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Growth of Korean Pine Seedlings Planted in Granite-forest Soil Treated with H_2SO_4, HNO_3 and HCl Solution

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Summary

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Growth of pine trees has declined recently near industrial areas in Korea. A possible cause of this decline is soil acidification. To find the tolerance level of pines against acid soil, 3-year-old Korean pine seedlings (*Pinus koraiensis* Sieb. et Zucc.) were planted in granite forest soil, treated with acid solutions of H_2SO_4, HNO_3 and HCl (SO_4^{2-} : NO_3^- : Cl^- = 5 : 3 : 2), and grown for 182 days. Five concentrations of H^+ ions in the soil were used (0 (control), 10, 30, 60 and 90 $mmolH^+ \cdot kg^{-1}$). With increasing H^+ in the soil, the concentrations of Ca, Mg, K, Al and Mn all increased (at < pH=3.8). Al and Mn concentrations increased significantly in all seedlings with increasing H^+. The effect of deliberate soil acidification on seedling growth was evaluated based on the (Ca+Mg+K) /Al ratio (i.e. base cation (BC)/Al ratio). Strong positive correlation was observed between the total dry mass (TDM) of seedlings and the BC/Al ratio ($r = 0.99$, $p<0.001$). When the BC/Al ratio reached 1.0, the TDM had fallen to 40%. These results show that artificial soil acidification reduces the growth of Korean pine seedlings, but less for the Red pine (*Pinus densiflora* Sieb. et Zucc.).

Introduction

In recent years, the growth of major pine species in Korea has declined near industrial areas (CHOI & al. 2003). Soil acidification caused by dry or wet

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deposition is usually accompanied by an increase in leaching of base cations (i.e. Ca^{2+}, Mg^{2+} and K^{+}) from the soil to the ground water. Moreover, there is an increase in Al and Mn in the rhizosphere. The health and vitality of pines are directly affected by nutrient deficiency and/or imbalance of cations and excess accumulation of Al and Mn (ULRICH 1989). Pine trees are dominant on forest soils that originated from granite. In forests suffering poor health, degraded areas should be rehabilitated using native species such as the Korean pine and Red pine. It is important to determine the effects of the observed increase in soil acidification on the natural regeneration of these pine species. The BC/A1 ratio (SVERDRUP & al. 1994) is a useful criterion for evaluating the specific tolerance of species against soil acidification. Here, we use this criterion to estimate the tolerance to acid of the Korean pine.

Material and Methods

Soil treatment

Brown forest soil deriving from granite was collected from a 26-year-old Korean pine forest within the university forest of Kyung Hee (Kwangju, Kyunggido, Korea). An acid solution prepared from H_2SO_4, HNO_3 and HCl, having anions in the mol ratio $SO_4^{2-} : NO_3^{-} : Cl^{-} = 5 : 3 : 2$, was applied to the soil. This is the anion ratio occurring in precipitation during the late 20th century near university forest of Kyung Hee (JIN & al. 1999). The soil H^{+} concentration was 0, 10, 30, 60 and 90 $mmolH^{+} \cdot kg^{-1}$. After one month of treatment, 3-year-old Korean pine (*Pinus koraiensis* Sieb. et Zucc.) seedlings (50 seedlings per treatment) were planted individually in plastic pots. They were raised in a well-ventilated greenhouse (sunlight 85%) and watered well to prevent natural wet and dry deposition.

Plant growth analysis

To determine the initial size of the seedlings, 21 individuals were selected at random. At 182 days after planting, five seedlings were sampled randomly from each treatment to determine the dry mass of each organ of the plant (needle, stem, root). The relative growth rate (RGR) and net assimilation rate (NAR) were calculated. The relative total dry mass (TDM) of the seedlings was calculated as follows: TDM (%) = (average TDM of the seedlings grown in the soil acidified with our solution) / (average TDM of the seedlings grown in the control soil)×100.

Measurement of element concentrations

The concentrations of water-soluble elements (Ca, Mg, K, Al and Mn) in soil were determined by an atomic absorption spectrophotometer (Z-8230, Hitachi Co. Tokyo, Japan) after mixing 20 g of soil with 100 ml of distilled water in a 300 ml Erlenmeyer flask, which was then shaken for 1 hour at 25°C. The soil pH was determined using a pH meter (CH-8603, Mettler-Toledo AG). Statistical analyses were carried out using the Mixed and Genmod procedures in the SAS system (SAS 1998). Tukey's Studentized Range (HSD) test was employed to separate means at $p<0.05$.

Results and Discussion

The pH of the soil solution decreased with increasing H^{+} load (Fig. 1). The concentration of water soluble Al, Mn, Ca and Mg increased significantly with decreasing soil pH (Table 1). Moreover, the concentrations of Al and Mn in each organ increased significantly with H^{+} loading (Table 2). The dry mass of the whole plant, each organ, RGR and NAR was significantly reduced at 60 and 90 mmol$H^+ \cdot kg^{-1}$ (Table 3, Fig. 2). We found a negative correlation between the needle Al concentration and the NAR (r = -0.94) or RGR (r = -0.95), and also between the needle Mn concentration and the NAR (r = -0.94) or RGR (r = -0.91) of the seedlings. Moreover, the water content of needles was significantly less at 60 and 90 mmol $H^+ \cdot kg^{-1}$ (Table 4). Meristem activity of the root tip is inhibited by an increase in Al concentration or by deficiencies of Ca and Mg of seedlings (ERICSSON & al. 1995). Even though Mn in foliage organs usually reduces photosynthetic function at PS II (KITAO & al. 1997), the combined effects of Al in roots and Mn in needles may reduce the total dry mass, RGR, NAR and needle water content of Korean pines.

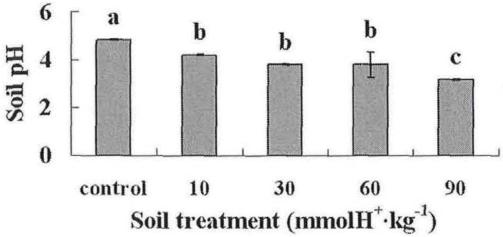

Fig. 1. Soil pH in each treatment. (n=6).

Table 1. The pH and concentration of water-soluble elements in soil immediately before transplantation. (n=6).

Soil treatment	Water-soluble element concentration ($\mu g \cdot g^{-1}$)					(Ca+Mg+K)/Al
	Ca	Mg	K	Al	Mn	($mol \cdot mol^{-1}$)
Control	66.2 e	2.08 e	10.4 e	1.4 d	0.83 e	37.29
10mmol$H^+ \cdot kg^{-1}$	92.9 d	6.66 d	15.4 d	9.9 cd	3.33 d	8.14
30mmol $H^+ \cdot kg^{-1}$	157.0 c	14.58 c	22.1 c	19.0 c	15.83 c	7.22
60mmol $H^+ \cdot kg^{-1}$	231.2 b	17.91 b	27.9 b	98.6 b	28.32 b	1.98
90mmol $H^+ \cdot kg^{-1}$	263.6 a	21.24 a	32.5 a	229.8 a	44.57 a	0.97

We found a strong positive correlation between the TDM of Korean pine seedlings and the BC/Al ratio, i.e. (Ca+Mg+K)/Al, in the soil (Fig. 3). The critical limits for growth are: soil pH below 4.4; labile aluminum higher than 2.0 mg L^{-1}; a BC/Al ratio below 1.0 (SVERDRUP & al. 1990). Similar findings have been reported for spruce and pines (AROVAARA & ILVESNIEMI 1990, BRUNNER & al. 1999, CHOI & al. 2004, ILVESNIEMI 1992, LEE & al. 1997, SVERDRUP & al. 1994). A threshold for critical acid deposition was determined using the molar BC/Al ratio in the soil solution with ratio 1.0. The TDM of *Cryptomeria japonica* (IZUTA & al. 1997) and *Pinus densiflora* (LEE & al. 1997) fell to 40~50% of control values.

Table 2. Concentrations of various minerals in needles and roots of Korean pine seedlings grown in the acid-treated brown forest soil. (unit = $mg \cdot g^{-1}$) (n=6).

	Soil treatment	Ca	Mg	K	Al	Mn	N
Needle	control	4.71 b	2.07 c	6.64 b	0.99 b	0.82 c	13.2 c
	10mmol$H^+ \cdot kg^{-1}$	5.89 a	2.52 ab	7.92 a	0.91 b	0.93 bc	14.5 ab
	30mmol $H^+ \cdot kg^{-1}$	5.37 ab	2.22 bc	7.06 ab	1.16 ab	0.93 bc	13.8 bc
	60mmol $H^+ \cdot kg^{-1}$	5.71 ab	2.27 abc	7.00 ab	1.36 ab	1.02 b	13.7 bc
	90mmol $H^+ \cdot kg^{-1}$	6.01 a	2.60 a	7.48 ab	1.62 a	1.24 a	14.9 a
Root	control	5.55 a	1.85 a	3.53 a	8.50 b	0.38 b	8.00 c
	10mmol$H^+ \cdot kg^{-1}$	3.59 b	1.29 b	2.51 b	8.52 b	0.41 b	10.6 ab
	30mmol $H^+ \cdot kg^{-1}$	4.15 b	1.03 c	2.59 b	8.15 b	0.39 b	10.7 ab
	60mmol $H^+ \cdot kg^{-1}$	2.65 c	1.20 bc	2.65 b	10.8 a	0.49 ab	10.1 b
	90mmol $H^+ \cdot kg^{-1}$	1.81 d	1.08 bc	2.30 b	11.7 a	0.54 a	11.2 a

Table 3. Effect of soil acidification on relative growth rate (RGR), net assimilation rate (NAR), relative total dry mass (TDM) of Korean pine seedlings during a 182 day growth period. (n=6).

Soil treatment	RGR	NAR	Relative TDM
		(% of control)	
Initial	100	100	100
Control	100 a	100 a	100
10mmol$H^+ \cdot kg^{-1}$	98 a	91 a	103.7
30mmol$H^+ \cdot kg^{-1}$	91 a	84 a	99.4
60mmol$H^+ \cdot kg^{-1}$	60 b	58 b	77.3
90mmol$H^+ \cdot kg^{-1}$	35 b	36 b	65.0

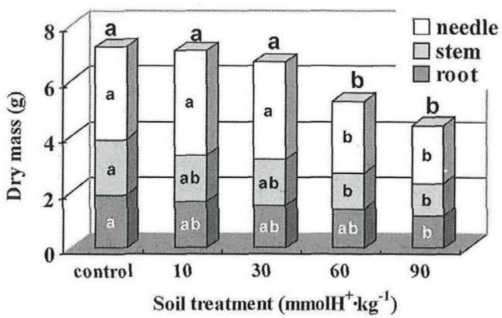

Fig. 2. Dry mass of pine seedlings in each treatment. (n=6).

Table 4. Water content of needles in each treatment. (n=6).

Soil treatment	Water content of needles (%)
Initial	58.6
Control	47.9 a
$10 mmol H^{+} \cdot kg^{-1}$	47.6 a
$30 mmol H^{+} \cdot kg^{-1}$	52.9 a
$60 mmol H^{+} \cdot kg^{-1}$	36.9 b
$90 mmol H^{+} \cdot kg^{-1}$	34.1 b

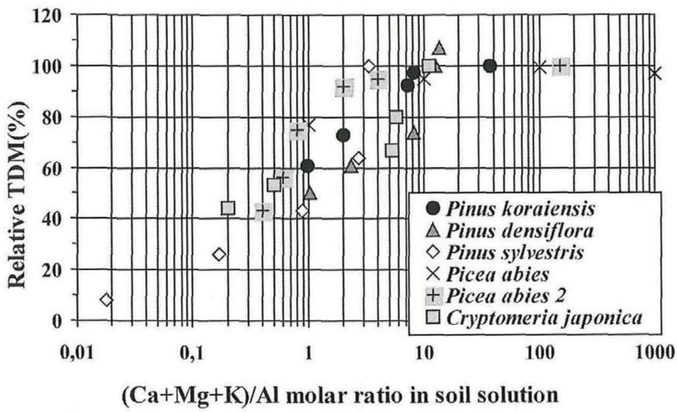

Fig. 3. Relation between the (Ca+Mg+K)/Al molar ratio in soil solution and relative total dry mass (TDM) of *Pinus koraiensis* (present study), *Pinus densiflora* (LEE & al. 1997), *Pinus sylvestris* (ILVESNIEMI 1992), *Picea abies* (BRUNNER & al. 1999), *Picea abies* 2 (AROVAARA & ILVESNIEMI 1990), *Cryptomeria japonica* (IZUTA & al. 1997).

At the same BC/Al of 1.0, the reduction in the TDM of Norway spruce seedlings was 20% (SVERDRUP & al. 1994), and was 50% for Red pine (LEE & al. 1999) and 55% for Scotch pine (ILVESNIEMI 1992). The reduction in TDM relative to spruce implies that pine species are more sensitive to soil acidification. Our present results indicate that Korean pine is more sensitive to a decline in the molar BC/Al ratio of the soil solution than Norway spruce. We also find that the Korean pine is more resistant to BC/Al than the Red pine. We conclude that the Korean pine is more suitable for forest rehabilitation in acidified regions than the Red pine or Scotch pine.

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