C-3.2.2 Studies on critical loads for acidic substances in forest soils

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Abstract

Sugi (*Cryptomeria japonica*) seedlings cultivated in low mineral soils revealed that potassium concentration in shoot clearly corresponded with soil exchangeable potassium concentration. Sugi seedlings cultivated in sufficient or low potassium soil revealed that their photosynthetic rate and stomatal conductance both decreased along with drought, but some delay occurred on seedlings grown in low potassium soil. In shrine or temple garden located in Kantoh area, potassium concentration of old Sugi needles or exchangeable potassium concentration of the soils were somewhat low in declined stands. Soil pH were very low in narrow area near stems in Sugi and Hinoki(*Chamaecyparis obtusa*) stands in southern Japan, because of low pH of the stemflow. Sugi seedlings were cultivated in two types of brown forest soil: acidic soil and neutral soil. For one and half years, total amount of additional H_2SO_4 (pH = 2) was 18750 ml each pot. There were little influences of H_2SO_4 solution on root development, root biomass and root activity. For the estimation of critical load by acid deposition in Japanese forests, the forest site database is formed and analyzed. Japanese forest soils are strongly acidic and have already contained plenty exchangeable aluminum. Exchangeable cation concentrations are useful information for estimation of acid buffering capacities. Exchangeable acidity is more useful and practical data than exchangeable cation, because of information size. The effects of volcanic ash erupted in quaternary period are clear in surface soil pH

1. Introduction

Acid deposition are widely observed in Japan. Effects of acid deposition on terrestrial ecosystem are chronic and accumulative. It is urgently required to estimate and evaluate the effects of acid deposition on the forest. Scientific information based on the plant physiology, soil chemistry, and soil ecology are necessary for the estimation of critical loads of acidic substances in forest soils.

It is well known that soil acidification causes mineral leaching from soil, but the influence of leaching on tree growth or physiological status is still unclear. For obtaining critical load of acidic deposition and its influence on forest health, leaching must be also taken into account of the effects of soil acidification.

The quality of precipitation falling on forests is altered during a brief but significant interaction with the surfaces of plants, resulting in the transfer of additional mineral matter to the forest floor. The chemistry of throughfall and stemflow were depend on tree species. The lower pH of stemflow will cause to acidity of the soil and dissolve Al ion in the area of stemflow zone. There is a strong suspicion that the acidification of soil results to dieback of trees.

The estimation and evaluation of the effect of acid deposition on forest environment are conducted from the point of forest soils and acid buffering capacity. In Europe, the evaluation using critical load modeling and maps has been tried in different levels (UN/ECE,1991). But even now, basic and data of forest soil and ecosystem are insufficient for these estimation and evaluation in Japan.

2. Research Objective

(1) To clarify the effects of mineral deficiency on the growth and physiological process of several tree species.

(2) To compare the soil acidity and fine root biomass on three stands: Sugi (*Cryptomeria japonica*), Hinoki(*Chamaecyparis obtusa*), and Kojii (*Castanopsis cuspidata*)

(3) To analyze a relationship between soil acidity and seedling growth, root development, root respiration etc. by pot culture experiment.

(4) To formulate the Japanese forest soils database using soil survey report and to characterize each forest soil groups for the national level estimation. Acid buffering capacities of each soil groups are also analyzed.

3. Research Methods

(1) Effects of mineral deficiency on the growth and physiological process

First, one year old Sugi seedlings were planted in acidic and low mineral soil, and potassium, calcium, magnesium salt were added combining two or three of them. Thereafter, growth and mineral concentration of seedlings and soil mineral condition were monthly monitored. Second, one year old Sugi and Hinoki seedlings were planted in potassium deficient or sufficient soil, and photosynthetic rate and stomatal conductance were periodically measured under drought condition. Third, shoot and soil samples collected from old Sugi and Hinoki stands located in shrine or temple gardens were analyzed their mineral concentration.

(2) Soil acidity and fine root biomass on forest stands

Research site is located at four adjacent forest stands at Tatsutayama experimental Forest of Kyushu research Center in Forestry and Forest Products Research Institute in the southern region of Japan. On Sugi, Hinoki, Kojii and Akamatsu (*Pinus densiflora*) stands, we collected surface soil samples and fine root samples in a layer of soil at 30 cm deep. Soil samples were air-dried soon after collection to prevent microbial changes and were pass through a 2-mm sieve. Soil pH, EC (electric conductivity), Y_1 were measured. Fine root were washed with water gently and were dried in forced-air oven at 60℃ and weighed.

In Sugi, Hinoki and Kojii stands, we collected respective 32 surface soil samples in the area near tree stem where we call stemflow zone. In this report, stemflow zone is defined the area of 2m x 2m in the center of stem. Using fine air-dried soil samples, soil pH and EC were measured.

(3) Pot culture experiment.

Using wagner pots (deep type), we cultured Sugi seedlings in two different soil types: acidic soil and neutral soil. 250 ml solution of H_2SO_4 (pH=2) was added each pot periodically for one and half year. At the same time, we added deionized water to the control pots. Total amount of additional H_2SO_4 and deionized water was 18750 ml for each pot. We controlled soil moisture to 35% periodically. Height and diameter of seedlings were measured each season. We collected soil samples in three layers of pot each 10 cm deep. A part of soil was used to analyze soil pH,, EC, Y_1, CEC (Cation Exchange Capacity) and Exchangeable Al. And we separated fine roots only from soil with water. A part of fine roots was measured root respiration by Wargberg method.

(4) Estimation of critical load on the surface soil in forests

The Japanese forest soil database of characterization of chemical properties was formulated using the Japanese Forest Soil Survey Reports (Total 331 reports). Site characteristics and soil properties of surface 2 layers are analyzed using 2164 sites, i.e. forest type, elevation, slope, surface geology, soil type, pH, Y_1, total-carbon, total-nitrogen, specific gravity. For detail analysis, soil characteristics in two deferent area of Chubu mountains and Kanto volcanic plain are examined using National Land Information Database. Soil buffering capacities of 106 surface soil samples are measured using soil column with spraying continuous artificial acid rain(100ppm H_2SO_4, 20hrs, 1.5meq/4cm diam). Acid buffering capacity (amount of acid input occurring pH depression from stable stage) and eluted ions are analyzed with soil chemical properties.

4. Results and discussion

(1) Effects of mineral deficiency on the growth and physiological process

In first experiment, seedling growth were not different between mineral treatments. Potassium concentration in shoot clearly corresponded with soil exchangeable potassium concentration. In second experiment, Photosynthetic rate and stomatal conductance decreased along with drought in both treatments, but decrease was delayed on seedlings grown in low potassium soil. Root growth was also somewhat inferior in them. In third observation, potassium concentration of Sugi needles or exchangeable potassium concentration in the soils were somewhat low in declined stands. Hinoki has broader range of foliar potassium concentration and no particular relationship between concentration of soil exchangeable potassium was detected.

Series of experiments showed that potassium is the most evident mineral reflecting soil mineral condition into plant tissue. Potassium also affected on physiological status of trees under stressed environment. It can be thought that potassium is key factor to detect mineral condition of trees or soils.

(2) Soil acidity and fine root biomass on forest stands

In Hinoki stand, soil pH was lower than other stands. Fine root biomass were lower in Sugi and Hinoki than in Akamatsu and Kojii. Especially fine root was developed to shallow layer in Hinoki. These results suggest that there is a week forest ecosystem in Hinoki.

As results of analyzing soil pH distribution , soil pH were very low in narrow area near stem in Sugi and Hinoki because of low pH of stemflow. Acidic soil developed to wider area and deeper layer in Hinoki stand than in Sugi and Kojii stands.

(3) Pot culture experiment.

Soil pH in upper part of H_2SO_4 watering pot fell to 3.6 from 4.8 in acid soil, 4.0-4.2 from 6.7 in neutral soil. Soil pH in middle and lower part of H_2SO_4 watering pot were not changed. Contents of Ca, Mg and Na ions in upper part of H_2SO_4 watering pots were lower than in middle and lower part of these pots. That result suggests that Ca, Mg and Na were easy to transfer to deeper layer. Nutrient contents except Na ion in deionized water pot were almost same in whole layer.

As a result of analyzing height and diameter of the seedlings, there were little differences in growth between H_2SO_4 watering pot and deionized water pot. There were little differences in fine root biomass and root respiration too. These results suggest that Sugi seedling resists acid and can grow.

(4) Estimation of critical load on the surface soil in forests

Average data of forest soils are as follows; surface layer pH(H_2O) 4.93, pH(KCl) 4.18,Y1 20.2 Total-carbon 10.7 % and Total-nitrogen 0.64%(Fig. 1). It means surface layer is already strongly acidic and contains plenty of exchangeable Al and organic matter. Dry Brown Forest Soils, Podzolic Soils, beech and Hinoki forests, granite soils are relatively strongly acidic, whereas Wet Brown Forest Soils, Black soils, Sugi and evergreen broad-leaved forests, limestone soils are relatively neutral. But the forest soil type is not valuable classification for this estimation, because these have wider variations and are difficult to differentiate. Only in case of volcanic ash area erupted in the Quarternary period, surface soils have clearly lower Y1 than others, although not of all Black Soils are neutral.

Statistical analysis using clustering are introduced for classification. Y1(exchangeable aluminum), specific gravity and total carbon (volcanic ash) are reasonable for it. Low Y1(4-7) groups are many Wet Brown Forest Soils and Black Soils. High Y1(30) groups are many Dry Brown Forest Soils and Dry Podzolic Soils.

Effects of volcanic ash can be identified in Japanese soils. Soil pH and Y1 of Brown Forest Soils distributed in Chubu area is clearly acidic than Kanto area. Black Soils in Chubu area is also acidic than Kanto. It is because the volcanic eruption in Chubu occurred in older period than Kanto. It concludes even the same soil types, soil chemical properties are characterized by area, surface geology and others. The national soil map drawn by soil type does not provide appropriate information for this purpose.

Soil buffering capacity of acidic soils (pH(H_2O)3.84-4.98) distributed in Podzolic area (Kiso area) are very low and have less relation to exchangeable cation contents(0.16-2.02meq/100g). The capacities of Hinoki forests are clearly low than other vegetative condition. It shows Hinoki is strongly resistant and may have some relation of acidic soil formation as deeper layers are less acidic.

The buffering capacities of 84 soil samples in different soil types show certain relation to the total cation contents. Three buffering stages are recognized as salt absorption by amorphous Fe and Al clay (pH 6), exchangeable cation (pH 5) and aluminum (pH4). Most of volcanic ash soils and neutral soils which have high exchangeable cations show strong buffering capacities. Low pH and high Y1 soils have quite low capacities. In ion exchange reaction, soils start to release much aluminum ion when most of exchangeable cations are eluted by strong acid. Buffering capacity has linear relation to exchangeable cation. Acidic soils such as Yellow Soils, Red Soils, Immature Soils and Podzolic Soils start to elution before cation deficiency because these have already plenty of exchangeable aluminum. For the classification in buffering capacity not only exchangeable cation but also Y1 is valuable as many Y1 data can be collected in soil survey reports.

For estimation and evaluation of critical load for acid deposition, following matter are indispensable. Japanese forest soils have already contain exchangeable aluminum. Exchangeable Ca/Al is already lower enough than theoretical criteria. Many healthy forest including natural coniferous forests are distributed in strong acid soils in Japan, especially high mountainous area. Exchangeable cation concentration is more useful data, but Y1 is also available. Forest acidity is strongly affected by volcanic ash. Ecosystem analysis is indispensable stage for the furture evaluation.

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Fig-1 Soil chemical characteristics in Japanese national forest (Average data)

Soil	Point		Surface layer (0-10cm)							Second layer (20cm-)						
Type	umbe	ltitud	S.G.	pH(H2O)	pH(KCl)	Y1	Tot-C	Tot-N	C/N	S.G.	pH(H2O)	pH(KCl)	Y1	Tot-C	Tot-N	C/N
BA	134	487	49	4.74	4.01	26.1	7.9	0.32	25	69	4.99	4.19	21.8	3.0	0.15	20
BB	257	640	43	4.70	3.96	28.4	10.5	1.85	20	56	5.11	4.30	20.3	3.8	0.22	17
BC	191	601	53	4.99	4.20	19.1	8.6	0.51	17	77	5.17	4.29	20.8	3.5	0.24	16
BD	318	633	42	5.13	4.45	13.6	10.1	0.68	15	66	5.31	4.48	11.0	4.4	0.35	13
BD(d)	209	627	50	4.98	4.21	16.7	9.5	0.58	17	63	5.21	4.35	13.5	3.5	0.25	15
BE	229	634	43	5.38	4.63	7.7	10.0	0.72	14	61	5.44	4.55	7.5	5.1	0.40	13
BF	25	336	30	5.48	4.77	3.7	9.9	0.68	14	105	5.47	4.39	8.4	2.7	0.24	13
Bl	4	530		5.23	3.97	10.2	8.8	0.63	15		5.58	4.23	8.9	4.0	0.26	15
BlABC	33	594	43	5.26	4.33	15.3	11.2	0.72	17	61	5.46	4.53	9.1	5.4	0.38	16
BlD	109	569	47	5.23	4.46	11.2	12.3	0.78	16	62	5.43	4.60	8.8	6.7	0.48	15
BlD(d)	47	732	42	5.05	4.20	15.8	12.3	0.81	16	55	5.31	4.49	10.9	7.0	0.46	15
BlE	48	663	39	5.10	4.30	12.8	13.9	0.92	15	52	5.30	4.51	9.7	8.4	0.52	15
DR	1	490		5.60	4.80	2.6	5.5	0.58	9		5.40	4.20	0.2	2.1	0.19	11
G	35	422		5.07	4.34	12.9	12.8	0.91	14		5.32	4.41	21.0	3.8	0.33	12
Im	42	309	74	5.06	4.36	12.3	6.0	0.38	18	102	5.40	4.41	10.8	2.3	0.18	16
P	21	720		4.75	3.81	18.5	17.6	1.25	16		5.20	4.19	13.7	11.8	0.64	19
PD1	32	933		4.09	3.17	36.5	15.0	0.72	23		4.63	3.75	37.2	5.5	0.27	23
PD2	36	999	47	4.18	3.41	44.9	17.1	0.88	22	38	4.78	4.02	24.9	7.1	0.38	19
PD3	129	847	32	4.35	3.63	35.0	14.5	0.69	21	42	4.98	4.18	21.0	5.4	0.28	20
PWh	70	1323	18	4.24	3.60	35.4	15.4	0.89	17	28	5.00	4.26	19.0	6.5	0.35	18
PWi	29	979		4.40	3.51	33.0	15.8	0.81	21		4.95	3.89	32.7	4.2	0.25	17
R	23	256	78	5.18	4.30	17.7	5.1	0.30	21	103	5.30	4.07	21.2	1.9	0.11	21
Y	3	160	100	5.20	4.27	14.2	4.7	0.27	18	124	4.73	3.67	62.4	0.5	0.06	8
dBD	46	718	48	4.90	4.20	15.6	11.3	0.75	15	60	5.26	4.39	9.5	5.6	0.39	14
gB	22	476		4.63	4.11	28.6	9.0	0.54	17		5.12	4.35	22.8	2.7	0.19	15
gRY	1	130	82	4.60	4.00	17.8	2.6	0.13	20	142	4.90	4.00	14.3	0.5	0.04	13
rB	17	301		5.02	4.11	18.0	9.6	0.63	20		5.37	4.30	20.7	1.8	0.27	14
yB	9	460	40	4.71	3.93	14.0	10.9	0.80	16	57	4.94	4.22	12.8	4.0	0.31	14
Total	2164	651	48	4.93	4.18	20.2	10.7	0.64	17	66	5.21	4.36	15.7	4.6	0.31	16