Effects of Air Pollution and Acid Deposition on Three *Pinus densiflora* (Japanese Red Pine) Forests in South Korea

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Abstract

Although a large area of forest damage due to acid deposition have not yet been found in South Korea, but some of local tree declines have been frequently reported especially for *Pinus densiflora* (Japanese red pine), the most common coniferous tree. In the present study, we evaluated the effects of acid deposition on forest, results of ambient SO₂, acid load, soil pH and tree decline monitored from 1988 to 2001 in urban, industrial and mountainous area along the gradient of atmospheric pollution were compared. During the study period, annual mean SO₂ concentrations in urban area averaged 13 ppb with a maximum of 31 ppb, 1989 and industrial and mountainous area averaged 14 ppb and 6 ppb, respectively. Annual mean acid loads were 0.09 and 0.11 kmol H⁺ ha⁻¹ in urban and industrial area, significantly comparable with 0.03 kmol H⁺ ha⁻¹ in mountainous. The surface soil of the red pine forest in urban and industrial area was acidified (pH 4.1 - 4.3), whereas pH 5.4 in mountainous area. On the other hand, based on defoliation and discoloration measured in 1996 and 2001, decline degree of the pine trees in two polluted areas was higher than that in mountainous area. The data indicate that the combined effects of high air pollution and acid deposition-induced soil acidification (possibly Ca deficit and Al toxicity) could adversely influence the Japanese red pine.

Key words: Air pollution, *Pinus densiflora*, Soil acidification, Tree decline

1. Introduction

Air pollution is a common phenomenon that is occurring in heavily urbanized or industrialized regions throughout world. The impacts of dry and wet acid depositions and soil acidification induced by them on tree vitality are the subject of comprehensive scientific discussions. Over the past thirty years in Europe and North America, many of witness of the negative impact of air pollution on different forests in regional or local scale have been announced (Johnson and Siccama, 1983; Mackenzie and Mohamed, 1989). Acid deposition is a serious environmental problem in East Asian countries such as China, Korea and Japan (Rodhe et al., 2002). Dry and wet deposition of acids from the atmosphere onto forest floors may gradually increase soil acidity (Krause et al., 1986; Driscoll et al., 2001). Acid deposition to forest soils with relatively low base saturation increases Al mobilization and shifts chemical speciation of Al which is toxic to terrestrial biota (Cronan and Schofield, 1990). Therefore, trees grown in forest soils acidified by air pollution and acid precipitation may be adversely affected, not only by the resultant nutrient deficiency, but also by increased level of phototoxic Al concentration (Cronan and Grigal, 1995).

In Korea like so many, increases in gaseous pollutants and acid deposition have been experienced since the 1970's incipient industrialization. Recently the acceleration of soil acidification and the visible tree damage in forest ecosystem have been documented, especially in pine forest of urban and industrial areas (Kim, 1996; Lee et al., 1998; Lee and Park, 2001). Long-term monitoring of air pollution and forest damage in Korea has been embarked in the Korea Forest Research Institute since 1986. Then a new nation-wide monitoring network in 1992 was established, which was constituted of total 65 permanent forest sites in whole country divided into 40 x 40 km² grid. In the national forest research, a case study called "Local Forest Change" has been carried out to assess the effects of atmospheric deposition on forest ecosystem at some selected sites with the gradient of local air quality. A representative coniferous species of the national and local permanent sites was *Pinus densiflora* (Japanese red pine), an economically and ecologically important tree.

This investigation was conducted to examine the effects of acid deposition on the red pine forest by comparing the results monitored from 1988 to 2001 of atmospheric quality, soil acidity, and tree decline in urban, industrial and mountainous area.
2. Materials and Methods

The study sites selected along the gradient of atmospheric pollution are located at Mt. Nam in Seoul (37°40'N, 126°58'E) as urban, Doowang in Ulsan (35°33'N, 129°19'E) as industrial, and Mt. Kyebang in Hongchon (37°50'N, 128°25'E) as mountainous area. The material rock is Granite, Mudrock and Gneiss in above described site order.

To obtain the site-specific estimation of atmospheric quality, monthly ambient SO₂ concentration was measured by colorimetric analysis, and pH (TOA HM-40V) and major inorganic cations and anions (Ion Chromatography, Waters 590) of wet-only rainfalls collected daily were determined. And annual mean of rainfall pH and ion concentrations was calculated by weighting rainfall volume to the ion concentration. The ionic composition of rainfall was presented only for the rainfalls collected from 1996 to 2001. Surface soils (0-15 and 0-30 cm) in each red pine forest were measured for pH (H₂O) as a main response factors to acid deposition. Also tree decline classified into four degrees (0-3) was determined through defoliation and discoloration estimation on 20 sample trees for each site both in 1996 and 2001.

3. Results and Discussion

The annual mean concentrations of SO₂ in urban, industrial and mountainous area during 1988 to 2001 were 13ppb, 14ppb and 6ppb, respectively, indicating the regional magnitude of S emission source. The SO₂ concentrations of all areas, however, were lower than 19ppb of IUFRO international standard (Mayer, 1985), and did not seem to be dangerous level. On the other hand, there was a trend in SO₂ concentration, particularly in urban and industrial areas (Fig. 1).

For the urban area, SO₂ concentration dramatically decreased from 1989 to 1995. The SO₂ concentration, however, in industrial area significantly increased until 1994, and the concentration decrease has processed since 1995. The decreasing SO₂ in the two areas after the mid 1990s is believed to be due to the desulfurizing facilities and expansive using of alternative energy like natural gas and LPG with much lower sulfur (Kim, 1996). On the other hand, mountainous area did not show significant change over the period.

The annual mean pH of rainfall during the period 1988 - 2001 was 5.0, 4.9, and 5.5 in urban, industrial and mountainous area, respectively. The increase in rainfall pH within the period was found in urban area and similar result was also observed in industrial area from 1993 to 2001 in Fig. 2. However, the mountainous area showed no change in the rainfall pH as the SO₂ concentration. The recovery of rainfall acidification in the two air-polluted areas might be attributed to the decrease of SO₂ as mentioned in Fig. 1. Even based on 2001 showing the highest rainfall pH in the whole study period, acid rain (pH < 5.6) in urban area accounted for 58% of the total measured rainfall and 92% in industrial area, but just 23% in mountainous area. Also it was a noticeable feature that the rainfall pH were negatively correlated to the SO₂ concentration at a statistically significant level p<0.001 in urban area and p<0.05 in industrial as well (Fig. 3). It suggests that the rainfall acidity in the two areas could be greatly attributed to sulfur dioxide.

For the urban and industrial area, H⁺ and SO₄²⁻ concentrations in rainfall were relatively higher than mountainous (Table I). As expected, sulfate and nitrate are believed to be dominant acid anions affecting rainfall acidity. In this way, the annual acid loads in urban and industrial area averaged 0.09 (0.06-0.18) and 0.11 (0.03-0.16) kmol H⁺ ha⁻¹ yr⁻¹, respectively, but 0.03 (0.02-0.03) kmol H⁺ ha⁻¹ yr⁻¹ in mountainous area.

Soil pH at 0-15 cm depth in urban and industrial area averaged 4.1 and 4.3, respectively, whereas pH 5.4 in mountainous area. The significantly low soil pH in urban and industrial forests could implicate the increase in base cation loss and Al dissolution (Krause et al., 1986; Driscoll et al., 2001). Since it is empirically true that Ca and Mg deficiency and Al
toxicity in soils with less than pH 4.5 may be
associated with increasing tree decline especially in
vulnerable forest, the soil acidity in urban and
industrial area might be detrimental to the tree health.
Ulrich (1989) proposed that soil acidification induced
by acid deposition is one of the causes for abnormal
tree growth in declining forest stands. Also,
Abrahamsen et al. (1994) concluded that acidic
deposition is likely to bring about increased nutrient
imbalance in Norwegian forest ecosystems, through
long-term acidification experiments.

![Annual mean pH of rainfall in three areas from 1988 to 2001.](image)

**Fig. 2.** Annual mean pH of rainfall in three areas from 1988 to 2001.

![Relationship between annual mean SO2 concentration and rainfall pH in urban and industrial area.](image)

**Fig. 3.** Relationship between annual mean SO2 concentration and rainfall pH in urban and industrial area, except for non-polluted mountainous area with no clear relation.

### Table 1. Annual volume-weighted mean concentrations (µmol L⁻¹) of cations and anions in rainfall from 1996 to 2001. Mean values with same letter are not significantly different according to the Duncan's new multiple range test at p<0.01. Number of samples in urban area is 237, 231 in industrial and 179 in mountainous, respectively.

<table>
<thead>
<tr>
<th></th>
<th>H⁺</th>
<th>NH₄⁺</th>
<th>K⁺</th>
<th>Na⁺</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>SO₄²⁻</th>
<th>NO₃⁻</th>
<th>Cl⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>9.4b</td>
<td>66.9b</td>
<td>20.5a</td>
<td>29.3b</td>
<td>36.8c</td>
<td>9.4b</td>
<td>30.1b</td>
<td>32.3a</td>
<td>28.3b</td>
</tr>
<tr>
<td>Industrial</td>
<td>13.8a</td>
<td>67.8ab</td>
<td>16.6b</td>
<td>61.7a</td>
<td>48.4a</td>
<td>14.0a</td>
<td>45.4a</td>
<td>25.6b</td>
<td>52.5a</td>
</tr>
<tr>
<td>Mountainous</td>
<td>3.3c</td>
<td>70.1a</td>
<td>19.0a</td>
<td>29.5a</td>
<td>40.4b</td>
<td>10.3b</td>
<td>20.2c</td>
<td>19.1c</td>
<td>22.1c</td>
</tr>
</tbody>
</table>

As shown in Fig. 4, in 1996 Japanese red pine in
urban, industrial and mountainous area showed 68%, 
62%, and 51% of the degree 1 and 2 (beginning and
moderate decline phase) in tree decline, respectively, 
and 74%, 70%, and 55% in 2001. The higher decline
degree (p<0.01) in two air-polluted areas could be
likely induced by low air quality, great acid load, and
much low soil pH as well, despite the average age of
the sample trees was similar (30-33 year) to those in
mountainous area. It has not been possible to find any
conclusive relation between tree decline and air
pollution (acid deposition) because many other natural
stress factors (e.g. meteorological fluctuation) have
influenced tree condition (Lindgren et al., 2000) 
However, tree decline has been noticed increased in
some industrial or near areas, in Europe and North
America (Johnson and Siccama, 1983; Mackenzie and
Mohamed, 1989).
Fig. 4. Comparison of tree decline degree in *Pinus densiflora* forests of urban, industrial and mountainous area in 1996 and 2001. Decline degree 0; <10% defoliation and 10–25% discoloration, degree 1; 0–10% defoliation and 25–60% discoloration or 10–25% defoliation and discoloration, and degree 2; 0–10% defoliation and >60% discoloration, 10–25% defoliation and >25% discoloration or 25–60% defoliation and 10–25% defoliation, respectively. Mean values with same letter are not significantly different according to the Duncan’s new multiple range test at p<0.01.

References


