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Effects of Simulated Acid Rain on Growth and Physiological Characteristics of *Ginkgo biloba* L. Seedlings and on Chemical Properties of the Tested Soil[1*]

-III. Effects on Chemical Properties of the Tested Soil-

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人工酸性雨가 銀杏나무 *Ginkgo biloba* L. 幼苗의 生長, 生理的 特性 및 土壤의 化學的 性質에 미치는 影響[1]

-III. 土壤의 化學的 性質에 미치는 影響-

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ABSTRACT

One-year-old seedlings of *Ginkgo biloba* were treated with various simulated acid rains(pH 2.0, pH 3.0, pH 4.0 and pH 5.0) to examine the effects of simulated acid rain on the chemical properties of the tested soil. The seedlings were grown in a pot(4500cm^3) containing one of three different soils(nursery soil, mixed soil and sandy soil). Simulated acid rain was made by diluting sulfuric and nitric acid solution(H^1SO^4 : HNO^3=3 : 1, V/V) with tap water and tap water(pH 6.4), and treated by 5mm each time for three minutes during the growing seasons(April to October 1985). Acid rain treatments were done three times per week to potted seedlings by spraying the solutions. The chemical properties of potting media were compared among three soil types as well as among the various pH levels. The results obtained in this study were as follows :

1. Exchangeable calcium and magnesium contents and base saturation of the soil decreased with decreasing pH levels of acid rain, and their decreasing rates were as follows : sandy soil was the highest, followed by mixed and nursery soils. However, exchangeable aluminum content rather increased as the pH levels decreased.
2. Available phosphate in the soil decreased as the pH levels of acid rain decreased. *Its content increased in nursery soil, compared with those before acid rain treatment, but decreased in mixed and sandy soils.*
3. Soil sulfate and nitrate contents *increased* remarkably as the pH levels decreased, and the only significant difference in the sulfate was found among the pH levels. Soil sulfate content was the highest in nursery soil, followed by mixed and sandy soils.

Key words : *Simulated acid rain ; chemical properties of the soil.*

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要 約

人工酸性雨가 土壤의 主要 化學的 性質에 미치는 影響을 究明하기 위하여, 天然降雨를 遮斷하고 苗圃土壤, 混合土壤 및 砂質土壤에 각각 盆植된 銀杏나무 幼苗(1-0, half-sib)에 人工酸性雨(黃酸과 窒酸을 3 : 1, v/v로 混合하여 수도물로 희석한 pH 2.0, 3.0, 4.0 및 5.0)와 수도물(pH 6.4)을 生育期間中(1985年 4月 28日~10月 19日)에 週 3回, 每回 5mm씩 處理하여 얻어진 結果는 다음과 같다.

1. 土壤의 置換性 Ca 및 Mg 含量과 鹽基飽和度는 pH 값이 낮을수록 減少하였고, 減少率은 砂質土壤, 混合土壤 및 苗圃土壤의 順으로 크게 나타났으며, 置換性 K와 Na 含量은 酸性雨處理에 의해 크게 영향받지 않았다. 置換性 Al 含量은 處理酸性雨의 pH 값이 낮을수록 현저히 增加하였다.
2. 土壤의 有效燐酸含量은 處理酸性雨의 pH 값이 낮을수록 減少했으며, 處理前에 비하여 苗圃土壤에서는 增加한 반면 混合土壤과 砂質土壤은 減少하였다.
3. 土壤의 sulfate 및 nitrate 含量은 pH 값이 낮을수록 높아졌으며, sulfate 含量만이 pH 간에 有意性이 認定되었으며, 그 含量은 苗圃土壤, 混合土壤 및 砂質土壤의 順으로 增加하였다.

Introduction

Due to buffering capacity, soils are less sensitive to short-term acid precipitation events than vegetation, streams of lakes. In general, agricultural soils are less susceptible to adverse nutritional effects than forest soils, because of a better nutrient status, buffering capacity, fertilization and liming treatment[38]. Adverse effects are initiated by increasing soil acidity[1,34,36,40,48]. Soil acidity increased due to acid rain on central Europe during the period 1966 through 1977[56].

Cronan[13], Lee and Weber[35] reported soil cation (Ca, Mg and K) leaching by artificial acid rain with lysimeter experiments. The more severe cation leaching occurred, the lower pH was treated. Similar results were reported by Cronan *et al*[14]., Hutchinson[25] and Johnson *et al*[28]. Soil base saturation was reduced by acid precipitation[3,7]. However soil nutrient leaching was differed from the sulfate adsorption capacity of the soil[1,26,29,43,51]. From the model experiments for predicting the effects of acid rain on soil leachate, acid rain caused slight increase in soil acidity and soil nutrient leaching until soil sulfate adsorption has reached equilibrium stage[5,6].

High soil acidity caused increasing of exchangeable aluminum[13,42,55], and alteration of ionic concentration in soil solution. The structure of humus substance and their chemical properties[48], disturbance of nutrient phytoavailability and nutrient cycling were reported according to acid precipitation[39,56,60]. As the soils become more acidic, some trace metal ions increased in soil solution[65]; Al and Fe ions increased in soil solution and on colloidal surfaces. These ions react with phosphate to form a number of insoluble phosphate minerals[8]. Foy *et al*[17]. explained symptoms of Al injury; foliar symptoms resemble those of P deficiency (overall stunting; small, dark green leaves and late maturity; purpling of stems, leaves and leaf veins; yellowing and death of leaf tips); root tips and lateral roots become thickened and turn brown. Similar results were reported by Hecht-Buchholz and Foy[22].

In calcareous soils, acid precipitation was good for plants with easy absorbing Fe and P[51], and acted beneficial factor for plant growth[30], and raised phytoavailability of nitrogen in pine stands[49]. Owing to the differences of soils in texture, base saturation and cation exchange capacity, determination of soil buffering capacity and sensitivity to acid precipitation varied from one to another[2,41,59,60]. The sensitivity of soil to acidification depends on the soil buffering capacity and pH. Non-calcareous soils with low CEC, a pH above 5.0 are the most sensitive to acidification[37]. The objectives of this study were to determine the effects of different pH levels of simulated acid rain on soil properties in pots where plants grow under controlled conditions.

Materials and Methods

Materials and Treatments

Plant materials, soils, simulated acid rain treatment and experimental designs were the same as those used in the previous report[31].

Soil Analysis

Soil texture was classified by pipette method and cation exchange capacity was measured by ammonium acetate method and acidity of soil solution(air-dried soil : $H^2O=1:1$, W/V) was determined with Univerasl Digital pH-meter.

Exchangeable cations(Ca, Mg, K and Na) in air-dried soil was leached first with neutral 1N NH_4OAc and its concentrations were determined by atomic absorption flame spectrophotometry(Shimadzu, AA-610S). Base saturation was calculated from the above figures and C.E.C. values of tested soils.

Exchangeable aluminum was leached with 1N-KCl and its amounts were measured by colorimetric eriochrome cyanine R method[62].

Available phosphate was leached with 0.03N NH_4F and 0.025N HCl, and its amounts were measured by colorimetric molybdenum blue method(Bray No. 1)

Sulfate was leached with acetate extracting solution consisting of 39g ammonium acetate in 1000 ml of 0.25N acetic acid, and its concentration was measured by precipitating $BaSO_4$ with $BaCl_2$. The degree of the resultant turbidity was measured spectrophotometrically and compared with standard solution[44].

Nitrate was leached with the extracting solutions consisting of 17.32g $Al_2(SO_4)_3$ $18H_2O$, 1.28g H_3BO_3 and 3.43g Ag_2SO_4 in 1l to water, and its concentration was measured by nitrateion electrode (Orion 901, Ion Analyzer).

Results and Discussion

Mean values of such soil chemical properties as soil acidity, exchangeable cations, base saturation, exchangeable aluminum, available phosphate, sulfate and nitrate measured on July 27, 1985, during the treatment, and on October, 20, 1985, at the end of treatment are listed in Tables 1 and 2.

Soil Acidity

The influences in soil pH were highly significant at 1% level between the pH levels for each soil types. As rain pH decreased, soil pH decreased. Its decreasing rate was more obvious in sandy soil, followed by mixed and nursery soil. It seems to be related to the differences in soil buffering capacity determined by soil texture, organic matter content, exchangeable cation concentration and cation exchange capacity of the tested soils. Such results were similar to those reported by Ulrich *et al*[56], who observed decrease in soil pH in (entral)Europe during the period 1966 through 1977, and those mentioned by Abrahamsen *et al*[3]., Bjor and Teigen[7] and Rippon[48], who studied that soil pH decreased with acid rain treatment. Lee *et al*[34]. reported that soil pH decreased with increasing SO_2 fumigation. Thus, decrease in soil pH would be explained by acid precipitation[4,36,40]. Mortvedt[39] and Wiklander[59] also reported that the sensitivity of various soils to acid precipitation depended on the buffering capacity, and Peterson[41] explained that entisols, inceptisols, ultisols, spodozols and oxisols were relatively sensitive to acid precipitation. Except for the pH 2.0 level, most of soil pH values measured in October were slightly higher than those in July. Such results seemed to be due to proton consumption through nutrient uptake by plants, activity of soil microbes and other soil processes, and increased exchangeable cations leached from plant tissues[12,35,58].

From these results, decrease in soil pH was true according to acid precipitation, but degree of soil pH change depended on the concentration of hydrogen ion in precipitation, and neutralization and ion exchange activities between hydroxyl attached to aluminum and iron of colloidal soil particles[47]. Therefore, soil buffering capacity, might be determined by cation exchange capacity, base saturation and sulfate adsorption capacity of the soil. However, considering the fact that sulfate adsorption capacity of the soil varied with the increasing solubility of Al and Fe and did with decreasing soil pH[9,54,68], and that forest soils have litter layer and relatively large amount of organic matter, forest soil pH is expected to decrease with more or less slow speed[61,65,55]. From above reports, the productivity of forest soils in Korea seemed to become poor due to adverse effect of acid rain, because forest soil was acidic(pH 5.4±0.05)[32,70] and belonged to inceptisols, entisols and ultisols in low cation exchange capacity and base saturation[57,63,69].

Exchangeable Cations and Base Saturation Degree of the Soils

The differences in exchangeable calcium content were significant between the levels of pH for all soil types, and those in magnesium and potassium contents were significant for some types of soil (Tables 1 and 2).

Exchangeable calcium content at pH 2.0 levels were remarkably dropped for all soil types as rain pH decreased, and those at other pH levels varied with measuring time. In general, the lower pH of the acid rain was treated, the lower contents of exchangeable calcium were detected. These were mainly resulted from the leaching of exchangeable calcium by acid rain affected various results of exchangeable calcium content, which might be ascribed to calcium contained in simulated acid rain, absorption by plants and leaching from plant tissue or soils after acid rain treatment. In nursery soil, exchangeable calcium content at most of the pH levels increased after acid rain treatment except for pH 2.0 level, and less slight reduced measured on July 27 for pH 2.0 level than those in other soil types. This means that nursery soil have higher buffering capacity than other soil types. In mixed and sandy soils, exchangeable calcium contents, in general, decreased after acid rain treatment, which indicated that more exchangeable calcium was leached in these soils by acid rain than in nursery

Table 1. Mean values of soil chemical propertes measured on July 27, 1985 by the levels of pH for each soil types

Soil types (C.E.C.)	Treatment	pH (1 : 1, H_5O)	Exchangeable cations (me/100g) Ca	Mg	K	Na	Base Sat. %	Exch. Al (me/100g)	(Al Sat.)	Avail. P_2O_5 (ppm)	SO_4 -S (ppm)	NO_3 -N (ppm)
Nursery	Before	4.91	3.18	.53	.59	.35	38.30	1.38	11.37	41.29	45.25	4.50
Soil	Control(pH 6.4)	4.89 a***	3.73 a	.59	.49	.44	43.24	1.23 a	10.16 a	49.88	74.43 a	14.27 a
	pH 5.0	4.82 ab	3.19 b	.47	.56	.28	37.15	1.58 a	13.01 a	54.51	119.10 ab	17.87 a
(12.14)	pH 4.0	4.78 ab	3.24 b	.53	.47	.42	38.33	1.54 a	12.69 a	53.89	141.90 bc	15.57 a
	pH 3.0	4.65 b	3.33 ab	.52	.58	.45	40.28	1.67 a	13.76 a	53.51	193.60 c	19.47 a
	pH 2.0	3.76 c	2.94 b	.47	.51	.35	35.10	2.40 b	19.80 b	44.95	1448.00 b	37.30 b
	F-values	45.00**	3.69*	2.31	.39	2.95	.49	9.40**	9.41**	3.36	913.1**	12.22**
Mixed	Before	5.04	2.10	.35	.25	.22	48.24	.67	10.54	23.31	32.78	3.90
Soil	Control(pH 6.4)	5.00 a	2.25 a	.41 a	.34	.39	54.26 a	.45 a	7.96 a	31.65 a	52.59 a	15.00 b
	pH 5.0	4.89 b	2.20 a	.34 b	.39	.31	51.60 ab	.56 a	9.00 a	29.32 a	84.83 a	14.90 b
(6.26)	pH 4.0	4.85 b	2.15 a	.36 ab	.34	.37	51.33 ab	.72 ab	11.40 ab	27.83 ab	89.66 a	12.40 ab
	pH 3.0	4.86 b	1.90 a	.32 b	.22	.26	43.08 b	.89 b	14.16 b	19.38 bc	134.70 a	11.17 a
	pH 2.0	3.16 c	1.06 b	.19 c	.29	.31	29.50 c	1.56 c	24.92 c	14.84 c	988.70 b	21.26 c
	F-value	306.4**	19.83**	13.19**	.53	3.07	14.90**	29.42**	30.53**	5.86*	89.54**	15.61**
Sandy	Before	5.75	1.51	.26	.06	.21	62.02	.22	6.90	8.09	14.61	3.50
Soil	Control(pH 6.4)	5.72 a	1.45 a	.34	.14	.38	70.31 a	.23 a	7.21 a	6.05 a	36.01 a	12.57 a
	pH 5.0	5.45 b	1.41 a	.28	.18	.34	67.89 a	.25 a	7.50 a	3.85 ab	68.47 a	13.20 bc
(3.19)	pH 4.0	5.37 b	1.50 a	.26	.08	.29	64.74 a	.27 a	8.11 a	3.47 ab	70.32 a	9.13 ab
	pH 3.0	5.25 b	1.55 a	.28	.09	.32	68.19 a	.31 a	9.42 a	3.09 b	87.01 a	7.37 a
	pH 2.0	3.30 c	.76 b	.21	.08	.29	40.74 b	1.40 b	42.66 b	1.56 b	545.40 b	13.87 c
	F-value	214.7**	24.21**	2.49	1.00	.38	24.05**	143.4**	143.4**	3.99**	67.17**	3.95**

* and ** indicate significances at 5% and 1% levels, respectively

*** Differences in letters in vertical columns indicate significant difference at 5% level for Duncan test.

Table 2. Mean values of soil chemical properties measured on October 20, 1985 by the levels of pH for each soil types

Soil types (C.E.C.)	Treatment	pH (1 : 1, H_2O)	Exchangeable cations (me/100g)				Base Sat.	Exch. Al		Avail. P_2O_5	SO_4 -S	NO_3 -N
			Ca	Mg	K	Na	%	(me/100g)	(Al Sat.)	(ppm)	(ppm)	(ppm)
Nursery	Before	4.91	3.18	.53	.59	.35	38.30	1.38	11.37	41.29	54.25	4.50
Soil	Control (pH 6.4)	5.01 a***	3.54 a	.53 a	.37	.28	38.85 a	1.53 a	12.60 a	51.97	76.77 a	5.00 a
	pH 5.0	4.86 b	3.38 ab	.51 a	.49	.28	38.44 a	1.62 a	13.35 a	48.28	106.00 a	7.47 a
(12.14)	pH 4.0	4.83 bc	3.28 ab	.49 a	.39	.31	36.93 a	1.58 a	13.07 a	50.09	162.80 a	5.27 a
	pH 3.0	4.72 c	2.79 b	.43 a	.35	.25	31.52 b	1.73 a	14.25 a	46.67	204.50 a	4.83 a
	pH 2.0	3.30 d	1.16 c	.23 b	.33	.29	16.53 c	2.80 b	23.04 b	36.63	2107.00 b	28.00 b
	F-values	354.1**	26.74**	16.52**	1.43	.32	34.71**	29.23**	29.46**	1.30	95.68**	19.54**
Mixed	Before	5.04	2.10	.35	.25	.22	48.24	.67	10.54	23.31	32.78	3.90
Soil	Control (pH 6.4)	5.05 a	2.00 a	.30 a	.13	.29	43.34 a	.82 a	13.05 a	21.81 a	72.28 a	4.60 a
	pH 5.0	4.96 a	1.90 a	.30 a	.12	.19	40.04 a	.86 a	13.74 a	17.43 ab	119.90 a	4.57 a
(6.26)	pH 4.0	4.88 ab	1.95 a	.30 a	.12	.28	42.17 a	.97 a	15.44 a	14.37 bc	125.90 a	3.73 a
	pH 3.0	4.78 b	1.85 a	.28 a	.15	.34	42.01 a	1.03 a	16.40 a	13.69 bc	181.70 a	3.80 a
	pH 2.0	3.37 c	.62 b	.13 b	.11	.26	17.94 b	1.85 b	29.55 b	10.64 c	1130.00 b	13.37 b
	F-value	160.2**	6.59**	39.61**	.61	1.77	7.06*	9.18**	9.17**	7.25**	36.30**	11.39**
Sandy	Before	5.75	1.51	.26	.06	.21	62.02	.22	6.90	8.09	14.61	3.50
Soil	Control (pH 6.4)	6.01 a	1.45 a	.26 a	.05 a	.19	59.17 a	.28 a	8.41 a	.60 a	65.25 a	4.13 a
	pH 5.0	5.42 b	1.51 a	.24 a	.05 a	.21	61.09 a	.29 a	8.81 a	.00 a	73.68 a	3.40 a
(3.19)	pH 4.0	5.38 b	1.50 a	.24 a	.05 a	.20	60.59 a	.32 a	9.62 a	1.27 ab	123.40 b	3.93 a
	pH 3.0	5.14 c	1.31 a	.22 ab	.04 ab	.21	54.21 a	.37 a	11.24 a	1.00 a	157.00 b	2.60 a
	pH 2.0	2.78 d	.41 b	.18 b	.04 b	.17	24.21 b	1.57 b	47.82 b	4.81 b	628.30 c	7.73 c
	F-value	836.4**	30.89**	4.40*	4.66*	.28	18.36**	73.68**	73.72**	4.81*	476.3**	8.62**

* and ** indicate significances at 5% and 1% levels, respectively

*** Differences in letters in vertical columns indicate significant difference at 5% level for Duncan test.

soil. From these results, it suggested that nursery soil had the highest buffering capacity to acid rain, followed by mixed and sandy soils.

Exchangeable magnesium content of the soils decreased in all soil types as acid rain treatment increased. Exchangeable magnesium content of some pH levels including control increased slightly in July, but decreased in October, and the contents were lower than those before treatment. In general, it decreased as rain pH decreased, which seemed to be resulted from magnesium leaching from soil by acid rain treatment. It suggested that exchangeable magnesium in soil might be more sensitive to acid deposition than exchangeable calcium. Slight increase in magnesium content of the soil treated with high pH acid rain might be come from the quantities of magnesium contained in acid rain and leached from plant tissues.

The differences in exchangeable potassium content of the soil between the levels of pH were not significant in nursery and mixed soils, but those measured in October in sandy soil were significant at 5% level (Tables 1 and 2). From these results, much potassium leaching did not occur due to acid rain in most of soil types except for low buffered, sandy soil.

The differences in exchangeable sodium content of the soil were not significant between the levels of pH for all soil types. Thus, sodium leaching by acid rain might not be problematic in any soil types.

Base saturation of the soil at pH 2.0 level decreased in all soil types as acid rain treatment increased, but those at other pH levels increased slightly in July and then decreased in October. Effects of acid rain treatment on base saturation varied with soil types and with the levels of pH, which may be resulted from the differences in buffering capacity by cation exchange capacity and proton consumption. In nursery soil, base saturation at most of the pH levels increased after acid rain treatment except for pH 2.0 and 3.0 levels, and less slight reduced measured on July 27 for pH 2.0 level than those in other soil types. This means that nursery soil have higher buffering capacity than other soil types. In mixed and sandy soils, base saturations, in general, decreased after acid rain treatment, and sharply reduced measured on July 27 for pH 2.0 levels than those in nursery soil. From these results, it suggested that nursery soil had the highest buffering capacity to acid rain, followed by mixed and sandy soils. Decrease in soil base saturation was mainly due to calcium or magnesium leaching. These results were similar to those reported by Cronan[13] and Cronan *et al*.[14], who found magnesium, calcium and potassium leaching in balsam-fir forest due to acid rain, and those reported by Lee and Weber[35] in lysimeter experiment. Hutchinson[25] and Johnson *et al*[27,28]. also explained soil nutrient loss and reduction of base saturation[3,7,50] due to acid rain. The differences in soil nutrient leaching between soil types might be resulted from the differences in soil nutrient status and sulfate adsorption capacity as reported by Abrahamsen[1] and Reuss[46].

Exchangeable Aluminum

The differences in exchangeable aluminum contents were significant at 1% level between the levels of pH for all soil types(Tables 1 and 2). Exchangeable aluminum content of the soil increased in all soil types as rain pH decreased. In nursery soil, exchangeable aluminum content ranged from 1.23 to 2.40me/100g in July, and from 1.53 to 2.80me/100g in October. In mixed soil, it ranged from 0.45 to 1.56 in July, and from 0.82 to 1.85 in October. In sandy soil, it ranged from 0.23 to 1.40 in July, and from 0.28 to 1.57 in October. These results were similar to those reported by Cronan and Schofield[15] and Ulrich *et al*[56], who showed the increase in exhcangeable aluminum content in soil by acid rain treatment, and also agreed with the report that there was a close correlation between exchangeable aluminum content and soil pH levels of soil organic matter contents[42,62,64].

Aluminum saturation in the soils increased sharply as rain pH decreased, and its increasing rate was the highest in sandy soil, followed by mixed and nursery soils. From these results and those reported by Reuss[45] who found that new equilibrium between aluminum and calcium in soil solution treated with acid rain had been reached as soil pH changed, high aluminum saturation might indicate shortage of such exchangeable cations as calcium and magnesium. This seems to be severe in low buffered soils.

Considering that exchangeable aluminum of the soil increased due to acid rain treatment and forest soils in Korea were very acidic[32,70] long-term acid rain might cause injuries to forest vegetation by the increase in exchangeable aluminum and shortage in exchangeable calcium and magnesium.

Available Phosphate

In nursery soil, the differences in available phosphate concentrations were not significant between the levels of pH. In mixed and sandy soils, those were significant at 1% level(Tables 1 and 2). In nursery soil, available phosphate concentration of the soils at pH 3.0 or higher increased after acid rain treatment than those before treatment. In mixed and sandy soils, however, those of the soils at all the levels of pH decreased after acid rain treatment. Available phosphate concentration of the soils decreased markedly as rain pH decreased. Increase in available phosphate after acid rain treatment in nursery soil might be due to high organic matter and exchangeable calcium content, being supported other reports that available phosphate concentration was increased by increasing concentrations of calcium[21,33], aluminum bound with humus reacted with phosphate depending little on pH, and phosphate adsorbed by aluminum in allophane was dependent markedly on the levels of pH[18].

Decrease in available phosphate in mixed and sandy soils after acid rain treatment might be resulted from relatively small amount of exchangeable calcium in the soil affecting low phosphate retention and relatively large amount of aluminum in mixed and sandy soils after acid rain treatment might be resulted from relatively small amount of exchangeable calcium in the soil affecting low phosphate retention and relatively large amount of aluminum in allophane by low organic matter. Decrease in the concentration of available phosphate in the soils with decreasing rain pH levels could be explained by adsorption of more phosphate by soluble Al and Fe[11,63].

In highly buffered, calcic and organic soils available phosphate concentration might increase by acid rain. In low buffered soils, however, it might be reduced markedly by acid rain.

Sulfate

Sulfate concentrations in the soils were significantly different between the levels of pH for all soil types(Table 1 and 2). Sulfate concentrations in the soils increased after acid rain treatment as rain pH decreased, and its concentrations were highest in nursery soil, followed by mixed and sandy soils. The results were similar to those reported by Haines[19] and Singh *et al*[54]., who found increased sulfate concentrations in the tested soil particles, and to those reported by Oh[67] with pot soil. Sulfate adsorption capacity in the soils was correlated to exchangeable cation concentration[60], and its capacity increased as rain pH decreased as well as soil organic matter and cation exchange capacity of the soil increased[26,53,68]. From these facts, sulfate adsorption capacity was the highest in nursery soil, followed by mixed and sandy soils. Sulfate adsorption by soils is an important property affecting both the availability of sulfate to plants and the leaching of sulfate and associated cations. In the soils affected by acid rain treatment, this property may determine the impact of acid rain on cation mobility and leaching[53].

The higher sulfate adsorption capacity of the soil was, the lower sensitivity of the soil to acid rain was[5,6,46]. Nursery soil in this study seems to be the least sensitive to acid rain treatment among all soil types. Increase in sulfate concentration in all soil types with decreasing rain pH levels might be explained by sulfate adsorption occurred in ion-exchange reaction between sulfate and hydrexyl bound Al and Fe of soil colloidal particles[10,20)23,43], and sulfate adsorption capacity increased with increasing exchangeable aluminum concentration in the soils[9,68].

Although sulfate concentration in forest soils was affected by absorption by plants and reduction by soil microbes, it seemed to increased soil sulfate might give detrimental effects on acidic forest soil in Korea.

Nitrate

Although nitrate concentration in the soil was significantly different between the levels of rain pH for all soil types, it had no particular relations with acid rain treatment(Tables 1 and 2). Nitrate concentrations in the soils increased in July, compared with those before treatment, and decreased in October for all soil types. Increase in soil nitrate measured in July seems to be resulted from the nitrate ion in simulated acid rain, being supported other reports that soil nitrate incrased with short-term simulated acid rain[2,40,49]. However, decrease in soil nitrate measured in October might be caused by nitrate loss due to environmental factors[52], high phytoavailability and leaching of nitrate, which has lower anion exchange capacity than sulfate. Soil nitrate concentration after acid rain treatment was the highest in nursery soil, followed by mixed and sandy soils, which might be resulted from the differences in anion exchange capacity among soil types. Nitrate concentrations of the soils at pH 2.0 levels were higher than those at other pH levels. At other pH levels, soil nitrate concentrations varied with soil types and with the levels of pH. Such results seemed to be due to nitrate concentration in simulated acid rain, nitrate absorption by plants, variations in nitrate contents by biochemical reactions and nitrate leaching from soils[23].

From the results above, nitrate in acid rain might benefit plant growth. However, the higher nitrate concentration of acid rain treated, the more leaching of exchangeable cations from the soil occurred[24]. It is suggested that more detailed study on the relations between nitrate in acid rain and soil properties is required in the future.

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