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Growth Decline of Pitch Pine Caused by Soil Acidification in Seoul Metropolitan Area

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首都圈地域에서 土壤의 酸性化에 의한 리기다소나무의 生長 減少

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ABSTRACT

To elucidate the cause of growth decline of pitch pine (*Pinus rigida*) in Seoul, tree density, tree age and physico-chemical properties of soils were investigated at 33 sites of pitch pine forests in metropolitan Seoul, its vicinity and rural areas. The physical properties of soils except for soil texture in Seoul did not differ from those in rural areas. pH values, base saturation, and Ca and Mg contents of soils in Seoul, however, were significantly lower than those in suburbs and rural areas. In contrast, soluble Al and SO_4^{2-}−S contents in Seoul were higher than those in rural areas. Low pH of forest soils in Seoul and suburbs seems to be caused by acid deposition. According to multiple regression analysis, growth of pitch pine in Seoul was affected by several factors in the following order: soil bulk density < Al content of soils < tree density < Mg contents of soil < tree age. We concluded that the acidification of forest soil can be a predisposing factor for the growth decline of pitch pine in metropolitan areas.

Key words: Al toxicity, Mg deficiency, Multiple regression analysis, Pitch pine decline, Soil acidification

INTRODUCTION

We have recently reported that the growth decline of pitch pine can be caused by abnormal vertical distribution of fine roots and low Mg content in tissues of pitch pine in Seoul and its vicinity (Rhyu *et al.* 1994, Rhyu and Kim 1994). These characteristics of pitch pine were similar to those of trees showing new forest decline syndrome caused by soil acidification in central Europe (Zech *et al.* 1990/1991). The soil acidification in Seoul caused by acidic deposition, therefore, was suspected to lead the growth decline of pitch pine (Rhyu *et al.* 1994). Besides, a high amount of sulfate input ($153.8 kg \cdot ha^{-1} \cdot yr^{-1}$) by through fall in red pine stand at the Seoul metropolitan area of was reported (Kim 1994). Rain with strong acidity in Seoul has been precipitating for decades (Rhyu 1994). Recently reduction of tree growth, low pH value and high Al content of forest soils in Seoul areas were reported by the Office of Forestry (1986~1988). However the cause of reduction in tree growth in Seoul remains unclear.

The porpose of this study was (1) to investigate the properties of forest soil in Seoul, its vicinity and in rural areas, and (2) to find factors affecting growth decline of pitch pine in Seoul metropolitan area.

METHODS

Thirty-three sites of pitch pine forests were selected at the Seoul metropolitan area, its vicinity and rural areas within 60 km radius from the center of Seoul (Fig. 1). The characteristics for 33 sites studied were previously described by Rhyu *et al.* (1994). At each site the soils were sampled in two soil depths of 0~5 cm and 5~10 cm with soil corer at 60 cm distance from five stems in each quadrat of 10m × 10m. Tree density

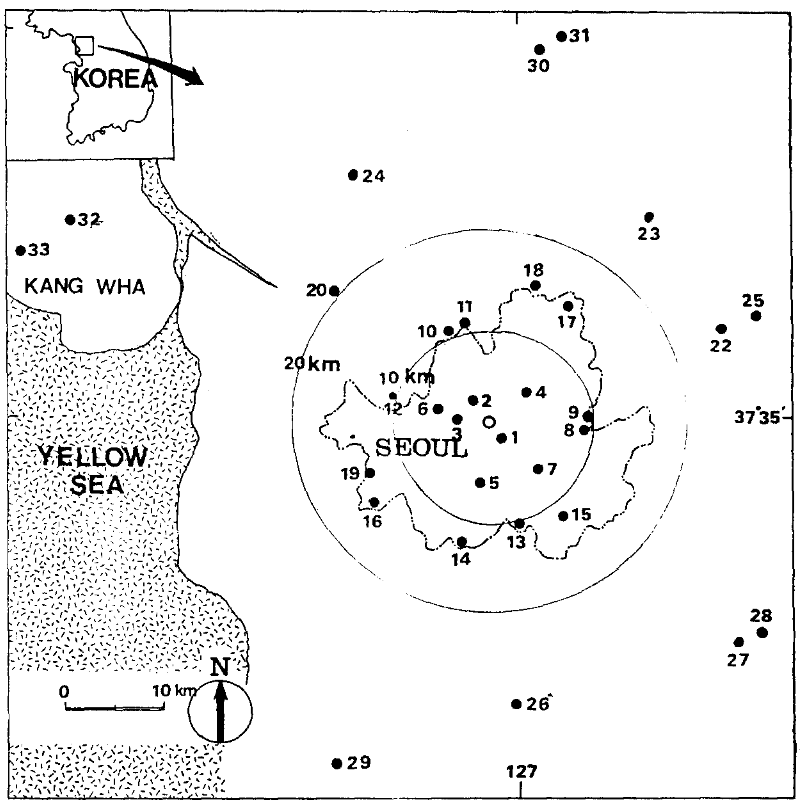

Fig. 1. Map showing 33 sampling sites in and near Seoul metropolitan area.

was measured in the field and tree age was determined from the annual rings. Soil bulk density was measured by soil bulk density meter.

Air-dried samples of soil were used for physico-chemical analysis. Soil texture was determined by the hydrometer method. Organic matter content of soil was determined by ashing the samples at 550°C for 4 hr. Exchangeable K, Na, Ca and Mg contents of soil were extracted in 1 N ammonium acetate (pH 4.8). K and Na contents were measured by flamephotometer (Coleman 51) while Ca and Mg contents were measured by atomic absorption spectrophotometer (GBC 901). pH of soil (soil:distilled water 1:5, w/v) was measured by pH meter (Fisher 230). Cation exchange capacity (CEC) was determined by Moore and Chapman' method (1986). Base saturation (BS) was calculated as a percentage of basic cations to CEC. Soluble Al content of soil extracted in 0.01 M SrCl2 (Joslin *et al.* 1988) was determined by Erichrome cyanine R (ASA 1982). Inorganic SO_4^{2-}−S of soil extracted in 500 ppm phosphorus was determined by the turbidimetric method (ASA 1982).

Variables for multiple regression analysis were used from the data of Rhyu *et al.* (1994) and Rhyu and Kim (1994). Statistical package used for multiple regression analysis and ANOVA test was SYSTAT program.

To make regional comparisons, we split all the samples into 3 geographic regions; 1) metropolitan Seoul which includs all sites within a radius of 10 km from the center of Seoul, 2) suburbs which includs sites within a radius between 10 km and 20 km from the center of Seoul, and 3) rural areas which includs those a radius between 20 km and 60 km from the center of Seoul (Fig. 1).

RESULTS

Physical properties of soil

Soil bulk densities in urban Seoul, its vicinity and rural areas were 1.48 g/cm^3, 1.47 g/cm^3 and 1.35 g/cm^3, respectively and did not differ among three areas (Table 1). Average sand contents of soil in urban Seoul, its vicinity and rural areas were 73.3%, 71.3% and 67.6%, respectively. Sand contents of soil in urban were higher than those in rural areas. Clay contents in Seoul, however, were lower than those in rural areas.

Chemical properties of soil

1) pH

Average pH values of soil depth of 0-10 cm in pitch pine forest ranged between pH 4.11~pH 5.33 for all 33 sites, and average pH values in Seoul, its vicinity and rural areas were 4.25, 4.53 and 4.70, respectively, and increased along with distance from the center of Seoul (Fig. 2) ($r=0.729$, $p<0.01$). pHs of soil in Seoul were significantly lower than those in suburbs and rural areas.

Table 1. Soil bulk density, soil texture and organic matter(O.M.) of soil and depth of litter layer in pitch pine forests

Site Number	Location	Soil bulk density (g/cm^3)	Soil texture			O.M. (%)	Litter layer (cm)
			Sand(%)	Silt(%)	Clay(%)		
Urban Area(0~10 km)							
1	Mt. Namsan	1.59	70.0	15.0	15.0	5.89	10.2
2	Mt. Inwangsan	0.92	80.0	10.0	10.0	6.24	3.4
3	Mt. Ansan	1.60	66.3	15.0	18.7	5.31	7.4
4	Jongam	1.80	75.0	10.0	15.0	4.93	9.2
5	Huksuk	1.52	76.3	15.0	8.7	5.08	7.4
6	Mt. Baekryensan	1.54	67.5	13.8	18.7	7.99	12.6
7	Samsung	1.38	71.3	13.7	15.0	7.18	10.5
8	Mt. Achasan-1	1.62	77.5	13.8	8.7	3.69	5.7
9	Mt. Achasan-2	1.30	80.0	12.5	7.5	4.92	4.9
	Mean	1.48	73.3	13.2	13.0	5.70	7.9
Suburban Area (10~20 km)							
10	Shindo	1.72	67.5	12.5	20.0	2.60	2.3
11	Mt. Nogosan	1.49	68.8	17.5	13.7	4.81	3.3
12	Hwajeon	1.54	72.5	15.0	12.5	5.97	6.4
13	Mt. Woomyensan	1.22	66.3	10.0	23.7	4.66	5.4
14	Mt. Kwanaksan	1.51	80.0	10.0	10.0	3.43	8.2
15	Mt. Daemosan	1.33	75.0	12.5	12.5	8.99	7.3
16	Gaebong	1.34	70.0	12.5	17.5	9.18	6.8
17	Mt. Suraksan	1.34	60.0	26.3	13.7	5.39	7.6
18	Mt. Dobongsan	1.66	80.0	11.3	8.7	4.06	10.4
19	Shinwhol	1.49	72.5	10.0	17.5	7.16	10.1
	Mean	1.47	71.3	15.1	16.7	5.60	6.8
Rural Area(20~60 km)							
20	Mt. Gobongsan	1.60	70.0	12.5	17.5	4.50	10.5
21	Mt. Yongmasan	1.65	65.0	15.0	20.0	5.68	3.2
22	Mt. Cheonmasan	0.93	66.3	11.3	22.4	10.87	5.9
23	Mt. Jukyeopsan	1.53	68.8	12.5	18.7	5.68	4.6
24	Paju	1.50	61.3	16.3	22.4	6.89	9.5
25	Hwado	1.20	68.8	11.2	20.0	10.88	4.7
26	Mt. Chilbosan	1.46	70.0	13.8	16.2	3.73	5.1
27	Mt. Nogonong	1.27	68.8	17.5	13.8	5.96	7.3
28	Mt. Taiwhasan	0.97	72.5	12.5	15.0	10.20	6.6
29	Sagang	1.09	63.8	18.8	17.4	7.48	4.2
30	Habongam	1.31	66.3	18.3	20.0	6.49	4.7
31	Sangbongam	1.37	62.5	15.0	22.5	6.76	8.9
32	Mt. Koryosan	1.47	67.5	10.0	22.5	6.38	4.7
33	Kanghwa	1.53	75.0	10.0	15.5	3.72	2.1
	Mean	1.35	67.6	13.7	17.6	6.80	5.9

2) Inorganic SO_4^{2-}-S

Average S contents in Seoul, suburbs and rural areas were 195.4, 158.6 and 89.8 mg/kg,

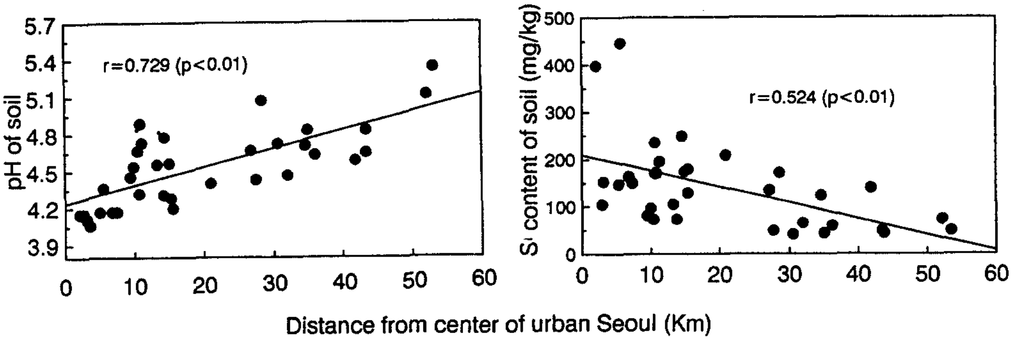

Fig. 2. Changes of pH(left) and SO_4^{2-}−S content(right) of soil in pitch pine forest along distance from the center of Seoul.

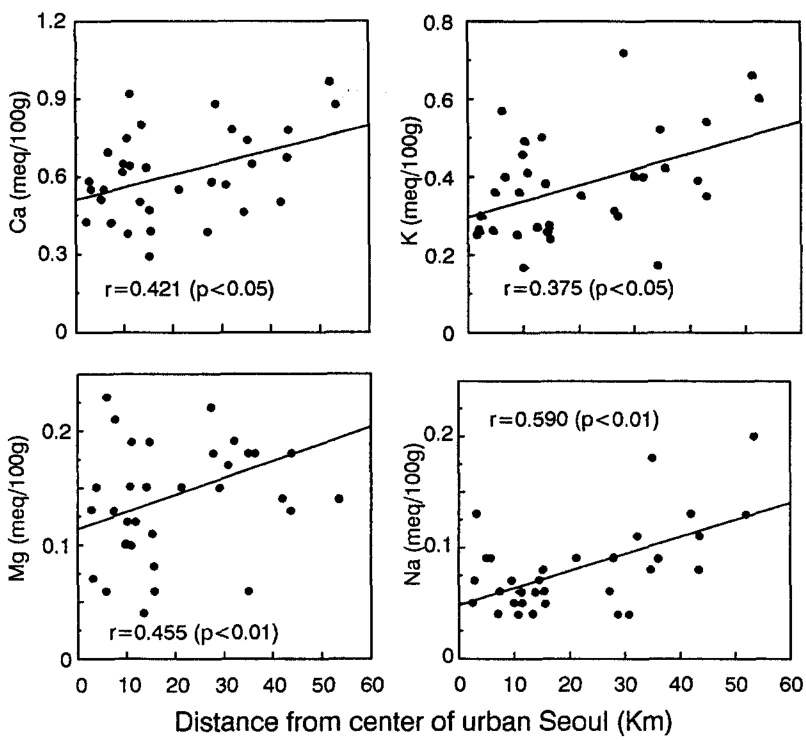

Fig. 3. Changes of Ca, Mg, K and Na contents of soil in pitch pine forest along distance from the center of Seoul.

respectively and were 2.2 times higher in Seoul, and 1.7 higher times in suburbs than those in rural areas (Fig. 2).

3) Exchangeable Ca, Mg, K and Na

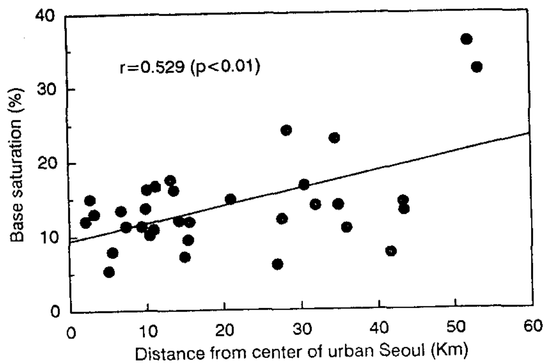

Fig. 4. Changes of base saturation of soil in pitch pine forest along distance from the center of Seoul.

Average Ca content in Seoul, suburbs and rural areas were 0.55, 0.58 and 0.67 meq/100g while Mg contents in these three areas were 0.34, 0.34 and 0.44 meq/100g, respectively. K contents in these three areas were 0.13, 0.12 and 0.17 meq/100g, and Na contents were 0.07, 0.06 and 1.00 meq/100g, respectively (Fig. 3). All the basic cations in Seoul and suburbs were lower than those in rural areas.

4) Base saturation (BS)

Average BSs in Seoul, suburbs and rural areas were 11.4, 12.8 and 17.0%, respectively and BSs of soil in Seoul and suburbs were lower than those in rural areas (Fig. 4).

5) Soluble Al

Average Al contents in Seoul, suburbs and rural areas were 296.0, 240.6 and 211.0 mg/kg, respectively. Al content of soil was 1.4 times higher in Seoul than that of rural areas (Fig. 4).

6) Cation exchange capacity (CEC)

Average CECs in Seoul, suburbs and rural areas were 10.44, 8.80 and 9.52 meq/100g, respectively, and CECs of soil did not differ among the three areas (Fig. 5).

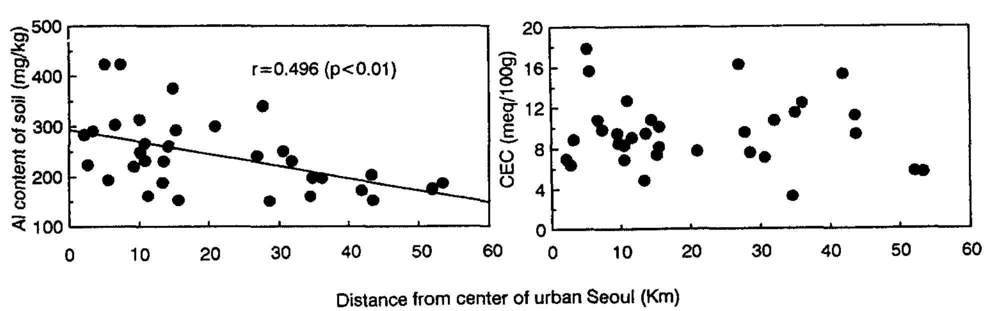

Fig. 5. Changes of Al content (left) and cation exchange capacity (right) of soil in pitch pine forest along distance from urban center of Seoul.

Factors affecting growth of pitch pine

To find factors affecting width (Y) of recent annual rings (1985-1989) of pitch pine,

Table 2. Results of stepwise multiple regression analysis of data on annual ring widths (annual rings between 1985 and 1989) and 22 environmental variables

Variables	Parameter estimate	Partial R^2	Model R^2	Significance level
Intercept	1.611			0.147
Age of tree	−0.091	0.407	0.407	0.001
Mg content of soil	3.189	0.154	0.561	0.004
Density of tree	0.089	0.045	0.606	0.080

Table 3. Results of stepwise multiple regression analysis of data on annual ring widths (annual rings between 1985~1989) and 16 variables of soil properties

Variables	Parameter estimate	Partial R^2	Model R^2	Significance level
Intercept	2.794			0.197
Mg content of soil	3.832	0.380	0.380	0.001
Al content of soil	−0.005	0.083	0.463	0.014
Soil bulk density	0.047	0.046	0.509	0.078
Sand content	−0.039	0.037	0.546	0.141

multiple regression analysis was carried out with independent variables of 22 factors which included biological properties, physico-chemical properties of sites or soils. Tree age (X_{age}), Mg contents of soil (X_{mg}) and tree density (X_{den}) were selected as important factors affecting annual ring widths among all 22 variables. Sixty percent of variation of annual ring width was accounted for equation below (Table 2).

$$Y = 1.611 + 3.189X_{Mg} + 0.089X_{Den} - 0.091X_{Age.}$$

Factors affecting annual ring widths were in the following order: tree age (40.7%) > Mg contents of soil (15.4%) > tree density (4.5%).

Among the 16 factors of soil properties, Mg content (X_{mg}), Al content (X_{Al}), soil bulk density (X_{bulk}) and sand contents (X_{sand}) were selected as factors affecting recent widths (Y) of annual rings (1985~1989) of pitch pine by the following equation (Table 3).

$$Y = 2.794 + 3.832X_{Mg} - 0.005X_{Al} + 0.047X_{Bulk} - 0.039X_{Sand}$$

Soil factors affecting annual ring widths were in the following order: Mg content (38.0%) > Al content (8.3%) > soil bulk density (4.6%) > sand content (3.7%). Therefore, important factors affecting growth decline of pitch pine in addition to biological factors were Mg deficiency and Al toxicity, which were associated with soil acidification.

DISCUSSION

Soil acidification in Seoul metropolitan area

Low pH of forest soils in Seoul and suburbs seemed to be caused by acid deposition

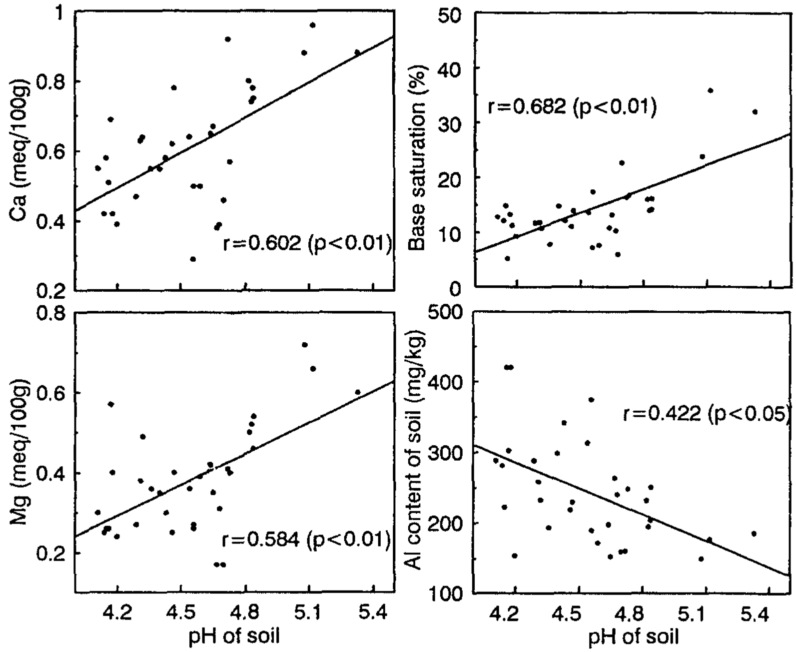

Fig. 6. Relationship between Ca content, Mg content, base saturation and Al content and pH of soil in 33 sites of pitch pine forest.

since significant level of SO_4^{2-}-S was contained in forest soils in urban areas, and SO_4^{2-} accounted for 61% of total acidic ions deposited as wet deposition in Seoul (Rhyu 1994). Besides, rain with strong acidity in Seoul has been precipitating for decades (Rhyu 1994). It was also worthwhile noting that soil acidification could be accelerated by stemflow and throughfall in pine forest in polluted Seoul because SO_4^{2-} concentrations in stemflow and throughfall were higher than those in rain as the result of the washout of acidic dry deposits (Kim 1994). SO_4^{2-} input by throughfall in red pine stand at Seoul metropolitan area was 153.8 kg ha^{-1} yr^{-1}, which was 2 times higher than that in Black forest showing forest decline syndromes in Germany (Kim 1994, Huettl 1989). In contrast soluble Al, exchangeable Ca, Mg, K and and Na contents of soil in Seoul were significantly lower than those in rural areas (Fig. 3). These results were supported by the previaus observation that Ca, Mg contents and BS of soil decreased with decrease of pH of soil with all statistical significances (Ke and Skelly 1990/1991) (Fig. 6). As soil acidification occurred, basic cations in soil were replaced with hydrogen ions in soil solution (Rhyu and Kim 1993). Replaced basic cations were combined with soluble anions (mostly sulphate and nitrate in polluted region) which were deposited from atmosphere, and these combined cations were leached through watertable (Abrahamsen & Dollard 1978). Acid soluble metals (Al^{3+}, Mn^{2+} and Fe^{2+}) from acid soil increased in also soil solutions (Rhyu and Kim 1993, Ulrich 1980).

The cause of growth decline of pitch pine in urban Seoul

Threes showing declining symptomes exhibited low Mg contents in needles and high Al contedts in fine roots of pitch pine in Seoul and its vicinity (Rhyu and Kim, 1994). In addition among factors of soil properties low Mg contents and high Al contents were selected as factors affecting the decrease of annual ring widths of pitch pine in metropolitan areas. Growth decline of pitch pine, therefore, may be directly caused by soil acidification.

In addition to direct effects of cations deficienccy and Al toxicity, abnormal vertical distribution of fine roots by Al toxicity was suspected indirectly to lead to the growth decline of pitch pine in Seoul. Rhyu *et al.* (1994) reported the growth decline of pitch pine can be caused by abnormal vertical distribution of fine roots in metropolitan areas. Ulrich (1990) comprised forest decline in central Europe as three phase: phase Ⅰ, in which the base saturation in soil is decreasing toward zero; phase Ⅱ, in which acid stress in the subsoil changes the depth gradient of the fine root system toward a superficial rooting; phase Ⅲ, in which the superficially rooting trees suffer more and more site-specific stressors. At present in Seoul, fine roots of pitch pine were superfically distributed on top soil or in litter layer (Rhyu *et al.* 1994). Superficially rooting trees might suffer from water deficit because of desiccation of superficial roots during the dry season and freezing during the winter. Therefore, the simultaneous discoloration and precocious shedding of needles of pitch pine observed in Seoul in 1989 might be related to water deficits in spring when relative humidity was the lowest and average wind speed was the highest. Water deficit of pitch pine during the dry season was thought to be directly affected by air pollutants and/or acidic deposits because water in needles of pitch pine in polluted Seoul losses more easily compared with that in needle in unpolluted rural areas (Rhyu 1994). It was thought that transpiration of water through needles was accelerated by destruction of surface or stomata of needles by air pollutants (especially O_3) or acidic deposits (Krause and Cannon 1991).

적 요

수도권에서 보고된 리기다소나무 생장감소의 원인을 밝히기 위하여 33 장소의 리기다소나무 숲에서 교목의 밀도, 수령 및 토양의 물리화학적 특성을 조사하였다. 토성을 제외하고 토양의 물리적 특성들은 도심지와 전원지에서 차가 없었다. 그러나 토양의 pH 값, 염기포화도 및 염기성 양이온 함량은 전원지에 비해 도심지에서 낮았지만, 수용성 Al 함량과 S 함량은 그 반대였다. 도심지의 토양산성화는 산성강하물에 의한 영향으로 해석된다. 다중회귀분석 결과, 수도권에서 리기다소나무 생장은 토양의 가비중<토양의 Al 함량<교목의 밀도<토양의 Mg 함량<수령의 순으로 영향이 컸다. 결론적으로 수도권에서 리기다소나무 생장의 감소는 1차적으로 토양산성화가 주요한 요인이었을 것으로 판단된다.

LITERATURE CITED

APHA. 1989. Standard methods for the examination of water and wastewater. APHA, Baltimore. 1482p.

ASA. 1981. Methods of soil analysis. American Society of Agronomy, Madison. 834p.

Chung, S.W., J.O. Bae, K.S. Koh, D.I. Choi, I.A. Huh, D. H. Kim, J.B. Lee, Y.M. Lee, H. Kim, G.T. Kim and E.S. Kim. 1991. A study on the assessment of damage by gaseous air pollutants and acid rain (I). Natioanl Institute of Environmental Research. NO. 91-06-306.

Joslin, J.D., J.M. Kelly, M.H. Wolfe, and L.E. Rustad. 1988. Elemental patterns in roots and foliage of mature spruce across a gradient of soil aluminium. Water, Air, and Soil Pollution 40:375-390.

Huettl, R.F. 1989. New types of forest damages in central Europe. *In* J.J. MacKenzie and M.T. El-Ashry(eds.)., Air pollution's toll on forest and crops. Yale University Press, New Haven and London. pp. 22-74.

Ke, J. and J.M. Skelly. 1990/1991. Foliar symptoms on Norway spruce and relationships to magnesium deficiencies. Water, Air, and Soil Pollution 54:75-90.

Kim, K.D. 1994. Inorganic nutrients input by precipitation, throughfall and stemflow in stands of *Pinus densiflora* and *Quercus mongolica*. M.S. Thesis, Seoul Nat'l Univ., Seoul. 77p.

Krause, C.R. and W.N. Cannon. 1991. Epistomatal wax injury to red spruce needles (*Picea abies*) grown in elevated levels of ozone and acidified rain. Scanning Electron Microscopy V:1173-1180.

Moore, P.D. and S.B. Chapman. 1986. Methods in plant ecology. Blackwell Sci. Pub. Oxford. 589p.

Office of Forestry. 1986-1988. Effects of air pollutions on the forest ecosystems. Ministry of Science and Technology. 191p.

Rhyu, T.C. 1994. Mechanism and recovery of *Pinus rigida* forest decline by acidic deposition in the metropolitan area of Seoul, Korea. Ph. D. Thesis, Seoul Nat'l Univ., Seoul. 219p.

Rhyu, T.C. and J.H. Kim. 1993. Cation leaching from soils percolated with simulated sulfuric acid rain. Korean J. Ecol. 16:169-180.

Rhyu, T.C., K.D. Kim and J.H. Kim. 1994. Growth decline and abnormal vertical distribution of fine roots of pitch pine in Seoul metropolitan area. Korean J. Ecol. 17:277-286.

Rhyu, T.C. and J.H. Kim. 1994. Cation deficiencies in needles and fine roots of pitch pine in Seoul metropolitan area. Korean J. Ecol. 17:261-275.

Ulrich, B. 1980. Die Wälder in Mitteleuropa Messergebnisse ihrer Umweltbetastung, Theorie ihrer Gefahrdung. Prognose ihrer Entwicklung-Allg. Forstz 25:1198-1202.

Ulrich, B. 1990. Wäldsterben: Forest decline in West Germany. Environ. Sci. Technol. 24:436-441.

Zech, W., B.U. Schneider and H. Role. 1990/1991. Elemental composition of leaves and wood of beech (*Fagus sylvatica* L.) on SO_2-polluted sites of the NE-Bavarian mountains. Water, Air, and Soil Pollution 54:97-106.

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