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Tree Decline and its Possible Causes around Mt. Bogdkhan in Mongolia

By

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Summary

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East Asian region consists of several climatic zones. Information on plant response to acid deposition in respective climatic zones is essential for evaluating effect of acid deposition on vegetation. However, in most part of East Asia including the (semi-) arid zone, sensitivity and/or physiological response of plants to acid deposition have not been enough studied.

A decline of larch trees (*Larix sibirica*) has been reported around the Bogdkhan Mountain near the city of Ulaanbaatar, Mongolia, and it has been suggested that air pollution derived from the thermal power plants was one of the possible causes. Surveys on air pollutants concentrations by passive samplers, field observation of tree decline and chemical properties of needles/soils were carried out in 2001 and 2003 at Bogdkhan Mountain in order to obtain information on relationship between air pollution and chemical/(eco-)physiological properties of plant and soil. Tree decline was observed not only on the slope facing the thermal power plant but also in reference forests because of insect attack. However, decline symptoms observed on the slope were different from those in the reference forests. In summer, concentrations of all the monitored pollutants except O_3 were not high; less than 5ppb (average concentration of two weeks), but O_3 concentration was relatively high (ca. 40ppb). From autumn to winter, concentrations of NOx increased probably due to increasing of combustion of coal/wood in winter. Mean concentrations of SO_2 and O_3 during the sampling period of the year 2003 were higher at the sites on the slope than those at the other sites. In addition, sulfur contents of larch needles were also higher on the slope than other sites. It was sug-

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gested that the slope facing the thermal power plant has received more negative effects than the other areas. Soil acidification due to acid deposition may hardly occur because of the high concentration of base cations; e.g. pH (H_2O) > 5.8, exchangeable Ca > 22.6 cmol(+)/kg in sites on the slope. Direct effects of air pollution, especially effects of O_3, should be considered as one of the possible causes for the tree decline on the slope as well as natural environmental factors such as insect attack.

Introduction

The East Asian region, as a result of rapid industrialization, faces increasing risks and problems related to excess deposition of acidic substances. To combat this problem, the Acid Deposition Monitoring Network in East Asia (EANET) started its regular-phase activities in 2001 after the preparatory phase from 1998 to 2000. Information on response of each plant species to acid deposition in these climatic zones is essential for evaluating effect of acid deposition on vegetation. However, in most part of East Asia including the (semi-) arid zone, sensitivity and/or physiological response of plants to acid deposition have not been enough studied. This is one of the issues that were described in the "Strategy paper for future direction of soil and vegetation monitoring of EANET" (TASK FORCE ON SOIL AND VEGETATION MONITORING OF EANET 2002).

Bogdkhan Mountain is a protected area with the territory of 41,651 ha located south of the city area of Ulaanbaatar, the capital of Mongolia, and 55 % of the area is covered by forest, in which 588 species of higher plants were recorded (MINISTRY OF NATURE AND THE ENVIRONMENT, MONGOLIA 1998). In recent years, a decline of larch trees (*Larix sibirica*) has been observed at the slopes in the mountain facing the city of Ulaanbaatar, and it has been suggested that air pollution was one of the possible causes since the prevailing wind flows from the direction of major emission sources including the thermal power plants. In fact, high contents of heavy metals were detected in lichens thallus collected in this area due probably to the effects of air pollution of Ulaanbaatar city (ENKHTUYA 2000). However, scientific reports on air pollution and/or tree decline were limited in Mongolia.

Based on the background above, Joint Research Project on plant sensitivity to acid deposition in Mongolia started in 2001. Surveys around the Bogdkhan Mountain were carried out in 2001 and 2003 in cooperation between Acid Deposition and Oxidant Research Center (Network Center for EANET) and Central Laboratory of Environmental Monitoring (CLEM) in order to obtain information on relationship between emission from a thermal power plant and chemical/(eco-)physiological properties of plant and soil. This paper describes the present situation of air pollution, tree decline, soil chemical properties, etc. in the forest area of the Bogdkhan Mountain, and discusses possible causes of tree decline in this area.

Material and Methods

Seven monitoring sites were established in the city area of Ulaanbaatar and the Bogdkhan Mountain. Sites A1 and A2 were in the city area, sites B, C and D were on the slope facing the Thermal Power Plant No.3 (Capacity, 300MW; No treatment system for SO_x/NO_x emission), and sites RF1 and RF2 were in reference forest areas. Locations of the monitoring sites were shown in Fig. 1.

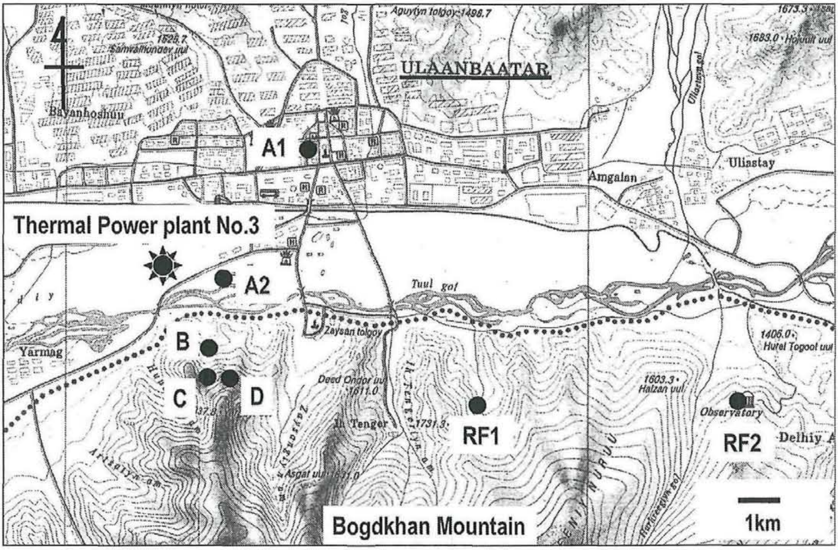

Fig. 1. Locations of the monitoring sites. Sites A1 and A2 were at the Ulaanbaatar Monitoring Station and the CLEM compound, respectively. Sites B, C and D were in a boundary area between grassland, an open forest and a closed forest, respectively. Sites RF1 and RF2 were at certain distance from the power plant as reference forest areas. Sites A1, RF1 and RF2 were newly added in 2003, while site D was surveyed only in 2001.

Measurement of tree size and observation of tree decline were carried out at sites B, C, RF1 and RF2 in the mountain. One round plot of 400 m^2 (radius 11.28 m) was established for measurement of tree size (species name, diameter at breast height (DBH) and height of tree) in the respective sites. Twenty trees were selected for observation in each plot. The decline scale of the EANET Technical Manual was used for observation (SECOND ISAG MEETING OF EANET 2000).

Concentrations of gaseous pollutants such as SO_2 and O_3 in the sites above were measured by using the passive sampler (Ogawa & Co., USA, Inc.) with basically two-week interval from the beginning of August to the end of November in 2001 and 2003. Filter papers impregnated with chemicals were set in the sampler for trapping acidic gasses. The samplers were installed on metal poles or tree trunks at heights of ca. 2m under canopies in forest areas. SO_2 deposited on the filter paper was dissolved in deionized water and oxidized to SO_4^{2-} using H_2O_2. As for O_3, it oxidized NO_2 on the filter paper to NO_3^-. The ions, SO_4^{2-} and NO_3^- (by O_3) were analyzed using ion chromatograph (DX-120, DIONEX). In 2001, NO and NO_X deposited on the filter were also analyzed by a colorimetric method using sulphanilamide and 1-Naphthyl ethylenediamine dihydrochloride (NEDA). Amount of acidic gasses were converted to mean air concentration during the exposure period using the following equations based on diffusion theories (KOUTRAKIS & al. 1993, SAITO & al. 1997, OGAWA & COMPANY, USA, Inc. 1998):

SO_2 (ppbv) = $\alpha SO_2 * WSO_2 / t$

NO (ppbv) = $\alpha NO * (WNO_X - WNO_2) / t$

NO_2 (ppbv) = $\alpha NO_2 * WNO_2 / t$

O_3 (ppbv) = $\alpha O_3 * WO_3 / t$,

where WSO_2, WNO_X, WNO_2 and WO_3 = collection volume [ng], $\alpha SO_2 = 39$, $\alpha NO = 60$, $\alpha NO_2 = 56$, and $\alpha O_3 = 37.8$ [ppbv*min/ng], and t = exposed time [min].

Larch needles were collected at sites A1, A2, B, C, RF1 and RF2 in 2003 before change of needle color in early autumn. The needles were collected from three trees in each site. Collected needles of the respective sites were mixed, and the composite samples were dried and ground into powders for chemical analysis. Concentrations of sulfur in the powdered needles were analyzed using elemental analyzer (EA2500, CE Instruments). Soil samples (0-10 cm depths) were collected at sites A2, B, C, and D in 2001. Contents of exchangeable cations were analyzed for the soils after air-drying and sieving.

Results and Discussion

Tree sizes of *Larix sibirica* were shown in Fig. 2a. At site B in the bottom of the slope facing the power plant, only young trees were observed and the sizes were three times smaller than trees in the other sites. Trees at site C were significantly smaller than trees at sites RF1 and RF2 in DBH, while they were not different from trees at RF2 in height.

Decline classes by the representative observation parameters were shown in Fig. 2b. Larger values of these parameters mean severer decline. Trees at site B were healthier than trees at the other sites. Trees at sites C and RF1 were worse than those at RF2 in vitality of trees.

Even in the reference area far from the thermal power plant, older trees were declined probably due to other environmental factors. Forests of Mongolia have been established in limited slopes under appropriate conditions of water and sunlight because of limited annual precipitation (less than 500 mm even in the mountainous area; MINISTRY OF NATURE AND THE ENVIRONMENT, MONGOLIA 1998), especially larch forests are mainly established in the northern and northeastern slopes in the Bogdkhan Mountain (ADYASUREN 1997). Changes in natural environmental factors might have caused severe effects on such forests. Younger trees as grown at site B might not have been affected by natural environmental factors.

Severe forest decline by insect attack has been reported in the Bogdkhan Mountain in recent years. A large area of forest decline could also be observed near RF1. In this area, trees attacked by insects showed severe defoliation not only on the crown but also in lower branches. Tree decline observed in site RF1 and RF2 might be mainly caused by the insect attack. However, trees at B and C on the slope facing the thermal power plant showed typical dieback symptoms mainly on the crown, which were different symptoms observed in site RF1 and RF2. Other effects than insect attack should be considered as possible causes for the decline of larch tree on the slope. It seems that both effects of natural and anthropogenic environmental factors should be discussed as well as synergistic effects of them.

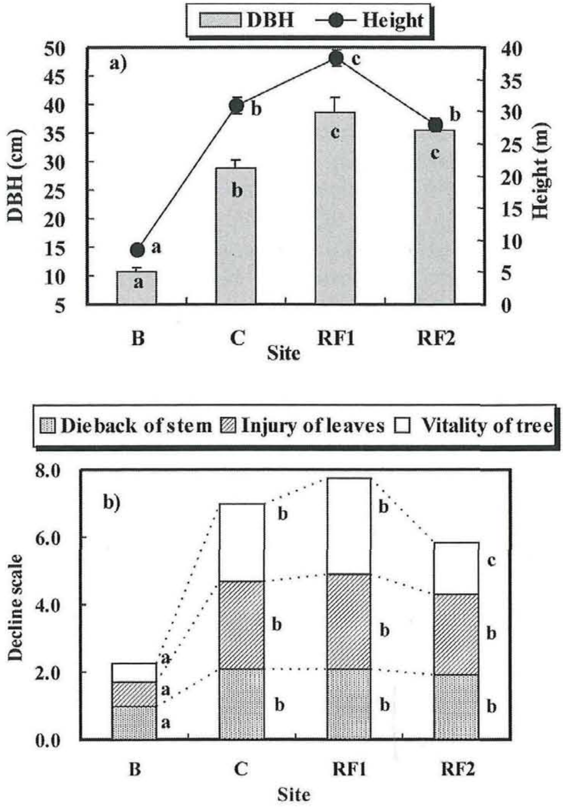

Fig. 2. Tree size (a) and decline condition (b) of *Larix sibirica* in Mt. Bogdkhan. Sites B and RF1 consisted of not only *Larix* sp. but also other species such as *Picea* sp. and *Betula* sp. Numbers of *Larix* trees were 19, 20, 11 and 20, in site B, C, RF1 and RF2, respectively. For recording observation of decline symptoms "dieback of stem" and "vitality of tree" were classified into five classes (0 to 4), and "injury of leaves" was classified into four classes (0 to 3). Plots of (b) show averages of the classes. "Vitality of tree" was recorded as total evaluation of the decline based on other observation parameters. Different letters (a, b or c) beside the plots mean significant ($P<0.05$) differences by Tukey's HSD test for the respective parameters.

Both concentrations of SO_2 and NO_X (only in 2001) in summer were lower than 5 ppb and 1 ppb (average concentration of two weeks) in the city and the mountainous area, respectively. These SO_2 concentrations were almost the same level as concentrations measured by the filter pack method (NETWORK CENTER FOR EANET 2002). Concentrations of NO_X increased up to ca. 15 ppb and ca. 10 ppb in the city and the mountainous area respectively, from late autumn to early winter. This seasonal trend was probably due to increasing of coal/wood combustion in winter. Seasonal change of SO_2 concentration was not very clear in this study. Concentrations of O_3 were relatively high (ca. 40 ppbv) in mid summer and gradually decreased from autumn to winter, especially in the city area. In the mountainous area, relatively high concentration (more than 30 ppbv) was recorded even in late autumn, 2003. Concentrations of O_3 were usually higher on the slope facing the thermal power plant than in the city area through the survey periods.

Mean concentrations of SO_2 and O_3 during the sampling period of the year 2003 were shown in Table 1. Concentrations of both SO_2 and O_3 were higher at sites B and C on the slope facing the thermal power plant than those at the other sites, while SO_2 concentration was relatively low. In addition, sulfur concentration of larch needles was higher on the slope (at B and C) than in the reference forests (at RF1 and RF2) as also shown in Table 1. Mean annual wind direction was northwest in the Bogdkhan Mountain (MINISTRY OF NATURE AND THE ENVIRONMENT, MONGOLIA 1998), and winds flowed mainly from the power plant to the slope. It was suggested that trees on the slope facing the power plant suffered more negative effects from air pollutants derived from the power plant than those at the other sites. Accumulation of sulfur with degradation of forests was also reported for pine trees (*Pinus sylvestris*) in an industrial area of East Siberian part of Russia (MIHKAILOVA 2000). Physiological impacts of sulfur accumulation on trees should be investigated.

Table 1. Mean and maximum concentration (ppbv) of SO_2 and O_3 during the sampling period of 2003, and sulfur concentrations (mg-S/g-dry needles) of *Larix sibirica*. *[1] Sampling period, July 31 to November 21; Values show mean and standard error in parenthesis; Different letters beside the data indicate significant difference ($P<0.05$) by Tukey's HSD test. *[2] Average values of triplicate sampling. *[3] Average values of triplicate analysis.

Site	Passive sampling*[1]				S conc. of needles*[3]
	SO_2		O_3		
	Mean	Max.*[2]	Mean	Max.*[2]	
A1	1.0 (0.4) ac	4.0	16.0 (1.8) a	27.4	1.5
A2	0.5 (0.2) a	1.6	21.7 (1.6) b	32.1	-
B	1.7 (0.4) bc	3.8	27.2 (1.5) c	35.1	1.8
C	1.6 (0.5) bc	3.9	30.8 (2.0) d	40.5	2.2
RF1	0.4 (0.1) a	1.1	22.1 (2.1) b	32.3	1.2
RF2	0.8 (0.2) ac	2.0	27.4 (1.8) c	34.5	1.1

Ozone concentration accumulated over a threshold of 40 ppb (AOT40) is used as an indicator to evaluate risk of O_3 in Europe recently (e.g. in Gothenburg Protocol; UN ECE 1999). However, concentrations measured by passive sampler cannot be directly used for the calculation of AOT40 without modeling approaches since O_3 concentrations generally fluctuates in a day and the highest values could be detected in daytime (GEROSA & al. 2003). In this study, mean O_3 concentration was ca. 30 ppb at site C and the maximum value of two-week average concentration was 42 ppb in summer, 2001. It was suggested that hourly data in daytime of summer season would be remarkably higher than the values obtained in this study.

Use of automatic (active) monitors should also be considered to detect hourly concentrations for the calculation of AOT40, although some problems such as lack of electric supply must be solved in mountainous area. The present study focused on air pollutants' concentrations under canopies in forests. However, it can be speculated that O_3 concentration would be higher at the canopy height (20-30 m), and therefore, concentrations at the top of canopy or open space near forests should also be assessed. Further study should be implemented to evaluate the risk of O_3 in the mountain.

Soil pH and contents of exchangeable base cations were relatively high; e.g. values of pH (H_2O) were 6.7, 5.9 and 5.8 in sites B, C, and D, respectively; values of exchangeable Ca were 46.1, 22.6 and 34.5 cmol(+)/kg. Soil acidification due to acid deposition might hardly occur because of the high concentration of base cations. Accumulation of heavy metals, such as Pb, Cu and Zn, cannot be detected in soil samples on the slope (detailed data is not shown here).

It was clarified that air pollutants such as SO_2 and O_3 were transported to the Bogdkhan Mountain, and the slope facing the thermal power plant suffered more negative effects of the pollution than the reference forests. Effects of air pollution, especially the effect of O_3, should be considered as one of the possible causes for tree decline on the slope, while effect of insect attack might be another important factor as observed in large extent of the Bogdkhan Mountain.

The present paper is probably the first scientific report that suggests relationship between air pollution and tree decline in Mongolia. In the future study, O_3 concentration at the canopy height or open space and also deposition amount of O_3 should be clarified for evaluating possible risk of O_3 in the Bogdkhan Mountain. Tree growth rates should also be studied for investigating synergistic effects of air pollution and natural environmental factors such as insects and climate.

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