C-1. 2. 3 Studies on the effects of environmental acidifying substances on nutrient cycling in forest ecosystem

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Abstract To develop methods for evaluating the effects of environmental acidic substances on forest ecosystems in east Asia, we investigated following subjects. 1) to observation of acid precipitation and forest conditions in China and Korea, and to compare elements budgets between forested catchments of Japan and Korea. 3) to investigate growth characteristics of Asian forest tree species on artificially acidifying soils conditions. 4) to determine nitrification rates of various types of soil and forest, and also to determine the effect of organic acids on soil acid buffering capacity.

Monitoring study on input and output budget of acidic substances in a small catchment under red pine forest has been carried out in Hachioji of Japan from July of 1996 to October of 1998 and in Chunchon of Korea from May to December of 1997 and from April to October of 1998. "Acid precipitation" and the accumulation of acidic substances were found in the Hachioji catchment. Although acid precipitation was not found in the Chunchon catchment, large amount of output of bases through the stream from soils and the accumulation of acidic substances were shown, resulting in the acidification of the whole catchment.

For tree growth on acidic soil, it is concluded that (1) Al dissolved into soil solution is an important limiting factor for growth and nutrient status of red pine and masson pine seedlings grown in acidic soil, (2) the (Ca+Mg+K)/Al molar ratio in soil solution is a useful indicator to evaluate and predict the effects of soil acidification due to acid deposition on Asian forest tree species at the present time and in the future, and (3) red pine is relatively sensitive to a reduction in the (Ca+Mg+K)/Al molar ratio in soil solution compared with masson pine and European tree species such as Norway spruce (*Picea abies* L.).

Soil nitrogen mineralization rates varied among soil and forest conditions. Although Sugi (*Cryptomeria japonica*) stands usually showed higher nitrification rates than Hinoki (*Chamaecyparis obtusa*) stands, controlling factor for determining nitrification rate is mainly determined by soil chemical properties like exchangeable cations. Oxalic acid also affects soil acidity such that Al became soluble even though soil pH did not decrease. It is necessary to consider these acidic sources for developing a critical load model.

Key Words Nutrient balances, Tree sensitivity for acidic soil, Nitrification, Korea, China

1. Introduction

To develop the methods for evaluating the effects of environmental acidic substances on forest ecosystems in east Asia, we investigated following subjects: 1) Effects of acid deposition on red pine (*Pinus densiflora*) forest in Japan and Korea, 2) Experimental studies on the effects of soil acidification on growth and nutrient status of red pine and masson pine seedlings, 3) Evaluation of soil nitrogen mineralization and nitrification rates on various types of forest stands.

2 Effects of Acid Deposition on Red pine (*Pinus densiflora*) Forest in Japan and Korea

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(1) Study site

Monitoring sites are located in a small catchment of Horinouchi River in Tama Hill region, Hachioji of Japan, 150-170 m above sea level, and 14.4 ℃ in annual mean temperature and 1601 mm in annual rainfall, and in a small catchment of Chunchon of Korea, 150 m above sea level, and 11.5 ℃ in annual mean temperature and 1405 mm in annual rainfall (Fig. 1). The Hachioji site is characterized by the stratum structure consiting of the Kazusa Sogun sediment, "Tama Loam", "Musashino Loam" and "Tachikawa Loam", which gave rise to Melanudands, Hapludands and Dystrochrepts. On the gentle slope hill there is dominant in red pines becuse of dry moisture condition. The Chunchon site is characterized by Chunchon granite rock (biotite granite rock) formed in Mesozoic, causing to Dystrochrepts under red pine forest. The open bulk precipitation, throughfall, stemflow, soil solution and strem water samples and soil samples were taken in the study sites of Hachioji and Chunchon.

(2) Results

Input of acidic substances

Acid precipitation, below pH 5.6, was found in Hachioji through a whole year. The weighted mean pH value of precipitation is 4.69 (1996-1997) and 4.90 (1998) and the input of H^+ amounted to 0.339 $kmol_c ha^{-1} yr^{-1}$ (1996-1997) in Hachioji. Ammonium and sodium were dominant cations and their inputs were 0.488 and 0.372 $kmol_c ha^{-1} yr^{-1}$ (1996-1997), respectively. Chloride, sulfate and nitrate ion showed the relation of 1:0.73:0.57. Although most of chloride ion were given by the sea salt, 90 % total sulfate ion input were caused by anthropogenic sources. In Chunchon the weighted mean pH value of precipitation is 5.29 (1997) and 5.74 (1998), of which input gives 0.052 $kmol_c ha^{-1}$ 6$months^{-1}$ (1997) and 0.029 $kmol_c ha^{-1}$7$months^{-1}$ (1998). Ammonium ion, 1.1 $kmol_c ha^{-1}$6$months^{-1}$ (1996) and 2.9 $kmol_c ha^{-1}$7$months^{-1}$ is the most important cation in Chunchon. Ion concentrations in throughfall were much higher than those of precipitation in both sites. The input of H^+ amounted to 0.162 $kmol_c ha^{-1} yr^{-1}$ (1996-1997) in Hachioji, and 0.101 or 0.150 $kmol_c ha^{-1}$6$months^{-1}$

(1997) and 0.038 or 0.069 $kmol_c ha^{-1}7months^{-1}$ (1998) in Chunchon. High concentrations of ions in red pine stemflow were found in both study sites. However, the input of H^+ through stemflow was small compared with the input through precipitation and throughfall. High concentrations of nitrate ion in soil solution were observed throughout a year in both Hachioji and chunchon.

Output of acidic substances

A small amount of H^+ output was observed in the stream water of Hachioji, which implied the accumulation of H^+ in the catchment. The output of chloride, sulfate and nitrate ion through stream water remarkably amounted to 0.060, 0.034 and 0.055 $kmol_c ha^{-1}yr^{-1}$ (1996-1997) in Hachioji. Meanwhile, in Chunchon the input of H^+ was quite small and the input of sulfate ion was 0.18 $kmol_c ha^{-1}6months^{-1}$ (1997) and 0.21 $kmol_c ha^{-1}6months^{-1}$ (1998).

Input and output budget of acidic substances

In Hachioji all of ions were accumulated in the catchment and proceeded the acidification of the catchment, based on the budget of ions, which was derived from the strong ion adsorption characteristics of Andisols (Table 1). On the other hand all of ions except for ammonium outflowed and H^+ was accumulated in the Chunchon catchment (Table 2). The effects of acidification in Chunchon appeared in the ion outflow, which affected by the high input of ammonium ion followed by nitrification to prodece H^+. Experimental Studies on the Effects of Soil Acidification on Growth and Nutrient Status of Red Pine and Masson Pine Seedlings

Table 1 Input and output budget study in Hachioji of Japan

	Ca	Mg	K	Na	Al	NH_4	H	Cl	SO_4	NO_3
						$kmol_c ha^{-1}$				
Budget A	0.190	0.023	0.079	0.315	0.105	0.485	0.339	0.785	0.580	0.428
Budget B	1.19	0.49	0.58	0.793	0.089	2.25	0.166	1.99	1.05	1.41

Duration: Oct. of 1996 to Nov. of 1997

Budget A: based on open bulk precipitation input, Budget B: based on throughfall plus stemflow input.

Table 2 Input and output budget study in Chumchon, Korea

	Ca	Mg	K	Na	NH_4	H^+	Cl	SO_4	NO_3	NO_2
						$kmol_c ha^{-1}6months^{-1}$				
1997	-0.20	-0.041	0.089	-0.27	1.1	0.033	0.049	0.44	0.18	0.0
1998	-0.22	0.0	0.24	-0.28	3.2	0.028	0.25	0.99	0.24	0.044

Duration: 1997 May to Oct., 1998 May to Oct.

+: retention in the catchment. -: export from the catchment

3. Experimental Studies on the Effects of Soil Acidification on Growth and Nutrient Status of Red Pine and Masson Pine Seedlings,

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(1) Effects of soil acidification on red pine seedlings

To obtain basic data concerning the effects of soil acidification induced by acid deposition on forest tree species growing in the East-Asia, dry weight growth, nutrient status and needle gas exchange rates of 2-year-old red pine seedlings (*Pinus densiflora* Sieb. et Zucc.) grown in brown forest soil acidified by adding H_2SO_4 solution were investigated. In the case of soil acidification without leaching of cations from the soil, H^+ was added as H_2SO_4 solution to the soil at 10, 30, 60 or 90 meq$\cdot L^{-1}$. The soil without the additional supply of H^+ was used as a control. In the case of soil acidification with leaching of cations from the soil, the soil acidified by the method described above was put in the container, and then deionized water was poured to the container. After 3 days, water was gradually pulled out from the bottom of the container, and the soil was air-dried. The seedlings were transplanted to the acidified or control soil, and then they were grown in a glasshouse (Fuchu, Tokyo) for 120 days from June to September 1996.

As shown in Table 3, Al concentration in the soil solution increased with increasing the amount of H^+ added to the soil. The total dry weight of red pine seedlings were decreased by the addition of H_2SO_4 solution to the soil. In the seedlings grown in the acidified soil, Al concentration increased in the underground part of the seedlings, but the concentrations of Ca and Mg decreased in the ground part of the seedlings. Whole-plant dry weight growth of red pine seedlings was dependent not only on the Al concentration, but also on the balance of Al and cations such as Ca, Mg and K in the soil solution. As shown in Fig. 1, when the (Ca+Mg+K)/Al molar ratio of soil solution became less than ca. 7.0, total dry weight per plant of the seedlings began to decrease, and it decreased to approximately 60% of the control value at the molar ratio of 1.0. The net photosynthetic rate of the seedlings grown in the acidified soil reduced with increasing the amount of H^+ added to the soil. In the seedlings grown in the acidified soil, the quantum yield and carboxylation efficiency of photosynthesis reduced, which suggests that the soil acidification induced an inhibition of photochemical reactions of photosynthesis and a reduction in the activity and/or amount of Rubisco.

(2) Effects of soil acidification on masson pine seedlings

To obtain basic data concerning the effects of soil acidification due to acid deposition on Chinese forest tree species, dry weight growth and nutrient status of masson pine seedlings (*Pinus massoniana* Lamb.) grown in yellow sand loam soil acidified by adding H_2SO_4 solution were investigated. The soils were collected from the forest floors of masson pine at Jinyunshan and Tongliang in Changqing-city. To acidify the two soils, H^+ was added as H_2SO_4 solution to the soils at 10, 40, 70, 90 and 120 meq$\cdot L^{-1}$. The soil without the additional supply of H^+ was used as a

control.

Table 3 The results of soil solution analysis conducted immediately before transplanting red pine seedlings to the potted brown forest soil.

Soil treatment	pH(H_2O)	Element concentration of soil solution (mmol·L^{-1})				
		Ca	Mg	K	Al	Mn
Without leaching						
Cont+D0.5%	4.93(0.03)	0.26(0.08)	0.17(0.07)	0.149(0.005)	0.06(0.00)	0.005(0.002)
Control	4.90(0.00)	0.11(0.02)	0.04(0.01)	0.086(0.004)	0.03(0.00)	0.002(0.000)
10meqH^+	4.33(0.02)	0.56(0.01)	0.32(0.00)	0.185(0.011)	0.14(0.00)	0.020(0.000)
30meqH^+	4.03(0.01)	0.95(0.00)	0.46(0.01)	0.222(0.007)	1.02(0.09)	0.049(0.001)
60meqH^+	3.78(0.01)	2.44(0.21)	1.19(0.13)	0.447(0.020)	4.92(0.57)	0.155(0.010)
90meqH^+	3.57(0.01)	2.96(0.36)	1.28(0.06)	0.381(0.036)	9.55(0.70)	0.188(0.003)
With leaching						
Control	5.18(0.02)	0.11(0.01)	0.10(0.00)	0.188(0.019)	0.04(0.02)	0.003(0.000)
10meqH^+	5.03(0.02)	0.21(0.01)	0.22(0.04)	0.166(0.010)	0.06(0.03)	0.009(0.001)
30meqH^+	4.23(0.01)	0.50(0.06)	0.34(0.04)	0.184(0.018)	0.34(0.00)	0.030(0.000)
60meqH^+	3.92(0.00)	0.82(0.04)	0.43(0.02)	0.239(0.001)	1.79(0.13)	0.047(0.001)
90meqH^+	3.78(0.00)	0.67(0.03)	0.39(0.00)	0.226(0.018)	3.83(0.34)	0.043(0.005)

Value in parenthesis shows standard deviation. The control seedlings were grown in the soil without supply of H^+.

The amount of H^+ added to the soil was 10, 30, 60 or 90 meq·L^{-1} soil. Cont+D0.5%, control soil+0.5% dolomite.

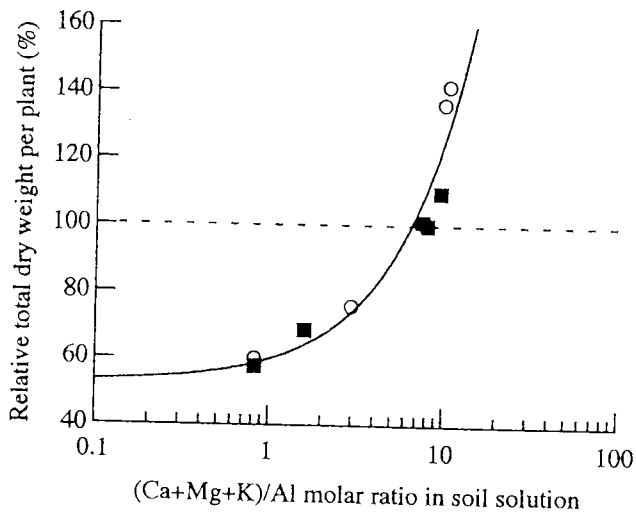

Fig. 1
The relationship between relative total dry weight per plant of red pine seedlings grown for 120 days in brown forest soil acidified by adding H_2SO_4 solution, and (Ca+Mg+K)/Al molar ratio in soil solution. In this figure, circle and square show soil acidification with leaching of cations from the soil and that without leaching of cations, respectively.

Table 4 The result of soil analysis conducted immediately before transplanting masson pine seedlings to the potted yellow sand loam.

Soil	H^+addition	pH	Element concentration ($\mu g \cdot g^{-1}$)					Ca/Al	(Ca+Mg+K)/Al
	($meq \cdot L^{-1}$)		Ca	Mg	K	Mn	Al	(Molar ratio)	(Molar ratio)
Tongliang	0	4.4	19	4	12	2	7	1.89	3.8
	10	3.9	18	8	18	8	24	0.52	1.4
	40	3.5	3	6	23	16	158	0.013	0.16
	70	3.3	3	4	24	18	280	0.007	0.09
	90	3.2	3	3	24	18	604	0.003	0.04
	120	3.0	3	3	25	18	954	0.002	0.02
Jinyunshan	0	4.4	21	3	12	1	11	1.33	2.4
	10	3.8	57	13	26	5	93	0.71	1.07
	40	3.3	5	5	25	5	485	0.007	0.06
	70	3.1	4	4	19	5	858	0.003	0.02
	90	2.9	3	2	13	4	980	0.002	0.01
	120	2.7	3	3	6	4	1528	0.001	0.006

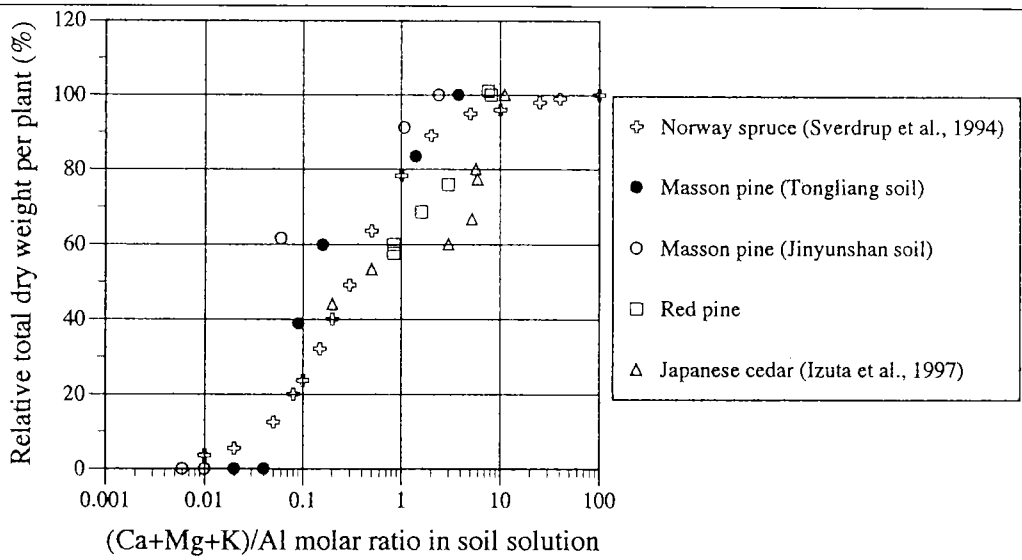

Fig. 2
The relationship between (Ca+Mg+K)/Al molar ratio in soil solution and relative total dry weight per plant of masson pine, red pine, Japanese cedar and Norway sprucseedlings.

One-year-old seedlings of masson seedlings were transplanted to the acidified or control soil on 13 June, 1997 (Tongliang soil) or on 10 July, 1997 (Jinyunshan soil), and then they were grown in a glasshouse for two growing seasons at Yunnan Dabanqiao Institute of Fruit Tree. On 10 November of 1998, the seedlings were harvested to determine dry weight and elemental concentrations.

As shown in Table 4, soil pH reduced, but water-soluble Al concentration increased with increasing the amount of H^+ added to the soil. The total dry weight per plant and plant height of masson pine seedlings grown in the acidified soil were reduced compared with the control values with increasing the amount of H^+ added to the soil. The seedlings grown in the Tongliang soil treatments of 90 and 120 $meq \cdot L^{-1}$ and those grown in the Jinyunshan soil treatments of 70, 90 and 120 $meq \cdot L^{-1}$ were dead during the growth period of 1997. The relative growth rate (RGR) of whole-plant dry weight and net assimilation rate (NAR) of the seedlings grown in the acidified soil were reduced compared with the control values, which suggests that the efficiency of dry

matter production or net photosynthetic rate was reduced by the soil acidification. The Ca concentration in the roots of the seedlings grown in the Tongliang soil was reduced by the soil acidification compared with the control value. As shown in Fig. 2, relative total dry weight per plant of the seedlings was reduced with reducing the (Ca+Mg+K)/Al molar ratio in the soil. The sensitivity to the reduction in the molar ratio of total dry weight in masson pine was similar to that in Norway spruce, but was relatively low compared with that in red pine and Japanese cedar [1),2)]

(3) Field Survey on Acid Deposition in Masson Pine Forests at Chongqing and Guiyangm, China

To obtain basic data for evaluating critical load of acid deposition for protecting Chinese forest ecosystem, field survey was conducted in Chongqing and Guiyangm to clarify the present situation of chemical properties of precipitation and soil, and plant nutrient status in masson pine forest (*Pinus massoniana* Lamb.). The collection of precipitation, soil and needles were carried out in masson pine forests at Jinyunshan and Nanshan in Chongqing-city (July, 1998), and at Lannigou and Huaxi in Guiyangm-city (August, 1998).

The average rain pH at Jinyunshan, Nanshan and Huaxi were 7.2, 6.7 and 6.8, respectively. The concentration of SO_4^{2-} in the precipitation was relatively high compared with that of NO_3^-. The concentrations of Ca, Mg, K and Cl in the throughfall were higher than those in the precipitation. The concentrations of Ca, Mg, K, Cl, SO_4^{2-} and NO_3^- in the stem flow were greater than those in the precipitation and throughfall at Jinyunshan and Huaxi. The pH of A-horizon soil at Jinyunshan, Nanshan, Lannigou and Huaxi were 4,4, 5,7, 7.8 and 4.6, respectively. In the A-horizon soil, water-soluble concentrations of Mn were very low, but those of Al were 33, 27, 20 and 14 $\mu g \cdot g^{-1}$ at Jinyunshan, Nanshan, Lannigou and Huaxi, respectively. The concentrations of Ca and K in the needles collected from mature masson pine at Lannigou, where the soil pH was relatively high, were higher than those at Jinyunshan, Nanshan and Huaxi. The concentration of Al in the needles collected from mature masson pine at Jinyunshan was relatively high compared with that at Lannigou and Huaxi.

(4) Conclusions of this part

Based on the results obtained in this study, it is concluded that (1) Al dissolved into soil solution is an important limiting factor for growth and nutrient status of red pine and masson pine seedlings grown in acidic soil, (2) the (Ca+Mg+K)/Al molar ratio in soil solution is a useful indicator to evaluate and predict the effects of soil acidification due to acid deposition on Asian forest tree species at the present time and in the future, and (3) red pine is relatively sensitive to a reduction in the (Ca+Mg+K)/Al molar ratio in soil solution compared with masson pine and European tree species such as Norway spruce (*Picea abies* L.).

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4 Soil Nitrogen Mineralization and Nitrification of Japanese Forest Soils and the Effect of Organic Acid for Soil Buffering Capacity

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We investigated nitrogen mineralization and nitrification rates of soils from various forest and soil types mainly from plantation forests (Fig. 4). Soil samples were collected from eastern Honshu area. Sugi (*Cryptomeria japonica*) stands usually showed higher nitrification rates than Hinoki (*Chamaecyparis obtusa*) stands (Fig. 5). When soil have higher nitrification rate, soil solution contained large amount of Ca and Mg that were electronically balanced with nitrate. This suggests that if the uptake rate of nitrate by vegetation decrease because of forest decline, soil acidity would be accelerated by leaching of cations.

Not all Sugi stands showed high nitrification rates. Sugi stands that grown on soils derived from granite and chart rocks showed low nitrification rates. Low nitrification rate soils were lower pH and smaller amount of exchangeable cations. We conclude that the controlling factors for determining nitrification rate are mainly soil chemical properties like exchangeable cations.

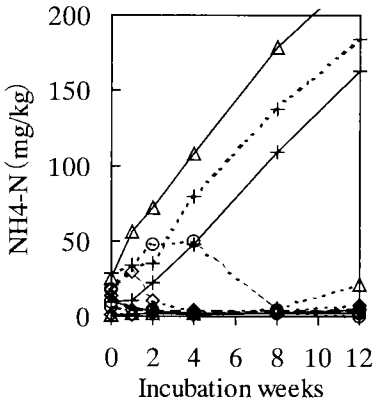

Fig. 4 Mineralization of soil nitrogen in Japanese forest soils.

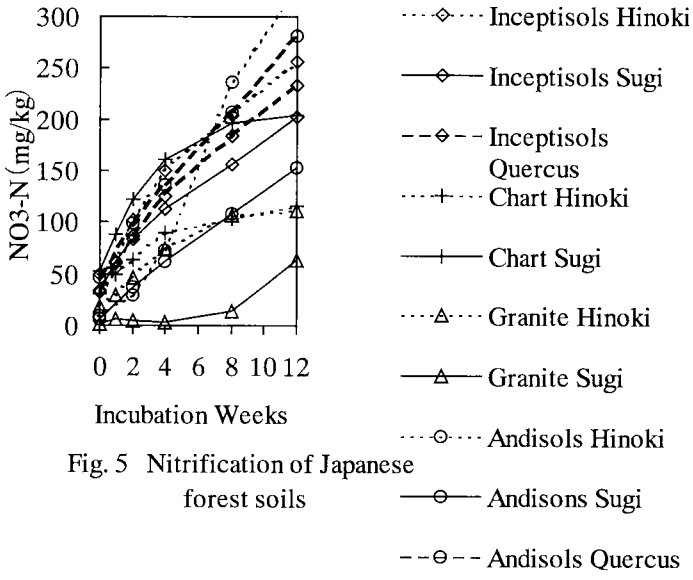

Fig. 5 Nitrification of Japanese forest soils

Because several kind of organic acids were found in forest soils, we evaluate the effect of organic acids on soil buffering capacity. In this study we used oxalic acid for this purpose. Buffering curves for oxalate were similar to those for sulfuric acids for soils that have lower contents of exchangeable cations, However, for soils with higher exchangeable cation contents, oxalate extract large amount of Al even though soil pH were rather high. Although toxicity of Al extracted by oxalate should be confirmed, it would be necessary to consider these acidic sources for development of critical load models.