, Wisconsin, USA, 1−760.

Nanzyo, M. , Yamasaki, S. and Honna. T. 2002. Changes in content of trace and ultratrace elements with an increase in noncristalline materials in volcanic ash soils of Japan. Clay Sci. 12, 25−32.

Parfitt, R.L. and Henmi, T. 1982. Comparison of an oxalate extraction method and an infrared spectroscopic method for determining allophane in soil clays, Soil Sci. Plant Nutr., 28, 183−190

Parfitt, R.L., and Kimble, J.M. 1989. Conditions for formation of allophane in soils, Soil Sci. Soc. Am. J., 53, 971−977

Saigusa, M., and Matsuyama, N. 1998. Distribution of allophanic Andosols and Non−allophanic Andosols in Japan, Tohoku J. Agric. Res., 48, 75−83.

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

Soil Survey Staff. 1999. Soil Taxonomy, A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2th Ed. Agriculture Handbook No. 436, United States Department of Agriculture, U.S. Government Printing Office, Washington DC 20402, 271−328.

Ugolini, F.C., Dahlgren, R., Shoji S., and Ito. T. 1988. An example of andosolization and podzolization as revealed by soil solution studies, Southern Hakkoda, northeastern Japan. Soil Sci., 145, 111−125.

Wada, K. 1980. Mineralogical characteristics of Andosols. p.87−107. In B.KG. Theng (ed.) Soils with variable charge. New Zealand Soc. Soil Sci., Lower Hutt, N.Z.

Wada, K. 1986. Ando Soils in Japan, Kyushu University Press, pp.276.

Yamasaki, S. 1996. Inductively coupled plasma mass spectrometry, In : Eds. T.W. Boutton and S. Yamasaki, Mass Spectrometry of Soils, Marcel Dekker,, Inc. New York, 459−491.

Yamasaki, S. 2000a. Soil Analysis by inductively coupled plasma mass spectrometry, BUNSEKI KAGAKU, 49, 217−224.

Yamasaki, S. 2000b. Inductively coupled plasma mass spectrometry in environmental analysis, In : Ed. R.A. Meyers, Encyclopedia of Analytical Chemistry, John Wiley & Sons Ltd, Chichester, 2672−2692.

Yamasaki, S., Takeda, A., Nanzyo, M., Taniyama, I., and Nakai, M. 2001. Background levels of trace and ultra−trace elements in soils of Japan, Soil Sci. Plant Nutr. 47, 755−765

JIFS, 2 : 89 − 93 (2005)

The Evaluation of Grazing Environment Condition: The Scales, the Slopes and the Ground Condition of Grazing Pasture

Daisuke KOHARI[1†], Takami KOSANO[2], Shusuke SATO[2] and Kazuo SUGAWARA[1]

[1] Graduate School of Agricultural Science, Tohoku University, Naruko, Miyagi 989−6711 Japan
[2] National Institute of Livestock and Grassland Science,768 Nishinasuno, Tochigi 329−2793 Japan

[†] Present address: Experimental Farm of Agricultural Production Technology, School of Agriculture,
Ibaraki University, Ami, Ibaraki 300−0393 Japan

Correspondence : Daisuke Kohari : Tel & Fax : +81−29−888−8705, E−mail : kohari@mx.ibaraki.ac.jp

Abstract

In a present paper, we reviewed some of the welfare concerns about grazing condition. It was thought that the largest scale of the grazing environment had to consider the range where the animal moved. On the other hand, the smallest scale of grazing environment might be needed to consider the inter−individual distance of animals. The slope of grazing environment might be considered advantageous because of the exercise provided. However, high sloping areas seem to be avoided as resting area and the sloping pasture with little resting area is not a good choice when trying to provide an adequate environment. The ground conditions of crowding area should be controlled by the location of amenities. We thought that the standards for cattle management should include ample evaluation of grazing environment and these information would be necessary to determine appropriate standards for grazing environment.

1. Introduction

In 1985 in Austria, Bartussek proposed a comprehensive evaluation standard of farm animal welfare called the Animal Needs Index (ANI). In the early 1990s, a more detailed and specific version was developed by several working groups. In 2000, ANI for cattle, "ANI 35L/2000−cattle," and in 2001, ANI for laying hens, "ANI 35L/2001−laying hens," were completed, and these are becoming a European standard of farm animal welfare. The standard for cattle, which has many guidelines for assessing the housing environment of cattle, is classified into 5 categories : (1) affording movement and locomotion, (2) affording social interaction, (3) type and condition of flooring, (4) light and air condition and (5) stockmanship. On the other hand, the guidelines regarding the grazing environment are very rough, listing only the number of pasturage days and the amount of pasturage time. The grazing environment provides the animals with not only freedom and amenity but also asperity, so we believe standards for cattle management should include ample evaluation of grazing environment. In this paper, we reviewed some of the major welfare concerns for cattle in a grazing environment.

2. The scale of the grazing environment

The provisions of feeding and resting are the most important elements for farm animal welfare. Especially in the case of grazing, little assistance is needed from stockperson, so it is necessary to think about the scale of the pasture or the location of amenities such as watering places and shade.

When considering the scale of pasture or the location of amenities, the nature of the locomotion of the animal would be important. There are many reports about the distance cattle can walk. Arnold and Dudzinski (1978) reported that the distance per day was 0.9−12.6 km, while Suzuki *et al.* (1984) reported that it was 3 − 5 km. It is likely that the season or the scale of the pasture affected these distances. Krohn *et al.* (1992) reported that the distance in summer was 2.5 km and in winter it was 0.8 km in a 10−ha pasture. Shepperd (1921) reported that the distance in a 12−ha pasture was 2.7 km per day and in a 260−ha pasture it was 8.9 km. In addition, Frazer and Broom (1990) reported that though the distance was 0.9 km in a 0.1-ha paddock, it was 24 km in range pasture in the dry season. They suggested that the distance was influenced by the location of food and water, and that the quality of grass was a stronger factor than the quantity of grass, milking stage, the body condition, or season. The evaluation of the scale of pasture will change whether the walking distance is considered as a "locomotion load" or "behavioural freedom." However, the distance reported by Frazer and Broom might be too long as an optimal distance, though it could be thought of as a walking potential.

Suzuki *et al.* (1984) suggested that if there were one shade in 10 ha or100 ha, it would be enough because the daily walking distance of cattle is 3 – 5 km. However, they were assuming the pasturage was in flat land. This distance must be shorter in our country, which has many mountainous areas. Holechek *et al.* (1995) suggested that the distance to a watering place should be less than 3.2 km in flat land, less than 0.8 km in wasteland and less than 1.6 km in hilly and sandy land. Sugiyama (2001) reported that the distance between walking areas per day was 462 m (walking area per day : 14.1 ha) in a mountainous area. Although she had not shown the tracks in a walking area where cattle moved, we concluded that the reported distance might be restrained because of the area being mountainous. Furthermore, the walking ability of calves was reported as 12 m per 30 min during the first week after birth and only 80 m per 30 min during the 2nd month (Frazer and Broom.1990). Therefore, it is necessary to consider the following load of calves when we evaluate the grazing environment of a breeding farm.

On the other hand, there are few reports on the minimum scale need for a grazing environment. Krohn *et al.* (1992, 1994) reported that cattle willingly use a pasture, and the provision of a pasture decreased abnormal behaviour such as bar-biting in the cow shed. Thus, the provision of pasture could be considered a beneficial element for cattle management. However, these open space provisions have to be satisfactry both quantitatively and qualitatively. Quantitative needs relate to the space occupation, social distance and flight distance. Qualitative needs relate to space-dependent activities such as eating, exploration, body care, kinetics and social behaviour (Frazer and Broom.1990).

The inter-individual distance of milking cow kept in intensive pasture was reported to be 8.8 m, and it was 9.2 m in extensive rangeland in Australia (Frazer and Broom.1990). When cattle lie down, most of them keep within 2-3 m of one another compared with 4-10 m when they graze. Furthermore, the distance broadens to a 25-m radius when a bull is present (Frazer and Broom.1990). In the Dairy Housing and Equipment Handbook (1976) of the United States, It has been recommended that the area need for a cow to move is 4 – 7 m^2 or 7 – 10 m^2 and the area need to lie or rest is 3 – 7 m^2. On the other hand, that of the United Kingdom is 9 – 12 m^2 (Wilson.1978). Based on these results, Kondo *et al.* (1986) studied the relationships of the herd structures to environmental factors. They indicated that the herd structure at the feedlot could be kept until 30 m^2 / cow like that at the grazing pasture. In addition, Sato *et al.* (1976) suggested that the herd would spread out as the herd density grew, and the cohesiveness of the herd tended to decrease when the herd density reached 35 a – 40 a / 4 cow. These results might serve as a reference when we consider the optimal scale for the grazing herd.

3. The slope of the grazing environment

Unlike many flat grazing lands in Europe, our country has many mountainous areas, so it is hard to exclude sloping area from the grazing land. Thus, the effect of slopes as part of the grazing environment must be considered. Mountainous area or sloping areas were considered better for animals than more gently sloping pasture or flat land in ANI (Bartussek *et al.* 2000), because they provide better exercise for the skeletal apparatus and circulation of the animals. Sawazaki *et al.* (1974a) reported that the width of body width and the skeletal apparatus of the store cattle farmed in mountainous area was better developed than that of cattle farmed in flat area, though they generally finished smallish. Furthermore, the effect of slopes heightened the resistance to diseases (Sawazaki *et al.*1974b), activated the metabolic and circulatory system and improved animals' oxygen-use-efficiency. As a result, the growth rate, the dressed carcass percentage, the marbling, the subcutaneous fat thickness and the rib-eye area was better in these cattle than in those raised in a flat area (Sawazaki. 1975). Henderson *et al.* (1966) reported that the exercise occurring in flat pasture accelerated metabolism through the cardiorespiratory training, and Kido and Hayashi (1999) indicated that type Ⅰ muscle fiber, which indicates high fat storing ability in fattening periods increased, increased at the superficial part of longissimus muscle, the rectus femoris muscle and the semimembranosus muscle, so raising cattle on sloped grazing land might be considered advantageous because of the exercise provided.

On the other hand, there are many reports that animals have a disadvantage with respect to resting area. Yasue *et al*. (1997) showed that resting behaviour of cattle was observed between 0 and 15 degrees of slope and was never observed when the slope was over 25 degrees. Ganskopp and Vavra (1987) suggested that grazing cattle avoided slopes over 30 % (about 16−17 degrees) . Mueggler (1965) reported that cattle used a 750−m radius area from the bottom in the 10 % sloping pasture, whereas they used only 30−m radius area from the bottom in the pasture with 65 % slopes. In addition, Yagi *et al*. (1983) estimated the energy expenditure by cattle in a mountainous pasture that included many slopes (under 6 degree : 65 %, 6 to 12 degrees : 20 %, 12 to 16 degrees : 15 %) and reported that the energy expenditure in the mountainous pasture was 1.9 to 2.4 times as large as that in the flat pasture. Thus, it is necessary to consider that slopes may require twice as large an energy expenditure as that of flat land.

Ide *et al*. (1998a, b) reported that in 0 to 6 degrees of slope, the cattle could move relatively freely, and in slopes up to 12 degrees cattle could move without cattle tracks. When the slope is 12 to 16 degrees, cattle tracks occur and their use is heightened. In slope of 16 degrees or more, the walking area was approximately limited to the cattle tracks. The gradient levels of the cattle tracks in high sloping area have been reported as less than 5 degrees (Oikawa *et al*. 1981), 0 to 6 degrees (Kamata *et al*.1981) and 2 to 4 degrees (Arnold and Dudzinski. 1978) and were nearly equal to the levels with high behavioural freeness reported by Ide *et al*. (1998 a, b) Therefore, the gradient levels up to 5 or 6 degrees might be appropriate to ensure cattle's behavioural freeness. Generally, high sloping areas seem to be avoided as resting area and the sloping pasture with little resting area is not a good choice when trying to provide an adequate environment.

4. The condition of the ground in the crowding area

The ground conditions of the resting area or crowding area are very important for the cattle−housing environment. In ANI (Bartussek *et al*. 2000), the slipperiness and the structural problems causing hoof injuries were evaluated as negative factors, and wet and muddy conditions of the floor at the outdoor area of the cowsheds restricted the locomotion of cattle and aggravated hoof diseases. Thus, the ground condition is very important.

It is well known that cattle often use the area around the watering place as a resting area (Arnold and Dudzinski.1978, Yasue *et al*.1999). These areas become muddy because they are wet and the ground becomes churned up by the cattle (Sato *et al*. 2002). In addition, the excreta of cattle accumulate around the watering place or resting area (Ide *et al*. 1998a, b, Yasue *et al*. 1993), making these areas unsanitary and contributing to mastitis and hoof diseases (Sato *et al*. 1995, 2002). Fisher *et al*. (2003) reported that the percentage of lying time is 20 % less in muddy areas than in general grazing pasture, and they indicated that the muddy ground was avoided for this purpose. These crowding areas could be controlled by the location of the watering place or the shade (Ganskoopp.2001, Inoue *et al*. 1969, Sakurai and Dohi.1988). Thus, the size of dirty area can possibly be decreased by spreading the location of these amenities.

5. Conclusion

The extensive beef production system of grazing has attracted a great deal of attention in both developing and developed countries recently from the viewpoint of environmental protection, amenity and animal welfare. However, there are few evaluations and standardizations like the ANI dealing with grazing conditions compared with many codes regarding housing condition, slaughter and transportation in various countries. This might be because it is thought that grazing is already an enriched condition. However, the negative elements described in this paper must also be taken into consideration. We have reviewed some of the welfare concerns about grazing condition in this paper. It might be possible to compose a standard of grazing environment. However, there are other issues about the grazing environment and there are not many studies to consult. We believe that more information about climate, the vegetation type, location of the shade or the shelter and the degree suffering of the ectoparasites and the transient-biters is also necessary to determine appropriate standards for grazing environment.

6. Acknowledgement

This study was supported in part by Grant-in-Aid for Scientific Research (A) (No.16208027) from Ministry of Education, Culture, Sports, Science and Technology (MEXT) to Dr S. Sato.

References

Arnold, G..W. and Dudzinski, M.L. (1978) Ethology of free-ranging domestic animals. Elsevier Scientific Publishing, NY. pp1-86.

Bartussek, H., Leeb, C.H. and Held, S. (2000) Animal Needs Index / ANI 35L/2000 cattle Federal Research Institute for Agriculture in Alpine Regions BAL Gumpenstein, Austria.

Dairy Housing and Equipment Handbook (1976) Midwest plan service committee of dairy housing work. Iowa state university, Ames.

Fisher, A.D., Stewart, M., Verlerk, G.A., Morrow, C.J. and Matthews, L.R. (2003) The effect of surface type on lying behaviour and stress responses of dairy cows during periodic weather-induced removal from pasture. Appl. Anim. Behav. Sci. 81 : 1-11.

Frazer, A.F. and Broom, D.M. (1990) Locomotion and other movement. In : Farm Animal Behaviour and Welfare. CAB International, London, UK. pp116-117.

Ganskopp, D. and Vavra, M. (1987) Slope use by cattle, feral horses, deer, and bighorn sheep. Northwest Sci. 61 : 74-81.

Holechek, J.L., Pieper, R.D. and Herbel, C.H. (1995) Range management-Principles and practices. 2nd ed. Prentice-Hall, Englewood Cliffs, NJ. pp 1-103.

Henderson, D.W., Goll, D.E. and Kline, E.A. (1966) Relationships of muscling and finish measurements from three different groups of beef carcasses with carcass yield. J. Anim. Sci. 25 : 323-328.

Ide, Y., Kojima, M. and Hayashi, H. (1998a) Topography and pasture management in the mountainous slopeland 1. The distribution of bare area and cattle dung. Grassl. Sci. 44 : 208-214 (in Japanese with English summary).

Ide, Y., Kojima, M. and Hayashi, H. (1998b) Topography and pasture management in the mountainous slopeland 2. Effects of the cattle dung distribution on soil fertility, forage grass production and degree of defoliations. Grassl. Sci. 44 : 215-222 (in Japanese with English summary).

Inoue, T., Hirose, M., Numakawa, T., Takai, S. and Ito, M. (1969) Study of public grassland use of grazing cattle. Miscell. Publ. Tohoku Nat. Agr. Exp. Sta. 10 : 21-25 (in Japanese, translated title by the present authors).

Kamata E., Okamoto K. and Nada Y. (1981) Morphological studies on cattle tracks. Bull. Kyushu Agr. Expt. Sta. 21 : 461-471 (in Japanese with English summary).

Kido, K. and Hayashi, Y. (1999) Effect of grazing in mountainous are to the type and diameter of muscle fiber in raising cattle. Proceedings of the 97th annual meeting of Japanese Society of Animal Science, pp129 (in Japanese, translated title by the present authors).

Kondo, S. (1986) Behavioural adaptation in group of cattle. J. Fac. Agric., Hokkaido Univ 15 : 192-233 (in Japanese with English summary).

Krohn, C.C., Munksgaard, L. and Jonasen, B. (1992) Behaviour of cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments. I. Experimental procedure, facilities, time budgets-durnal and seasonal conditions. Appl. Anim. Behav. Sci. 34 : 37-47.

Krohn, C.C. (1994) Behaviour of dairy cows kept in extensive (loose housing / pasture) or intensive (tie stall) environments. Ⅲ. Grooming, exploration and abnormal behaviour. Appl. Anim. Behav. Sci. 42 : 73-86.

Mueggler, W. F. (1965) Cattle distribution on steep slope. J. Range Manage. 18 : 255-257.

Oikawa, M., Shimamura, K., Ushiyama, M. and Fukuyama, M. (1981) Cattle behavior and pasture management in the slope land. I. Forms of cattle tracks and their characteristics. Bull. Natl. Grassl. Res. Inst. 18 : 105-126 (in Japanese with English summary).

Sato, Y. (1995) The preventive technique of the muddy condition around the cowshed without paving with concrete. Agric. Consult. 31 : 59-61 (in Japanese, translated title by the present authors).

Sato, Y., Nakamura, M., Yayou, K. and Ito, S. (2002) The preventive technique of the muddy condition by the wooden grating. Jpn. J. Livest. Management 38 : 54−55 (in Japanese, translated title by the present authors).

Sato, S., Ito, I. and Hayashi, K. (1976) Studies on the spatial pattern of grazing cattle. II. The influences of seasons and the paddock size. J. Jpn. Soc. Grassl. Sci. 22 : 313−318 (in Japanese with English summary).

Sakurai, M. and Dohi, H. (1988) The study of the thermoregulatory behaviour in grazing cattle. I. The effect of the heat to the coat temperature and heat−avoiding behaviour of grazing cattle. Bull. Natl. Grassl. Res. Inst. 38 : 1−11 (in Japanese with English summary, translated title by the present authors).

Sawazaki, T., Hirose, H., Kikuchi, T., Kyuma, T., Takizawa, S., Takahashi, M., Fuchimukai, S., Onodera, T., Katabira, T. and Yoshida, U. (1974a) Effect of the rearing in mountainous regions on the productivity of beef cattle. I. Growth and body type of the beef cattle. Jpn. J. Zootech Sci. 45 : 597−602 (in Japanese with English summary).

Sawazaki, T., Hirose, H., Kikuchi, T., Kyuma, T., Takizawa, S., Takahashi, M., Fuchimukai, S., Onodera, T., Katabira, T. and Yoshida, U. (1974b) Effect of the rearing in mountainous regions on the productivity of beef cattle. II. Physiological conditions of feeder and fatting cattle. Jpn. J. Zootech Sci. 45 : 638−643 (in Japanese with English summary).

Sawazaki, T., Hirose, H., Kikuchi, T., Kyuma, T., Takizawa, S., Takahashi, M., Fuchimukai, S., Onodera, T., Katabira, T. and Yoshida, U. (1975) Effect of the rearing in mountainous regions on the productivity of beef cattle. III. Production of fatting cattle. Jpn. J. Zootech Sci. 46 : 469−476 (in Japanese with English summary).

Shepperd, J.H. (1921) The trail of the short grass steer. N. D. Agric. Coll. Bull. 154. 8.

Sugiyama, M. (2001) The analysis of grazing land use of Japanese Shorthorn cows by GPS and GIS in a national forest without fencing. Mr. Thesis, Graduate School of Agricultural Science, Tohoku University (in Japanese)

Suzuki, S., Kitahara, T., Yoshimura, Y. and Suyama, T. (1984) Function and placement of shade trees for grazing cattle. Bull. Natl. Grassl. Res. Inst. 29 : 1−20 (in Japanese with English summary)

Yagi, M., Inudo, Y., Mino, S., Takimoto, Y. and Nakanishi, Y. (1983) Investigation on grazing behaviour, moving gradient and walking speed of grazing beef cattle. Bull. Kyushu Agr. Expt. Sta. 23 : 321−335 (in Japanese with English summary).

Yasue, T., Kondo, S., Okubo, M. and Asahida, K. (1993) The effect of elevation and slope of hilly pasture on cattle distribution at grazing and resting during summer season. Jpn. J. Livest. Management. 29 : 61−68 (in Japanese with English summary).

Yasue, T., Kondo, S., Okubo, M., Asahida, Y. (1997) The effect of paddock topography on resting−site preference of grazing cattle in a hilly pasture during summer season. Grassl. Sci. 43 : 196−201.

Yasue, T., Kondo, S., Okubo, M., Asahida, K. (1999) Climatic characteristics of the resting site for grazing cattle in a hilly pasture during summer season. Jpn. J. Livest. Management. 34 : 77−85.

Wilson, H. C. (1978) Beef cattle and Veal calves : In The care and management of farm animals (ed. by Scott, W.N.). Bailliére Tindall, London. pp29−52.

JIFS, 2 : 95 − 106 (2005) review

Ammonia−Assimilating Microbes in the Animal Waste Treatment Systems

Hiraku SASAKI [1], Takako SASAKI and Yutaka NAKAI*

Laboratory of Animal Health and Management, Graduate School of Agricultural Science, Tohoku University, Naruko−machi, Miyagi, 989−6711, Japan

[1] Current address : Animal Research Center, Tokyo Medical University, Shinjuku−ku, Tokyo, 160−8402, Japan
*** Corresponding author : Yutaka Nakai (nakai@mail.bios.tohoku.ac.jp)**

Key words : ammonia, animal waste, compost, lagoon, microbe

Abstract

Ammonia assimilation by microbes is one of important steps of ammonia removal from animal waste treatment systems. We have investigated about distribution and abundance of ammonia−assimilating microbes in the animal waste treatment systems. Ammonia assimilating microorganisms were isolated from the animal waste treatment systems by nitrogen−limited medium. Many of isolates utilized ammonia even when they were cultivated in the media containing viable microbial flora of the animal waste treatment systems. Almost of the dominant species which were detected by analysis of microbial community structure did not coincide with isolates which showed the high ammonia−assimilating ability in the lagoon, but some species by analysis of actinomycetes community structure coincided with the high ammonia−assimilating isolates in the compost. These results suggested that ammonia−assimilating microbes existed as non−dominant species in the microbial community in a lagoon, but some of cultured actinomycetes were the member of dominant species in the actinomycetes community in compost.

Introduction

Recently, the large−scale livestock operations have increased in number rapidly in Japan. Simultaneously, the complaint about odorous volatilization from animal manure and their treatment systems has also been increasing. Among them, ammonia is one of the most odorous materials volatilized from animal manure treatment systems. The ammonia emission results in the generation of malodor as well as the loss of nitrogen compounds from the composting materials (Nakai, 2001). Moreover, ammonia may give rise to eutrophication or acidification of water environments (Eghball and Power, 1994; Horn et al., 1994). Biological control of ammonia volatilization is needed for retention of nitrogen compounds in the compost and preservation of the environment.

Ammonia−oxidizing microbes are generally considered to major contributor for ammonia removal from manure treatment systems. Tiquia and Tam (2000) reported that long term (35 days) was required before microbial oxidation of ammonia and nitrite began in the composting process of the mixture of chicken litter. Therefore, the assimilation of ammonia by heterotrophs was more important than the nitrification by autotrophs in the early stages of composting (Nakai et al. 1999; Nakai 2001). Many species of microbes were investigated to assimilate ammonia through glutamine synthesis (Merrick & Edwards 1995; Patriarca et al. 2002). In the pathway, glutamate is used as microbial nitrogen compound (Schneider et al. 1998; Michel−Reydellet & Kaminski 1999). Although ammonia−assimilating microbes exist in animal waste treatment systems, their distribution, abundance and ability of the ammonia assimilation have been known little.

In the present paper, we review results about the isolation of ammonia−assimilating microbes from the animal waste treatment systems and evaluation of their ammonia−assimilating ability (Sasaki et al., 2002; Sasaki et al., 2004a) and the dominancy of ammonia−assimilating microbes in microbial community in the animal waste treatment systems (Sasaki et al., 2004b).

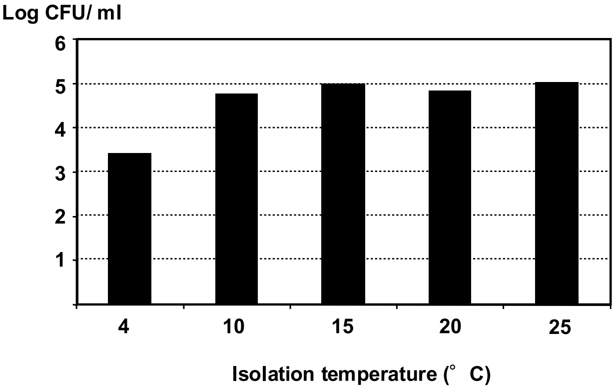


Fig. 1.Change of the numbers of ammonia‒assimilating microbes at 4°C, 10°C, 15°C, 20°C and 25°C, respectively.

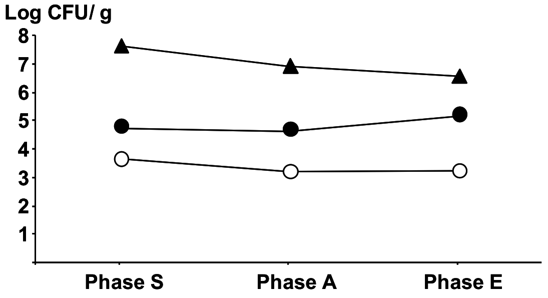


Fig. 2. Change of the numbers of aerobes and ammonia-assimilating microbes in the composting process.

(▲) : aerobes, (●) : ammonia-assimilating microbes at 37°C for 72 h, (○) : Numbers of ammonia-assimilating microbes at 55°C for 72 h.

Isolation of ammonia-assimilating microbes from the animal waste treatment systems

For the isolation of ammonia‒assimilating microbes, we used nitrogen‒limited medium which contained ammonia as a sole nitrogen source. Nitrogen‒limited medium composed of 5.0g of glucose, 0.25g of NH_4Cl, 0.1g of $Fe(NH_4)_2H(C_6H_5O_7)_2$, 0.5g of NaCl, 0.5g of $MgSO_4 \cdot 7H_2O$, 0.1g of $MnCl_2 \cdot 4H_2O$, 3.2g of K_2HPO_4 and 1.0g of KH_2PO_4 in 1L of distilled water, 1.5% of gellan gum was added to the nitrogen‒limited medium for the plate medium. The numbers of ammonia assimilating microbes in the lagoon for wastewater from a paddock of dairy cattle were 3.4, 4.8, 5.0, 4.8 and 5.0 (Log CFU/ ml) on the culture plate which were incubated for 168h at 4°C, 10°C, 15 °C, 20°C and 25°C, respectively (Fig. 1). Especially, numbers of ammonia assimilating microbes on the plate incubated at 4°C were lower than those of ammonia assimilating microbes on the plate incubated at the other temperature.

Figure 2 showed numbers of aerobes at 37° C incubation and those of ammonia‒assimilating microbes at 37°C and 55°C, respectively, in the cattle manure composting processes for 72 h. The numbers of aerobes were decreased from 7.6 to 6.6 Log CFU/ g as the composting process proceeded. Ammonia‒assimilating microbes were at the range of 4.6 to 5.1 Log CFU/ g at 37°C incubation. While at 55°C, numbers were lower and they were at the range of 3.2 to 3.7 Log CFU/ g. Ammonia‒assimilating microbes were not detected at 70°C. Numbers of ammonia‒assimilating microbes at 37°C incubation in three stages of composting were 0.13%, 0.49% and 3.90% of numbers of total aerobes, respectively. Also, numbers of ammonia‒assimilating microbes at 55°C incubation in three stages were 0.01%, 0.02% and 0.05% of those of total aerobes, respectively. These results suggested that the proportion of the ammonia‒assimilating microbes increased in the composting process.

The ability of isolates to assimilate ammonia

The lagoon‒extract medium or the compost‒extract medium was used for measuring ammonia assimilation of isolates. Table one showed ammonia consumption of isolates from the lagoon in sterilized lagoon‒extract medium incubated for 72h at 4° C, 10°C, 15°C, 20°C and 25°C, respectively. All isolates did not produce nitrite, and they were confirmed not to be ammonia‒oxidizing microbes. 15 of them showed the consumption more than 90% of ammonia in the medium. The isolates which showed especially high ammonia assimilation in the pure culture was cultivated in non‒sterilized

Table 1. A distribution of ammonia consumption of ammonia‒assimilating bacteria at isolation temperature from a lagoon

Item	Isolaton temperature (°C)				
	4	10	15	20	25
Ammonia consumption (%)					
>90	0	3	1	4	7
90‒70	0	0	0	0	0
70‒50	0	0	0	0	0
50‒30	0	0	0	1	1
<30	3	0	5	6	3
Total number of isolates	3	3	6	11	11

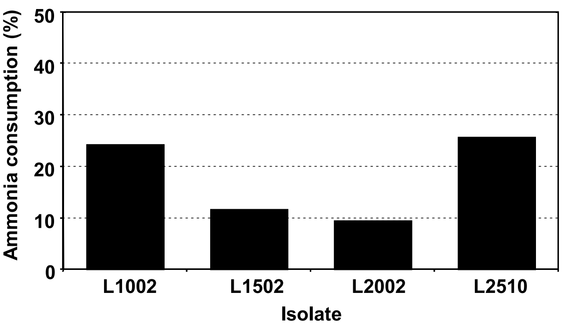


Fig. 3. Ammonia consumption of selected isolates for 72 h at each isolated temperature in non-sterilized lagoon extract medium.

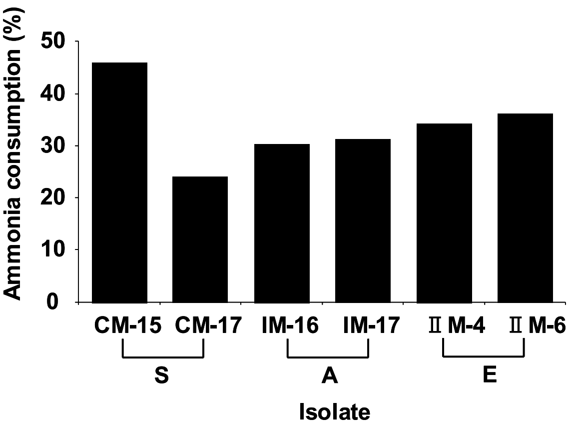


Fig. 4. Ammonia consumption of selected isolates from each stage of the composting process at 37°C cultivation for 72 h in non-sterilized compost-extract medium.

S : Isolated from starting point of the lag phase (phase S), A : Isolated from the end of the active composting phase (phase A), E : Isolated from the end of the secondary composting phase (phase E). Ammonia concentration of compost-extract medium was 64.7, 55.6 and 55.4 mg/ l with the uninoculated control in the pre-fermentation, the primary fermentation and the secondary fermentation, respectively.

lagoon-extract medium (Fig. 3). L1002 isolated at 10°C and L2510 isolated at 25°C showed relatively high ammonia consumption, 24.4% and 25.8%, respectively. Also, L1502 isolated at 15°C and L2002 isolated at 20°C showed significant ammonia consumption, 9.5% and 11.7%, respectively. Figure four showed ammonia consumption of isolates, which showed especially high ammonia consumption in sterilized compost-extract medium, in non-sterilized compost-extract medium incubated for 72 h at 37°C. CM-15 showed the highest ammonia consumption (46.0%) among the isolates. Other isolates showed significant ammonia

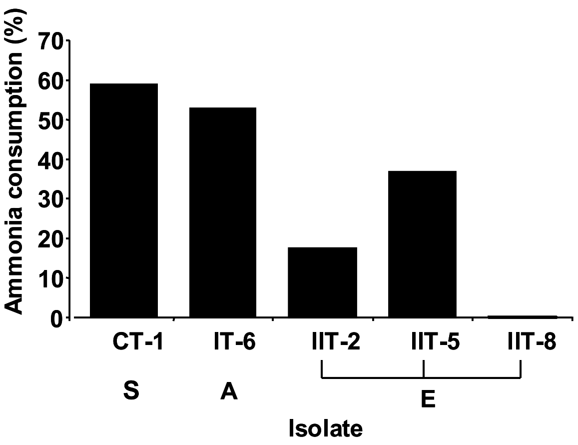


Fig. 5. Ammonia consumption of selected isolates from each stage of the composting process at 55°C cultivation for 72 h in non-sterilized compost-extract medium.

S : Isolated from starting point of the lag phase (phase S), A : Isolated from the end of the active composting phase (phase A), E : Isolated from the end of the secondary composting phase (phase E). Ammonia concentration of compost-extract medium was 53.7, 46.1 and 45.9 mg/ l with the uninoculated control in the pre-fermentation, the primary fermentation and the secondary fermentation, respectively.

consumption at the range of 24.0 to 36.0%. Figure 5 showed ammonia consumption of isolates in non-sterilized compost-extract medium at 55° C. CT-1 isolated from the starting point of the lag phase showed 59.0% of ammonia consumption, and IT-6 from the end of the active composting phase showed 52.8%. These results indicated that ammonia-assimilating microbes could assimilate ammonia even in the complex microbial community of the animal waste treatment systems.

Identification of high ammonia-assimilating isolates

Isolates which showed high ammonia consumption in non-sterilized lagoon and compost-extract medium were identified. L2510 was identified as *Enterobacteriaceae*, which showed 99% similarity to *Buttiauxella agrestis* (GenBank accession no. AJ293684), *B. brennerae* (AJ233401), *Enterobacter nimipressuralis* (Z96077) and *Obesumbacterium proteus* (AJ233422). L1002 showed 100% similarity to *Pseudomonas cedrella* (AF064461), *P. fluorescens* (AF094729), *P. gessardii* (AF074384), *P. libaniensis* (AF057645) and *P. putida* (AF095892). Most of

Table 2. High ammonia-assimilating microbes isolated at 37°C identified on the basis of percent similarity to 16S rDNA sequence

Phase*	Isolate	Species identification (GenBank accession no.)	Similarity %
S			
	CM-15	*Zoogloea ramigera* (X74915)	100
	CM-17	*Mycobacterium marinum* (U92088)	99
		M. neoaurum (AF268445)	99
		M. peregrinum (AF058712)	99
		M. smegmatis (X52922)	99
A			
	IM-16	*Pseudomonas* sp. (AF288724)	97
	IM-17	*Pseudomonas* sp. (AF288724)	97
E			
	IIM-4	*Streptomyces scabies* (Y15509)	100
	IIM-6	*Streptomyces scabies* (Y15509)	100

*Samples were obtained at starting point of the lag phase (phase S), the end of the active composting phase (phase A) and the end of the secondary composting phase (phase E).

Table 3. High ammonia-assimilating microbes isolated at 55°C identified on the basis of percent similarity to 16S rDNA sequence

Phase*	Isolate	Species identification (GenBank accession no.)	Similarity %
S			
	CT-1	*Roseiflexus castenholzii* (AB041226)	90
A			
	IT-6	*Bacillus smithii* (Z26935)	99
E			
	IIT-5	*Bacillus smithii* (Z26935)	99

*Samples were obtained at starting point of the lag phase (phase S), the end of the active composting phase (phase A) and the end of the secondary composting phase (phase E).

microbes assimilate ammonia via the glutamine synthetase/ glutamate synthase (GS/ GOGAT) system (Merrick and Edward, 1995; Arcondeguy et al., 2001). This pathway operates efficiently even at low ammonia concentration in mostly gram-positive bacteria (Dean & Aronson 1980; Hu et al. 1999). Furthermore, enteric bacteria possess both the pathway and an additional one, the reductive amination of 2-oxoglutarate catalyzed by biosynthetic glutamate dehydrogenase (GDH; Ikeda et al. 1996; Hu at al. 1999). This pathway operates efficiently only at high ammonia concentration. L2510 considered to be one of species of *Enterobacteriaceae*. The isolate may possess both GS/ GOGAT and GDH pathway to assimilate ammonia in lagoon treatment system.

Table 2 showed identification results of high ammonia-assimilating microbes in non-sterilized compost-extract medium at 37°C incubation. CM-15 was *Zoogloea ramigera* (X74915; similarity, 100%). CM-17 showed 99% similarity to *Mycobacterium marinum* (U92088), *M. neoaurum* (AF268445), *M. peregrinum* (AF058712) and *M. smegmatis* (X52922). Although a little arrangement of sequenced genes of IM-16 and IM-17 differed, both showed 97% similarity to *Pseudomonas* sp. (AF288724). Moreover, arrangement of sequenced genes of IIM-4 and IIM-6 was the completely the same, and both of them were *Streptomyces scabies* (Y15509; similarity, 100%). Isolates at 55°C were identified as genera of thermophile or endosporogenous (Table 3). CT-1 showed 90% similarity to *Roseiflexus castenholzii* (AB041226), and both IT-6 and IIT-5 showed 99% similarity to *Bacillus smithii* (Z26935). Changes of substances and concentrations of nutrients and shifts of temperature in the process of composting may affect the ability of ammonia assimilation; consequently, dominant species of ammonia-assimilating microbes may be selected under the influence of these complex environmental conditions.

Table 4. Number of isolates which highly consumed ammonia in the media at each isolation temperature

	Isolation temperature	
Ammonia consumption %	10°C	37°C
>50	0	1(2)
40-30	0	0
30-20	0	1(2)
20-10	1(3)	2(4)
10-0	6(17)	6(13)
<0	29(80)	36(79)
Total number of isolate	36	46

() : % of total number of isolates.

Table 5. High ammonia-assimilating microbes at 10°C identified on the basis of percent similarity to 16S rDNA sequence

Isolate	Ammonia consumption %	Organism (accession no.)	Similarity %	Source
B1001	10.8	*Janthinobacterium lividum* (AF174648)	99	bottom
M1001	6.4	*Acinetobacter* sp. (M59058)	99	middle
M1002	6.4	*Lactosphaera* sp. (AF394926)	99	middle
		L. pasteurii (X87150)	99	middle
B1002	3.2	*Pseudomonas fluorescens* (AF094730)	97	bottom
		P. lundensis (AB021395)	97	bottom
		P. lundensis (D84027)	97	bottom
B1003	2.6	*Agrococcus jenesis* (X92492)	99	bottom
S1001	1.4	Unidentified bacterium (Z93992)	99	surface
B1004	1.4	Unidentified bacterium (Z93992)	99	bottom

Isolation of aerobes and evaluation of their ammonia-assimilating ability

We investigated the dominancy of ammonia−assimilating microbes in the natural habitants. Trypto Soy (TS) agar was used as a non−selective medium for the isolation of aerobes. We picked up colonies randomly in these plates, and obtained totally 36 and 46 isolates at 10°C and 37°C cultivation from a lagoon, respectively (Table 4). At 10°C cultivation, 80% of isolates did not consume ammonia in the medium. At 37°C cultivation, 79% of isolates did not consume ammonia. Isolates which showed ammonia consumption in the medium were identified by DNA analysis. At 10°C, B1001 which showed 10.8% ammonia consumption had 99% of sequence similarity to *Janthinobacterium lividum* (Table 5). At 37°C, S3701 which showed 52.7% consumption had 99% of sequence similarity to *Bacillus* sp. (Table 6). Most of other identified isolates were endosporogenous or the closely related to the genus Pseudomonas. Ammonia−assimilating microbes were about 20% among isolates cultured by TS agar from a lagoon. Almost of the high ammonia−assimilating microbes belong to the genus *Bacillus*, but this genus has not been reported as a dominant genus in the wastewater treatment systems by many studies (Wagner et al. 1993, 1994; Manz et al. 1994; Snaidr et al. 1997; Sekiguchi et al. 1998). Thus, the ammonia−assimilating microbes might not be the dominant species in a lagoon. High ammonia−assimilating microbes isolated by nitrogen−limited medium were identified as *Enterobacteriaceae* and the genus *Pseudomonas* (Sasaki et al., 2002). Their closely related species were not isolated by non−selective medium. Isolation of high ammonia−assimilating microbes may require the selective pressure.

We obtained 89 isolates at 37°C cultivation from the composting process by use of TS agar. 75 of them consumed more than 5% of ammonia in the medium and 13 isolates consumed more than 90% of ammonia in the medium. Especially, 11 isolates consumed more than 94% of ammonia. We obtained 47 isolates by cultivation at 55°C from the composting process. 13 of them consumed more than 5% of ammonia in the medium. Isolates which showed high ammonia consumption in the medium at 37°C cultivation were identified by DNA analysis (Table 7). They showed high similarity to *Enterobacteriaceae (Leclercia adecarboxylata),*

Table 6. High ammonia-assimilating microbes at 37°C identified on the basis of percent similarity to 16S rDNA sequence

Isolate	Ammonia consumption %	Organism (accession no.)	Similarity %	Source
S3701	52.7	*Bacillus* sp. (AJ000648)	100	surface
B3701	24.1	*Bacillus licheniformis* (AJ293011)	100	bottom
S3702	13.8	*Bacillus pumilus* (AB035917)	99	surface
B3703	11.8	*Pseudomonas* sp. (AF205134)	99	bottom
B3704	9.5	*Bacillus pumilus* (AB035917)	99	bottom
M3701	7.4	*Corynebacterium xerosis* (M59058)	99	middle
M3702	7.4	Uncultured gamma proteobacterium (AJ301569)	99	middle
M3703	6.7	*Pseudomonas* sp. (AY039626)	99	middle
S3703	5.9	*Bacillus* sp. (D55731)	98	surface
B3705	5.9	*Pseudomonas pseudoalcaligenes* (D87104)	100	bottom

Table 7. Identification of separated bands on the basis of percent similarity to 16S rDNA sequence

Band No.	Organism (accession no.)	Similarity %
1	Unidentified soil organism (U42885)	90
2	Uncultured bacterium (AF428984)	90
3	*Syntrophus acidotrophicus* (U86447)	97
4	Unidentified bacterium (Z93992)	98
5	*Pseudomonas* sp. (AJ007004)	95
6	*Pseudomonas taetrolens* (AJ288293)	94
7	*Pseudomonas* sp. (AF139998)	97
8	*Spirochaeta thermophila* (X62809)	97
9	*Thermoanaerobacter wiegelii* (X92513)	97

Brevibacteriaceae (Brevibacterium liquefaciens), Xanthomonadaceae (Stenotrophomonas minatitlanensis), Pseudomonadaceae (Pseudomonas sp., P. aeruginosa, P. alcaligenes, P. pseudoalcaligenes, Pseudomonas sp., P. putida) and Actinomycetales (Promicromonospora citrea, Streptomyces thermocarboxydus, S. thermotolerans, S. bellus). Isolates from 55°C were identified as thermophile or endosporogenous (Table 8). Only 10% of the isolates consumed more than 5% of ammonia in the medium at 55°C cultivation while 70% of the isolates at 37°C cultivation consumed more than 5% of ammonia. Nakasaki et al. (1985) reported that thermophiles grew not by the anabolism but by the catabolism at the high temperature stage in the composting process. Coultate and Sundaram (1975) reported that *Bacillus* stearothermophilus actively oxidized glucose at optimum growth temperature in spite of decreasing their cell yields. The genus *Bacillus* has been characterized as dominant species in hot compost (Blanc et al., 1997; Fujino and Kume, 1991; Strom, 1985). *Bacillus* isolates in this study were thermophilic dominant, but they might not actively assimilate ammonia as the anabolism in the composting process.

Table 8. High ammonia-assimilating microbes at 37°C identified on the basis of percent similarity to 16S rDNA sequence

Phase*	Ammonia consumption %	Organism (accession no.)	Similarity %
S	98.1	*Leclercia adecarboxylata* (AJ277977)	98
	97.5	*Brevibacterium liquefaciens* (AJ251417)	100
T	99.1	*Stenotrophomonas minatitlanensis* (AF273082)	97
	99.3	*Pseudomonas* sp. (AJ387904)	99
		P. aeruginosa (Z76672)	99
A	96.5	*Brevibacterium liquefaciens* (AJ251417)	100
	95.5	*Promicromonospora citrea* (X83808)	99
	93.2	*Stenotrophomonas minatitlanensis* (AF273082)	99
E	96.6	*Pseudomonas alcaligenes* (Z76653)	100
		P. pseudoalcaligenes (D87104)	100
	98.0	*Pseudomonas* sp. (AJ387904)	99
		P. aeruginosa (Z76672)	99
	97.4	*Pseudomonas* sp. (AJ132994)	99
		P. putida (D37925)	99
	94.7	*Streptomyces thermocarboxydus* (U94490)	99
		S. thermotolerans (AJ399482)	99
		S. bellus (AJ399476)	99

*Samples were obtained at starting point of the lag phase (phase S), the thermophilic phase (phase T), the end of the active composting phase (phase A) and the end of the secondary composting phase (phase E).

Analysis of microbial community structure

We observed their dominancy in the microbial community by polymerase chain reaction−denaturing gradient gel electrophoresis (PCR−DGGE; Muyzer et al. 1993; Heuer et al. 1997). The structures of microbial community in the different depth of a lagoon were shown by PCR−DGGE analysis (Fig 6). The banding pattern of the surface lagoon water was obviously different from that of the middle depth and the bottom of a lagoon. The banding patterns of the middle depth and the bottom of a lagoon were similar each other. Bands were identified as *Syntrophus acidotrophicus*, *Pseudomonas taetrolen*, *Spirochaeta thermophila* and *Thermoanaerobacter wiegelii* (Table 9). PCR−DGGE analysis showed existence of microbes which were closely related to unidentified bacterium (Z93992) in the middle depth and the bottom. They showed 99% similarity to isolates from the surface and the bottom. The strain shown by PCR−DGGE method was not the same strain of

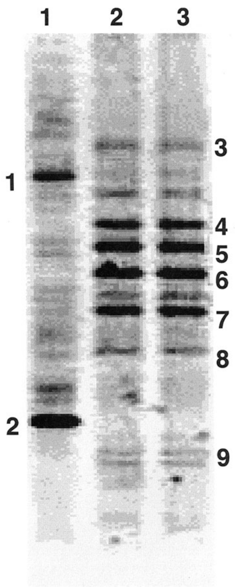


Fig. 6. Analysis of microbial communities by PCR-DGGE with whole microbial primers obtained from the surface (0-30cm, Lane 1), the middle depth (70-100cm, Lane 2) and the bottom (160-190cm, Lane 3) of a lagoon for wastewater from paddock of dairy cattle.

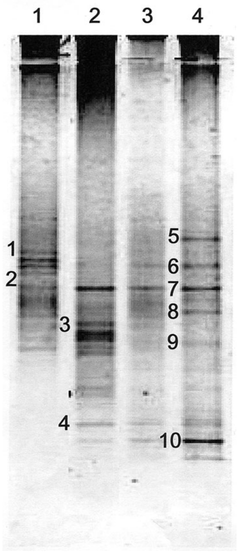


Fig. 7. Analysis of four compost communities by PCR−DGGE with whole microbial primers. Samples were obtained at starting point of the lag phase (phase S, Lane 1), the thermophilic phase (phase T, Lane 2), the end of the active composting phase (phase A, Lane 3) and the end of the secondary composting phase (phase E, Lane 4).

Table 9. High ammonia-assimilating microbes at 55°C identified on the basis of percent similarity to 16S rDNA sequence

Phase*	Ammonia consumption %	Organism (accession no.)	Similarity %
S	7.7	*Bacillus* sp. (AB024598)	97
	6.5	*Bacillus thermosphaericus* (X90640)	99
T	16.7	*Thermoactinomyces vulgaris* (AF138739)	100
	99.3	*T. candidus* (AF138732)	100
	10.8	*Bacillus smithii* (Z26935)	99
A	12.6	*Brevibacillus* sp. (AY062020)	99
E	20.0	*Bacillus thermosphaericus* (X90640)	99
	16.6	Blackwater bioreactor bacterium (AF394170)	99

*Samples were obtained at starting point of the lag phase (phase S), the thermophilic phase (phase T), the end of the active composting phase (phase A) and the end of the secondary composting phase (phase E).

cultivated isolate from a lagoon but may belong to the same species. This result indicated that only a few high ammonia−assimilating isolates is dominant in a lagoon microbial community.

Figure 7 showed the structures of microbial community during the composting process by PCR−DGGE with eubacterial primers. The banding pattern changed obviously during the composting process. At the starting point (phase S), bands were concentrated at the middle of the gel where the denaturant concentration was low to middle. At the thermophilic phase (phase T), the predominant bands moved to the lower part of the gel. At the end of the secondary composting (phase E), bands were clear and dispersed in the gel. The separated bands showed similarity to *Pacifibacter primarius* and *Pseudomonas* spp. (Table 10). However, 6 bands showed high similarity to uncultured or unidentified organisms. We also analyzed profile of actinomycete in the composting (Fig. 8). The predominant bands located at the upper to middle part of the gel at the starting point (phase S), and bands became clear

Table 10. Identification of separated bands on the basis of percent similarity to 16S rDNA sequence in total microbes

Band No.	Organism (accession no.)	Similarity %
1	Uncultured bacterium SJA-64 (AJ009472)	94
2	*Pseudomonas* sp. (AB052965)	97
3	Uncultured alpha proteobacterium (AJ318148)	94
4	Unidentified bacterium (AF317773)	95
5	*Pacifibacter primarius* (AB073132)	94
6	*Pseudomonas stuuzeri* (U26419)	97
7	*Pseudomonas mendocina* (AJ006109)	91
8	Uncultured gamma proteobacterium (AJ297453)	94
9	Bacterial species (spore B) (X91170)	97
10	Uncultured compost bacterium (AB034709)	97

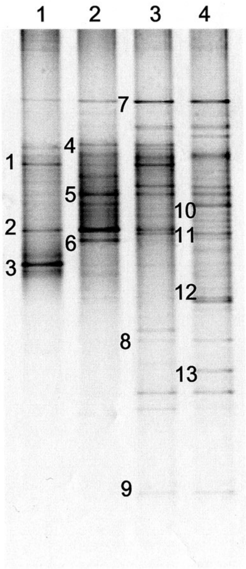


Fig. 8.
Analysis of four compost communities by PCR-DGGE with actinomycete-specific primers. Samples were obtained at starting point of the lag phase (phaseS, Lane 1), the thermophilic phase (phase T, Lane 2), the end of the active composting phase (phase A, Lane 3) and the end of the secondary composting phase (phase E, Lane 4).

at the end of the secondary composting (phase E). These bands showed similarity to *Actinomycetales (Microbacterium arborescence, Promicromonospora citrea, Streptomyces thermovulgaris, S. thermocarboxydus, S. thermotolerans, S. bellus)* and *Thermoanaerobacteriaceae* (Clostridiaceae str. PB). 5 of 12 bands showed similarity to uncultured organisms. *P. citrea* and *S. thermocarboxydus* (*S. thermotolerans or S. bellus*) were also identified by the cultivation. Although band number 3 that showed high similarity to *P. citrea* was detected from phase T and in the isolates from phase A, band number 11 that showed high similarity to *S. thermocarboxydus* from phase E both in the bands and in the isolates. The strains shown by the PCR−DGGE method were not the same strains of cultivated isolate but may belong to the same species. As a result of phylogenetic analysis (data not shown), identified actinomycetes in the DGGE bands were divided into three clusters as the high (G+C) subvision of gram−positive, *Verrucomicrobium* and the other group. Bands number 8, 9 and 12 (similarity to uncultured actinobacterium clone; AF333522) formed a cluster as a new taxon. *P. citrea* and *Streptomyces* spp., were also identified as dominant species in the composting process by PCR−DGGE. They were not same strains identified by the cultivation method, but belonged to the same species detected by the cultivation method. These species have been known to be widely distributed ones in feces, soils and composts (Bakalidou et al., 2002; Ichida et al., 2001; Kim et al., 1998; Sukesan and Watwood, 1998). Therefore, they might be dominant species among high ammonia−assimilating microbes in the composting processes except the starting point of the lag phase. The structure of microbial community changed markedly in the thermophilic phase. It is reported that the structure of microbial community changes at high temperature in the compost and the soils (Norris et al., 2002; Pedro et al., 2001). Although ammonia volatilization has generally known when temperature and pH raised in composting, high ammonia−assimilating strains which were coincided by cultivation and PCR−DGGE were not isolated in this phase. However, the microbes, that possess high ammonia−assimilating ability, may exist in the thermophilic phase. Thus, the cultivation, isolation and monitoring methods for the thermophilic phase in composting process should be developed.

C/N ratios in environment may affect the

Table 11. Identification of separated bands on the basis of percent similarity to 16S rDNA sequence in actinomycetes

Band No.	Organism (accession no.)	Similarity %
1	*Microbacterium arborescence* (X77443)	97
2	*Corynebacterium* sp. (AF262996)	98
3	*Promicromonospora citrea* (X83808)	100
4	*Deinococcus*-like south pole bacterium 1 (AF239213)	90
5	Uncultured bacterium FukuN106 (AJ289983)	92
6	*Streptomyces thermovulgaris* (Z68094)	97
7	Uncultured verrucomicrobium DEV022 (AJ401118)	99
8	Uncultured actinobacterium clone (AF333522)	92
9	Uncultured actinobacterium clone (AF333522)	90
10	*Nocardioides thermolilacinus* (AF005019)	98
11	*Streptomyces thermocarboxydus* (U94490)	100
	S. thermotolerans (AJ399482)	100
	S. bellus (AJ399476)	100
12	Uncultured actinobacterium clone (AF333522)	91
13	Clostridiaceae str.PB (AB020336)	92

microbial ammonia assimilation and the microbial degradation of organic nitrogen (Zehr and Ward, 2002). The contribution of ammonia-oxidizing and ammonia-assimilating microbes for ammonia removal in animal waste treatment systems have been not well known. These mechanisms should be clarified in the prospective study.

Acknowledgments

We are grateful to the staff of Laboratory of Animal Health and Management, Graduate School of Agricultural Science, Tohoku University for technical assistance and helpful advice. We also thank Fumihiro Yusa of the Field Science Center, Graduate School of Agricultural Science, Tohoku University for technical assistance. This study was supported in part by a grant from the Livestock Technology Association, Japan.

References

Arcondeguy T., R. Jack & M. Merrick (2001) P(II) signal transduction proteins, pivotal players in microbial nitrogen control. Microbiol. Mol. Biol. Rev. 65 : 80-105.

Bakalidou A., P. Kampfer, M. Berchtold, T. Kuhnigk, M. Wenzel & H. Konig (2002) *Cellulosimicrobium variabile* sp. nov., a cellulolytic bacterium from the hindgut of the termite *Mastotermes darwiniensis*. Int. J. Syst. Evol. Microbiol. 52 : 1185-1192.

Blanc M., L. Marilley, T. Beffa & M. Aragno (1997) Rapid identification of heterotrophic, thermophilic, spore-forming bacteria isolated from hot composts. Int. J. Syst. Evol. Microbiol. 47 : 1246-1248.

Coultate, T. P. & T. K.Sundaram (1975) Energetics of *Bacillus stearothermophilus* growth : Molar growth yield and temperature effects on growth efficiency. J. Bacteriol. 121 : 55-64.

Dean, D. R. & A. I. Aronson (1980) Selection of *Bacillus subtilis* mutants impaired in ammonia assimilation. J. Bacteriol. 141 : 985-988.

Eghball, B. & J. F. Power (1994) Beef cattle feedlot manure management. J. Soil Wat. Conserv. 49 : 113-122.

Fujino, Y. & S. Kume (1991) Isolation and identification of thermophilic bacteria from sewage sludge compost. J. Ferment. Bioengineer. 72 : 334-337.

Heuer, H., M. Krsek, P. Baker, K. Smalla & E.M. Wellington (1997) Analysis of actinomycete communities by specific amplification of genes encoding 16S rRNA and gel-electrophoretic separation in denaturing gradients. Appl. Environ. Microbiol. 63 : 3233-3241.

Horn, H.H.V., A. C. Wilkie, W. J. Powers & R. A. Nordsted (1994) Components of dairy manure management systems. J. Dairy Sci. 77 : 2008-2030.

Hu, P., T. Leighton, G. Ishkhanova & S. Kustu (1999) Sensing of nitrogen limitation by *Bacillus subtilis* : Comparison to enteric bacteria. J.

Bacteriol. 181 : 5042−5050.

Ichida, J. M., L. Krizova, C. A. LeFevre, H. M. Keener, D. L. Elwell & E. H. Burtt Jr. (2001) Bacterial inoculum enhances keratin degradation and biofilm formation in poultry compost. J. Microbiol. Methods 47 : 199−208.

Ikeda, T. P., A. E. Shauger & S. Kutsu (1996) *Salmonella typhimurium* apparently perceives external nitrogen limitation as internal glutamine limitation. J. Mol. Biol. 259 : 589−607.

Kim, S. B., C. Falconer, E. Williams & M. Goodfellow (1998) *Streptomyces thermocarboxydovorans* sp. nov. and *Streptomyces thermocarboxydus* sp. nov., two moderately thermophilic carboxydotrophic species from soil. Int. J. Syst. Evol. Microbiol. 48 : 59−68.

Manz, W., M. Wagner, R. I. Amann & K. H. Schleifer (1994) In situ characterization of the microbial consortia active in two wastewater treatment plants. Wat. Res. 28 : 1715−1723.

Merrick, M. & R. A. Edwards (1995) Nitrogen control in bacteria. Microbiol. Rev. 59 : 604−622.

Michel−Reydellet, N. & P. A. Kaminski (1999) *Azorhizobium caulinodans* PII and GlnK proteins control nitrogen fixation and ammonia assimilation. J. Bacteriol. 181 : 2655−2658.

Muyzer, G., E. C. Waal & A. G. Uitterilinden (1993) Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction−amplified genes coding for 16S rDNA. Appl. Environ. Microbiol. 59 : 695−700.

Nakai, Y., T. Abe, C. Kohda & T. Ando (1999) Water characteristics and microbial flora in a lagoon system for wastewater from a paddock of dairy cattle. Anim. Sci. J. 70 : 38−42.

Nakai, Y. (2001) Animal waste management and microorganisms. Anim. Sci. J. 72 : 1−13.

Nakasaki, K., M. Sasaki, M. Shoda & H. Kubota (1985) Effect of temperature on composting of sewage sludge. Appl. Environ. Microbiol. 49 : 1526−1530.

Norris, T. B., J. M. Wraith, R. W. Castenholz & T. R. McDermott (2002) Soil microbial community structure across a thermal gradient following a geothermal heating event. Appl. Environ. Microbiol. 68 : 6300−6309.

Patriarca, E. J., R. Tate & M. Iaccarino (2002) Key role of bacterial NH^{4+} metabolism in Rhizobium−Plant symbiosis. Microbiol. Mol. Biol. Rev. 66 : 203−222.

Pedro, M. S., S. Haruta, M. Hazaka, R. Shimada, C. Yoshida, K. Hiura, M. Ishii & Y. Igarashi (2001) Denaturing gradient gel electrophoresis analyses of microbial community from field−scale composter. J. Biosci. Bioeng. 91 : 159−165.

Sasaki, H., G. Maruyama, H. Suzuki, J. Nonaka, M. Sato, T. Sasaki, M. Ohta & Y. Nakai (2002) Characterization of ammonia−assimilating bacteria in a lagoon for wastewater from a paddock of dairy cattle. Anim. Sci. J. 73 : 73−76.

Sasaki, H., G. Maruyama, H. Suzuki, J. Nonaka, M. Sato, T. Sasaki, M. Ohta & Y. Nakai (2004a) Distribution of ammonia assimilating bacteria in the composting process. Compost Sci. Utili. 12 : 108−113.

Sasaki, H., O. Kitazume, T. Sasaki & Y. Nakai (2004b) Ammonia−assimilating microbes in microbial community in a lagoon for wastewater from paddock of dairy cattle. Anim. Sci. J. 75 : 79−84.

Schneider, B. L., A. K. Kiupakins & L. J. Reitzer (1998) Arginine catabolism and the arginine succinyltransferase pathway in *Esherichia coli*. J. Bacteriol. 180 : 4278−4286.

Sekiguchi, Y., Y. Kamagata, K. Syutsubo, A. Ohashi, H. Harada & K. Nakamura (1998) Phylogenetic diversity of mesophilic and thermophilic granular sludges determined by 16S rRNA gene analysis. Microbiology 144 : 2655−2665.

Snaidr, J., R. Amann, I. Huber, W. Ludwig & K. H. Schleifer (1997) Phylogenetic analysis in situ identification of bacteria in activated sludge. Appl. Environ. Microbiol. 63 : 2884−2896.

Strom, P. F. (1985) Identification of thermophilic bacteria in solid−waste composting. Appl. Environ. Microbiol. 50 : 906−913.

Sukesan, S. & M. E. Watwood (1998) Effects of hydrocarbon enrichment on trichloroethylene biodegradation and microbial populations in finished compost. J. Appl. Microbiol. 85 : 635−642.

Tiquia, S. M. & N. F. Y. Tam (2000) Fate of nitrogen during composting of chiken litter. Environ. Pollut. 110 : 535−541.

Wagner, M., R. Amann, H. Lemmer & K. Schleifer (1993) Probing activated sludge with oligonucleotides specific for proteobacteria :

Inadequacy of culture-dependent methods for describing microbial community structure. Appl. Environ. Microbiol. 59 : 1520–1525.

Wagner, M., R. Erhart, W. Manz, R. Amann, H. Lemmer, D. Wedi & K. Schleifer (1994) Deplopment of an rRNA-targeted oligonucleotide probe specific for the genus *Acinetobacter* and its application for in situ monitoring in activated sludge. Appl. Environ. Microbiol. 60 : 792–800.

Zehr, J. P. & B. B. Ward (2002) Nitrogen cycling in the ocean : New perspectives on processes and paradigms. Appl. Environ. Microbiol. 68 : 1015–1024.

JIFS, 2 : 107 − 112 (2005) original paper

Band versus Nursery Pot Application of Polyolefin−coated Fertilizer for Bell Peppers Grown in the Field

Attila OMBODI [1,*] and Masahiko SAIGUSA [1]

[1] Graduate School of Agricultural Science, Tohoku University, Japan
* Present : Sgent Istovan University, Hungary

Key word : band application, bell pepper, controlled−release fertilizer, nursery pot application, polyolefin−coated fertilizer

Abstract

Using a single basal application of controlled−release fertilizers for bell peppers is a perspective method, because by the elimination of top−dressings, labour and energy costs can be reduced. In this study, effects of band and nursery pot applications of polyolefin−coated fertilizers (POCF) on bell peppers grown in the field were compared at two different application rates, in 1997 and 1998. As a consequence of continuous nutrient supply, a good yield could be achieved in case of both application methods. Application methods significantly affected the generative/vegetative balance of the bell pepper plants, and thus the yield. Both years, early plant development and early yield were much better for the nursery pot application treatments than for the band application treatments, due to the better seedlings and to the quicker seedling establishment. Results of total yield were unambiguous for the two years. It was concluded that the nursery pot application method can be a very effective fertilization method for reducing labour and energy costs, but seedlings must be transplanted before the lag time of the sigmoid−type POCF ends. Using POCFs, 25% decrease in the amount of fertilizer applied did not decrease the yield of bell peppers.

Introduction

Similarly to most of the fruit vegetables, a split application of fertilizers is a common practice in bell pepper cultivation (Zatyko, 1993; Rubatzky and Yamaguchi, 1997) for maintaining adequate vegetative and generative growth throughout the whole growing period. With the application of slow/controlled release fertilizers, a continuous supply of nutrients can be carried out and potential salt injury can be avoided throughout the growing period, and thus balanced plant growth can be maintained (Hochmuth, 1992). Single basal application of controlled−release fertilizers were found to result similar or better yield than the usual fertilization methods in case of bell peppers (Everett, 1976; Csizinsky, 1994). Bigger early yield (Csizinsky, 1994), cost savings as a result of elimination of top−dressings and reduced environmental loading (Shaviv and Mikkelsen, 1994; Trenkel 1997) make this method a viable alternative to split application of conventional fertilizers.

Nutrient release of sigmoid−type polyolefin−coated fertilizers (POCFs) − a kind of controlled−release fertilizer − is repressed during a specific period after application (Gandeza and Shoji, 1992). Using these kind of fertilizers, the full amount of fertilizer can be put into the nursery box or pot without causing salt injury to the seedlings (Sato et al., 1993). Nursery box application of POCF is already widely used for rice cultivation in Japan (Saigusa, 1999). The nursery pot application method can be a very effective fertilization method for reducing labour and energy costs, as it can eliminate every task in the field related to fertilization.

Considering the things mentioned above, the objective of this study was to compare the effects of band application and nursery pot application of POCF for bell peppers grown in the field.

Materials and Methods

Field experiments were conducted with a Hungarian bell pepper variety (*Capsicum annuum L.* cv. Boni) in Northern−Japan, at the Field Science Centre of Tohoku University (Narugo, Miyagi Prefecture) in 1997 and 1998. The soil used is Allic Pachic Mellanudand (pH was 6.48 and 6.65, EC was 0.22 and 0.31 dS m^{-1}, inorganic N content was 14 and 15 mg kg^{-1}, Bray−II P_2O_5 content was 1.3 and 1.1 mg kg^{-1}, exchangeable K content was 0.58 and 0.50 cmol kg^{-1} in 1997 and 1998, respectively). During the growing period daily average air temperature was 18.2 and 18.6 °C, sum of sunshine hours was 533 and 427, sum of rainfall was 899 and 1413 mm in 1997 and 1998, respectively.

Treatments were composed of two different application methods (nursery pot and band) and two different fertilizer rates (30 g N, 25.7 g P_2O_5 and 30 g K_2O per m^2 as 100% amount and 75% amount). Band 75% treatment was conducted just in 1998. For the Band treatments, 70−day type polyolefin−coated NPK (14−12−14) fertilizer was placed into 15cm wide bands, at the depth of 15 cm under the plant rows at the time of transplanting (May 24. in 1997 and May 21. in 1998). In the name of the fertilizers, the number of days means that how long it takes for the fertilizer to release 80% of its N content in water at 25 °C (Gandeza et al., 1991).

For this experiment, three kinds of seedlings were raised in plastic pots with 9 cm diameter filled with a nursery soil mixture containing 150mg N, 350mg P_2O_5 and 150 mg K_2O per litre. For the seedlings of the Band treatments, N level of the mixture was raised to 300 mg per litre (Knavel, 1977) by adding a 12−18−14 analysis compound fertilizer. For the Pot 100% and Pot 75% treatments, 27 and 20 g of 100−day sigmoid type polyolefin−coated NPK (14−12−14) fertilizer per pot was applied, respectively, at the time of planting seedlings into the nursery pots (April 18. in 1997 and April 23. in 1998). During the seedling raising, daily average air temperature was 18.7 °C and 20.0 °C in 1997 and 1998, respectively.

Seedlings were transplanted to the field in a twin−row arrangement advised by Zatyko (1993). Plant density was 7.8 per m^2. One plot was formed by 10 plants and corresponded to one replication. The central six plants of each plot were used for the measurements. Treatments were replicated three times. Plots were arranged in three blocks. Plastic sheets were placed around each plot into the soil until 20cm depth. At the sides of the experiment, guarding rows were formed.

Net bags, each filled with 3.00g of POCF, were placed into the soil at the depth of 7cm and 15 cm in the case of the 100−day sigmoid type and the 70−day type fertilizer, respectively. Bags were retrieved at the time of each top−dressing and at the end of the experiment. Following washing, crashing in a mortar, filtration (filter paper No. 6, Advantec) and filling up, N, P and K contents of the resulted filtrate were measured and nutrient release rates of the POCF were calculated.

At the end of the seedling raising, four representative seedlings per treatment were sampled and their dry weight was measured. Leaf colour of the youngest fully developed leaves (with Minolta SPAD 502 colorimeter) and plant length were measured at 2−3 weeks interval throughout the growing periods. Matured ivory white fruits were harvested at one−week intervals. Fruits were sampled for NPK analysis three times during the harvest period. After the last harvest, plants were cut out and analysed for NPK contents.

Statistically significant differences between the treatments were determined by the least significant difference of ANOVA at 95% probability level using Excel 7.0 computer software.

Results and measurements

According to the nutrient release rate measurements with both fertilizers, a continuous supply of nutrients could be carried out throughout the growing period. In both years, ratio of released nutrients was more for the 70−day linear type fertilizer (91% for N, 71% for P_2O_5, 79% for K_2O) than for the 100−day sigmoid type fertilizer (82 − 88% for N, 54% for P_2O_5, 67% for K_2O). The high N release rates show that the choice of 70−day linear and 100−day sigmoid types was appropriate.

From the time of fertilizer application to the pot until the transplanting, cumulative temperature in the pot was 676 °C in 1997 and 574 °C in 1998. According to the nitrogen release measurements, in 1997 there were 320 and 406 mg and in 1998 there were 201 and 245 mg of available fertilizer N per pot in the Pot 75% and Pot 100% treatments, respectively, as opposed to the 139 mg N per pot value for the conventional seedlings. As a result of more available N and the continuous nutrient release, seedlings of the Pot treatments were more developed than the conventional seedlings. Seedling dry weight was 1.90, 2.18 and 2.41 g per plant in 1997 and 2.36, 2.70 and 2.82 g per plant in 1998 for the conventional seedlings, Pot 75% seedlings and Pot 100% seedlings, respectively. Seedlings of the pot

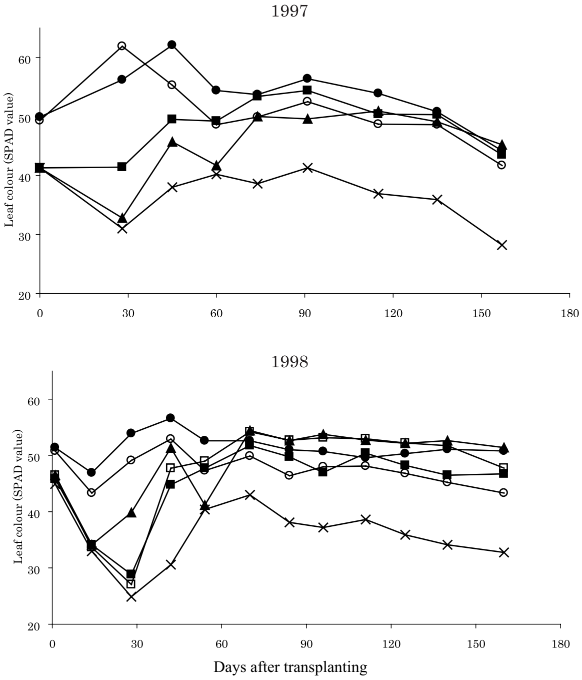


Fig. 1. Changes in leaf colour of paprika plants

× No Nitrogen ▲ RAF ☐ POC-NPK Band 75%
■ POC-NPK Band 100% ○ POC-NPK Pot 75%
● POC-NPK Pot 100% RAF : readily available fertiliger

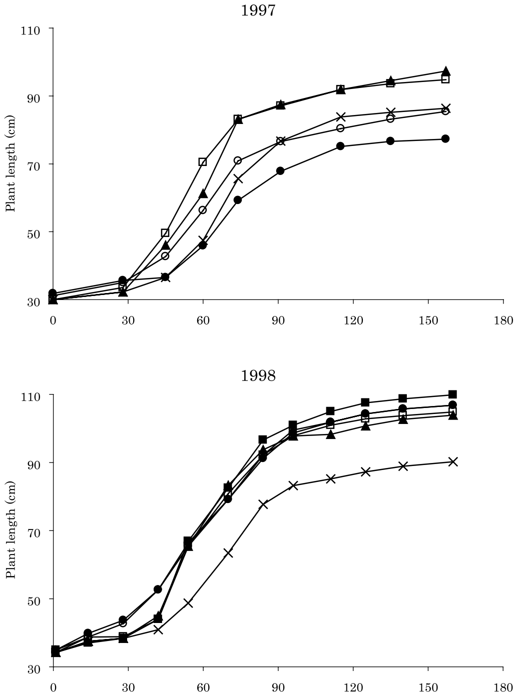


Fig. 2. Changes in length of paprika plants

× No Nitrogen ▲ RAF ☐ POC-NPK Band 75%
■ POC-NPK Band 100% ○ POC-NPK Pot 75%
● POC-NPK Pot 100% RAF : readily available fertiliger

treatments also had more favourable shoot/root ratio and phosphorus status, establishing the possibility of a better early development after transplanting.

Plant length and leaf colour were measured in order to monitor plant development throughout the growing period. Results of the two years showed different tendency. In 1997, very high SPAD values, as leaf colour, indicated excess N supply for the Pot 75% and Pot 100% treatments during the period of seedling establishment (Fig.1.). As a result, a difference in plant length developed in favour of the Band 100% treatment, which remained throughout the growing period. In 1998, development of roots was very slow early in the growth period, which resulted very low SPAD values and smaller plants in the Band 75% and 100% treatments (Fig.2.). Presumably roots could reach the fertilizer band just with a considerable delay. According to these results, applying fertilizer particles closer to the roots in the case of nursery pot application resulted in quicker seedling establishment, and thus superior early development.

Results of nutrient uptake also differed between the two years (Table1.2). In 1997, in agreement with the results of plant development, NPK uptake was the highest in the Band 100% treatment and the lowest in the Pot 100% treatment. Nitrogen uptake for this latter treatment was even 14% lower than for the Pot 75% treatment. Thus, in 1997, nursery pot application of POCF at the rate of 30g N m^{-2} may have slightly retarded the growth of paprika plants. In 1998, N uptake was lower in the 75% treatments than in the 100% treatments (Table1.). However, P uptake was higher in the 75% treatments than in the corresponding 100% treatments, indicating that roots could take up more nutrients directly from the fertilizer placements in the 75% treatments. Both years, potassium uptakes were larger than the amount of potassium fertilizer applied. That is why it is advisable to supply POC-NPK (14-12-14) fertilizers with additional potassium fertilizers.

Results of stem + leaves fresh weight were in good agreement with the results of the nutrient uptake (Table3.). However as the treatments significantly affected the generative/vegetative balance of the bell pepper plants (Table3.), in this experiment bigger vegetative mass production did not automatically resulted in bigger yield. Ratio of fruits from the total plant weight was higher for the Pot treatments than

Table 1. Effects of different fertilization methods on nitrogen content, uptake and use efficiency of paprika plants

	Nitrogen content Stem-leaves (mg/g DW)	Nitrogen content Fruits (mg/g DW)	Above ground nitrogen uptake (g/m^2)	Fertilizer nitrogen efficiency (%)	Corrected efficiency (%)
			1997		
RAF	23.6 ^{b*}	28.5 ^{a}	21.9 ^{a}	47.3	47.3
POC-NPK Band 100%	21.5 ^{b}	26.2 ^{b}	23.0 ^{a}	51.0	56.0
POC-NPK Pot 75%	24.7 ^{ab}	26.2 ^{b}	20.5 ^{ab}	56.9	69.3
POC-NPK Pot 100%	28.9 ^{a}	26.3 ^{b}	17.7 ^{b}	33.3	40.7
No nitrogen	15.5 ^{c}	24.2 ^{c}	7.7 ^{c}		
			1998		
RAF	23.2 ^{a*}	30.2 ^{a}	21.2 ^{ab}	44.6	44.6
POC-NPK Band 75%	18.9 ^{b}	29.1 ^{a}	21.5 ^{ab}	60.9	67.1
POC-NPK Band 100%	20.3 ^{ab}	28.7 ^{ab}	21.9 ^{ab}	47.0	51.9
POC-NPK Pot 75%	18.5 ^{b}	28.0 ^{ab}	20.2 ^{b}	55.1	63.3
POC-NPK Pot 100%	21.4 ^{ab}	29.2 ^{a}	22.8 ^{a}	50.0	57.1
No nitrogen	14.3 ^{c}	25.9 ^{b}	7.8 ^{c}		

(RAF = readily available fertilizer, POC-NPK Pot = polyolefin-coated NPK fertilizer, Pot = nursery pot application, Band = band application, 75% = 22.5 - 19.3 - 22.5 NPK/m^2 fertilization level, 100% = 30 - 25.7 - 30 NPK/m^2 fertilization level)

* Means separated in columns by Duncan's multiple range test, P < 5%

	Phosphorus content stem-leaves (mg P/g DW)	Phosphorus content fruits (mg P/g DW)	Above ground phosphorus uptake (g/m^2)	Potassium content stem-leves (mg K/g DW)	Potassium content fruits (mg K/g DW)	Above ground potassium uptake (g/m^2)
			1997			
RAF	1.7 ^{c*}	4.1 ^{b}	2.3 ^{ab}	26.1 ^{b}	36.1 ^{ab}	25.8 ^{ab}
POC-NPK Band 100%	1.8 ^{c}	4.0 ^{b}	2.8 ^{a}	24.9 ^{b}	32.9 ^{c}	27.8 ^{a}
POC-NPK Pot 75%	2.4 ^{b}	4.3 ^{ab}	2.7 ^{ab}	28.2 ^{b}	34.2 ^{bc}	25.1 ^{ab}
POC-NPK Pot 100%	2.4 ^{b}	4.1 ^{b}	2.2 ^{b}	31.8 ^{ab}	33.6 ^{c}	21.2 ^{b}
No nitrogen	3.5 ^{a}	4.5 ^{a}	1.6 ^{c}	35.4 ^{a}	37.8 ^{a}	15.0 ^{c}
			1998			
RAF	2.0 ^{b*}	4.4 ^{b}	2.3 ^{cd}	30.7 ^{b}	33.2 ^{b}	26.0 ^{a}
POC-NPK Band 75%	2.1 ^{b}	4.7 ^{ab}	2.9 ^{ab}	31.1 ^{b}	35.0 ^{b}	30.6 ^{a}
POC-NPK Band 100%	2.0 ^{b}	4.3 ^{b}	2.6 ^{bc}	29.4 ^{b}	33.6 ^{b}	29.1 ^{a}
POC-NPK Pot 75%	2.7 ^{b}	4.7 ^{ab}	3.2 ^{a}	28.1 ^{b}	32.6 ^{b}	26.7 ^{a}
POC-NPK Pot 100%	2.1 ^{b}	4.5 ^{b}	2.9 ^{ab}	30.7 ^{b}	32.5 ^{b}	29.0 ^{a}
No nitrogen	5.0 ^{a}	5.3 ^{a}	2.2 ^{d}	37.7 ^{a}	39.6 ^{a}	17.0 ^{b}

(RAF = readily available fertilizer, POC-NPK Pot = polyolefin-coated NPK fertilizer, Pot = nursery pot application, Band = band application, 75% = 22.5 - 19.3 - 22.5 NPK/m^2 fertilization level, 100% = 30 - 25.7 - 30 NPK/m^2 fertilization level)

* Means separated in columns by Duncan's multiple range test, P < 5%

for the Band treatments.

As a consequence of continuous nutrient supply, using a single basal application of POCF, a good yield could be achieved for every treatment (Table 3, Fig3). Both years, early yield was 2.5 times higher in the Pot treatments than in the Band treatments. As prices are usually considerably higher early in the season than later, nursery pot application method could provide higher revenue than band application in spite of a lower total yield, as it was the case in 1997. The better early plant development resulted better early yield in the Pot treatments. However, in 1997 in the Pot treatments, the big early yield and the excess nutrient supply during seedling establishment caused reduced development of the vegetative parts and eventually resulted in lower total yield than in the Band treatments. In 1998, the smoother seedling establishment and appropriate vegetative growth resulted even higher total yield for the Pot treatments than in the Band treatments.

According to these results, nursery pot application was more effective than band application. However, this method is quite risky under field conditions, as seedlings must be transplanted before the release

Table 3. Effects of different fertilization methods on fresh and dry mass productions of paprika plants

	Fresh weight			Fruit FW/ above ground FW	Dry weight			Fruit DW/ above ground DW
	Stem -leaves	Fruits	Above ground		Stem -leaves	Fruits	Above ground	
		(g/m^2)		(%)		(g/m^2)		(%)
				1997				
RAF	2727 ^{a*}	5599 ^{b}	8326 ^{b}	67.2 ^{c}	532 ^{a}	329 ^{b}	861 ^{a}	38.2 ^{c}
POC-NPK Band 100%	2681 ^{a}	7294 ^{a}	9975 ^{a}	73.1 ^{b}	526 ^{a}	447 ^{a}	973 ^{a}	45.9 ^{b}
POC-NPK Pot 75%	2118 ^{b}	6357 ^{b}	8475 ^{b}	75.1 ^{ab}	420 ^{a}	388 ^{ab}	808 ^{a}	48.2 ^{b}
POC-NPK Pot 100%	1688 ^{b}	6092 ^{b}	7780 ^{b}	78.3 ^{a}	276 ^{b}	370 ^{b}	646 ^{b}	57.4 ^{a}
No nitrogen	1629 ^{b}	2650 ^{c}	4279 ^{c}	61.4 ^{d}	257 ^{b}	155 ^{c}	412 ^{c}	37.5 ^{c}
				1998				
RAF	2773 ^{ab*}	4897 ^{c}	7670 ^{b}	63.4 ^{c}	533 ^{ab}	291 ^{c}	824 ^{a}	35.3 ^{bc}
POC-NPK Band 75%	2766 ^{ab}	6372 ^{ab}	9138 ^{a}	69.7 ^{ab}	566 ^{ab}	372 ^{ab}	938 ^{a}	39.7 ^{ab}
POC-NPK Band 100%	2965 ^{a}	5665 ^{b}	8630 ^{ab}	65.6 ^{bc}	606 ^{a}	334 ^{bc}	940 ^{a}	35.8 ^{b}
POC-NPK Pot 75%	2382 ^{b}	7089 ^{a}	9471 ^{a}	74.8 ^{a}	469 ^{b}	414 ^{a}	883 ^{a}	46.9 ^{a}
POC-NPK Pot 100%	2596 ^{ab}	6611 ^{ab}	9207 ^{a}	71.8 ^{a}	531 ^{ab}	390 ^{ab}	921 ^{a}	42.5 ^{ab}
No nitrogen	1539 ^{c}	2326 ^{d}	3865 ^{c}	60.2 ^{c}	320 ^{c}	124 ^{d}	444 ^{b}	28.0 ^{c}

(RAF = readily available fertilizer, POC-NPK Pot = polyolefin-coated NPK fertilizer, Pot = nursery pot application,
Band = band application, 75% = 22.5 - 19.3 - 22.5 NPK/m^2 fertilization level, 100% = 30 - 25.7 - 30 NPK/m^2 fertilization level)
* Means separated in columns by Duncan's multiple range test, $P < 5\%$

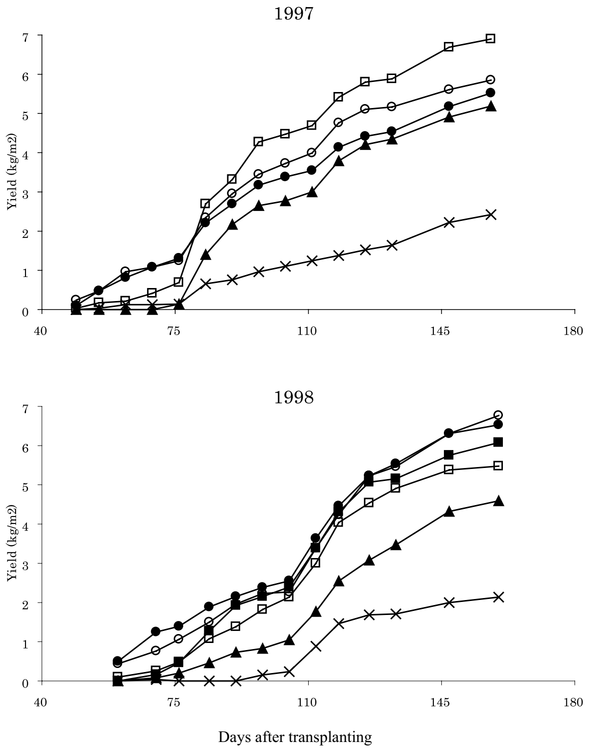


Fig. 3. Changes in cumulative yield of paprika plants

× No Nitrogen ▲ RAF □ POC-NPK Band 75%
■ POC-NPK Band 100% ○ POC-NPK Pot 75%
● POC-NPK Pot 100% RAF : readily available fertiliger

of nutrients from the sigmoid-type POCF reaches its linear phase, because nutrient accumulation during seedling establishment in the nursery pots can reach toxic levels. The difference between the results of the two experimental years showed well the importance of the timing of transplanting in case of this fertilization method.

Both years, the 75% treatments produced slightly higher yields than the corresponding 100% treatments (Table 3, Fig3). Thus in this experiment, using POCFs, the amount of applied fertilizer could be decreased by 25% without reducing the yield of bell peppers.

Conclusions

It was concluded that nursery pot application was more effective than band application for a single basal application of total fertilizer using POCFs in case of bell peppers grown in the field. Using POCFs amount of applied fertilizer could be decreased by 25% without reducing the yield.

Table 4. Effects of different fertilization methods on yield of paprika plants

	Yield (kg/m^2)	Fruit number (pieces/m^2)	Average fruit weight (g/fruit)
1997			
RAF	5.25^{b*}	54.9^{b}	95.7^{a}
POC-NPK Band 100%	6.97^{a}	71.0^{a}	98.5^{a}
POC-NPK Pot 75%	5.91^{b}	68.8^{a}	86.1^{b}
POC-NPK Pot 100%	5.59^{b}	65.0^{ab}	86.0^{b}
No nitrogen	2.46^{c}	30.5^{c}	80.1^{b}
1998			
RAF	4.56^{c*}	48.8^{c}	89.1^{a}
POC-NPK Band 75%	6.02^{ab}	70.1^{ab}	91.6^{a}
POC-NPK Band 100%	5.44^{bc}	61.8^{bc}	90.8^{a}
POC-NPK Pot 75%	6.72^{a}	82.1^{a}	89.9^{a}
POC-NPK Pot 100%	6.47^{ab}	77.5^{a}	91.4^{a}
No nitrogen	2.15^{d}	28.3^{d}	81.5^{b}

(RAF = readily available fertilizer, POC-NPK Pot = polyolefin-coated NPK fertilizer,
Band = band application, Pot = nursery pot application,
75% = 22.5 - 19.3 - 22.5 NPK/m^2 fertilization level,
100% = 30 - 25.7 - 30 NPK/m^2 fertilization level)
* Means separated in columns by Duncan's multiple range test, $P < 5\%$

References

Csizinszky, A. A. (1994) Yields response of bell pepper and tomato to controlled-release fertilizers on sand. J. Plant Nutr. 17 : 1535-1549.

Everett, P.H. (1977) Controlled release fertilizers : Effect of rates and placements on plant stand, early growth and fruit yield of peppers. Proc. Fla. State Hort. Soc. 90 : 390-393.

Gandeza, A.T., S. Shoji, & I. Yamada (1991) Simulation of crop response to polyolefin-coated urea : I. Field dissolution. Soil Sci. Soc. Am. J. 55 : 1462-1467.

Gandeza, A. T. & S. Shoji (1992) Properties of polyolefin-coated fertilizers. In : Controlled release fertilizers with polyolefin coating. pp. 22-33. Shoji, S. and A.T. Gandeza (eds.), Konno Printing Co. Ltd., Sendai.

Hochmuth, G. J. (1992) Concepts and practices for improving nitrogen management for vegetables. HorTechnology. 2 : 121-125.

Knavel, D. E. (1977) The influences of nitrogen on pepper transplant growth and yielding potential of plants grown with different levels of soil nitrogen. J. Amer. Soc. Hort. Sci. 102 : 533-535.

Rubatzky, V. E. & M. Yamaguchi (1997) World vegetables : Principles, production and nutritive values. 2nd edition. Chapman & Hall, New York.

Sato, T., K. Shibuya, M. Saigusa & T. Abe (1993) Single basal application of total fertilizer with controlled-release coated urea on non-tilled rice culture. Jap. J. Crop. Sci. 62 : 408-413, (in Japanese with English summary).

Saigusa, M. (1999) Slow release nitrogen fertilizers and plant nutrition. In : Nitrogen nutrition and plant growth. pp.305-335. H.R. Srivastava and R.P. Singh (eds.). Oxford & IBH Publishing Co. PVT. LTD., New Delhi.

Shaviv, A. & R. L. Mikkelsen (1993) Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation-A review. Fertilizer Research. 35 : 1-12.

Trenkel, M. E. (1997) Improving fertilizer use efficiency; Controlled-release and stabilized fertilizers in agriculture. International Fertilizer Industry Association, Paris.

Zatyko, L. (Ed.) (1993) Paprika. 2nd edition. Mezogazda Kiado, Budapest (in Hungarian).

JIFS, 2 : 113 − 121 (2005) original paper

Low Genetic Differentiation with High Genetic Variability Observed in Common Coastal Starfish *Asterina pectinifera* around Japan Inferred from Isozyme Analysis

[*1] Masayori YAMASHITA, [*2] Miéko KOMATSU and [*1] Akihiro KIJIMA

[*1] Lab. Integrative Aquatic Biology, Field Science Center, Graduate School of Agricultural Science, Tohoku University,Onagawa, Oshika, Miyagi, 986−2242, Japan

[*2] Faculty of Science, Toyama University, Toyama, 930−8555, Japan

Key words : Isozymes, genetic variability, *Asterina pectinifera*, starfish, genetic differentiation

Abstract

Genetic variability and geographic population structure in population of the common coastal starfish *Asterina pectinifera* were examined in nine localities around Japan through isozyme analysis. Surveying 28 enzymes by using starch gel electrophoresis, it was found that eight loci controlling seven enzymes were useable as genetic markers. Genetic variability of this species estimated from the 8 loci followed; the proportion of variant loci ranged from 0.63 to 1.00 with a mean of 0.80, expected average heterozygosity was from 0.176 to 0.208 with a mean of 0.184, and mean number of alleles per locus ranged from 2.5 to 3.8 with a mean of 3.0. The genetic variability of this species was comparatively high among aquatic animals. In order to evaluate genetic differences among the nine localities around Japan, the allelic and genotypic homogeneity tests were carried out and Nei's genetic distance was calculated between every pair of the nine localities. Significant differences among localities showed at only a few loci, but genetic distances were low between any pair of localities. Thus, genetic differentiation has not occurred among localities around Japan in *A. pectinifera*.

Introduction

Starfish *Asterina pectinifera*, which lives on rocky coastal shores and sandy floors in shallow water, is one of the most common species on coastal area around Japan (Oguro 1995). Starfish, including the species, are commonly recognized as a nuisance mainly because of the damage to commercial bivalves and getting tangled in fishing nets. Since they do not have industrial value, few studies have been carried out for biological/genetic resources. However, the starfish is considered to be one of the important constituent members as a scavenger in the coastal ecological system. Therefore, the population structure should be analyzed for conservation of coastal environment and sustainable yield of the starfish. It should be difficult, however, to carry out such a study by ecological observation like other marine animals. Genetic approach using genetic markers is effective for such a study.

In a genetic study on population structure, Matsuoka et al. (1995) examined the starfish *A. pectinifera* sampled from Mutsu Bay and Fukaura in Aomori prefecture using 23 allozyme loci as genetic marker detected by polyacrylamide gel eletrophoresis (PAGE), and described the samples were genetically divergent despite only 20 or 30 km away from each other. And Matsuoka and Asano (2003) reported genetic variation of this species in the northern part of Japan using same method. However, their sample sizes were too small to detect genetic variability and genetic divergence. Moreover, estimation of genetic characteristics based on PAGE reported by them could not be compared with the results from starch gel electrophoresis as previously reported (Yamashita et al. 2005). The aims of this study are (1) to detect isozyme marker genes by using starch gel electrophoresis, (2) to estimate genetic variability, and (3) to quantify the genetic difference and population structure of the starfish *A. pectinifera* around Japan.

Materials and Methods

Starfish *Asterina pectinifera* examined in this study were collected from 9 localities around Japan

Table 1. Sampling sites, dates and the shape of specimens (mean ± standard deviation)

locality name	prefecture	n^{*1}	sampling date	R^{*2}(mm)	r^{*3}(mm)	wet weight(g)
Yoichi	Hokkaido	34	Aug 2001	47.6 ± 10.9	29.4 ± 7.3	45.6 ± 26.4
Usujiri	Hokkaido	39	Jun 2000	38.4 ± 4.8	22.6 ± 3.5	21.1 ± 7.4
Asamushi	Aomori	137	Dec 2000	55.2 ± 7.3	35.1 ± 5.4	57.0 ± 21.1
Rikuzentakata	Iwate	84	Nov 2000	49.9 ± 8.1	31.0 ± 5.6	42.4 ± 19.7
Onagawa	Miyagi	50	Oct 2000	51.6 ± 7.5	30.0 ± 4.9	49.2 ± 21.1
Izumisano	Osaka	100	Aug 2001	43.5 ± 6.6	25.8 ± 4.0	32.1 ± 14.1
Kure	Hiroshima	58	Oct 2001	40.7 ± 5.8	25.4 ± 17.9	22.4 ± 9.3
Namerikawa	Toyama	98	Oct 1999	49.5 ± 4.6	27.4 ± 3.3	51.3 ± 12.4
Miyazu	Tyoto	46	Jul 2001	41.5 ± 5.5	25.2 ± 4.4	30.4 ± 12.4

*1, number of animals; *2, radius length; *3, interradius length

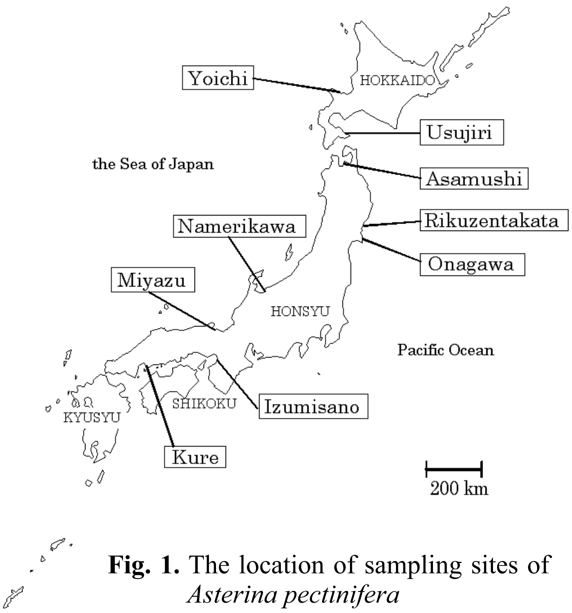


Fig. 1. The location of sampling sites of *Asterina pectinifera*

from April 1999 to October 2001 as shown in Fig. 1 and Table 1. Collected samples were kept cool and transferred to our laboratory where they were kept alive under running seawater until dissection.

Isozymes were detected by using horizontal starch gel electrophoresis following the method of Fujio and Ikeda (1999). The tube feet, pyloric caeca and rectal sac were used to detect isozymes expressed in these tissues. The procedure and condition of electrophoresis were the same as previously reported (Yamashita et al. 2005).

A total of 28 enzymes were examined, as shown in Table 2. When isozymes were encoded by several loci, these loci were numbered in order of decreasing anodal mobility. Alleles were named according to the mobility of their products relative to the most common allele in the samples of Onagawa, which was assigned a value of *100*. Chi−square tests were carried out to examine whether observed genotype numbers accorded with those expected under Hardy−Weinberg equilibrium (HWE).

Genetic variability was measured by using the average number of alleles per locus (A/L), the proportion of polymorphic loci (P), the proportion of variant loci less than polymorphism (V), and observed and expected average heterozygosity (Ho and He). Here, the polymorphic locus was defined as the locus that had the maximum allele frequency of $\leqq$ 0.95. The observed heterozygosity was a direct count of heterozygous individuals in the sample, and expected heterozygosity was calculated as $1-\Sigma\Sigma x_{ij}^2/n$, where x_{ij} was the frequency of *j*−th allele of *i*−th locus and *n* was equal to number of loci examined.

The extent of genetic differences among localities was estimated using several measures. The gene diversity coefficient (G_{ST}) was calculated as $(H_T-H_S)/H_T$, where H_T (total genetic diversity) was the expected average heterozygosity in the total population and H_S (mean genetic diversity per area) was the mean of the expected average heterozygosities within localities. Nei's genetic distances (Nei 1972) between localities were calculated. The above−mentioned measures were calculated using Microsoft excel. Tests to examine genetic differences among localities were carried out using a population genetic software package, Genepop ver. 3.1 (Raymond and Rousset 1995). With regard to these tests, the null hypothesis was H_0 : "the allelic (sub−option 1 or 2 in option 3) and genotypic (sub−option 3 or 4 in option 3) distribution is identical across localities." Tests were performed for each locus.

The genetic relationship among the localities was estimated constructing dendrogrms by unweighted

Table 2. Examined enzymes, expected loci as genetic marker and condition of electrophoresis.

	enzyme name	abbreviation	EC. number	buffer*	pH	expected loci
1	Acid phosphatase	ACP	EC. 3.1.3.2			
2	Adenylate Kinase	AK	EC. 2.7.4.3			
3	Alcohol Dehydrogenase	ADH	EC. 1.1.1.1			
4	Aldolase	ALD	EC. 4.1.2.13			
5	Alkaline Phosphatase	ALP	EC. 3.1.3.1			
6	Aspartate Aminotransferase	AAT	EC. 2.6.1.1			
7	Creatine Kinase	CK	EC. 2.7.3.2			
8	Diaphorase	DIA	EC. 1.6.−.−			
9	Esterase	EST	EC. 3.1.1.1			
10	Fructose−1,6−Diphosphatase	FDP	EC. 3.1.3.11			
11	Fumarate Hydratase	FH	EC. 4.2.1.2			
12	Galactose Dehydrogenase	GAD	EC. 1.1.1.48			
13	Glucose−6−Phosphate Dehydrogenase	G6PD	EC. 1.1.1.49			
14	Glucosephosphate Isomerase	GPI	EC. 5.3.1.9			
15	Glutamate Dehydrogenase	GDH	EC. 1.4.1.3			
16	Glycerol−3−Phosphate Dehydrogenase	αGPD	EC. 1.1.1.12	T−C	7	*αGpd*
17	Hexokinase	HK	EC. 2.7.1.1	T−C	7	*Hk*
18	Isocitrate Dehydrogenase	IDH	EC. 1.1.1.42			
19	Lactate Dehydrogenase	LDH	EC. 1.1.1.27			
20	Leucine Aminopeptidase	LAP	EC. 3.4.11.1			
21	Malate Dehydrogenase	MDH	EC. 1.1.1.37	T−C	8	*Mdh−1,2*
22	Malic Enzyme	ME	EC. 1.1.1.40			
23	Mannose−6−Phosphate Isomerase	MPI	EC. 5.3.1.8	T−C	8	*Mpi*
24	Octanol Dehydrogenase	ODH	EC. 1.1.1.73			
25	Phosphoglucomutase	PGM	EC. 2.7.5.1			
26	6−Phosphogluconate Dehydrogenase	6PGD	EC. 1.1.1.44	T−C	7	*6Pgd*
27	Solbitol Dehydrogenase	SDH	EC. 1.1.1.14	T−C	8	*Sdh*
28	Superoxide Dismutase	SOD	EC. 1.15.1.1	T−C	7	*Sod*

* T−C: tris citerate buffer

pair−group method with averaging (UPGMA) (Sneath and Sokal 1973) and neighbor joining method (NJ) (Saitou and Nei 1987) using the PHYLIP computer package (Felsenstein 1993).

Results

Genetic control of isozymes

A total of 28 enzymes were examined in the tube feet, pyloric caeca and rectal sac. Among them, tissue specific patterns were not obtained, but comparatively clear zymograms were observed in the tube feet. Using the tube feet, enzyme activity was observed in 21 enzymes except ADH, FH, GAD, G6PD, GDH, LDH and ODH. But distinctly clear band patterns were not necessarily observed in all active enzymes. Finally, eight loci coding seven enzymes, namely *αGpd*, HK, MDH, MPI, *6Pgd*, SDH and SOD, were estimated as genetic markers as shown in Table 2.

Typical zymograms of these markers were shown in Fig. 2. Six enzymes with exception of MDH, showed single active zone on the anodal area, then these were controlled by single locus. MDH

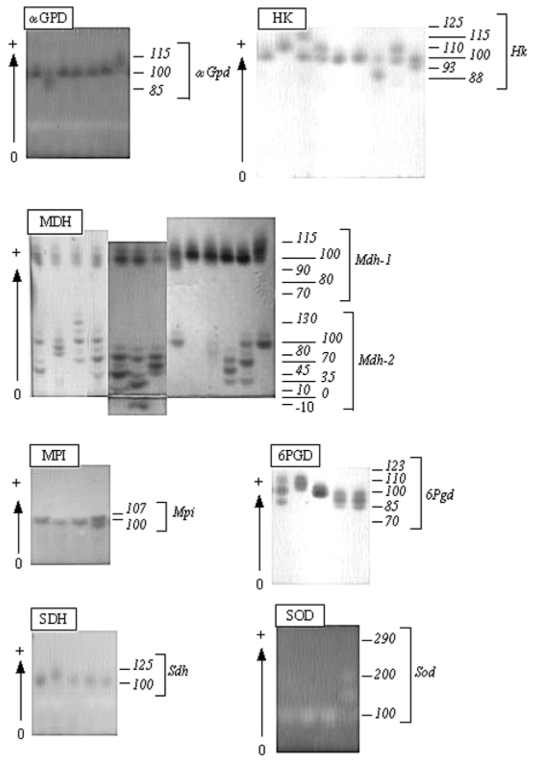


Fig. 2. Electrophoretic band patterns of isozymes in *Asterina pectinifera*

Table 3. Allele frequencies in nine localities for *Asterina pectinifera*. Numbers in parenthesis are sample size.

locus	allele	Yoichi	Usujiri	Asamushi	Rikuzentakata	Onagawa	Izumisano	Kure	Namerikawa	Miyazu
αGpd	*115*	0.015	0	0.036	0.012	0.010	0.010	0.026	0.065	0.033
	100	0.985	1.000	0.960	0.982	0.990	0.990	0.974	0.935	0.967
	85	0	0	0.004	0.006	0	0	0	0	0
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
Hk	*125*	0	0.013	0	0	0	0	0	0	0
	115	0	0.013	0.011	0	0.010	0	0	0	0.011
	110	0.088	0.077	0.146	0.190	0.120	0.175	0.224	0.175	0.120
	100	0.838	0.858	0.777	0.750	0.840	0.760	0.724	0.755	0.782
	93	0.059	0.013	0.062	0.060	0.020	0.060	0.052	0.070	0.087
	88	0.015	0.026	0.004	0	0.010	0.005	0	0	0
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
Mdh-1	*115*	0	0	0	0.006	0.010	0	0	0	0
	100	0.985	0.974	0.974	0.982	0.980	0.980	0.957	0.985	1.000
	90	0	0.013	0.004	0.006	0.010	0.000	0.034	0.015	0
	80	0.015	0.013	0.015	0.006	0	0.020	0.009	0	0
	70	0	0	0.007	0	0	0	0	0	0
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
Mdh-2	*130*	0.029	0	0.047	0.065	0.050	0.050	0.026	0.050	0.011
	100	0.455	0.462	0.529	0.476	0.530	0.445	0.473	0.495	0.511
	80	0	0	0	0	0.010	0	0	0	0
	70	0.397	0.410	0.328	0.351	0.280	0.430	0.362	0.315	0.380
	45	0.074	0.064	0.033	0.036	0.070	0.025	0.078	0.050	0.054
	35	0.015	0.038	0.033	0.036	0.050	0.045	0.052	0.060	0.033
	10	0.015	0.026	0.015	0.012	0	0	0	0.005	0
	0	0	0	0.015	0.018	0.010	0.005	0.009	0.020	0.011
	-10	0.015	0	0	0.006	0	0	0	0.005	0
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
Mpi	*107*	0	0	0.007	0	0	0	0	0	0
	100	1.000	1.000	0.993	1.000	1.000	1.000	1.000	1.000	1.000
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
6Pgd	*123*	0	0	0.004	0	0	0	0	0	0
	110	0.088	0.038	0.026	0.042	0.070	0.040	0.009	0.065	0.065
	100	0.794	0.757	0.839	0.767	0.840	0.840	0.724	0.790	0.848
	85	0.118	0.179	0.124	0.179	0.080	0.115	0.267	0.145	0.087
	70	0	0.026	0.007	0.012	0.010	0.005	0	0	0
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
Sdh	*125*	0	0	0.004	0.018	0.010	0.005	0	0	0
	100	1.000	1.000	0.996	0.982	0.990	0.995	1.000	1.000	1.000
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）
Sod	*290*	0	0	0	0.006	0	0	0.009	0	0
	200	0.059	0.051	0.018	0.018	0.030	0.030	0.026	0.015	0.065
	100	0.941	0.949	0.982	0.976	0.970	0.970	0.965	0.985	0.935
		（34）	(39)	(137)	(84)	(50)	（100）	（58）	(100)	（46）

Table 4. Genetic variability in 9 localities for *Asterina pectinifera*. A/L, allels per locus; P, proportion of polymorphic loci; V, proportion of variable loci less than polymorphic; Ho, observed heterozygosity; He, expected heterozygosity; R, provability of recognition of individuals. Fractions in parenthesis are (number of genotypic combination)/(sample size).

	No. of loci	A/L	P	V	P+V	Ho	He	R
Yoichi	8	2.8	0.50	0.25	0.75	0.195	0.179	0.706 (24/34)
Usujiri	8	2.9	0.50	0.13	0.63	0.173	0.176	0.744 (29/39)
Asamushi	8	3.8	0.38	0.62	1.00	0.190	0.181	0.547 (52/95)
Rikuzentakata	8	3.5	0.38	0.50	0.88	0.193	0.196	0.655 (55/84)
Onagawa	8	3.3	0.38	0.50	0.88	0.140	0.166	0.660 (33/50)
Izumisano	8	2.9	0.38	0.50	0.88	0.183	0.176	0.729 (51/70)
Kure	8	2.8	0.38	0.38	0.76	0.198	0.208	0.672 (39/58)
Namerikawa	8	2.8	0.50	0.25	0.75	0.189	0.197	0.650 (65/100)
Miyazdu	8	2.5	0.50	0.13	0.63	0.168	0.176	0.808 (21/26)
average	8	3.0	0.43	0.36	0.80	0.181	0.184	0.686

showed various band patterns in two separate zones. Therefore, it was estimated that MDH was encoded at two loci (*Mdh−1*, *Mdh−2*).

Genetic variability of isozymes

Allele frequencies of each locality were given in Table 3. The results of chi−square tests for all loci of each locality showed only three significant deviations of genotypic frequencies from those expected under HWE (*Hk* at Rikuzentakata and *6Pgd* at Yochi and Miyazu). After pooling the rare alleles, chi−square tests indicated no significant deviation, and this species were under condition of HWE.

All of eight loci were genetically variable at no less than one locality. And *Hk*, *Mdh−2* and *6Pgd* were polymorphic in all examined localities. Genetic variability was estimated based on eight marker gene as shown in Table 4. The mean number of alleles per locus (A/L) ranged from 2.5 to 3.8, with a mean of 3.0. The proportion of polymorphic loci (P) was 0.38 to 0.50 with a mean of 0.43. The proportion of variable loci less than polymorphic (V) was distributed from 0.13 to 0.62 with a mean of 0.36. The observed average heterozygosity (Ho) ranged from 0.140 to 0.198 with a mean of 0.181 and the expected one (He) did from 0.166 to 0.208 with mean of 0.184.

Genetic differentiation

In order to estimate an extent of genetic differences among examined all localities, a homogeneity test of genetic composition was carried out and the G_{ST} value was calculated (Table 5). In tests using allele frequencies, *αGpd* and *6Pgd* showed a significant difference at the significance level (α) = 0.01, and *Hk* at α = 0.05. Genotype frequencies also showed a significant difference at *αGpd* ($P < 0.01$) and *6Pgd* ($P < 0.05$). G_{ST} value was 0.010.

Next, a number of loci showing a significantly different allele frequencies and Nei's genetic distance between every pair of localities are shown in Table 6. Significant differences of allele frequencies were shown in 16 pairs out of 36, but the number of loci showing a significant difference was small (0 or 1) in most pairs. Also, a significant difference was not observed in any pair of localities at *Mdh−2* which was the most variable locus examined in this study. The minimum genetic distance was 0.00077 between

Table 5. The results of tests of genetic differentiation among all samples by GENEPOP and the value of G_{ST}. "Genic" and "genotypic" show the tests about distribution of alleles and genotypes, respectively. (*, P<0.05; **, P<0.01)

	genic	genotypic
locus	P-value	P-value
αGpd	0.0420 *	0.0246 *
Hk	0.0326 *	0.0508
Mdh-1	0.1944	0.1288
Mdh-2	0.3526	0.3290
Mpi	0.7621	0.4385
6Pgd	0.0070 **	0.0154 *
Sdh	0.4163	0.3536
Sod	0.1763	0.3026
G_{ST}	0.010	

Table 6. Nei's genetic distance among localities where *Asterina pectinifera* were sampled (blow diagonal), and number of loci that showed significantly different allele friquency between localities at α= 0.05 (above diagonal).

	Yoichi	Usujiri	Asamushi	Rikuzen takata	Onagawa	Izumisano	Kure	Namerikawa	Miyazu
Yoichi	–	0	0	0	0	0	2	0	0
Usujiri	0.00108	–	1	1	0	1	1	2	0
Asamushi	0.00237	0.00341	–	0	0	0	1	0	1
Rikuzentakata	0.00264	0.00303	0.00125	–	0	0	0	1	0
Onagawa	0.00229	0.00356	0.00126	0.00297	–	0	2	2	0
Izumisano	0.00193	0.00307	0.00164	0.00136	0.00345	–	1	2	0
Kure	0.00548	0.00444	0.00395	0.00148	0.00666	0.00388	–	1	1
Namerikawa	0.00282	0.00405	0.00077	0.00089	0.00211	0.00209	0.00274	–	1
Miyazdu	0.00121	0.00304	0.00114	0.00252	0.00187	0.00149	0.00563	0.00186	–

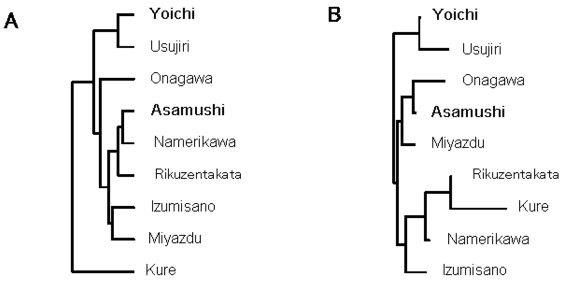


Fig. 3. Dendrograms constructed by UPGMA(A) and NJ(B) based on Nei's genetic distance among 9 localities

Asamushi and Namerikawa, the maximum was 0.00666 between Onagawa and Kure, and average was 0.00263.

In order to reveal genetic relationship among 9 localities, two kind of dendrograms were constructed through UPGMA and NJ methods based on the genetic distance matrix (Fig. 3). Clear geographical relationship was not observed in both dendrograms.

Discussion

Detection of isozymes

In the present study, 8 loci were estimated from substrate-specific 7 enzymes as genetic marker for *A. pectinifera*. Matsuoka et al. (1995) and Matsuoka and Asano (2003) estimated 23 loci from 12 enzymes extracted from pyloric caeca of *A. pectinifera* using PAGE. However, non-substrate-specific enzyme loci, i.e. three loci from alkaline phosphatase (ALK), four from leucine amino peptidase (LAP), two from amylase (AMY) and two from nothing dehydrogenase (NDH), were included. As non-substrate-specific enzymes were often controlled by several loci, careful attention should be paid to using these enzymes as genetic marker. Except these loci, eleven loci controlling eight enzymes were estimated by them. And a critical difference exists between their estimation and our result. They reported MDH to be a monomeric enzyme but the authors showed to be dimeric enzyme based on the evidence of typical phenotypes of variation on the gel (see Fig. 2). Even if the experimental conditions differ, the enzyme structure does not change. Therefore, it is unable to compare our results with the data from Matsuoka et al. (1995) and Matsuoka and Asano (2003). In other starfish, in *Linckia laevigata* 7 loci from 6 enzymes were estimated (Williams and Benzie 1993), in *Acanthaster planci* 14 from 12 (Nishida and Lucas 1988) and 9 from 7 (Benzie and Stoddart 1992), in *Leptasterias epichlora* and *L. hexactis* 14 from 12 (11 from 10 except non-substrate-specific enzymes) (Kwast et al. 1990), and in *Asterias amurensis* 12 from 10 (Yamashita et al. 2005). These numbers of estimated loci in starfish species were not so many. From the facts mentioned above, it is likely to be harder to detect isozymes in starfish than fish or mollusca. Indeed, the activity of some examined enzymes rapidly disappeared even though the tissues were frozen at −30 ℃ . This would be one of the factors that causes the detection of isozymes difficult in starfish species.

Genetic variability

Comparing the genetic variability of *A. pectinifera* with other marine animals, the values in the present study were higher than that averaged from 41 fish species (P = 0.194±0.023, He = 0.059±0.007) reported by Fujio and Kato (1979) and from 25 shellfish (P = 0.412±0.030, He = 0.147±0.011) (Fujio et al. 1983). In other starfish, average heterozygosity (He) was reported as 0.402, 0.199, 0.255, 0.164 and 0.254 in *Linckia laevigata* (Williams and Benzie 1993), in *Acanthaster planci* (Nishida and Lucas 1988, Benzie and Stoddart 1992), and in *Leptasterias epichlora* and *L. hexactis* (Kwast et al. 1990), respectively. Compared with these reports about other aquatic animals, relatively high genetic variability was found in the starfish including *A. pectinifera*.

Soul (1976) and Nei and Graur (1984) showed the correlation between genetic variability and effective population size. Assuming that the isozyme markers used in the present study are neutral against natural selection, the fact that such high genetic variability exists in *A. pectinifera* population suggests this species have considerably large effective population size. As a practical matter, *A. pectinifera* inhabits broadly around coastal area of not only Japan but east Asia.

Genetic uniformity of A. pectinifera population

G_{ST} of *A. pectinifera* was 0.010, that is, the genetic diversity derived from the difference among localities is only 1% and most of the variability exists within locality. The results of homogeneity tests of allele and genotype frequencies suggest that the genetic composition of this species is not quite homogeneous through the whole sampling range. But in the loci showing significantly different allele and/or genotype frequencies, a single common dominant allele always existed across the all localities examined in the present study. And there is no cline of allele frequencies along geographical locations. With regard to Nei's genetic distance, the values were small, independent of geographic distance. Nei (1975) summarized that the genetic distance estimated from various animals using protein polymorphism was approximately the order of 1.0 between species, 0.1 between subspecies and 0.01 among local races. Compared with the report, the values in the present study were much smaller than upper limit among local races. With regard to dendrograms, although the topologies are not altogether identical between UPGMA and NJ trees, this result paradoxically suggests that the genetic composition should be very similar among localities and there shouldn't be enough difference to divide them genetically. Thus, the extent of genetic divergence of *A. pectinifera* is quite small, in other words, this species has uniform genetic composition across most coastal area of Japan.

Contrary to our results, Matsuoka et al. (1995) reported Nei's genetic distance was no less than 0.041 between Mutsu Bay and Fukaura, both of which are located near by Asamushi in Aomori prefecture, that value is over ten times larger than the average shown in the present study. Their result substantially depended on the genetic difference estimated from the loci expected from MDH and LAP. However nevertheless their estimation about the loci of these enzymes was obscure as mentioned above.

This study showed that *A. pectinifera* was under HWE in all localities examined and had low genetic differences with high genetic variability. The dispersal during the planktonic larval phase for about one month (Komatsu and Oguro 1988) seems to bring about the genetic homogeneity like this. In marine animals, there are many reports suggesting that presence (and its period) or absence of floating property (dispersal potential) of egg, larva and/or juvenile is closely related to gene flow and the important factor to form population structure (Hunt 1993, Doherty et al. 1995, Arndt and Smith 1998 and Bernardi 2000). The genetic uniformity throughout extensive geographical range was reported in other asteroid, *Linckia laevigata* (Williams and Benzie 1993, 1996). They suggested the larval life remaining in the water column during 28 d of that species caused high gene flow and the genetic composition to be homogeneous. Williams and Benzie (1993) showed the negative correlation between the dispersal ability and genetic differentiation. Taking account of the length of planktonic larval phase in *A. pectinifera*, which is considerably long among aquatic animals with pelagic larval phase, the results in the present study agree with their opinion. In order to maintain homogeneous genetic composition extensively, gene flow must have been continuous and as large scale as a great number of individuals exchange among local areas. The effective population size of *A. pectinifera* is expected to be very large because of its high genetic variability, so that probably the scale of gene flow will be large.

The results shown in the present study is the first information about the genetic variability and divergence of *A. pectinifera* sampled from a wide range of coastal area around Japan. That data will be the basic information for maintenance of the starfish population in coastal fishing places and aquaculture areas.

References

Arndt, A. & M. Smith (1998) Genetic diversity and population structure in two species of sea cucumber : differing patterns according to mode of development. Mol. Ecol., 7 : 1053−1064.

Benzie, J. A. H. & J. A. Stoddart (1992) Genetic structure of outbreaking and non−outbreaking crown−of−thorns starfish(*Acanthaster planci*) populations on the Great Barrier Reef. Marine Biology 112 : 119−130.

Bernardy, G. (2000) Barriers to gene flow In Enbiotoca jacksoni, a marine fish lacking a pelegic larval stage. Evolution, 54(1) : 226−237.

Doherty, P., S. Planes & P. Mather (1995) Gene flow and larval duration in seven species of fish from the Great Barrier Reef. Ecology, 76(8) : 2373−2391.

Felsenstein, J. (1993) PHYLIP : phylogeny inference package. Vers. 3.5c. Distributed by author. Department of Genetics, Univ. of Washington, Seattle.

Fujio, Y. & M. Ikeda (1999) Procedure of isozyme analysis and DNA analysis as genetic marker. Oyster research center. (Sendai)

Fujio, Y. & Y. Kato (1979) Genetic variation in fish populations. Bull. Japan. Soc. Sci. Fish., 45 : 1169−1178.

Fujio, Y., R. Yamanaka & J. P. Smith (1983). Genetic variation in marine Molluscs. Bull. Japan. Soc. Sci. Fish., 49 : 809−1817.

Hart, M. W., M. Byrne & M. J. Smith (1997) Molecular phylogenetic analysis of life−history evolution In Asterinid starfish. Evolution, 51(6) : 1848−1861.

Hunt, A. (1993) Effects of constrasting patterns of larval dispersal on the genetic connectedness of local populations of two intertidal starfish, Patiriella calcar and P. exigua. Marine Ecology Progress Series, 92 : 179−186.

Hayashi, R. (1974) Eleutherozoa Asteroidea. Systematic Zoology vol.8, supervised by Uchida R, Nakayama−Shoten Co. (Tokyo)

Komatsu, E. & C. Oguro (1988) Echinodermata (3) Asteroidea. Developmental Experiment of Marine Invertebrates, supervised by Dan K, edited by Ishikawa Y and Mumakunai T, Baifukan Co. (Tokyo)

Komatsu, E., M. Kawai and C. Oguro (1993) The development of the seastar, *Asterias amurensis* Lütken, with a consideration to the systematic relation to *Asrerias amurensis versicolo*r Sladen. Zoological Science (Tokyo). 10(SUPPL.) : 176.

Kwast, K. E., D. W. Foltz & W. B. Stickle (1990) Population genetics and systematics of the Leptasterias hexactis (Echinodermta : Asteroidea) species complex. Marine Biology, 105 : 477−489.

Nishida, M. & J. S. Lucas (1988) genetic differences between geographic populations of the Crown−of−thorns starfish throughout the Pacific region. Mar. Biol., 98 : 359−368.

Matsuoka, N & H. Asano (2003) Genetic variation in northern Japanese population of the starfish *Asterina pectinifera*. Zoological Science, 20 : 985−988.

Matsuoka, N., K. Kohyama & H. Asano (1995) Genetic distance and enzyme variation In local populations of two echinoderms from Japanese waters. Comp. Biochem. Physiol., 110 : 225−233.

Oguro, C. (1995) Echinodermata Asterozoa Asteroidea. Guide to Seashore Animals of Japan with Color Pictures and Keys Vol. Ⅱ . Edited by Nishimura S, Hoikusha (Tokyo) : 513−529.

Oguro, C. & M. Komatsu (1988) Echinodermata Asteroidea. Development of invertebrates vol. two, ed. Dan K, Sekiguchi K, Ando H and Watanabe H, 339−356.

Raymond, M. & F. Rousset (1995) GENEPOP (version 1.2) : population genetics software for exact tests and ecumenicism. J. Heredity, 86 : 248−249.

Saitou, N. & M. Nei (1987) The neighbor−joining method : A new method for reconstructing phylogenetic trees. Mol. Bio. Evol., 4 : 406−425.

Sneath, P. H. A. & P. R. Sokal (1973) Numerical Taxonomy. Freeman, San Francisco.

Wada, H., M. Komatsu & N. Satho (1996) Mitochondrial rDNA phylogeny of the Asteroidea suggests the primitiveness of the Paxillosida. Mol. Phyl. and Evol., 6 : 97−106.

Williams, S. T. & J. A. H. Benzie (1993) Genetic consequences of long larval life in the starfish *Linckia laevigata* (Echinodermata : Asteroidea) on the Great Barrier Reef. Marine Biology, 117 : 71–77.

Yamashita, M., M. Komatsu & A. Kijima (2005) Genetic variability and geographical population structure in coastal starfish *Asterias amurensis* Lü tken around Japan estimated by isozyme analysis, Fish Genet. Breed. Sci., 34(2) : 99–109.

List of scientific papers in 2003 published by field science group in Grasduate School of Agricultural Science, Tohoku University

The Forest–Andisols Group

Inoue, H., T. Ito and M. Saigusa (2003) No–tillage cultivation of corn using controlled release fertilizer. 12th International World Fertilizer Congress "Fertilization in the Third Millenium –Fertilizer, Food Security and Environmental Protection" Proceedings, 2 : 1028–1034.

Kimura, M., K. Seiwa, Y. Suyama and N. Ueno (2003) Flowering system of heterodichogamous Juglans ailanthifolia. Plant Species Biology, 18(2–3) : 75–84.

Mizuno, N., K. Nizamidin, M. Nanzyo, H. Yoshida and Y. Amano (2003) Judging conducive soils from clay mineralogical properties and soil chemical method to suppress fro potato common scap. Soil Microorganisms, 58(2) : 97–103. (In Japanese)

Morikawa, C. K. and M. Saigusa (2003) Effect of continuous applications of low–acidulent fertilizer on acidification of an andisol and plant growth. *Comm. Soil Sci. Plant Anl.*, 34(5–6) : 619–628.

Nanzyo, M., Y. Ebuchi and H. Kanno (2003) Apatie in the pyroclastic flow deposits (1990–1995) of the Unzen volcano, Japan, and its utilization by buckwheat. Phosphorus Research Bulletin, 16 : 1–10.

Nizamidin, K., M. Nanzyo, Y. Amano and N. Mizuno (2003) Soil factors affecting 0.1 M HCl–soluble Cu of Andosols in Hokkaido, Japan. Jpn. J. Soil Sci. Plant Nutr., 74 (6) : 801–804. (In Japanese)

Nizamidin, K., M. Nanzyo, Y. Amano, T. Mizuno, H. Yoshida and N. Mizuno (2003) Clay mineralogical properties of volcanic ash soils in Hokkaido, Japan. J. Rakuno Gakuen Univ., 28(1) : 7–45. (In Japanese)

Satoh,M., K. Hikosaka, T. Sasaki, Y. Suyama, T. Yanai, M. Ohta and Y. Nakai (2003) Characteristics of a Novel Type of Bovine Cryptosporidium andersoni. Applied and Environmental Microbiology, 69(1) : 691–692.

Seiwa, K. (2003) Seeds. Encydopedia of Ecology leds. Y. Iwasa, T. Matsumoto, and K. Kikuzawa, pp. 238–239, Kyoritu Shuppan, Tokyo

Takahashi, T. (2003) Soil clay and environmental conservation. J. Clay Sci. Soc. Jpn., 42(3) : 154–157. (In Japanese)

Takahashi, T. (2003) Acidity characteristics and edaphology of Kuroboku soils (Andosols). Pedologist, 47(2) : 122–128. (In Japanese)

Takahashi, T., T. Sato, A. Sato and M. Nanzyo (2003) Relationship between 1 M KCl–extractable aluminum and pyrophosphate–extractable aluminum in A horizons of non–allophanic Andosols. Soil Science and Plant Nutrition, 49(6) : 729–733.

Tian, X. and M. Saigusa (2003) Response of dent corn and sweet corn to two different forms of *co–situs* application methods of controlled release fertilizer in upland field of a volcanic ash soil.Tohoku J. of Agr. Res., 54(1–2) : 1–15.

Ueno, N. and K. Seiwa (2003) Gender–specific shoot structure and functions in relation to habitat conditions in a dioecious tree, Salix sachalinensis. Journal of Forest Research, 8(1) : 9–16.

The Ruminant Production Group

Asai K., T. Yamaguchi, T. Kuroishi, Y. Komine, K. Kai, K. Komine and K. Kumagai (2003) Differential gene expression of cytokine and cell surface molecules in T cell subpopulation derived from mammary gland secretion of cows. Am. J. Reprod.Immunol., 50(6) : 453–462.

Deguchi, Y., S. Sato and K. Sugawara (2003) The situation of crop damage by wild large mammals and conservation of the mammals in Tohoku region. Tohoku Journal of Animal Science and Technology, 52 : 61–64.

Deguchi, Y., S. Sato and K. Sugawara (2003) Estimating the ratio of the forage corn damage by Asiatic black bear (*Ursus thibetanus*) . Tohoku Journal of Animal Science and Technology, 53 : 9–12.

Hashiba, T. and T. Yamaguchi eds. (2003) Textbook of biology for life science, 2nd ed., Baihukan, Tokyo. (Book : in Japanese)

Hirata, M., S. Ogura (2003) Spatiotemporal variation in herbage mass in a grazed pasture : an approach at a feeding station scale. Grassland Science, 49 :

280−285 (special issue).

Kamada, H., I. Konaka, S. Masaki, Y. Takayama, M. Amari, T. Takezawa, H. Ikumo and Y. Obara (2003) Effects of sodium selenite supplementation on reproductive performance and body fluid properties in pregnant Holstein heifers. Anim. Sci. J., 74 : 363−368.

Kitade, K., T. Nishita, M. Yamato, K. Sakamoto, A. Hagino, K. Katoh, and Y. Obara, Expression and localization of carbonic anhydrase in bovine mammary gland and secretion in milk. Comp. Biochem. Physiol., 134A : 349−354.

Kuroishi, T., K. Komine, K. Asai, J. Kobayashi, K. Watanabe, T.Yamaguchi, S. Kamata and K. Kumagai (2003) Inflammatory Responses of Bovine Polymorphonuclear Neutrophils Induced by Staphylococcal Enterotoxin C via Stimulation of Mononuclear Cells. Clin. Diagn. Lab. Immunol., 10(6) : 1011−1018.

Kushibiki, S., K. Hodate, H. Shingu, Y. Obara, E. Touno, M. Shinoda and Y. Yokomizo, (2003) Metabolic and lactational responses during recombinant bovine tumor necrosis factor−α treatmment in lactating cows. J.Dairy Sci., 86 : 819−827.

Matsuzaki, M., T. Sato, K. Watanabe, N. Shiba, E. Tsuneishi and T. Yamaguchi (2003) Immunohistochemical detection of pituitary transcription factor−1 in paraffin sections of bovine adenohypophysis after wet heat−induced antigen retrieval. Anim. Sci. J., 74(2) : 137−143.

Nakai, Y. (2003) Harmonization between beef production and environment. Beef Journal, 2003(1) : 24−29. (review : in Japanese)

Nakai, Y., M. Omura and T.Ichida (2003) Farming and livestock in Germany (1). Animal Production Research, 57(7) : 808−812. (review : in Japanese)

Nakai, Y., M. Omura, and T. Ichida (2003) Farming and livestock in Germany (2). Animal Production Research, 57(8) : 916−920 (review : in Japanese)

Ninomiya, S., R. Kusunose, S. Sato, M. Terata and K. Sugawara (2004) Effects of feeding methods on eating frustration in stabled horses. Animal Science Journal, 75 : 465−469.

Obara, Y. (2003) Mechanism of fat marbling in muscle by leptin and vascular endothelial growth factor in beef cattle. Annual Report of Ito Foundation, 21 : 150−154. (review : in Japanese)

Otawa, K., M. Sato, T. Sasaki, H. Sasaki, J. Nonaka, K. Ito, T. Kuroki and Y. Nakai (2003)Epidemiologic and genetic analysis of shiga−toxigenic Escherichia coli. Bulletin of Integrated Field Science, 19 : 19−25. (review : in Japanese)

Satoh. M., K. Hikosaka, Y. Sasaki, Y. Suyama, T. Yanai, M. Ohta and Y. Nakai (2003) Characteristics of a novel type of bovine Cryptosporidium. Appl. Environ. Microbial., 69(1) : 691−692.

Takahashi, T., S. Ogura and K. Sugawara (2003) Plant type selection of grazing cattle in sown and native grassland. Bulletin of Integrated Field Science Center, 19 : 13−17.

Takeda, K., S. Sato and K. Sugawara (2003) Familiarity and group size affect emotional stress in Japanese Black heifers. Applied Animal Behaviour Science, 82 : 1−11.

Watanabe, N., A. Nishiwaki and K. Sugawara (2003) Seed production of *Carex albata* Boott in sown pasture. Grassland Science, 49 : 49−51.

Watanabe, K., H. Sato, T. Kobayash, K. Katoh and Y. Obara (2003) Determination of intestinal disappearance of lysine and methionine derived from ruminally protected lysinne and methionine in Holstein heifers. Asian−Australasian J. Anim. Sci., 16 : 549−554.

Wu, E., K. Saito, S. Sato and K. Sugawara (2003) Effects of surface application of phosphorus and lime materials on arbuscular mycorrhizal colonization of orchardgrass in grazing pasture. Grassland Science, 49 : 52−54.

Yokota,T., T. Ito, T. Ono, M. Takahashi and M. Saigusa (2003) : Composition of inorganic phosphate in cattle manure composts with different production conditions. Jpn. J. Soil Sci. Plant Nutr., 74 : 133−140. (In Japanese)

Yokota,T., T. Ito, and M. Saigusa(2003) Measurement of total phosphorus and organic phosphorus contents of animal mature composts by the dry combustion method. Soil Sci. Plant Nutr., 49(2), 267−272

Yokota,T., M. Saigusa and T. Ito (2003) : Possibility of using sludge from water purification plants in animal manure composts to suppress phosphate and potassium dissolubility and organic matter decomposition. Journal of Japanese Society of Waste Management Experts, 14 : 183−190. (In Japanese)

Yonekura, S., T. Senoo, Y. Kobayashi, T. Yonezawa, K. Katoh and Y. Obara (2003) Effect of acetate and butyrate on the expression of leptin and short-form leptin receptor in bovine and rat anterior pituitary cells. Gen. Comp. Endcrinol., 133 : 165-172.

Yoshida M., K. Katoh and Y. Obara. (2003) ACTH secretion in the ruminant. Chikusan no Kenkyu, 57 : 1275-1283. (review : in Japanese)

The rice Production Groups

Goto, Y. (2003) Tillering behavior of rice plants. Jpn. J. Crop Sci., 72 : 1-10. (In Japanese)

Ito, T., Y. Ninomiya, M. Hanaki, K. Shibuya and M. Saigusa (2003) Soil properties and nitrogen adsorption activity of rice (Oryza sativa L.) in two no-tillage alluvial paddy soils. Bulltetin of Integrated Field Science Center., 19 : 1-6.(In Japanese)

Maekawa, K., K. Watanabe, T. Kanto, M. Aino and M. Saigusa (2003) Effect of Soluble Silicic Acid on Suppression of Rice Leaf Blast, Jpn. J. Soil Sci. Plant Nutr., 74, 293-299. (In Japanese)

Morikawa, C. K., M. Saigusa, H. Nakanishi, N. Nishizawa and S. Mori (2003) Co-situs application of control release fertilizers to alleviate iron chlorosis of paddy rice grown in calcareous soil, The 6th ESAFS International Conference Soil Management Technology on Low-productivity and Degraded Soils (Taipei, TAIWAN) Extended Abstracts, 95-96.

Okawa, S., A. Makino and T. Mae (2003) Effect of irradiance on the partitioning of assimilated carbon during the early phase of grain filling in rice. Ann. Bot., 92 (3) : 357-364.

Saigusa, M., H. Heinai, K. Shibuya, H. Okazaki and K. Yoshida (2003) Effect of acidified porous hydrate calsium silicate applied in a nursery bed soil on growth and nutrient uptake of rice seedling. Jpn. J. Soil Sci. Plant Nutr., 74 : 333-337. (In Japanese)

Saigusa, M., A. Ombodi, T. Owashi and H. Watanebe (2003) Supply of aimed form of nitrogen using controlled availability fertilizer. 12th International World Fertilizer Congress "Fertilization in the Third Millenium-Fertilizer, Food Security and Environmental Protection" Proceedings, 1 : 315-321.

Sato, Y. and T. Nishio (2003) Mutation detection in rice waxy mutants by PCR-RF-SSCP. Theor Appl Genet, 107 : 560-567.

Sudo, E., A. Makino and T. Mae (2003) Differences between rice and wheat in ribulose-1,5-bisphosphate regeneration capacity per unit of leaf-N content. Plant Cell Environ., 26 (2) : 255-263.

Tashiro,T., M. Saigusa, K. Chiba and K. Shibuya (2003) No-till direct seedling culture of rice (Oryza sativa L.) without covering soil using controlled release fertilizers. 12th International World Fertilizer Congress "Fertilization in the Third Millenium-Fertilizer, Food Security and Environmental Protection" Proceedings, 1 : 354-358.

Ushio, A., A. Makino, S. Yokota, H. Naoki and T. Mae (2003) Xanthophyll cycle pigments and the water-water cycle in transgenic rice with decreased amounts of ribulose-1,5-bisphosphate carboxylase and the wild-type rice grown with different N levels.Soil Sci. plant nutr., 49 (1) : 77-83.

Watanabe, H. and M. Saigusa (2003) Effects of the combined application of ethephon and gibberellin on the rice seedling growth growing under direct seeding cultivation. Proceedings of the Plant Growth Regulation Society of America : , 139-141.

Zhang, W. H., Y. J. Cui and M. Kokubun (2003) Factors affecting yield improvement of rice cultivars released in Tohoku region -Variation of grain filling percentage under high nitrogen application. Tohoku J. Crop Sci., 46 : 65-66. (In Japanese).

Marine Bio-production Group

Asuma, K., N. Horiki and N. Taniguchi (2003) Annual stock fluctuations of Ayu, Plecoglissus altivelis, in the coastal waters of the central Wakayama Prefecture Japan. Suisanzoshoku,51(3) : 263-271.

Hancz, C., I. Magyary, T. Molnar, S. Sato, P. Horn, and N. Taniguchi (2003) Evaluation of color intensity enhanced by paprika as feed additive in gold fish and koi carp using computer-assisted image analysis. Fish. Sci., 69 : 1158-1161.

Ikeda, M., M. Nunokawa and N. Taniguchi (2003) Lack of mitochondrial gene flow between

populations of endangered amphidromous fish *Plecoglossus altivelis* ryukyuensis inhabiting Amami−oshima island. Fish. Sci., 69 : 1162−1168.

Kaneko, K. and M. Omori (2003) Diel and tidal migrations and predator−prey relationships of macrobenthic animals in intertidal sandy beaches of Sendai Bay, northern Japan. Benthos Res., 58(1), 43 – 49.

Kanno, M. and A. Kijima (2003) Studies on color variations of Japanese sea cucumber, Stichopus japonicus : a review. Bull. Integrated Field Science Center, 19 : 33−37.

Kanno, M. and A. Kijima (2003) Genetic differentiation among three color variaants of Japanese sea cucumber Stichopus japonicus. Fisheries Science, 69 : 806−812.

Li, Q., C. Park, T. Kobayashi and A. Kijima (2003) Inheritance of microsatellite DNA markers in the Pacific abalone Haliotis discus hannai. Marine Biotech., 5 : 331−338.

Li, Q., C. Park and A. Kijima (2003) Allelic transmission of microsatellites and application of kinship analysis in newly hatched Pacific abalone larvae. Fisheries Sci., 69 : 883−889.

Mae, Y., N. Arai, Y. Kartavtsev and A. Kijima (2003) Genetic differentiation between Japan and Far East Russia in coastal oyster drill Nucella freycineti. Bull. Integrated Field Science Center, 19 : 39−45.(In Japanese)

Nakadate, M., T. Shikano and N. Taniguchi (2003) Inbreeding depression and heterosis in various quantitative traits of the guppy *Poecilia reticulate*. Aquaculture, 220 : 219−226.

Noguchi, D., S. Dong and N. Taniguchi (2003) Assignment of individuals for amphidromous and landlocked populations of ayu, Plecoglossus altivelis by relatedness estimator. Suisanzoshoku, 51(2) : 219−224.

Noguchi, D., M. Ikeda, M. Nakajima and N. Taniguchi (2003) Isolation and characterization of microsatellite DNA markers for population genetic study of masu salmon, Oncorhnchus masou masou. 33 : 61−66.

Ohara, K., T. Ariyoshi, E. Sumida and N. Taniguchi (2003) Clonal diversity in the Japanese silver crucian carp, *Carassius langsdorfii* inferred from genetic markers. Zool. Sci., 20 : 797−804.

Ohara, K. and N. Taniguchi (2003) Preliminary study on genetic diversity evaluated by 11 microsatellite markers in Kuromejina *Girella leonine* and Mejina *Girella punctata*. Fish. Sci., 69 : 861−863.

Ortega−Villaizan Romo, M., M. Nakajima and N. Taniguchi (2003) Isolation and characterization of microsatellite DNA markers in the rare species barfin flounder (*Verasper moseri*) and its closely related species spotten halibut (Verasper variegatus). Molecular Ecology Notes, 3 : 629−631.

Park, C., Q. Li, T. Kobayashi and A. Kijima (2003) Characterization of novel microsatellite DNA markers in the Pacific abalone, Haliotis discus hannai. Fish Genet. Breed. Sci.,32(1) : 1−6.

Plaza−Pasten, G., S. Katayama and M. Omori (2003) Timing of parturition, planktonic duration, and settlement pattern of the black rockfish, Sebastes inermis, Env. Biol. Fish., 68, 229−239.

Sano, M., M. Omori and K. Taniguchi (2003) Predator−prey systems of drifting seaweed communities off Tohoku coast, northern Japan, as determined by feeding habit analysis of phytal animals, Fish. Sci., 69 : 260−268.

Shikano, T. and N. Taniguchi (2003) DNA markers for estimation of inbreeding depression and heterosis in the guppy Poecilia reticulate. Aquaculture Reserach, 34 : 905−911.

Takagi, M., S. Chow, T. Okamura, V. P. Scholey, A. Kanazawa, D. Margules, J. B. Wexler and N. Taniguchi (2003) Mendelian inheritance and variation of four microsatellite DNA markers in the yellowfin tuna *Thunnus albacores*. Fish. Sci., 69 : 1306−1308.

Taniguchi, N. (2003) Genetic factors in broodstock management for seed production. Reviews in Fish Biology and Fisheries., 13 : 177−183, Kluwer Academic Publishers, Dordnecht. The Netherland.

Taniguchi, N., R. Perez−Enriquez and E. Nugroho (2003) DNA markers as a tool for genetic management of broodstock for aquaculture. In Aquatic Genomics [N. Shimizu, T. Aoki, I. Hirono and F. Takashima (EDS.), 417−429, Springer−Verlag, Tokyo.

Watanabe, T., M. Yoshida, M. Nakajima and N. Taniguchi (2003) Isolation and characterization of 43 microsatellite DNA markers for guppy (*Poecilia reticulate*). Molecular Ecology Notes, 3 : 487−490.

List of scientific papers in 2004 published by field science group in Grasduate School of Agricultural Science, Tohoku University

The Forest −Andisols Group

Akahane, I., M. Nanzyo and T. Takahashi. (2004) Significance of hydrous iron oxides in enhancing P sorption of soils with the addition of sodium hydrosulfite ($Na_2S_2O_4$). Soil Science and Plant Nutrition, 50(8) : 1317−1320.

Dahlgren, R. A., M. Saigusa and F. C. Ugolini (2004) : The nature, properties and management of volcanic soils, *Advances in Agronomy*, 82 : 113−181.

Hirai, H., H. Hashimoto. H. Tanaka and T. Ito (2004) : Soil classification of soils developed at the eastern foot of Mt. Nantai by means of Unified Soil Classification System of Japan 2nd Approximation (2002) and correlation with Soil Classification of National Soil Survey. Pedlogist, 48 : 16−23. (In Japanese)

Ito, T. (2004) Soil classification system in the world and application to agriculture and forestry. 2. Soil Taxonomy 2nd edition : Outline and characteristics. Jpn. J. Soil Sci. Plant Nutr., 75 : 729−736.(In Japanese)

Ito, T., N. Kikawa, T. Yokota, K. Shibuya and M. Saigusa (2004) Comparative study on the response of grain sorghum (*sorghum bicolor L.*) to soil test phosphorus in Silandic and Aluandic Andosols, ibid, 316−317.

Ito, T., A. Mitamura, Y. Yamada, M. Nakae and M. Saigusa (2004) Chemical and clay mineralogical properties of acidified allophonic Andosols in tea (*Cammellia sinensis*) fields, ibid, 132−133.

Kanno, H. (2004) Morphological and chemical characteristics of tephra−derived soils in Changbaishan, Northeast China, 10th Century great eruption of Baitoushan Volcano, Northeast China, and its Historic Effect, CNEAS Monograph Series, 16 : 55−96.

Kanno, H. and K. Seiwa (2004) Sexual vs. vegetative reproduction in relation to forest dynamics in the understorey shrub, Hydrangea paniculata (Saxifragaceae). Plant Ecology, 170 : 43−53.

Kanno, M., J. Yokoyama, Y. Suyama, M. Ohyama, T. Itoh and M. Suzuki (2004) Geographical distribution of two haplotypes of chloroplast DNA in four oakspecies (Quercus) in Japan. Journal of Plant Research, 117 (4) : 311−317.

Matsumori, K., M. Saigusa and T. Ito (2004) Development of no−tillage dibber planter for soybean (Part 1)−Principles and equipments on no−tillage dibber planter−. J. Jpn. Soc. Agr. Machinery, 66 : 90−97.(In Japanese)

Matsumori, K., M. Saigusa and T. Ito (2004) Weed control in glyphosate−resistant soybean under no−tillage cultivation. Tohoku Weed J., 4 : 8−13. (In Japanese)

Matsuyama, N., M. Saigusa and K. Kudo (2004) Acidification of Andosols by heavy application of fertilizer with special reference to soil productivity, ibid, 332−333.

Morikawa, C. K. and M. Saigusa (2004) : Mineral composition and accumulation of silicon in tissues of blueberry (*Vaccinum corymbosus cv. Bluecrop*) cuttings, *Plant and Soil*, 258, 1−8.

Morikawa, C. K. and M. Saigusa (2004) Effects of simulated acid rain and heavy application of fertilizer on Andisol acidification and its effect on crop growth, Proceedings of the 6th International Symposium on Plant–Soil Interactions at Low pH, 124−125.

Nanzyo, M. (2004) Research core of biological−production ecosystem in the fields of forest, grassland and volcanic ash soils, J. Integr. Field Sci., 1 : 7−15.

Nanzyo, M., H. Kanno and S. Obara (2004) Effect of reducing conditions on P sorption of soils, Soil Sci. Plant Nutr., 50 (7) : 1028−1028.

Nanzyo, M., N. Wada and H. Kanno (2004) Phosphorus foraging root development of Brassica rapa nothovar. grown in a phosphorus−deficient nonallophanic Andisol., Plant Soil, 265 : 325−333.

Prokaj, E., M. Saigusa, K. Kitamura and K. Suzuki (2004) Comparison of the growth responses of highbush and rabbiteye blueberry cultivars to different soil pHs, ibid, 278−279.

Prokaj, E., M. Saigusa, K. Kitamura and K. Suzuki (2004) Growth responses of blueberry softwood cuttings to atmospheric carbon dioxide enrichment, *Tohoku Journal of Agricultural Research*, 54(3−4) : 13−21, March.

Saigusa, M. and N. Matsuyama (2004) Distribution and agronomic aspects of non-allophanic Andosols, ibid, 334-335.

Saito,K., Y. Suyama, S. Sato and K. Sugawara (2004) Defoliation effects on thecommunity structure of arbuscular mycorrhizal fungi based on 18S rDNA sequences. Mycorrhiza : in press.

Seiwa, K. (2004) Sexual reproduction. Ecophysiology of Woody Plants (ed. T. Koike), pp. 158-175, Asakura shoten, Tokyo.

Seiwa, K. (2004) Seed germination and ecophysiology of tree seedlings. Ecophysiology of Woody Plants ed. (T. Koike), pp. 175-183, Asakura shoten, Tokyo.

Suyama, Y. (2004) Identification of mother trees based on microsatellite analysis of maternal tissues from seeds, fruits, and seedlings. Journal of Japanese Forestry Society, 86(2) : 177-183. (In Japanese with English Summary)

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(3) : 431-437.

Tian, X., C. K. Morikawa and M. Saigusa (2004) Effect of controlled release fertilizers on mitigation of soil acidification in nonallophanic Andisols, ibid, 146-147.

Tomita, M. and K. Seiwa (2004) Influence of canopy tree phenology on understorey populations of Fagus crenata. Journal of Vegetation Science, 15 : 379-388.

The Ruminant Production Group

Abe, N., H. Takazaki, H. Naekawa, S. Sato and K. Sugawara (2004) Development of mock-fighting behaviour toward the handler and its relation to behavioural and physiological characteristics in caressed beef suckler calves. *Nihon Chikusan Gakkaiho*, 75 : 221-227.

Abe, N., H. Takazaki, S. Sato and K. Sugawara, (2004) Punishment training of mock-fighting behaviour to human in calves. *Nihon Chikusan Gakkaiho*, 75 : 417-422.

Hayashi S., H. Aso, K. Watanabe, H. Nara, M.T. Rose, S. Ohwada and T. Yamaguchi (2004) Sequence of IGF-I, IGF-II, and HGF expression in regenerating skeletal muscle. Histochem. Cell Biol., 122(5) : 427-434.

Hirayama, T. and K. Katoh (2004) Effects of fistula size on rumen internal pressure and passage rate of feed in goats. Small Ruminant Res., 56 : 277-280.

Hirayama, T., K.Katoh and Y. Obara (2004) Effects of heat exposure on nutrient digestibility, rumen contraction, and hormone secretion in goats. Anim. Sci. J., 75 : 237-243.

Hirayama, T., K. Katoh and Y. Obara (2004) Effects of heat exposure and restricted feeding on behavior, digestibility and growth hormone secretion in goats. AJAS, 17 : 655-658.

Katoh, K., M. Asari, H. Ishiwata, Y. Sasaki and Y.Obara (2004) Saturated fatty acids suppress adrenocorticotropic hormone (ACTH) release from rat anterior pituitary cells in vitro. *Comp. Biochem. Physiol*., 137 A : 357-364.

Katoh, K., A. Matsuda, A. Ishigami, S. Yonekura, H. Ishiwata, C. Chen and Y. Obara (2004) Suppressing effects of bisphenol A on the secretory function of ovine anterior pituitary cells. *Cell Biol. Interntl*, 48 : 463-469.

Katoh, K., R. Shimoguchi, H. Ishiwata and Y. Obara (2004) Rapid suppressing action of insulin-like growth factor-I (IGF-I) on GH release from anterior pituitary cells of goats. *Domest. Anim. Endocrinol*., 26 : 177-188.

Kohari, D., S. Sato and K. Sugawara (2004) Initiatives and behavioral sequence of maternal behavior in Japanese Black and Japanese Shorthorn cattle (*Bos Taurus*). *Animal Science Journal*, 75 : 457-463.

Komine K., T. Kuroishi, Y. Komine, K. Watanabe, J. Kobayashi, T. Yamaguchi, S. Kamata, and K. Kumagai (2004) Induction of nitric oxide production mediated by tumor necrosis factor alpha on staphylococcal enterotoxin C-stimulated bovine mammary gland cells. Clin. Diagn. Lab. Immunol., 11(1) : 203-210.

Kumagai, C., T. Ito and M. Saigusa (2004) : Integrated amelioration of acid soil by functional cattle mature compost with controlled decomposition rate, Proceedings of the 6th International Symposium on Plant–Soil Interactions at Low pH, 314-315.

Nakai Y. (2004) Microbial additives and microbial communities in composting processes. Animal Production Research, 58(11) : 1186-1192 (review : in Japanese)

Nakai, Y. (2004) Recent researches and technologies for environment−harmonizing animal production. Monthly Report of Agriculture Forestry and Fisheries Finance Corporation, 642 : 2−5. (review : in Japanese)

Nakai, Y. (2004) Ruminant Research Core in the Graduate School of Agricultural Science. *Animal Science Journal*, 75(2) : 282−283. (review : in Japanese)

Nakai, Y. (2004) Roles of microbes in the composting process. In : Handbook of composting with microbes (ed. Nakai Y), Nikugyu Shinpou Sya Co., Ltd., Tokyo, pp30−44. (Book : in Japanese)

Nakai, Y. (2004) Characteristics of microbes in the composting process. In : Handbook of composting with microbes (ed. Nakai Y), Nikugyu Shinpou Sya Co., Ltd., Tokyo, pp107−115. (Book : In Japanese)

Nakai, Y. (2004) Roles and characteristics of microbes in the composting process. In : Handbook of swine manure treatment (ed. Haga K), Chikusan Shuppan Sya Co., Ltd., Tokyo, pp106−114. (Book : in Japanese)

Nakai,Y., K. Hikosaka, M. Sato, T. Sasaki, Y. Kaneta, and N.Okazaki (2004) Detection of Cryptosporidium muris type oocysts in a farm and survey in domestic and wild animals in and around the farrm. J. Vet. Med. Sci., 66(8) : 983−984.

Nakai, Y., M. Sato, S. Wakase (2004) Recent topics of animal health and management. Tohoku J. Agricultural Research, 55(1−2) : 31−38. (review)

Ninomiya, S., R. Kusunose, S. Sato, M. Terata and K. Sugawara (2004) Effects of feeding methods on eating frustration in stabled horses. *Animal Science Journal*, 75 : 465−469.

Obara, Y. and K. Katoh (2004) Mini−review : Recent progress in the research on physiologically active peptides altered by weaning and nutrition in the ruminant. *Tohoku J. Agricul. Res.*, 55 : 11−18. (review)

Obara, Y. and F. Terada (2004) Modern progress in nutrition and metabolism in dairy cows. *Proc. Jpn. Soc. Anim. Nutr. Metab.*, 48 : 59−77 (review)

Ogura, S. (2004) Spatial pattern. In : *"Field and Laboratory Methods for Grassland Science"* (ed. by Japanese Society of Grassland Science), Japan Livestock Technology Association, Tokyo, pp200−206. (review)

Ogura, S., K. Sato, J. Chiba, K. Yusa and Y. Nakai (2004) Effects of milking interval on milk production in Kawatabi Field Science Center. *Bulletine of Integrated Field Science Center* 20 (In press).

Ogura, S., R. Sekino and M. Hirata (2004) Foraging behavior of cattle in a bahiagrass (*Paspalum notatum Flügge*) pasture : Investigation at a feeding station scale. Grassland Science, 50 : 147−153.

Ogura, S. and K. Sugawara (2004) Grazing use of native pastures by beef cattle in Japan : recent researches on plant−animal interactions in native pastures. The *Tohoku Journal of Agricultural Research*, 55 : 39−44.

Otawa, K. and Y. Nakai (2004) Genetic analysis of shiga−toxigenic *Escherichia coli* in a dairy region. J. Miyagi Prefectural Vet. Med. Assoc, 57(1) : 5−13. (review : in Japanese)

Otawa, K., M. Sato, T. Sasaki, H. Sasaki, J. Nonaka, K. Ito, T. Kuroki and Y. Nakai (2004) Genetic analysis of shiga−toxigenic Escherichia coli isolates from cattle in a limited region. *Animal Science Journal*, 75 : 261−269.

Sakata, K., Md. A. HOQUE, T. Hirai, D Tsukaguchi, M. Tomaru, K. Suzuki and T. Oikawa (2004) Estimation of genetic parameters, and genetic and environmental effects on progeny carcass traits of a nucleus breeding population in Japanese Black Cattle. *Tohoku Journal of Agricultural Research*, 55(1−2) : 1−10.

Sakurai, K., S. Ohkura, S. Matsuyama, K. Katoh, Y. Obara and H. Okamura (2004) Body growth and plasma concentrations of metabolites and metabolic hormones during the pubertal period in female Shiba goats. *J. Repro. Develop.*, 50 : 197−205.

Sasaki, H., G. Maruyama, H. Suzuki, J. Nonaka, M. Sato, T. Sasaki, M. Ohta, Y. Nakai (2004) Distribution of ammonia−assimilating bacteria in the composting process. Compost Science and Utilization., 12(2) : 108−113.

Sasaki, H., O. Kitazume, T. Sasaki and Y. Nakai (2004) Ammonia−assimilating microbes in microbial community in a lagoon for wastewater from paddock of dairy cattle. *Animal Science Journal.*, 75 : 79−84.

Sasaki H. and Y. Nakai (2004) Ammonia assimilating microbes in animal manure treatment systems. J. Integrated Field Science, 2 : (review)

Sato M, and Y. Nakai (2004) Phylogeny of Cryptosporidia. Bulletin of Integrated Field Science, 20 : (review : in Japanese)

Shinsho, H., A. Nishiwaki and K. Sugawara (2004) Seed germination trait of *Weigela hortensis* K.Koch, invasive shrub in grassland. *Grassland Science*, 50 : 369-371.

Sugiyama, M., S. Sato, T. Yashe, Y. Deguchi and K. Sugawara (2004) The distribution of dry matter and nutrients of edible plant groups in the national agro-forest in northeast Japan. *Grassland Science*, 50 : 294-299.

Suzuki, K., M. Nakagawa, K. Katoh, H. Kadowaki, T. Shibata, H. Uchida, Y. Obara and A. Nishida (2004) Genetic correlation of serum IGF-1 in pigs : Genetic correlation between serum insulin-like growth factor-1 concentration and performance and meat quality traits in Duroc pigs. *J. Anim*. Sci., 82 : 994-999.

Takasu M., Y. Ohba, T. Ito, I. Hosoda, K. Katoh, K. Kitoh and H. Kitagawa (2004) Test of the factor stimulating growth-hormone release and analysis of 10-hour hormone secretion in Japanese Black cattle with normal and with retarted growth. *J. Jpn. Vet. Med. Assoc*., 57 : 175-179.

Takenouchi T., N. Miyashita, K. Ozutsumi, M.T. Rose and H. Aso (2004) Role of caveolin-1 and cytoskeletal proteins, actin and vimentin, in adipogenesis of bovine intramuscular preadipocyte cells. Cell Biol. Int., 28(8-9) : 615-623.

Tahara K., H.Aso, T. Yamasaki, M.T. Rose, A. Takasuga, Y. Sugimoto, T. Yamaguchi, S. Takano (2004) Cloning and expression of type XII collagen isoforms during bovine adipogenesis. Differentiation., 72(4) : 113-122.

Tsuda, T., K. Katoh and Y. Obara (2004) Animal Physiology (2nd Ed) YOKENDO, Tokyo. (review : in Japanese)

Watanabe, K., S. Hayashi, H. Nara, S. Ohwada, H. Aso and T. Yamaguchi (2004) Bovine Myoblast Differentiation. Tohoku J. Agric. Res., 55(1-2) : 67-73. (review)

Yonezawa, T., K. Katoh and Y. Obara (2004) Existence of GPR40 functioning in a human breast cancer cell line, MCF-7. *Biochem. Biophys. Res. Commun*., 314 : 805-809.

Yonezawa, T., S. Yonekura, Y. Kobayashi, A. Hagino, K. Katoh and Y. Obara (2004) Effects of long-chain fatty acids on cytosolic triacylglycerol accumulation and lipid droplet formation in primary cultured bovine mammary epithelial cells. *J. Dairy Sci*., 87 : 2527-2534.

Yonezawa, T., S. Yonekura, M. Sanosaka, A. Hagino, K. Katoh and Y. Obara (2004) Octanoate stimulates cytosolic triacylglycerol accumulation and CD36 messenger ribonucleic acid expression but inhibits Acetyl coenzyme A calboxylase activity in primary cultured bovine mammary epithelial cells. *J. Dairy Res*., 71 : 1-7.

The rice Production Groups

Heinai,H., H. Watanabe and M. Saigusa (2004) Effects of acidified porous hydrate calcium silicate applied in nursery bed soil on growth of rice (*Oryza sativa L.*) seedlings, Proceedings of the 6th International Symposium on Plant–Soil Interactions at Low pH, 340-341.

Hirotsu, N., A. Makino, A. Ushio and T. Mae (2004) Changes in the thermal dissipation and the electron flow in the water-water cycle in rice grown under conditions of physiologically low temperature. Plant Cell Physiol., 45 (5) : 635-644.

Ishizuka, M., A. Makino, Y. Suzuki and T. Mae (2004) Amount of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) protein and levels of mRNAs of *rbc*S and *rbc*L in the leaves of different positions in transgenic rice plants with decreased content of Rubisco. Soil Sci. Plant Nutr., 50 (2) : 233-239.

Ito, T., T. Horikawa and M. Saigusa (2004) Effective amelioration of flooded acid sulfate soil by the application of basic slag, Proceedings of the 6th International Symposium on Plant–Soil Interactions at Low pH, 322-323.

Mae, T (2004) Leaf senescence and nitrogen metabolism. In "Plant Cell Death Processes" Ed. by Nooden, L., Elsevier Academic, Press New York.,157-168.

Morikawa, C. K., M. Saigusa, H. Nakanishi, N. K. Nishizawa, K. Hasegawa and S. Mori (2004) Co-situs application of controlled-release fertilizers to alleviate iron chlorosis of paddy rice grown in calcareous soil, Soil Sci. Plant Nutr., 50(7) : 1013-1021.

Morikawa, C. K., M. Saigusa, R. Yamamoto, H. Nakanishi, M. Suzuki, N. Nishizawa and S. Mori (2004) Impact of iron deficiency tolerant transgenic rice on the environment, *Bulltin of Integrated Field Science Center*, 20.(In Japanese)

Nakamura, T., M. Kasuya, T. Nakajima, Y. Goto and M. Kokubun (2004) Characteristics of various processes between flowering and pollen germination of spikelets sterilized by the cool temperature at the young microspore stage in rice plants. Tohoku J. Crop Sci., 47 : 25–26. (In Japanese).

Saigusa, M., N. Kobayashi and A. Yamamoto (2004) Chenges of Silicon Concentration in Flooded Water of an Enlarged Paddy Field, Jpn. J. Soil Sci. Plant Nutr., 75 : 1–7 (In Japanese)

Saigusa, M., Hossain. Md.Z and K. Shibuya (2004) No-tillage transplanting system of rice with controlled availability fertilizer in a nursery box—nitrogen use efficiency of controlled availability fertilizer of rice plant in three different paddy fields—, *Integrated Field Science*, 1 : 67–73.

Saigusa, M., H. Yuki and K. Suzuki (2004) A trial of environmentally conscious cultivation of *Zizania latifolia Turcz*. in cold region, Tohoku J. of Crop Sci., 47 : 85–86.

Shirasawa, K., S. Kishitani and T. Nishio (2004) Conversion of AFLP markers to sequence-specific markers for closely related lines in rice by use of the rice genome sequence. Mol. Breed., 14 : 283–292.

Shirasawa, K., L. Monna, S. Kishitani and T. Nishio (2004) Single nucleotide polymorphisms in randomly selected genes among japonica rice (Oryza sativa L.) varieties identified by PCR-RF-SSCP. DNA Research, 11 : 275–283.

Watanabe, H., M. Saigusa, S. Hase, T. Hayakawa and S. Satoh (2004) Cloning of a cDNA encoding an ETR2-like protein (Os-ERL1) from deep water rice (Oryza sativa L.) and increase in its mRNA level by submergence, ethylene, and gibberellin treatments, *Journal of Experimental Botany*, 55(399) : 1145–1148, May.

Watanabe, H., R. Yusa and M. Saigusa (2004) Rice growth and occurrence of rice blast by the cultivation with application of compost during cool weather damage in 2003, 23–26.

Yamakawa, Y., M. Saigusa, M. Okada and K. Kobayashi (2004) Nutrient uptake by rice and soil solution composition under atmospheric CO_2 enrichment, *Plant and Soil*, 259 : 367–372.

Zhang, W. and M. Kokubun (2004) Historical changes in grain yield and photosynthetic rate of rice cultivars released in the 20th century in Tohoku region. Plant Prod. Sci., 7 : 6–44.

Zhang, W.H. and M. Kokubun (2004) Yield improvement of rice cultivars released in Tohoku region –Evaluation of yield under low nitrogen application –. Tohoku J. Crop Sci., 47 : 45–46. (In Japanese).

Zhang, W. and M. Kokubun (2004) Historical changes in grain yield and photosynthetic rate of rice cultivars released in the 20th century in Tohoku region. Plant Prod. Sci., 7 : 36–44.

Zhao, X. L. and M. Saigusa (2004) Effect of porous hydrated calcium silicate on sorption and desorption of cadmium by soils, *Soil Sci. Plant Nutr*., 50(3) : 315–319.

Marine Bio-production Group

Barinova, A., E. Yadrenkina, M. Nakajima and N. Taniguchi (2004) Identification and characterization of microsatellite DNA markers developed in ide *Leuciscus idus* and Siberian roach *Rutilus rutilus*. Molecular Ecology Notes, 4 : 86–88.

Guido, P., M. Omori, S. Katayama and K. Kimura (2004) Classification of Juvenile Rockfish, *Sebastes inermis*, to *Zostera* and *Sargassum* beds, using the macrostructure and chemistry of otoliths, *Mar. Biol*., 145 : 1243 –1255.

Li, Q., C. Park, T. Kobayashi and A. Kijima (2004) Loss of genetic variation in hatchery strains of the Pacific abalone (Haliotis discus hannai) at microsatellite loci. Aquaculture, 235 : 207–222.

Li, Q., T. Hisatsune and A. Kijima (2004) Effects of Ultraviolet Irradiation on Inactivation of Egg Chromosomes and Nuclear Behavior During Early Development of Pacific Oyster. Marine Biotechnology, 6 : 291–297.

Nugroho. E. and N. Taniguchi (2004) Daily change of genetic variability in hatchery population of red sea bream during spawning season. Fish. Sci., 70 : 608–644.

Osada,M., M.Harata, M.Kishida and A.Kijima (2004) Molecular cloning and expression analysis of vitellogenin in scallop, Patinopecten yessoensis (Bivalvia, Mollusca). Molecular Reproduction & Development, 67 : 273–281.

Plaza, G., S. Katayama and M. Omori (2004)

Spatio−temporal patterns of parturition of the black rockfish Sebastes inermis in Sendai Bay, northern Japan, *Fsih. Sci.*, 70(2) : 256−263.

Romana−Eguia, M. R., M. Ikeda, Z. Basiao and N. Taniguchi (2004) Genetic diversity in farmed Asian Nile and red hybrid tilapia stocks evaluated from microsatellite and mitochondria DNA analysis. Aquaculture, 236 : 131−150.

Sun, Y., S.Liu, G.Zhao, S. He, Q. Wu, N. Taniguchi and Q. Yu (2004) Genetic structure of Chinese sucker population *Myxocyprinus asiaticus* in the Yangtze river based on mitochondrial DNA marker., 70 : 412−420.

Takekawa, A., K. Sasaki and M. Omori (2004) Diel activity and vertical distribution of Lysianassoid amphipods dominant in Onagawa Bay, north−eastern Japan, Fish. Sci., 70 : 971−977.

Tomiyama, T., K. Sasaki and M. Omori (2004) Predator−prey size relatiohship in siphon cropping between the juvenile stone flounder Platichthys bicoloratus and the bivalvia *Nuttallia olivacea, Fish. Sci.*, 70 : 531−536.

Taniguchi N. (2004) Broodstock management for stock enhancement programs of marine fish with assistance of DNA marker (a Review). In Stockenhancement and sea ranching [K. M. Leber, S. Kitada, H.L. Blankenship, T. Svasand (EDS.), 329−338, Blackwell publishing, Oxford.

Watanabe, T., K. Yamasaki, S. Seki and N. Taniguchi (2004) Detection of ayu sex−linked DNA markers using homologous clones. Fish. Sci., 70 : 47−52.

Yamaguchi, M., T. Fujioka, T. Saruwatari and M. Omori (2004) Spawning behaviour of shira−uo Salangichthys microdon in captivity, Nippon Suisan Gakkaishi, 70 : 693−698.

Yamaguchi, M., S. Katayama and M. Omori (2004) Migration pattern of shirauo *Salangichthys microdon* Bleeker, in the Ishikari River system and adjecent mearshore area, Japan, as estimated by otolith microchemistry analysis, Fish. Sci., 70 : 546−552.

Integrated Field Control Group

Ishitsuka, N., G. Saito, K. Ouchi, S. Uratsuka (2004) Observation of Japanese Rice Paddy Field Using Multi Wave Length and Full Polorimeteric SAR, *Advances in the Astronautical Sciences*, 117 : 565–576.

Kunii, D., M. Saigusa, T. Ito and K. Suzuki (2004) Change of water quality in Ohkawa River and Nanakitadawa River with reference to their watershed environment, *Bulltin of Integrated Field Science Center*, 20. (In Japanese)

Nagatani, I. and G Saito (2004) Early Detection System of Drought in East Asia Using Time Series NOAA−NDVI, *Advances in the Astronautical Sciences*, 117 : 559 – 564.

Saito, G., (2004) The history and future of remote sensing for agriculture, The Proceedings for T*he 30th Memorial Symposium for Remote Sensing by SICE*, 47–48. (In Japanese)

Saito, G., Y. Matano and T. Kato (2004) A Trial Study of Soil Classification Using Satellite Data, −Application of ASTER Spectral Data on Agricultural Land Mapping −, *Research Core International Workshop of Integrated Field Science*, *−New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems*−

Saito, G., I. Nagatani and X. Xong (2004) Agricultural Monitoring Using Semi−Real Time Remote Sensing Data, Remote Sensing for Agriculture and the Environment, 202−211, S. Stamatiadis, J. M. Lynch and J. S. Schepers (EDS.), OECD, Greece, ISDN 960−88000−8−0

Saito,G., S. Ogawa, I. Nagatani, N. Ishituka, J. Chen, N. Kosaka, M. Shiokawa (2004) Application of Hyper Spectral Data for Agricultural Field, *Advances in the Astronautical Sciences*, 117 : 577−586.

Song, X., G. Saito, M. Kodama and H. Sawada (2004) Early detection system of drought in East Asia using NDVI from NOAA/AVHRR data, *Int. J. Remote Sensing,* 25(16) : 3105−3111.

Yamamoto, S., G. Saito, Y. Suyama and K. Seiwa (2004) Analysis for Landcover and Landcover Changes at Mt. Kuricoma Area Using Aerial Photos and Satellite Data, *The Proceedings for The Autumn Conference in 2004 of The Japanese Agricultural Systems Society (JASS)*, 49−50. (In Japanese)

Yamamoto, S., G. Saito, Y. Suyama and K. Seiwa (2004) A Study of The Distribution of Beech Forests Northern Japan Using Aerial Photos and Satellite Images, *Proceedings of The 25th Asian Conference on Remote Sensing*, 1 : 680−685.

2nd International Workshop of Integrated Field Science

New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems
--- Circum Pacific Volcanic Zone ---

Program

Date: 1-6 August 2004
Venue: No.1 Lecture Room, Graduate School of Agricultural Science, Tohoku University, Sendai, Japan

Tuesday 3 August 2004: Field study
Friday 6 August 2004: Open workshop

10:00-10:20 Opening Ceremony
Chair: Tadashi TAKAHASHI
Dr. Yukio AKIBA
Dean of Graduate School of Agricultural Science, Tohoku University
Dr. Masahiko SAIGUSA
Director of Field Science Center, Graduate School of Agricultural Science, Tohoku University

10:20 -10:40 Unique properties of Andisols and perspectives on their application
Masami NANZYO
10:40 -11:00 Soil development in volcanic materials
Randy A. DAHLGREN
11:00 -11:20 Variable charges of soils across Andisol/Spodosol transition in Alaska Andisols
Chien-Lu PING, and G.J. MICHAELSON
11:20 -11:40 Morphological and chemical characteristics of tephra-derived soils in Changbai Volcano area, northeast China
Hitoshi KANNO
11:40 -12:00 Introduction, classification, and adsorption characteristics of Cheju soils.
Hae-Nam HYUN and Kwan-Cheol SONG

12:00 -14:00 Lunch and poster discussion

14:00 -14:20 Partial rejuvenation of the soils in Intavas Techno Demo Farm, Bukidnon, Mindanao, Philippines by volcanic ash material
Clarita D. BACATIO, Hideo KUBOTERA, Masami NANZYO and Ichiro YAMADA

14:20 -14:40 Properties and utilization of Andisols in Indonesia
Dian FIANTIS, Nurhajati HAKIM, and E. Van RANST
14:40 -15:00 Andisols of New Zealand and South Australia
David J. LOWE and David J. PALMER
15:00 -15:20 Modifying a soil carbon turnover model considering unique properties of Andisols
Yasuhito SHIRATO and Ichiro TANIYAMA

15:20 −15:40	Coffee break
15:40 −16:00	Phosphorus dynamics and availability in Andisols Toyoaki ITO, Naoto KIKAWA and Masahiko SAIGUSA
16:00 −16:20	Al dynamics in nonallophanic Andisols from northeastern Japan Tadashi TAKAHASHI and Masami NANZYO
16:20 −16:40	Effects of gypsum on amelioration of subsoil acidity of Andisols, Mitsuru TOMA, Masahiko SAIGUSA, Nikolla QAFOKU, and Malcolm SUMNER
16:40 −17:00	Changes in elemental composition with andosolization Masami NANZYO and Tadashi TAKAHASHI
17:00 −17:05	Closing remarks Dr. Masahiko. SAIGUSA

Opening Address by the Dean

Distinguished soil scientists from overseas countries, ladies and gentlemen, it is my great pleasure to make an opening address of the 2nd International Workshop on Integrated Field Science on behalf of the Graduate School of Agricultural Science, Tohoku University.

Field science is basically a major part of agricultural science and we started a new Integrated Field Science Center in 2003 re−organizing the previous University Farm located at Kawatabi and Education and Research Center of Marine Bio−Resources at Onagawa. The major aim of the re−organization is to develop an environmentally friendly food production system covering wide range of forests, grasslands, paddy fields and sea that are closely connected with water flow, atmosphere and human activities. The re−established Field Science Center is made up with five scientific cores; Forest Andisols Core, Ruminant Production Core, Rice Production Core, Marine Bio production Core and Integrated Field Control Core.

In our Graduate School of Agricultural Science, keeping step with the rapid pace of scientific development, we have started to perform 21st century−oriented agricultural science by acknowledging agricultural science's relation to the bio−industry and the need to deal with problems of food production, health and environment that form the basis of human existence.

One of the characteristics of the integrated field science, as a major part of agricultural science, is collaboration among researchers from different disciplines and different areas. Accordingly, each research core, in our Field Science Center, holds an international workshop alternately every year. And this is workshop organized by Forest−Andosols core's.

The topic for workshop today is New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems −the Circum Pacific Volcanic Zone−. The circum−pacific zone is also called as the ring of fire. It is a huge global−scale ring and the most active volcanic area in the world. The volcanic ash soils distributed along the ring of fire is under various climates and various cultures or human activities.

Today, we have distinguished guest speakers from 6 countries along the ring of fire. Each of you has your own interesting volcanic ash soils in your country and I am sure it is very fruitful for us to exchange knowledge and experiences on these interesting soils. Finally, I sincerely hope all of you will enjoy this workshop in our Graduate School of Agricultural Science.

August 6th, 2004
Dean Professor Dr. Yukio Akiba,
Graduate School of Agricultural Science, Tohoku University

Information to authors from Journal of Integrated Field Science (JIFS)

The journal publishes articles in all areas of agricultural field science. The journal is an English magazine started in 2003 fiscal year when Integrative Field Science Center, Graduate School of Agricultural Science, Tohoku University, has started.

Our journal places the edit committee. Under the committee, an original paper including short paper, proceedings, a review, description, and data are published. An original paper undergoes two revisers' (referee) examination.

Our journal publishes one volume in principle every year, and all of the manuscripts are published on the web site as e−journal.

Manuscript creation point

Please write a contribution paper according to the form of the paper of our journal. In your paper, (1)Title, (2)running title, (3)Affiliation and its address, (4) e−mail address of corresponding author, (5)key words (five to seven words not appearing in the title) (6) Abstract (about 250 words) (7) Introduction, Materials and Method, Results, Discussion (Results and Discussion), (Acknowledgement), References, Table file, Figure file, Legend of figures are included.

All of your paper will be written in A4 size paper by Word file or a text file. Tables are made by excel file and figures are made by Power Point file. Both files (on the PC disket or CD−R, or CD−RW file) and two copies of printed paper (or PDF file) are sent to our editoral board. If you do not make your paper by these software, please contact our committee.

Address : Editoral Board, Integrative Field Science Center, Graduate School of Agricultural Science, Tohoku University, Naruko, Miyagi, 989−6711, JAPAN
e−mail : a−kijima@mail.tains.tohoku.ac.jp