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Water Deficit of Pitch Pines Caused by Superficial Rooting and Air Pollutants in Seoul and Its Vicinity

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To make regional comparisons of water status of pitch pine, the temporal changes of water status in pitch pine were investigated at different areas; urban Seoul (heavily polluted area), surburb of Seoul (lightly polluted area), and rural area (control). The effects of air pollutants, acid rain and chemical properties of soil on water deficit in pitch pine were also investigated. Water content of needles growing at polluted areas were usually lower than that at unpolluted area. Water saturation deficit of needles growing at polluted areas were usually higher than that at unpolluted area especially in dry season. These results indicated that water in needles growing at polluted areas were usually more deficient than that at unpolluted area, and were more deficient in April than other months. At polluted areas, the older the needles were, the more quickly transpirated the water in the needle was. At unpolluted areas, however, water in old needles was not so quickly transpirated as those at polluted areas. Water potential of needles of pitch pine seedlings treated with simulated acid rain (SAR) of pH 3.5 decreased more quickly than that of needles treated with SAR of pH 5.6. Loss of water through epicuticular layer was greater in the following order: magnesium deficiency+100 μM aluminium>100 μM aluminium>magnesium deficiency>control. In addition to Mg deficiency and Al toxicity, growth decline of pitch pine widely occurring in polluted Seoul could to a large extent be due to cuticle degredation and abnormal vertical distribution of fine roots, which lead to water stress, particularly in dry seasons.

Keywords: pitch pine decline, superficial rooting, water stress, acid rain, air pollutants

Forest decline syndromes showing color changes in foliage and foliage loss (*i.e.* a decrease in canopy density) have increased dramatically from all parts of the world since early 1980s (Krause *et al.*, 1986; Nilsson and Duinker, 1987). However the primary cause of the decline was not clearly known yet, but deficiency of basic cations, Al toxicity, ion imbalance, climate change or mixed stressors have been reported as major contributors causing forest decline syndromes (Krause *et al.*, 1986). Especially, among trees showing decline syndromes, trees with a damaged cuticle caused by acidic deposits or air pollutants are affected in their resistance against water stress in drought seasons (Mengel *et al.*, 1989). In this way acidic deposits or air pollutants could be involved directly in forest decline syndromes.

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In metropolitan areas of Seoul color changes in needle, needle loss, and poor crown development in pitch pines in spring of 1989 were observed (Kim, 1990). Also it was reported that pitch pines with poor canopy mostly showed the abnormal vertical distribution of fine roots and the low content of Mg in its tissues (Rhyu *et al.*, 1994; Rhyu and Kim, 1994). The cause of needle yellowing and its shedding in pitch pines in spring at Seoul metropolitan areas was suspected to the water deficit caused 1) by the increase of transpiration through epicuticular degradation by air pollutants, and 2) by the decrease of absorption of water through abnormally grown fine roots in acidic soil (Rhyu, 1994).

Therefore, it was believed that abnormal vertical distribution of fine roots and cuticle damage have an influence on the water status of the pitch pine. The purpose of this study was to compare the temporal changes in water status among pitch pines

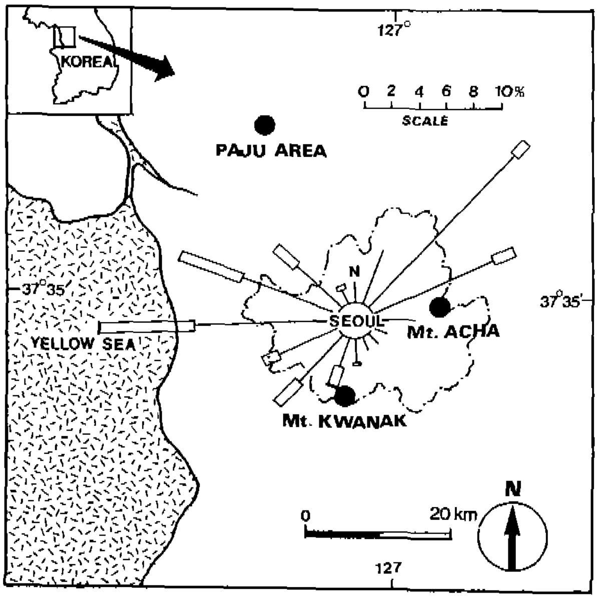

Fig. 1. Map showing the sampling sites (closed circles) and wind-rose in 1992 in and near metropolitan area of Seoul.

growing at urban, surburb and rural areas, and to investigate the effects of air pollutants, acid rain and soil properties on water deficit in the pitch pine.

STUDY AREAS

We selected the study sites considering the distance from the center of Seoul, the direction of wind, the properties of soil, the degree of plant damage and the vertical distribution of fine roots of the pitch pine (Rhyu, 1994). Mt. Acha, Mt. Kwanak and Paju, Kyonggi-do were selected as heavily polluted areas from urban Seoul, lightly polluted area from the surburb of Seoul, and unpolluted area from rural areas, respectively (Fig. 1).

The vertical distribution of fine roots of pitch pines at three areas investigated by Rhyu *et al.* (1994) was described in Table 1. Fine roots of the pitch pine at Mt. Acha and Mt. Kwanak were distributed more in litter layer than in soil layer compared with those at Paju (Table 1).

In Seoul, mean annual air temperature was 12.1℃ and mean annual precipitation was 961 mm (Fig. 2). These data are mean values measured for 10 y at the Meteorological Station of Seoul.

All sites selected are facing south. The parent rock is weathered granite, and all soils with high content

Table 1. Vertical distribution of fine roots of pitch pine growing at Mt. Acha, Mt. Kwanak and Paju areas

	Amount of fine roots (kg/ha)		
	Mt. Acha	Mt. Kwanak	Paju area
Litter layer	435.2 (38.6%)	672.0 (45.3%)	27.2 (2.0%)
0- 5 cm of soil	504.6 (44.8%)	647.7 (43.7%)	926.0 (69.8%)
5-10 cm of soil	187.1 (16.6%)	163.1 (11.0%)	374.4 (28.2%)

Data from Rhyu (1994).

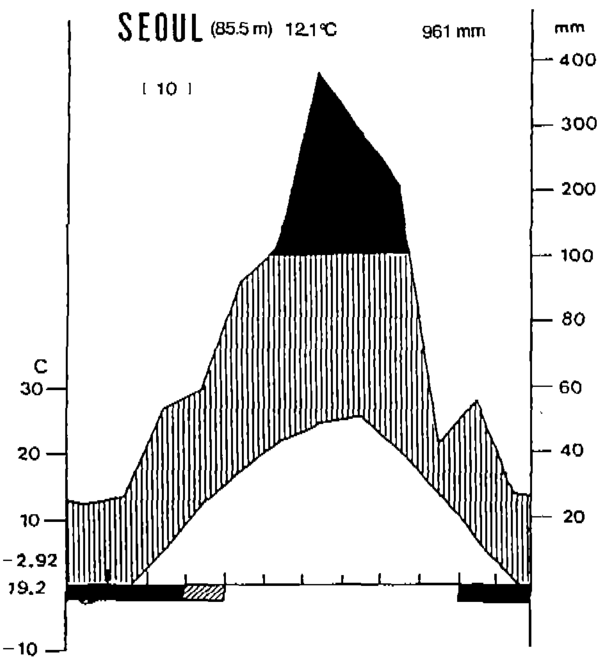

Fig. 2. Climate-diagram for the investigated areas. Data from the Meteorological Auxiliary Station in Seoul.

of sand are shallow. The vegetation of the study area was very poor in species richness, and the tree layer at all sites was composed almost entirely of pitch pines.

Site 1: Mt. Acha—This site (37°35′N, 127°06′E) is located at 9.9 km to northeast from the center of Seoul and has been reported as a heavily polluted area (Office of Environment, 1990). Most of the needles of previous y of pitch pines were shed. The coverage of tree layer, shrub layer and herb layer were 60, 40 and 20%, respectively. The shrub layer and the herb layer were dominated by *Lespedeza cyrtobotrya* and *Carex lanceolata,* respectively.

Site 2: Mt. Kwanak—This site (37°26′N, 126°56′E) is located at 13.4 km to south from the center of Seoul and is thought as a lightly polluted area. Most of the needles of previous y of pitch pines were shed. The coverages of tree layer, shrub layer and herb layer were 80, 30 and 10%, respectively. The shrub layer and the herb layer were dominated by *Quercus mongolica*, *Rhododendron mucronulatum* and *Spodiopogon cotulifer*, respectively.

Site 3: Paju, Kyonggi-do—This site (37°48'N, 126° 50'E) is located at 30.6 km to northwest from the center of Seoul and was selected as a relatively unpolluted area. Previous year's needles of pitch pines existed. Coverage of tree layer, shrub layer and herb layer were 90, 30 and 10%, respectively. The shrub layer were dominated by *Robinia pseudo-acacia* and *Q. dentata*.

MATERIALS AND METHODS

Sampling of pitch pine branches

Upper, middle and lower branches from pitch pines (*Pinus rigida* Mill.) were sampled with a fishing pole and a hook every 10 d from January to July in 1992 at heavily polluted Mt. Acha, lightly polluted Mt. Kwanak, and unpolluted Paju areas. Branches were sampled from 5 trees at each site. The branches were carried to laboratory in polyethylene bag as quickly as possible in order to reduce transpiration.

Culture of plants and treatment of simulated rain or ions

Pitch pine cones were collected at Mt. Kwanak in the fall of 1991 and seeds were germinated in vermiculite early in April, 1992. Nine seedlings were transferred from vermiculite to acid washed sand early in May and then grown in greenhouse. All seedlings were sufficiently supplied with nutrient solution (control) (Cumming and Weistein, 1990) and treatment solutions, which were 100 μM Al (+Al), Al and Mg deficiency (+Al−Mg) and Mg deficiency (−Mg) (Rhyu, 1994), at every 2 d until late September, 1992.

The pH 3.5 of simulated acid rain (SAR) was adjusted by adding H_2SO_4 and HNO_3 in a 3 : 1 equivalent ratio to the distilled water. The pH 5.6 of control rain was adjusted by dissolving CO_2 to the distilled water.

Seedlings were soaked completely with SAR by hand sprayer for 30 min. These procedures were carried out every 2 d from May to September.

Measurements of water content and water saturation deficit

The water content (WC) and the water saturation deficit (WSD) of needles were determined with the following equations by Barrs and Weatherley (1962):

$$\text{WC (\%)} = \frac{\text{fr wt} - \text{dry wt}}{\text{dry wt}} \times 100$$

$$\text{WSD (\%)} = \frac{\text{saturated wt} - \text{fr wt}}{\text{saturated wt} - \text{dry wt}} \times 100$$

Measurements of RWC

In order to compare transpiration rates of needles with different ages, needles were sampled from current branches (9 month-old) in January, 1992, and previous branches (14 month-old) and current branches (2 month-old) in June, 1992 at 3 sites. In order to compare transpiration rates of shoots of pitch pine seedlings grown in different soils with SAR for 4 months, shoots of seedlings were sampled. Needles or shoots saturated with water were placed in dark room (4℃), and then relative water content (RWC) of needles and shoots were determined after 2, 4, 12, 20, 30, 44 and 56 h, and 2, 6, 12, 20, 30, 54, 78, 102 and 126 h, respectively, by the following equation:

$$\text{RWC (\%)} = \frac{\text{fr wt} - \text{dry wt}}{\text{saturated wt} - \text{dry wt}} \times 100$$

Measurements of water potential

Water potential of needles treated with simulated rain for 4 months were determined by using a microvoltmeter (Wescor, HR-33T) after 1, 4, 6, 7, 8, 9, 10, 11 and 12 d after water withdrawal. The measurements of water potential of the needles were replicated 4 times.

RESULTS

Seasonal changes in water content of needles

Water content of needles of pitch pines grown at three areas was ranged between 130-150% in January,

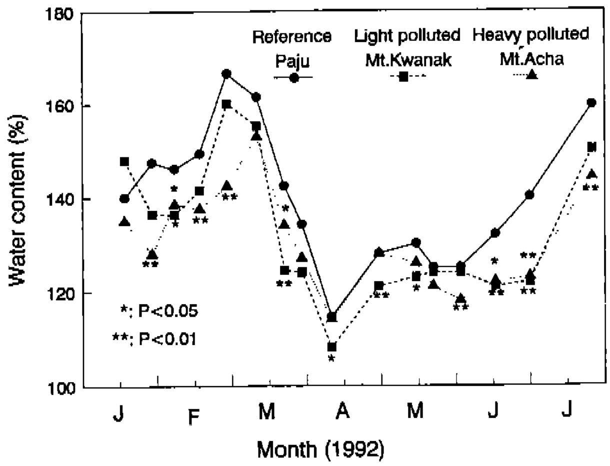

Fig. 3. Seasonal changes of water content (*in situ*) of pitch pine needles growing at Mt. Acha as a heavily polluted area, Mt. Kwanak as a lightly polluted area and Paju, Kyoggi-do as an unpolluted area from January, 1992 to July, 1992.

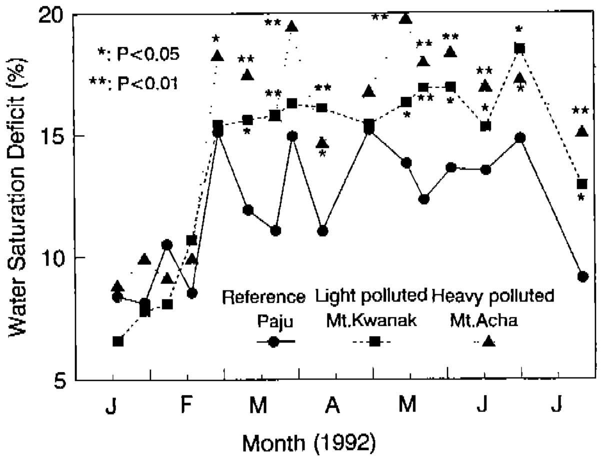

Fig. 4. Seasonal changes of water saturation deficits (WSD) (*in situ*) of pitch pine needles growing at Mt. Acha as a heavily polluted area, Mt. Kwanak as a lightly polluted area and Paju, Kyoggi-do as an unpolluted area from January, 1992 to July, 1992.

between 140-170% in early March, between 107-115% in mid-April, and between 140-160% in mid-July, and was the lowest in early April (Fig. 3). WC of needles growing at Mt. Acha and Mt. Kwanak (polluted areas) usually lower than that at Paju, Kyonggi-do (unpolluted area).

Seasonal changes in WSD of needles

WSD of needles of pitch pines ranged 6.6-10.7% in January-February, between 11.0-19.7% in March-June, between 7.1-15.0% in July among three sites, and was the highest in April (Fig. 4). Value of WSD of needles at Mt. Acha during spring was higher than those 11.0-15.1% at Paju. Value of WSD of needles growing at polluted areas was usually higher than that at unpolluted area. These results indicated that water in the needles growing at the polluted areas was usually more deficient than that at unpolluted area, and was more deficient in April than other months.

Temporal changes in RWC of needles with different ages

RWC of 2 month-old needles grown at Paju, Mt. Kwanak and Mt. Acha were 96, 96 and 97% after 2 h of water saturation, and 78, 78 and 79% after 56 h of water saturation, respectively (Fig. 5).

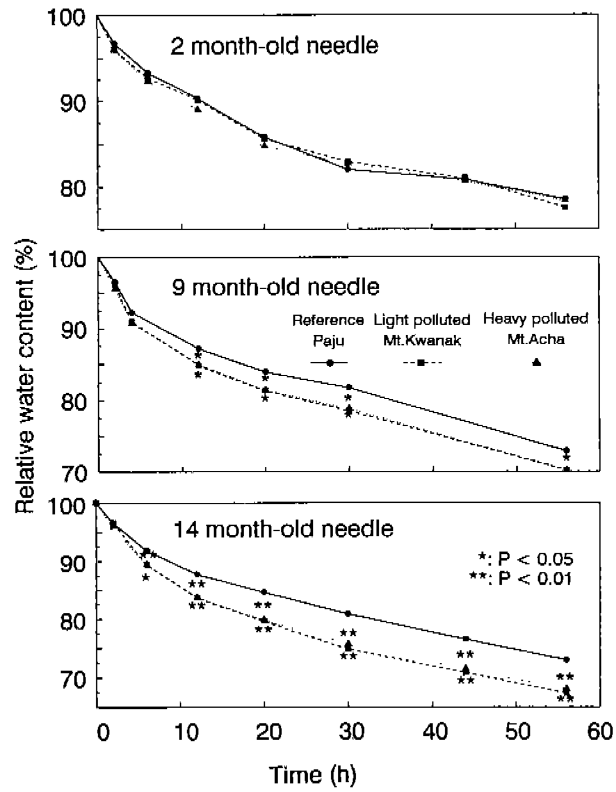

Fig. 5. Temporal changes of relative water content of 2, 9 and 14 month-old needles detached from pitch pine growing at Mt. Acha as a heavily polluted area, Mt. Kwanak as a lightly polluted area and Paju, Kyonggi-do as an unpolluted area.

RWC's of young needles did not differ among the areas. RWC's of 9-month old needles grown at Paju, Mt. Kwanak and Mt. Acha were 92, 91 and 91% after 2 h, 84, 81 and 81% after 20 h, and 73, 70 and 70% after 56 h, respectively. RWC's of 9 month-old needles grown at polluted areas decreased more quickly than that at unpolluted area. RWC's of 14 month-old needles grown at Paju, Mt. Kwanak and Mt. Acha were 92, 89 and 89% after 6 h, 85, 80 and 80% after 20 h, and 73, 67 and 68% after 56 h, respectively. RWC's of 14 month-old needles grown at polluted areas decreased more quickly than that at unpolluted area. At polluted areas, the older the needles were, the more quickly transpirated the water in needles was. But at unpolluted area, water in old needles was not so quickly transpirated as those at polluted areas.

Temporal changes in water potential of needles after water withdrawal

Water potential of needles treated with SAR (pH 5.6 and pH 3.5) for 5 months decreased slowly from 4 d after water withdrawal, and it decreased quickly from 10 d (Fig. 6). Water potential of needles treated with SAR of pH 3.5 decreased more quickly than that of needles treated with SAR of pH 5.6 for 5 months.

Temporal changes in RWC of shoots treated with SAR

RWC of shoots treated with SAR (pH 5.6 and pH 3.5) for 5 months decreased along with time (Fig. 7). Effect of SAR of pH 3.5 on loss of water through epicuticular layer was small at first. But the loss increased from 102 h after water saturation.

Loss of water through epicuticular layer of shoots growing in varying chemical treatments decreased along with time in the following order as soil conditions became worsen: −Mg+Al>+Al>−Mg>control (Fig. 8). The effect of acidity of SAR on the loss was small than the effect of nutrient deficiency or aluminium toxicity.

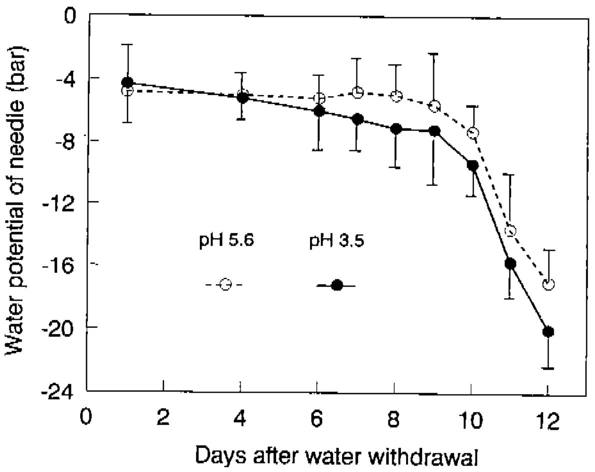

Fig. 6. Decline trends of water potential of needles of pitch pine seedlings after water withdrawal. The seedlings were cultured under conditions of spraying with pH 3.5 or pH 5.6 of simulated rain for 5 months.

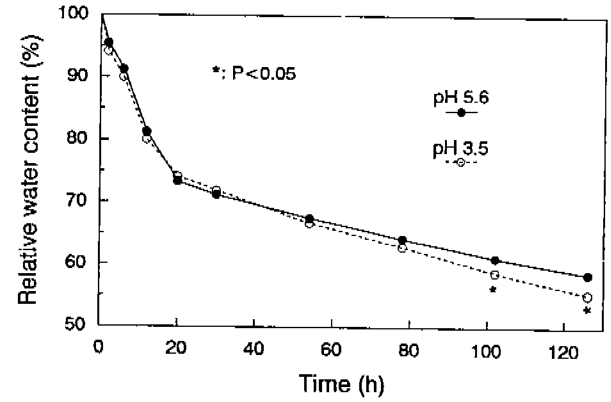

Fig. 7. Temporal changes of relative water content of shoots detached from pitch pine seedlings grown for 5 months in greenhouse. The seedlings were cultured under conditions of spraying with simulated rain of pH 3.5 or pH 5.6 for 5 months.

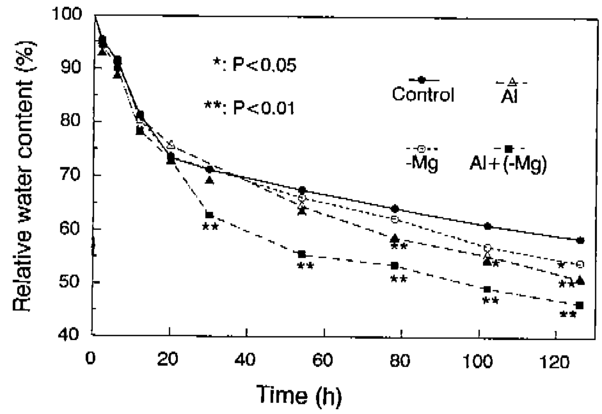

Fig. 8. Temporal changes of relative water content of shoots detached from pitch pine seedlings grown for 5 months in sand culture. The seedlings were grown under conditions of control, Mg deficiency (−Mg), 100 μM Al plus litter extract (Al+Lit), 100 μM Al (Al), and 100 μM Al plus Mg deficiency (Al−Mg) cy spraying with simulated rain of pH 5.6 for 5 months.

DISCUSSION

WC of needles of pitch pines with superficial rooting at Mt. Acha and Mt. Kwanak in metropolitan areas of Seoul (polluted areas) was always less than those of needles of pitch pines with deep soil rooting at Paju (unpolluted area) from January to July (Fig. 3). Contrary to WC, WSD, which indicates the degree of water deficit in plants, was higher in pitch pines with superficial rooting at urban Seoul (polluted area) than that with deep soil rooting at unpolluted area (Fig. 4). WC of needles was small in early April at all areas. Difference of WSD of needles between polluted and unpolluted areas was greater especially in spring, a dry season in Korea. Water deficit in pitch pines in spring was thought to be caused by the higher wind speed and the lower relative humidity in spring compared to other seasons in Korea (KMA, 1991).

The water deficit in pitch pine at metropolitan area of Seoul can be explained by several causes. Firstly, fine roots of pitch pine were distributed more in litter layer or shallow soil layer and the amount of fine roots was smaller compared with that at control area (Rhyu and Kim, 1994). Lee (1984) reported that growth of red pine growing at shallow soil was worse than that grown at deep soil because roots growing at shallow soil can not use much amount of water. Pitch pines with superficial fine rooting, therefore, can not absorb much water especially during dry season compared with those growing in deep soil layer. Ulrich (1990) hypothesized that one of the causes of forest decline in Europe is an abnormal distribution of fine roots.

Secondly, the epicuticular transpiration through young needles (2 month-old) exposed to polluted atmosphere for short period did not differ from that exposed to unpolluted atmosphere (Fig. 5). But epicuticular transpirations of old needles (9 and 14 month-old) exposed at polluted areas for long period were higher than those at unpolluted area. These results suggested either a loss of capacity for stomatal closure or increased epicuticular transpiration by the air pollutants (O_3, SO_2 and/or acidic deposits) or the dusts. The water deficit of pitch pine, therefore, might occur by needle damage caused directly by the air pollutants or the dusts. These results are in accordance with Godzik and Piskornik (1966) which showed that leaves from a polluted area dried faster than those taken from an unpolluted area. Krause (1981, 1983) and Karhu and Huttunen (1986) reported that amount of epicuticular wax decreased by air pollutants and degradation of epicuticular layer was severe in January and Feburuary when concentration of air polluants was the highest in the atmosphere. Pierre and Queiroz (1988) reported that air pollutants (SO_2) increased transpiration from plants.

Thirdly, pitch pine seedlings lost water more quickly by SAR of pH 3.5 than by that of pH 5.6 (Figs. 6 and 7). This result is in accordance with Mengel *et al.* (1988) which showed that the cuticular transpiration was significantly increased by pretreatment with acidic fog of pH 3.0. These results suggested that epicuticular wax layer was directly damaged by acidic deposits. This suggetion was proved with SEM micrographs of damaged epicuticular wax layer by Mengel *et al.* (1988). Lee *et al.* (1990) reported that change in water potential of loblolly pine seedling after treatment of acid rain and O_3 was sensitive to dry season. The water deficit of pitch pine in polluted Seoul, therefore, can occur directly by acidic deposits.

Fourthly, pitch pine seedlings grown in soil with many stressors (*i.e.* Mg deficiency and Al toxicity for plants) lost water more easily than those grown in control soil (Fig. 8). This result might be explained by two assumptions. 1) As stressors (*i.e.* increase of soluble Al^{3+} and H^+ ions, and cation deficiency in soil) for the growth of fine roots in acidic soil increase, energy (*i.e.* carbohydrates) synthesized in needles should be translocated to fine roots to cope with stressors (Rhyu, 1994). Therefore, epicuticular layer of needle will be thin, and transpiration through epicuticular layer will occur easily. 2) Pitch pine in acidic soil might be inhibited to the use of soil water by Al toxicity in fine roots (Zhao *et al.*, 1987).

In conclusion, pitch pines with a degraded epicuticular wax layer directly caused by acidic deposits or air pollutants might lose water easily by cuticular transpiration. In addition, as these trees have superficial rooting caused indirectly by acid deposition, pitch pine can not sufficiently use soil water. Therefore, needles from upper branches in pitch pine will be susceptible to water stress. It can, therefore, be assumed that the decline of pitch pine widely occurring in polluted Seoul could to a large extent be caused by cuticle degradation and abnormal vertical distribution of fine roots, which lead to water stress, particularly in dry seasons, in addition to Mg deficiency and Al toxicity. This would be in agreement with our observations that the decline symptoms in spring were yellowing of needles followed by needle shedding from upper branches. This process is a protection mechanism against water stress. It is not directly lethal, but if water stress occurs frequently, as is the case of trees with damaged needle waxes, the tree will lose needles more and more and will finally die.

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首都圈 地域에서 잔뿌리의 上向分布와 大氣汚染 物質에 의한 리기다소나무 水分 不足

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적 요

오염 정도가 다른 3지역, 즉 도심, 주변지 및 전원지에 생육하는 리기다소나무의 수분 상태를 1-7월까지 10일 간격으로 조사하였다. 대기 오염, 산성 빗물, 토양 특성이 리기다소나무 수분 상태에 미치는 영향을 조사하였다. 오염된 도심지에서 생육하는 리기다소나무 잎의 수분 함량은 대조지의 것보다 언제나 낮았다. 또한 잎의 수분포화결차는 후자보다 전자가 대부분 높은 값을 보였다. 특히 잎의 수분 부족은 4월에 심하였다. 그리고 오염지에서 잎의 연령이 오래될수록 대조지의 것에 비해 더욱 빨리 건조해졌다. pH 3.5의 인공 산성 빗물이 5개월 동안 처리된 리기다소나무 유식물은 건조 처리 후 정상 빗물(pH 5.6)이 처리된 것보다 일찍 수분퍼텐셜이 낮아졌다. 그리고 여러 가지 무기이온이 처리된 토양에서 생육한 리기다소나무 유식물의 수분은 건조 후 다음과 같은 순서로 빨리 없어졌다. 대조구<Mg 부족구<Al 처리구<Al 처리+Mg 부족구. 이와 같은 결과를 종합해 볼 때, 대도시인 서울에서 일어나는 리기다소나무의 생장 감소는 토양의 산성화 이외에 대기오염에 의한 잎 큐티클층의 붕괴, 비정상적인 잔뿌리의 분포에 의한 수분 흡수의 감소 등으로 인한 식물체의 수분 부족으로 인하여 일어났음을 시사한다.

주요어: 리기다소나무 쇠퇴, 수분 스트레스, 산성비, 대기 오염 물질, 천근성 잔뿌리

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