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Chemical Characteristics of Rainfall and Throughfall in *Pinus koraiensis* and *Larix leptolepis* Forests in Korea

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Abstract : This study evaluated the chemical characteristics of rainfall and throughfall in *Pinus koraiensis* and *Larix leptolepis* forests. We analyzed pH, EC, and concentrations of cations and anions in rainfall, throughfall and stemflow collected from both forest types in the experimental forests of the central Korea. The concentrations of chemical elements were much higher in throughfall and stemflow than in rainfall for both forest types, and were significantly different among the seasons. Comparing the chemical elements between the *P. koraiensis* and *L. leptolepis* plantations, there were not significantly differences in throughfall, but the concentrations of almost elements of stemflow in *P. koraiensis* were almost lower than those in *L. leptolepis.* For seasonal inputs to the forest floor, more than half of the total input of Ca^{2+}, NO_3^- and SO_4^{2-} was observed in spring. This suggests that air pollutants such as NOx and SOx accompanying calcium-rich aeolian Yellow Sand (Asian dust) from China could have an important influence on nutrient cycles in Korean forests.

Key words : *acid deposition, anion, cation, stemflow, throughfall, Yellow Sand*

Introduction

Many researches on acid rain have been conducted especially in Europe, North America, Japan and China for a few decades (Sassa *et al.*, 1991; Thomas, 1991; Ishizuka, 1992; Koptsik, 1997; Houbao *et al.*, 1999; Uri and Dennis, 2003), and recently the interest has been extended to Asian area because of drastic industrialization of Asian countries (Carmicheal, 1997; Supat, 2001). In Korea, investigation on acid rain in the field of forestry has been spreaded out over the country since 1990 and the studies have been focused on the effects of artificial acid rain on forest soils (Kim *et al.*, 1996) and the response of forest ecosystems to the deposition of acidic materials (Lee *et al.*, 1997; Han and Lee, 1997; Chun *et al.*, 1997, 1998a, 1998b; Park and Woo, 1998; Jeong *et al.*, 2000; Kim *et al.*, 2001). On the other hand, the accumulation of observation data for acid rain in various forest sites has been insufficient in Korea.

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We have been analyzed pH, EC and concentrations of cations and anions in rainfall, throughfall and stemflow collected in the experimental forests of the College of Forest Sciences, Kangwon National University, Korea. The purpose of this study was to clarify the chemical characteristics of acidic deposition in *Pinus koraiensis* and *Larix leptolepis* forests, which occupy more than half of plantation forest in Korea (Forestry Administration, 1997).

Materials and Methods

The experimental forest of Kangwon National University is located in Kangwon province (127° 48′-52′E, 37° 46′-51′N) about 100 km from Seoul (Figure 1). Investigation areas were 4th and 6th compartment in the experimental forest and the altitude ranges from 255 m to 899 m above sea level. This surveyed area belongs to temperate forest in which the main tree species were *Quercus mongolica*, *Q. variabilis*, *Q. aliena*, *Fraxinus rhynchophylla*, *Cornus controversa*, *Lindera obtusiloba* and *Lespedeza bicolor.* The precipitation is approxi-

Table 1. The diameter at breast height, height, crown diameter, age, number of trees per ha and altitude of each forest stand.

Compartment	Tree species	D.B.H. (cm)	Height of Tree (m)	Crown diameter (m)	Age of Tree (year)	Tree/ha	Altitude (m)
6th	*Larix leptolepis*	19.0	18.0	8.0	24	600	600
	Larix leptolepis	28.0	24.0	12.0	30	600	600
	Pinus koraiensis	23.0	11.0	6.0	23	600	600
	Pinus koraiensis	27.0	14.0	7.0	27	600	600
4th	*Larix leptolepis*	22.0	23.0	5.0	28	700	450
	Larix leptolepis	23.0	24.0	10.0	28	700	450
	Pinus koraiensis	17.0	12.0	5.0	18	1100	540
	Pinus koraiensis	20.0	13.0	5.5	19	1100	540

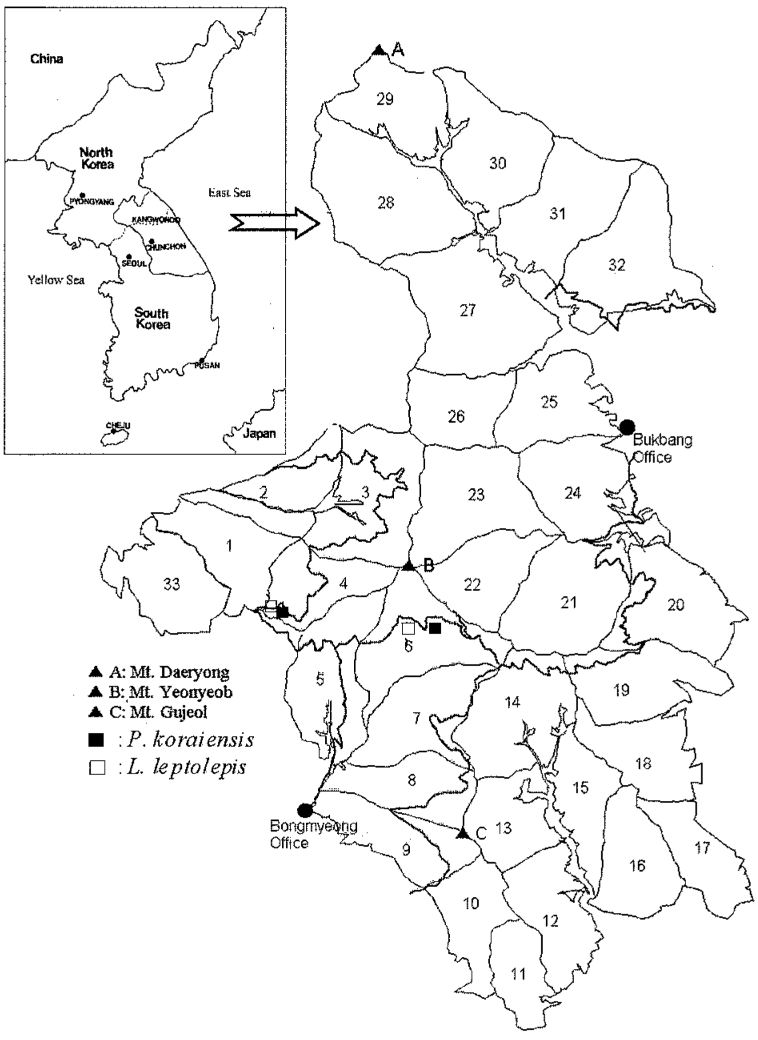

Figure 1. Location of study area.

mately 1154.9 mm and the mean temperature is about 11.1 in 2000. The precipitation from April to September was about 70% of total precipitation. The soils have generally formed from granite parent material. The soil type is a slightly dry brown forest soil (B_2) (Jin *et al.*, 1994). Tree species, selected for throughfall and stemflow measurement, are *P. koraiensis* and *L. leptolepis* in plantation areas and the four individual trees of each species were used in this study. Table 1 shows the diameter at breast height, height, crown diameter, age, number of trees per ha and altitude of each forest stand.

Rainfall was collected using a 20-cm funnel connected to a 20-L polyethylene bottle in an open area of the experimental forests. Throughfall was collected using the same method as for rainfall within each plot. Stemflow was collected using a synthetic rubber sheet with an

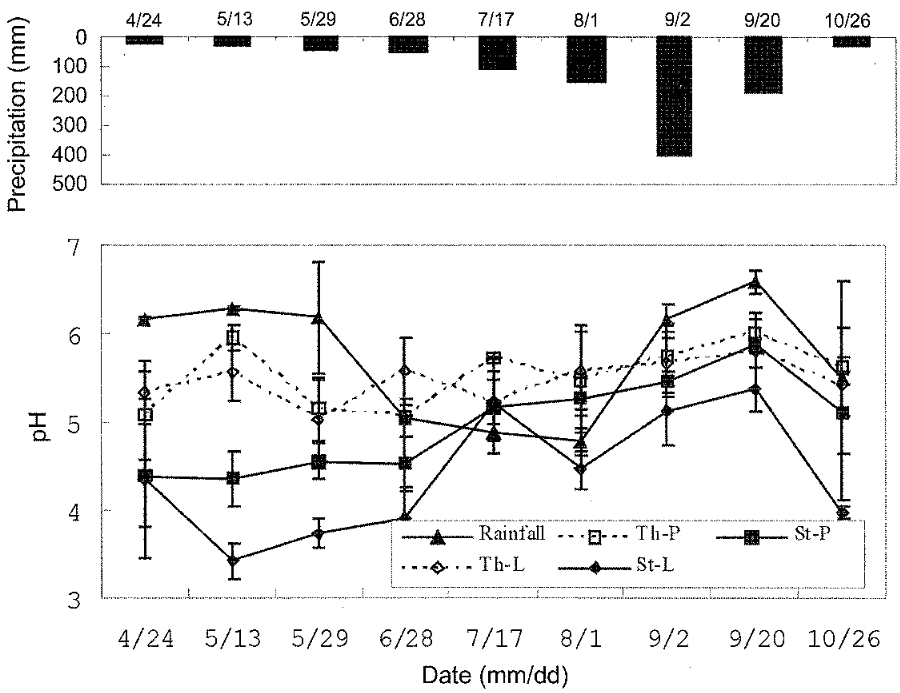

Figure 2. Variations in precipitation and the pH values of rainfall, throughfall and stemflow in *P. koraiensis* and *L. leptolepis*. Error bar illustrates the standard deviation. (Th-P : Throughfall of *Pinus koraiensis*, Th-L : Throughfall of *Larix leptolepis*, St-P : Stemflow of *P. koraiensis*, St-L : Stemflow of *L. leptolepis*)

acutely angled edge attached around the stem by silicon to avoid leakage; collected stemflow was stored in a 200-L polyethylene container. Rainfall, throughfall and stemflow were collected after every rainfall event from April 24 to October 26, 2000. From December to February, sampling was not performed because of snow fall. In addition, there was no sampling in March 2000 because rainfall never exceeded 5 mm per day. The pH and EC values were measured within 12 h after sampling using pH and EC meter (model 1230, Orion Corp., USA) after filtration with a 0.2 μm membrane filter. Cations such as sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}) and potassium (K^+) were analyzed using an atomic absorption spectrophotometer (AA-6800, SHIMADZU Corp., Japan). Anions such as chloride (Cl^-), nitrate (NO_3^-) and sulfate (SO_4^{2-}) in the collected solutions were analyzed using ion chromatography (DX-120, DIONEX Corp., USA). In order to estimate the seasonal contribution of inputs to the forest floor, all data were divided into three seasons, spring (April, May), summer (June-August) and fall (September, October). From the volumes of throughfall and stemflow in each forest stand, the total amount of elemental input to the forest floor was estimated.

Data were analyzed statistically using Excel statistic 2000 (SSRI Co. Ltd., 1995). Means of the two stands, precipitation components were compared using analysis of variance (ANOVA) followed by the least significant difference (LSD) test. Data were used the volume weighted mean.

Results and Discussion

Figure 2 showed seasonal variation in the volume weighted mean pH values of rainfall, throughfall and stemflow of *P. koraiensis* and *L. leptolepis* in the study period. The mean pH values of rainfall ranged from 4.77 to 6.39 (average: 5.74). The mean pH of throughfall of *P. koraiensis* ranged from 4.72 to 6.30 (average: 5.51), 4.71 to 5.90 (average: 5.29) for *L. leptolepis*. The mean pH values of stemflow of *P. koraiensis* ranged from 4.33 to 6.01 (average: 4.85), 3.53 to 5.50 (average: 4.44) for *L. leptolepis*. The pH values of stemflow were significantly lower than those of rainfall and throughfall in both species ($P<0.01$). These results were agreed with Houbao *et al.* (1999) reported that the pH of stemflow was much lower than rainfall and throughfall in a Chinese fir plantation.

Comparing the results from the two species, the pH values of stemflow of *L. leptolepis* were lower than those of *P. koraiensis*. Our results support the earlier reports that the pH of stemflow varies with tree species in Korea (Chun *et al.*, 1998a, 1998b; Kim *et al.*, 2001).

Through the observation period, the lowest pH value for stemflow occurred in April and May and was accompanied by high concentration of cations. Several mechanisms for the reduction of pH in stemflow have been demonstrated (Takenaka and Win, 1999); these include leaching of organic acid, dissolution of acidic dry deposition and ion exchange on the stem surface. Takenaka

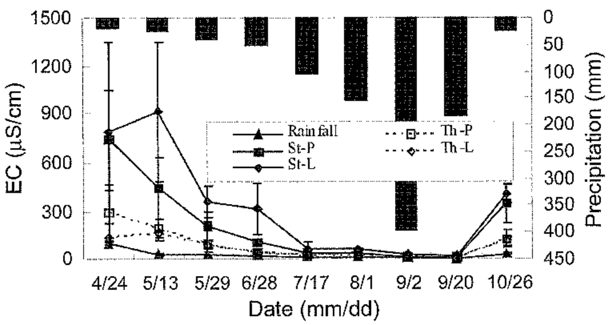

Figure 3. Variations in precipitation and the EC values of rainfall, throughfall and stemflow in *P. koraiensis* and *L. leptolepis*.

and Win (1999) emphasized that ion exchange between cations and protons on the surface of the stem is an essential mechanism in the reduction of pH in stemflow. Since a corresponding decrease in pH values was not observed in rainfall and throughfall in spring, however, it is unlikely that deposition in this season included particularly acidic materials such H^+ ion (Bredemeier, 1988). On the other hand, the cations concentrations were high in spring (Figure 4). Therefore, it is considered that one possible reason for the low pH of stemflow in spring might be a high concentration of cations in rainfall which could exchange protons on the stem surface.

The volume weighted EC values ranged from 2.5 to 101 µS/cm (average: 28.8 µS/cm) for rainfall, but were much higher for throughfall and stemflow ($P<0.05$ for *P. koraiensis* and $P<0.01$ for *L. leptolepis*) (Figure 3). The mean EC values of stemflow were higher than those of throughfall in both *P. koraiensis* (233.2 µS/cm for stemflow versus 120.5 µS/cm for throughfall) and *L. leptolepis* (306.8 µS/cm versus 85.2 µS/cm). The increase of EC values from rainfall to throughfall or stemflow has been reported in various forests (Jeong *et al.*, 2000; Sanada *et al.*, 1991), e.g. 27 µS/cm in rainfall, 59-69 µS/cm in throughfall and 97-125 µS/cm in stemflow for *Abies holophylla* and *P. koraiensis*.

The comparison between the two species indicates that the stemflow of *L. leptolepis* had higher EC values than those of *P. koraiensis*, but no such difference was found in throughfall. A similar trend was observed in the results of ion concentrations (Figure 4 and 5). The differences in EC and ion concentration between throughfall and stemflow are likely to be a result of the difference in crown sizes of the two species. Because *L. leptolepis* has a larger crown than *P. koraiensis*, deposition of particulates would be greater in the crown of *L. leptolepis* and dissolved into stemflow.

As described above, the EC values and ion concentrations in all samples showed a distinct seasonal variation in which the values in April were highest and those in August or September were lowest (Figures 3, 4 and 5). The values measured in spring were extremely high compared with published data obtained from Japanese forests (Takenaka *et al.*, 1995; Gao *et al.*, 2001). For nitrate and sulfate in particular, which mainly originate from acidic air pollutants, the concentrations in rainfall during spring were more than ten times those measured in summer. The throughfall and stemflow data, which

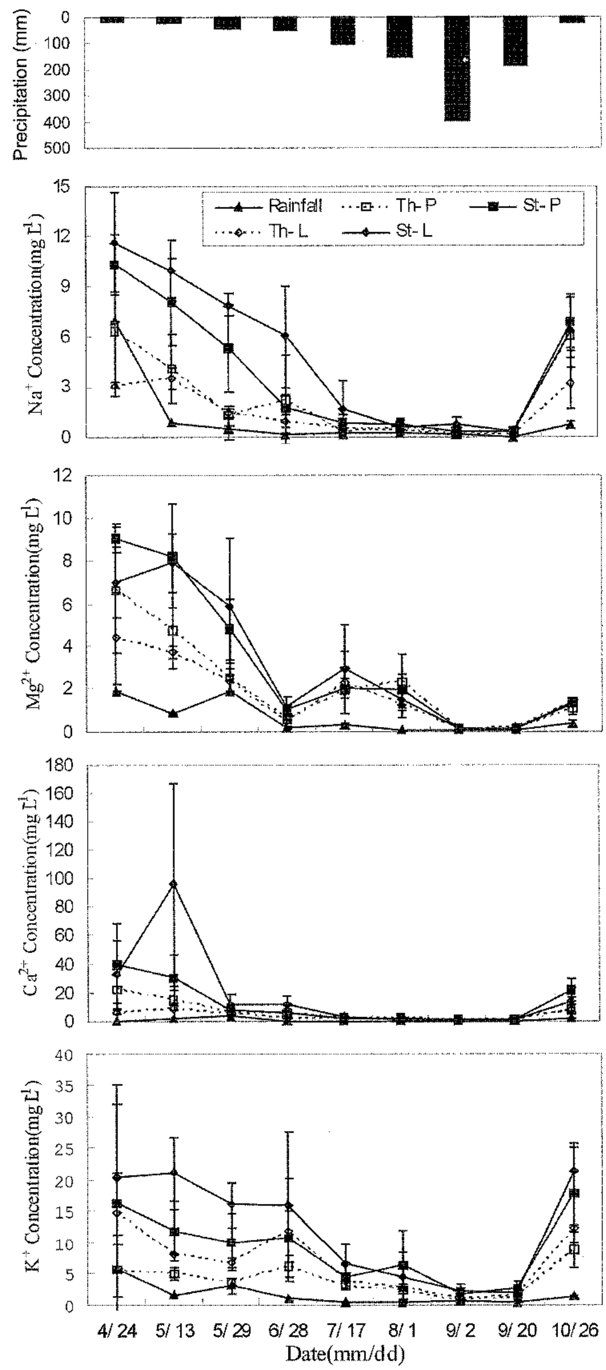

Figure 4. Variations in precipitation and cation concentrations of rainfall, throughfall and stemflow in *P. koraiensis* and *L. leptolepis*.

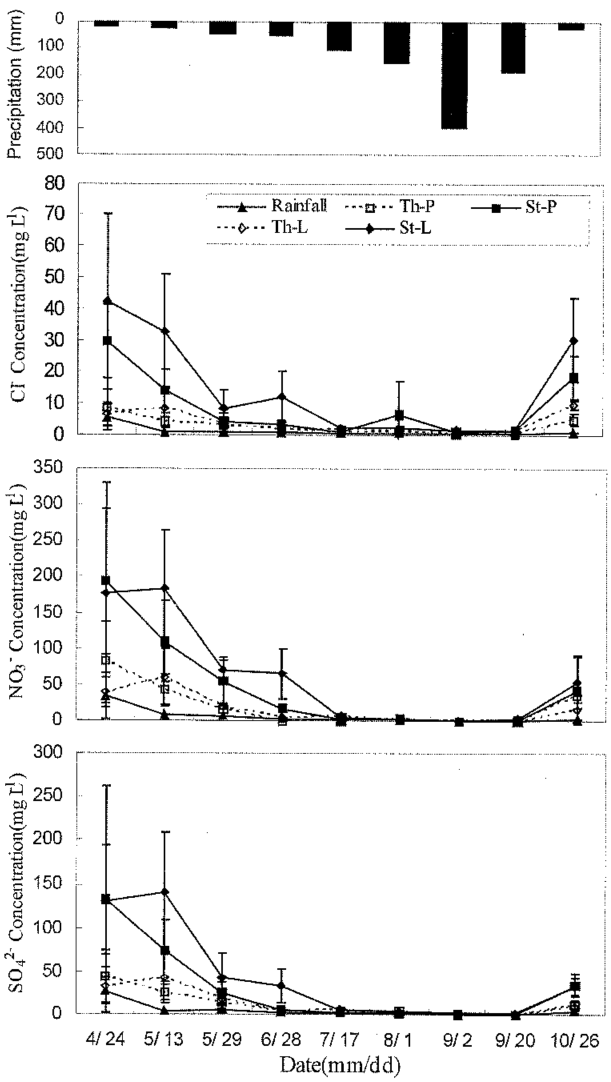

Figure 5. Variations in precipitation and anion concentrations of rainfall, throughfall and stemflow in *P. koraiensis* and *L. leptolepis*.

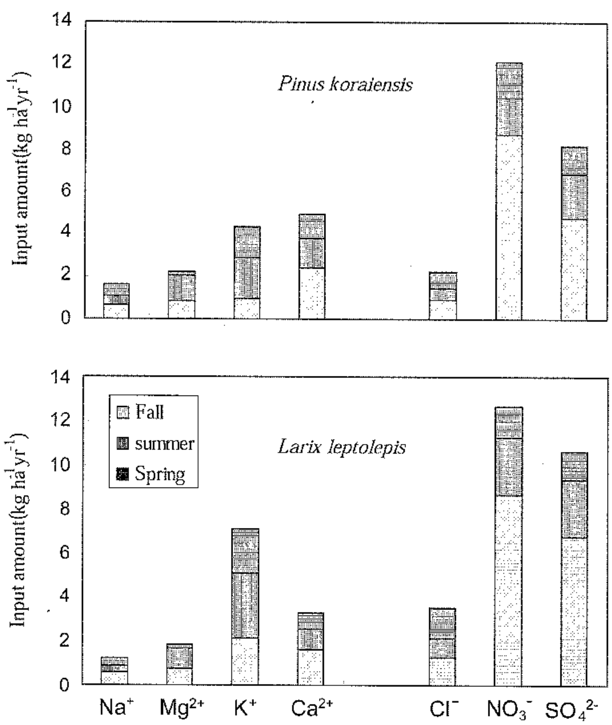

Figure 6. Seasonal input of various elements into *P. koraiensis* and *L. leptolepis* forest stands.

reflects the contribution of dry deposition, displayed the same tendency. In the previous reports, Chun *et al.* (1997) and Han and Lee (1997) indicated that pH value of rainfall showed a clear seasonal change such as higher value in spring than summer and fall. Also, Chun *et al.* (1998a) found that pH, EC and anions concentrations of stemflow showed a distinct seasonal variation from June, 1996 to September, 1998 in the same study area. Our results support the previous observation. In particular, the intensive input in spring could be attributed to the effect of dry deposition, that is, aeolian dust originating from China to the west (locally referred to as Yellow Sand or Asian dust). In present, the deposition of Yellow Sand is a serious problem in spring (Chohji *et al.*, 1997) and continues from early spring until May every year in Korea.

To estimate the seasonal inputs to the forest floor, the total inputs of each ion were calculated for each season using rainfall distribution data in the two forest stands. In the study period, the precipitation was 996mm and the rates of throughfall and stemflow in *P. koraiensis* and *L. leptolepis* were 76% and 3%, and 80% and 2%, respectively. The results are shown in Figure 6. More than half of the total inputs of No3− and So42− and nearly half the Ca^{2+} were estimated to be supplied in spring. This finding demonstrates that the contribution of aeolian dust such as Yellow Sand to nutrient cycles in forest is considerable. It has been reported that Yellow Sand contains not only silicates, $CaCO_3$ or CaO, but also acidic pollutants containing nitrate and sulfate (Chung *et al.*, 2000, 2001). These facts suggested that the contribution of this Yellow Sand appears to determine the chemical composition of rainfall, throughfall and stemflow in spring seanson, Korea.

Comparing the input data between the *P. koraiensis* and *L. leptolepis* plantations, there were not significantly differences, but input of K^+ from *L. leptolepis* was higher than those from *P. koraiensis*. This is considered to be due to the characteristic of *L. leptolepis* that K^+ leaching from leaves and barks.

The chemical analysis of precipitation in *P. koraiensis* and *L. leptolepis* forests in Korea shows the regional importance of intensive inputs of nitrate, sulfate and calcium in spring. Although the observation in this study was carried out only for wet deposition from April to October, it is assumed that the amount of dry deposition of these ions in winter and early spring would be not insubstantial. Therefore, it is necessary to quantify the inputs of dry deposition throughout a full year to gain a more complete understanding of the effects of acid deposition on the nutrient cycles, especially of nitrogen, of these forest ecosystems.

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