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Effects of Soil Chemical Properties on Forest Decline in Miyake Island, Japan

By

S. YOSHINAGA[1], K. ABE & T. OKAMOTO

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Summary

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The distribution and chemical properties of the volcanic ash produced by the eruption in the summer of 2000 of the Mt. Oyama crater in Miyake Island were determined to assess the effects of deposition of volcanic ash on forest decline since the eruption. Soils derived from the volcanic ash showed a low permeability and reduced aeration as a result of their silty-to-clayey texture, high bulk density, and hardness, which could damage root systems and check the growth of new roots. Extract of the soils with pure water showed strongly acidic pH values and high electric conductivity (EC) values: the predominant species present were Ca^{2+}, Al^{3+}, and SO_4^{2-}, suggesting that the extracts were saturated with gypsum ($CaSO_4$). In addition to soil acidification and accumulation of gypsum, toxic Al^{3+}, leached from soil minerals to the soil solution as a result of the acid soil environment, is damaging to plant roots.

Introduction

Forest decline as a result of atmospheric acidification by environmental pollution has been reported in many industrial countries (ABRHAMSEN & al. 1977, OMASA 1998). In recent years, acidification through deposition of acid pollutants transported over a long distance has been observed around the world (GALLOWAY 2001). Besides such anthropogenic acidification, natural acidification caused by emissions of acidic gases accompanying volcanic eruptions has damaged forests, particularly in Japan.

The Mt. Oyama crater in Miyake Island, located approximately 200 km south of Tokyo (Fig. 1), erupted in the summer of 2000. This volcanic activity was

[1] Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan. Fax: +81-29-873-1542, e-mail: yoshinag@ffpri.affrc.go.jp

characterized by the eruption of volcanic ash and the emission of volcanic gas containing a large amount of sulfur dioxide (SO_2). The daily emission of volcanic gas was up to 20 Gg until the end of 2000. Although the emission of volcanic gas has been decreasing in recent years, the daily emission was still 5–10 Gg per day in 2004 (MAJ 2004), the largest such emission in the world. Vegetation on the upper mountainside of Mt. Oyama was destroyed by the direct effects of the eruption, and the forest on the slopes of Mt. Oyama has been declining since the eruption. Although the emissions have been studied in detail since the eruption, only a few investigations have been conducted on the deposition of volcanic ash and its impact upon the vegetation. In this paper, we discuss the distribution and the chemical properties of volcanic ash from the eruption of 2000 to evaluate their influence on the decline of the forest.

Material and Methods

The forest damage on the upper slopes of Mt. Oyama was classified through the interpretation of aerial photographs taken in February 2001 into four classes: (1) denuded area caused by deposition of volcanic ash, (2) severely damaged area containing dead trunks and branches, (3) damaged area where live trees still remain, and (4) sporadically damaged areas characterized by local dead tree leaves.

Soils derived from the volcanic ash of the eruption in 2000 were investigated at 29 sites on the slopes of Mt. Oyama after October 2001 to clarify the distribution of the volcanic ash. Unfortunately we could not investigate before October 2001, because no visitors were permitted to stay on Miyake Island from September 2000 to June 2001. Moreover, we could not investigate the summit and the upper slopes of Mt. Oyama in detail, because entrance into these areas has been strictly prohibited because of the volcanic gas emissions.

Soil samples collected at three sites in August 2000, just after the eruption, and at 10 sites from October to December 2001 were used for the chemical analysis. Collected soil samples were dried and extracted with pure water at soil/water ratios of up to 1:5 (EBMSEA 1997). The pH value and electric conductivity (EC) of the extracts were measured by using a pH meter and an EC meter, respectively. The chemical compositions of the extracts were measured by ion-chromatography (Dionex DX-320) and inductively coupled plasma–optical emission spectroscopy (ICP-AES; ARL Maxim), after the samples had been passed through a membrane filter of 0.22µm and diluted with pure water.

Results and Discussion

Before the eruption, Miyake Island was covered by a laurel forest of *Castanopsis cuspidata* var. *Sieboldii* (Makino) Nakai and *Machilus Thunbergii Sieb.* Et Zucc. and man-made forests of *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Endl. on the lower slopes of Mt. Oyama and in the coastal area, a forest in early succession with pioneer species represented by *Alnus sieboldiana* Matsum. on the upper slopes, and grassland around the crater. This vegetation was mostly damaged by the volcanic ash deposition and the volcanic gas emission. The denuded area caused by the thick volcanic ash deposition (1) was distributed around the crater and extended northeast and southwest down the mountain (Fig. 2). Severely damaged areas where only dead trunks and branches remained (2) and damaged

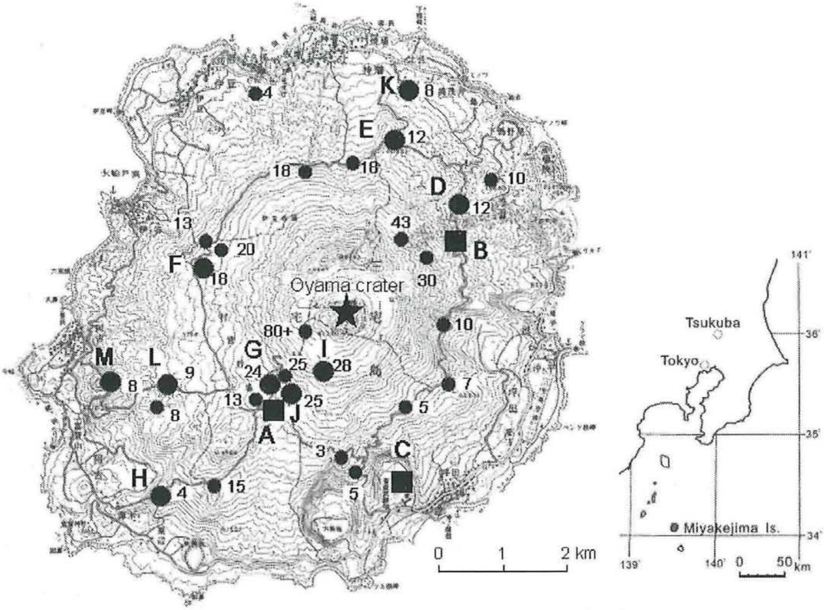

Fig. 1. Location map of Miyakejima Island, and distribution of volcanic ash of 2000. The thickness (cm) of the volcanic ash of each site is shown in the figure by symbols. Squares indicate the location of sampling in 2000. Large circles with letters indicate the location of sampling in Autumn 2001. A small circle indicates locations where only the soil thickness was measured.

areas where live trees still remained (3) were distributed around the denuded area. Sporadically damaged areas, characterized by local dead tree leaves (4), were spread on the northern and eastern lower slope. These results agree well with the distribution of forest decline interpreted from field observations by KAMIJO 2001. Forest decline is in progress as a result of the volcanic gas emissions.

Volcanic ash of the eruption in 2000 was more than 1m thick around the crater; the evidence for the thickness of volcanic ash was obtained as a result of soil investigation and a few results from outcrops. The thickness decreased with increasing distance from the crater, being about 10cm midway up the mountain and less than 4cm along the coast (Fig. 1). Deposits of volcanic ash were thicker on the northeast and southwest slopes than on the northwest and southeast slopes.

The pH value of extracts of samples collected in August 2000 and from October to December 2001 showed a strong acidity with a pH value of 3.0–4.5. The EC values were also remarkably high, exceeding 200 mS m^{-1}, except for the results from three sites. In the extracts of samples from 2000, Ca^{2+} was the dominant cation and Mg^{2+} was a co-existing cation, while SO_4^{2-} was the dominant anion (Fig. 3). In the extracts of samples collected in 2001, Ca^{2+} and SO_4^{2-} remained as dominant components, but Al^{3+} was found as the second dominant cation (Fig. 4).

X-ray diffraction analysis revealed that both sets of samples contained a large amount of crystallized gypsum ($CaSO_4$). These results agree with the chemical properties of volcanic ash deposited on crop fields and bare ground in the coastal area and the lower slopes of Mt. Oyama (KATO & al. 2002, YAZAWA & al. 2002).

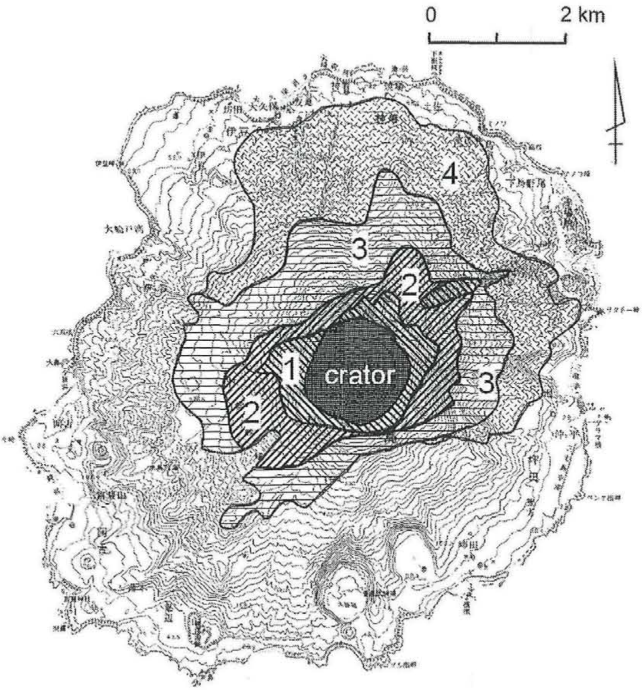

Fig. 2. Map showing the degree of forest decline in Miyake Island.

Many scientists have pointed out that volcanic gas containing large amounts of sulfur dioxide has been a major cause of the forest decline in Miyakejima Island (KAMIJO 2001, YAMANISHI & al. 2003). Gaseous sulfur dioxide could block gas exchange at the surfaces of leaves (TAKAMATSU & al. 2000). Furthermore, the dissolution of gaseous sulfur dioxide in rainwater could create sulfuric acid, which would damage plants by dissolving the cuticles of their leaves. It is certain that sulfur dioxide gas is still being emitted.

Although the deposition of volcanic ash occurred during June to September 2000, it might still be causing serious damage to the health of the forest by changing the tree growth environment. The deposited volcanic ash is characterized by a low permeability and reduced aeration as a result of its silty-to-clayey texture, high bulk density, and hardness; therefore, root systems buried under such soils may suffer from physical deterioration. The thickness of the volcanic ash showed a similar distribution to the degree of forest decline. This coincidence suggests that the deposition of the volcanic ash itself has damaged living trees, particularly their root systems.

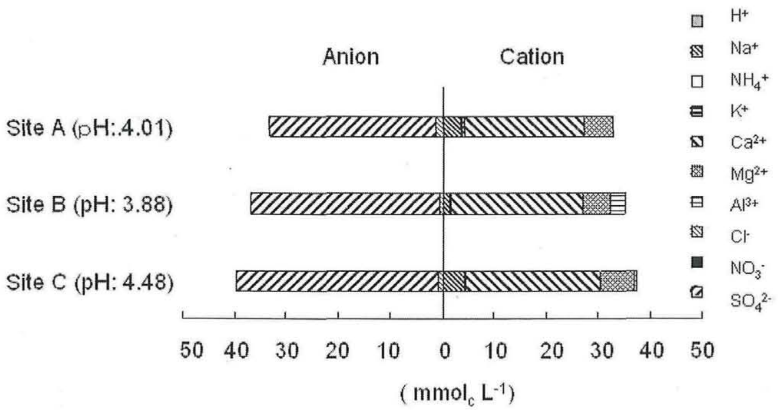

Fig. 3. Chemical composition of extracts of the volcanic ashes collected at Aug 17, 2000.

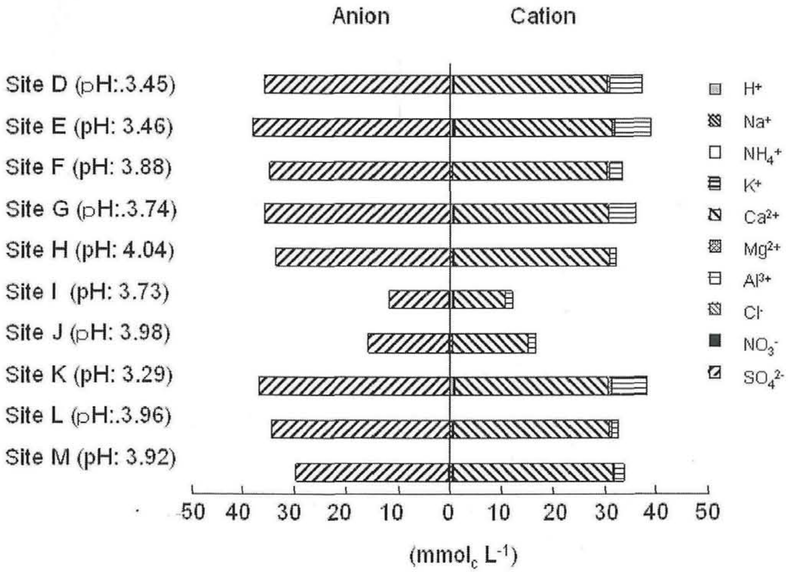

Fig. 4. Chemical composition of extracts of the volcanic ashes collected in Autumn 2001.

At the same time, the volcanic ash shows a strongly acidic pH value and a high EC value, suggesting that a high concentration of salts has accumulated in the soil. Actually, the extracts contain high Ca^{2+} and SO_4^{2-} concentrations, which are equal to or exceed the concentrations of these components contained in saturated solutions of gypsum. Therefore, the soil derived from the volcanic ash is saturated with gypsum and classified into gypsic soils. The gypsum is formed through the reaction of calcium in the minerals with oxidized sulfur-containing crystals in the volcanic ash and/or sulfuric acid generated by the dissolution of sulfur dioxide gas in rainwater. In addition to soil acidification and the accumulation of gypsum, toxic Al^{3+} leached from soil minerals to the soil solution as a result of the acid soil environment formed after the deposition damages the health of plant roots (FOY & al. 1978, ULRICH 1983). Furthermore, the lack of nutrients, particularly nitrogen, in the volcanic ash could be another cause of forest decline.

As described above, the forests in Miyake Island have been declining because of the deposition of volcanic ash; however, the level of gypsum in the volcanic ash has been decreasing as a result of leaching by rainwater. Moreover, we detected mitigation in the acidity of the volcanic ash as well as a decline in toxic Al^{3+} concentrations in the soil solution. These improvements in soil conditions may yet lead to the recovery of the forest vegetation in Miyake Island.

Acknowledgements

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