C－3 Studies on Critical Load of Acid Substances

(2) Studies on Critical Load in Soils

① Experimental Studies on the Evaluation of Critical Load in Soil-Plant Ecosystem

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[Abstract]

Effects of soil acidification on dry weight growth of Japanese cedar seedlings (Cryptomeria japonica D.Don) were investigated in soils originated from different parent materials. Dry weight growth of the seedlings was supressed with increasing the amounts of H^+ added for controlling the soil acidification. The growth reduction of the plants was greater in brown forest soil and red-yellow soil than in andosol when equal mounts of H^+ were added to each soil.There was a highly negative correlation between the dry weight growth of the seedlings and the concentration of water-soluble Al in the soils.The threshold concentration of the mentioned Al for inducing growth reduction was 20 μg/g(ppm). When the molar ratio of (Ca+Mg+K)/Al in brown forest soil(originated from granite) was lowered below 10, the dry weight growth was depressed, e.g. ca. 50% reduction at the ratio of 1.0.

Key Words Acid Deposition, Brown Forest Soil,Soil Acidification, Cation Leaching,Japanese Cedar,Growth Effects

1. Introduction

Little is known about the effects of soil acidification on tree species native to Japan[3,5]. Izuta et al.[3] have investigated growth and nutrient status of two-year-old seedlings of Japanese cedar(Cryptomeria japonica) grown in andosol artificially acidified by adding H_2SO_4 solution from the surface of the potted soil at one-day-intervals for 80 days, and reported that the dry weight growth and concentration of Ca and Mg of the seedlings were significantly reduced by the additional supply of H^+ to the soil.

In this study, we investigated growth and nutrient staus of Japanese cedar seedlings grown in soils originated from different materials which were artificially acidified by adding H_2SO_4 solution before use.

2. Research objective

For obtaining basic data for evaluating critical load of acid deposition in forest ecosystem, the effects of soil acidification on dry weight growth of two-year-old Japanese cedar seedlings grown in soils originated from different materials were investigated.

3. Research method

(1) Two-year-old seedlings of Japanese cedar (Cryptomeria japonica D.Don) were grown in andosol originated from volcanic ash, red-yellow soil originated from sedimentary rocks and brown forest soil(granite as a mother rock). One week before transplanting the seedlings, the three soils were artificially acidified by the addition of H_2SO_4 solution at 10, 30, 60 or 100 meqH^+/L soil. The seedlings were grown in a greenhouse for 12 weeks in summer. The control soil was used without the additional supply of H^+. There were minor differences of soil pH(H_2O) value between soil at the initial harvest and that at the final harvest of the plant below 0.14 in all the treatments of tested soils. Data of soil pH at the initial harvest were applied for the analyses(Table 1).

Plant materials harvested at the initial and final samplings were dried and weighed to calculate the relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio(LAR) of the seedlings during the growth period. The dried plant materials were used for the measurements of element concentration, i.e. Ca, Mg, K and Al.

Soil analysis was conducted at the initial and final harvests of the seedlings. The concentration of Ca, Mg, K and Al in soils was determined with the atomic absorption spectrophotometer.

(2) The growth experiment was also conducted using brown forest soil from granite as a mother rock acidified by adding H_2SO_4 solution with or without leaching of cations from the soil. In soil acidification with leaching of cations from soil, diluted H_2SO_4 solution adjusted to pH 2.0 was added to the soil contained in a 500ml-pot with holes at the bottom (510 g air-dried soil/pot) at the volumes of 1.0, 1.5, 3.0 or 5.0 L/pot, which correspond to 20, 30, 60 and 100 meqH^+/L soil, respectively. In soil acidification without leaching, the soil was contaminated with H_2SO_4 solution of 1 L at 0.19 N or 0.27 , which corresponds to 20 and 30 meqH^+/L soil, respectively. The control soil was used without the additional supply of H^+. After the teatments of soil adicification,

the seedlings were tranplanted into the acidfied soil or the control soil, and then were grown in a greenhouse for 100 days in summer. Sampling and treatment of plant materials and soil analyses were the same as mentioned before.

4. Results

(1) Effects of soil acidification on growth of Japanese cedar seedlings grown in soils from different parent materials

Dry weight growth of the seedlings was reduced with increasing the amounts of H^+ added to the soils. The growth reduction of the seedlings was greater in brown forest soil and red-yellow soil than in andosol,and the growth reduction was closely related to the increase of Al concentration in soil. There was a highly negative correlation between the relative growth rate of the seedlings and the concentration of water-soluble Al in the soil(Fig.1). When the concentration of the mentioned Al in brown forest soils originated from different parent materials exceeded ca. 20μg/g air-dried soil, dry weight growth of Japanese cedar seedlings grown in the acidified soil began to reduce(Fig. 2). From the facts. the threshold concentration of the water-soluble Al in soil solution was obtained to be ca. 20 μg/g (ppm) in terms of apparent growth reduction of Japanese cedar seedling.

(2) Effects of soil acidification on growth and nutrient status of Japanese cedar seedlings grown in brown forest soil with different soil nutritions

The soil acidification was increased by adding H_2SO_4 solution and the concentration of water-soluble Al in soil increased with increasing the amount of H^+ added to the soil. When the concentration of water-soluble Al in soil was below ca. 100μg/g(ppm), the degree of reduction in the dry weight growth was greater in the seedlings grown in the acidified soils with leaching of cations than in those grown in the acidified soils without leaching (Fig.3). However,a positive correlation was observed between the dry weight growth of the seedlings and the molar ratio of Ca and Al(=Ca/Al ratio), Mg/Al ratio , K/Al ratio or (Ca+Mg+K)/Al ratio in the soil. Especially, the (Ca+Mg+K)/Al ratio gave the best consistency with the dry weight growth of the seedlings (Fig.4). The concentration of Ca, Mg or K in the roots tended to be reduced with decreasing the molar Ca/Al ratio, Mg/Al ratio or K/Al ratio in the soil, respectively. From the reuslts obtained in this study, the molar ratios in the soil such as (Ca+Mg+K)/Al and Ca/Al are considered to be useful indicators for evaluating the critical load of acidic deposition for the damage to forest trees in Japan.

5. Discussion

The important limiting factors for growth, physiological functions and nutrient status of plants grown in acid soils are considered to be high soil acidity itself, relatively high concentrations of metals such as Al and Mn in the soil solution and/or reduced availability of certain plant essential elements[1,6]. In the present experiments, when the seedlings were grown in andosol,red-yellow soil and brown forest soil artificially acidified by adding H_2SO_4 solution,the reduction in the dry weight growth of the seedlings was induced by low soil pH(H_2O) below 4.5(ref. Fig.1).There was a highly negative correlation between concentration of water-soluble Al in the acidified soils and dry weight growth of the seedlings. The difference between pH(H_2O) value of the control soil and that of the acidified soil in red-yellow soil and in brown forest soil was apparently greater than that in andosol, even when the same amount of H^+ was added to the soils. This indicates that a buffering capacity for proton input of red-yellow soil and brown forest soil was lower than that of andosol. For this reason, the concentration of water-soluble Al was greatly increased in red-yellow soil and in brown forest soil, but was not in andosol, with increasing the amount of H^+ added to the soils. As shown in Fig. 1,a negative correlation was observed between concentration of water-soluble Al in soils and relative growth rate of Japanese cedar seedlings, regardless of the difference of soil species. The threshold concentration of the mentioned Al for inducing growth reduction ws 20 μg/g(ppm). Therefore,excess Al dissolved in red-yellow soil and brown forest soil by the additional supply of H^+ is considered to be one of the limiting factors for the growth of the plant.

Recently, molar ratio of cation and Al in soil and nutrient solution have been regarded as more important factors for growth and nutrient status of woody plants than Al concentration itself[2,4]. For example, normal growth of European beech and Norway spruce hydroponically grown in a nutritent solution has been claimed to demand a molar ratio of Ca and Al(Ca/Al ratio) higher than 1.0 [7].

In the present experiment, there was a positive correlation between dry weight growth of Japanese cedar seedling grown in brown forest soils acidified by adding H_2SO_4 solution with leaching of cations from the soil and molar (Ca+Mg+K)/Al ratio in the soil. When the molar ratio of (Ca+Mg+K)/Al in brown forest soil was lowered below 10, the dry weight growth was depressed, e.g. ca. 50% reduction at the ratio 1.0 (Fig.4). Recently, Sverdrup et al.[8] have proposed the critical load map of acid deposition in Swedish forest ecosystem on the basis of the molar ratio of (Ca+Mg+K)/Al=1.0, which was obtained in

Norway spruce and scotch pine in Europe. The difference in Norway spruce and Japanese cedar seedlings of the relationship between (Ca+Mg+K)/Al ratio and dry weight growth,as shown in Fig.5, indicates relatively higher sensitivity in the latter plant than in the former one for the decrease of (Ca+Mg+K)/Al ratio.

From the results obtained in this study, the molar ratios in the soil such as (Ca+Mg+K)/Al and Ca/Al are considered to be useful for evaluating the critical load of acidic deposition for the forest decline in Japan.

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Table 1. The results of soil analysis conducted at starting the experiment

Soil	Soil treatment ($meqH^+/L$)	Water soluble element concentration ($\mu g/g$ dry soil)				
		pH(H_2O)	Ca	Mg	Mn	Al
Andosol	Control	4.79 (0.01)	43.3 (0.3)	13.0 (0.1)	7.4 (0.1)	n.d.
	10	4.58 (0.01)	66.9 (0.1)	19.8 (0.1)	12.6 (0.1)	n.d.
	30	4.40 (0.00)	101.2 (0.6)	32.0 (0.0)	25.9 (0.1)	3.0 (0.5)
	60	4.20 (0.00)	163.1 (0.5)	62.6 (0.3)	65.0 (0.0)	15.0 (0.6)
	100	3.97 (0.02)	206.3 (1.4)	113.8 (1.0)	174.2 (1.0)	64.4 (0.2)
Red-yellow soil	Control	4.50 (0.00)	8.7 (0.1)	2.1 (0.1)	4.9 (0.1)	n.d.
	10	4.19 (0.01)	23.9 (0.3)	5.6 (0.1)	14.8 (0.2)	2.9 (0.2)
	30	3.72 (0.01)	48.1 (0.1)	11.2 (0.0)	55.0 (0.2)	46.1 (0.5)
	60	3.45 (0.00)	48.7 (0.7)	13.0 (0.3)	105.5 (2.0)	175.7 (1.5)
	100	3.26 (0.01)	44.0 (0.3)	14.3 (0.0)	126.6 (2.0)	346.9 (0.1)
Brown forest soil	Control	4.30 (0.00)	22.7 (0.1)	6.5 (0.0)	4.1 (0.1)	3.6 (0.4)
	10	4.10 (0.00)	42.8 (0.2)	11.6 (0.1)	8.8 (0.0)	11.8 (0.5)
	30	3.75 (0.00)	63.8 (0.1)	15.5 (0.2)	24.5 (0.0)	91.7 (0.1)
	60	3.59 (0.01)	60.3 (2.4)	18.6 (0.2)	43.0 (0.3)	269.7 (1.1)
	100	3.45 (0.00)	50.2 (1.3)	20.7 (0.3)	53.5 (0.8)	473.4 (1.6)

Value in parenthesis shows standard deviation.
n.d., not detected.

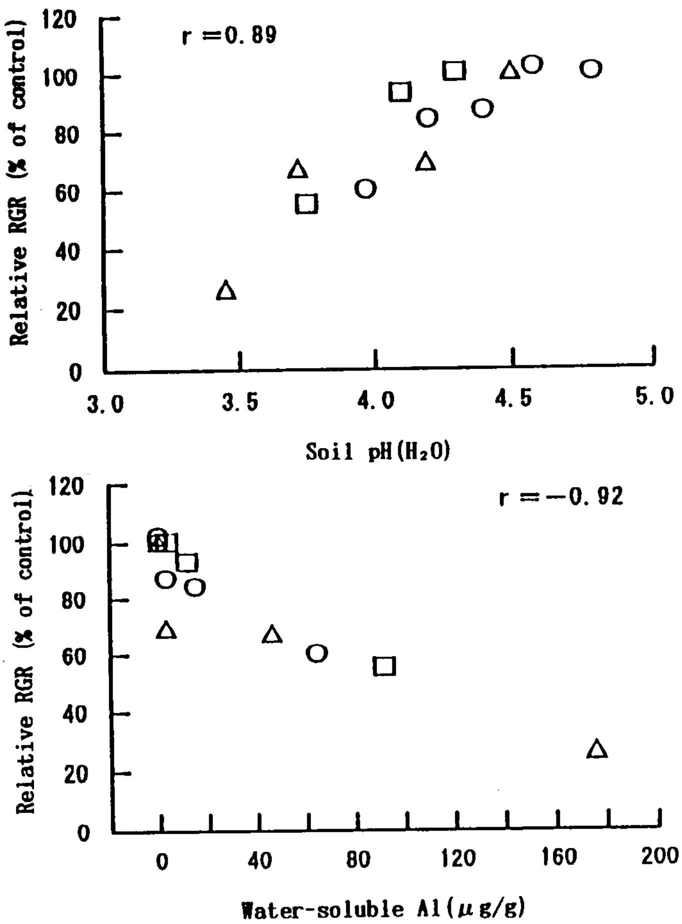

Fig.1 Relationship between soil pH(H_2O), water-soluble Al and relative growth rate (RGR, % of control) of Japanese cedar seedlings grwon for 12 weeks.
○ Andosol △ Red-yellow soil □ Brown forest soil

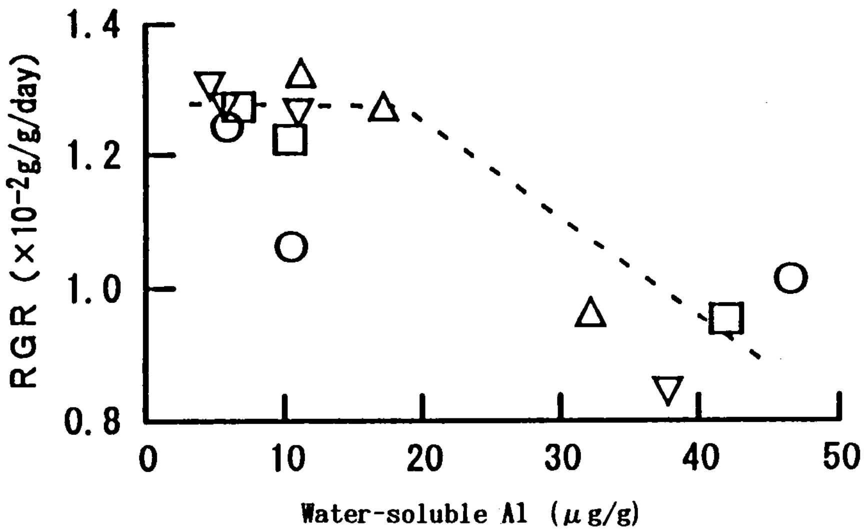

Fig.2 Relationship between water-soluble Al in soil and relative growth rate of Japanese cedar seedlings grwon in brown forest soils with different parent materials.
○ Volcanic ash □ Granite(Seto)
△ Granite(Kusaki) ▽ Sand stone

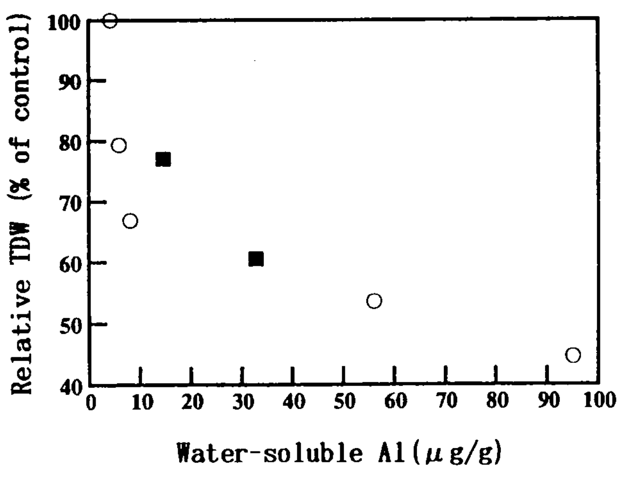

Fig.3 Relationship between water-soluble Al in soil and plant dry weight (TDW, % of control) of Japanese cedar seedlings at final harvest.
○ With cation leaching ■ Without leaching

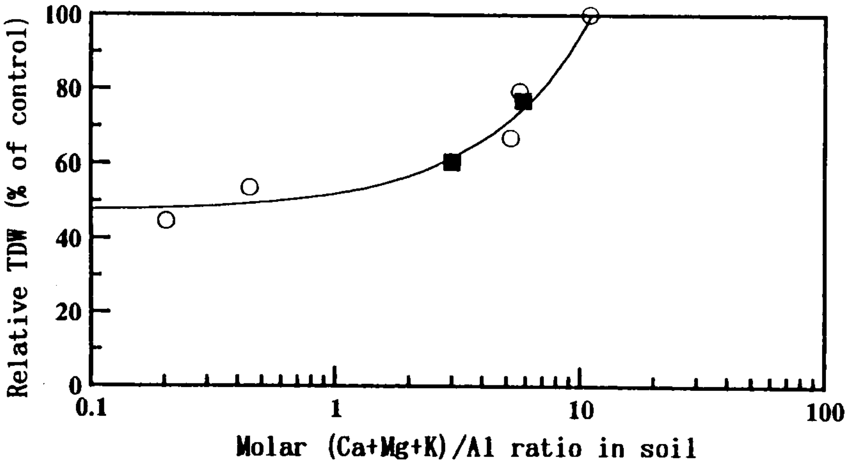

Fig.4 Relationship between malar (Ca+Mg+K)/Al ratio in brown forest soil and total dry weight of a whole plant (TDW) of Japanese cedar seedlings at final harvest. Relative TDW (%) was calculated by (TDW of the seedlings grown in the acidified soil /TDW of the seedlings grown in the control soil) × 100.
○ With cation leaching ■ Without leaching

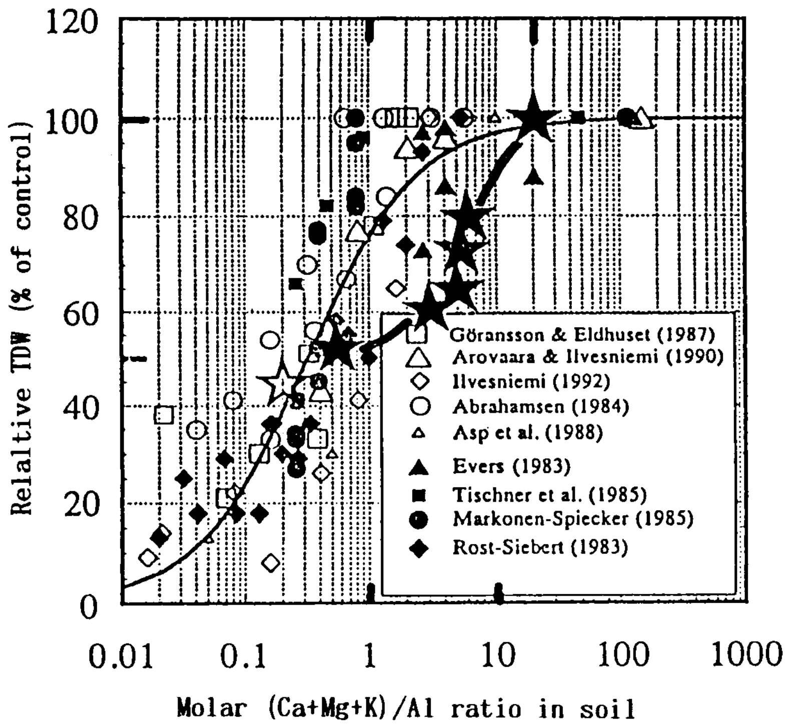

Fig.5 Relationship between molar (Ca+Mg+K)/Al ratio in soil and total plant dry weight (TDW, % of control) in Norway spruce, adapted from Sverdrup et al.[8].
★ data of Japanese cedar seedlings obtained in this study