Leaching characteristics of leaf litter, soil and bedrock in a stream basin of the Southern Kyusyu Mountains

Hirokazu Kitamura

Laboratory of Landscape Conservation, Minami-Kyushu University, Miyakonojo, Miyazaki 885-0035, Japan

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To clarify the decomposition and leaching rate of *Quercus glauca* leaves and compare overall leaching characteristics of the substances originating from rock weathering, soil and leaf litter of the evergreen species, two sampling points were selected and samples of leaves, soil and rock were collected. Collected leaves were washed with distilled water and well dried. Two sets of beakers for each *Quercus glauca* tree were prepared, each with five replicates (subsamples). Each beaker was filled with 1000 ml of distilled water or stream water. Three randomly selected leaves were then weighed and placed into each beaker. Soil and rock particles smaller than 2 mm in diameter collected in each sampling point were selected for subsamples in each sample using a sieve. Two sets of beaker were prepared. Each beaker was filled with 1000 ml of stream water or distilled water. 2 g of each sub-sample was placed into each beaker. Then, each sample was allowed to stand at ambient temperature. At 30 days after submersion, the concentrations of TC (total carbon), TN (total nitrogen), SiO_2, and cations were measured. After 90 days of incubation, the weight of leaves and the concentrations of the substances were measured. The 30-day incubation of leaves for leachate preparation was sufficient to achieve full leaching of the cuticle, which may be a physical obstacle to leaching of several substances, from the leaves used by TC release-rates analysis. Cations were also released immediately after submergence. The order of materials from which substances are released, from the most rapid to the slowest, was leaves > soil > rock. It is possible that lower cation release rates in stream water than in distilled water for the first 30 days and net negative values of cation release for the 30th to 90th days were induced by microbial consumption in stream water. It has been said that minerals, such as K^+, Mg^{2+} and Ca^{2+}, in streams almost entirely originates from the weathering of silicate materials. However, based on the observed results, changes in water composition are predicted from the natural input and subsequent leaching of leaf litter.

Key words: stream water composition, cation, leaching, *Quercus glauca*.

1. Introduction

Water falling to the surface of a stream basin as rain undergoes major modification of its chemical composition. Some water may infiltrate the soil and some may immediately run off the surface or pass deep underground only to finally emerge much later in a stream, aside from the fraction lost by evaporation. In these processes, water comes in contact with bedrock, soil and vegetation, reacting with primary minerals contained in them[4]. Stream water composition is therefore affected by several natural conditions including geology and vegetation of the basin. The chemical composition of stream water is mainly influenced by rock weathering. For example, it is said that 80-90% of the stream water output of Na^+, K^+, Mg^{2+} and Ca^{2+} comes from rock weathering[1].

On the other hand, allochthonous material, such as leaves (leaf litter), is a primary energy source for secondary consumers in small streams. Organic matter is decomposed through a variety of physical, chemical and biological processes[1]. After leaves fall into streams, soluble chemicals are leached from the plant tissue, and the leaf tissue is colonized by microbes (known as conditioning) and fragmented by mechanical abrasion and invertebrate activity. The instream processing of this organic material produces dissolved organic matter[15] and inorganic nutrients[2] by leaching. As considerable quantities of allochthonous material enter lotic ecosystems from riparian forests[5], substances derived from the decomposition of leaf litter may have an important effect on stream water quality.

However, except for phosphate and nitrogen, relatively little is known of the dynamics of leachates, particularly the ionic components. The dependence of woodland stream ecosystems on allochthonous organic matter, primarily in the form of autumn-shed leaf litter, is well documented. However, few studies have examined the chemical constituents of leachates derived from evergreen leaf litter, or their effect on stream water quality during initial decomposition and conditioning. Our previous experimental studies of evergreen leaves of *Quercus glauca* submerged in stream water for 30 days[10,11,12] showed that the decrease in the weight of the leaves released soluble leachates, such as total carbon (TC) and total nitrogen (TN), as well as the cations K^+, Mg^{2+} and Ca^{2+}, indicating that *Quercus glauca* leaf litter is one of the primary sources of soluble leachates in stream water. The same experiments also showed that the tough outer surfaces of evergreen leaves (e.g., the cuticle) may delay leaching and subsequent weight loss in leaves. Some of these studies, however, did not provide a detailed understanding of the leaching characteristics (leaching rates and leaching material) of leaves and material resulting from rock weathering, including soil.

The purpose of the present study was therefore to clarify the decomposition and leaching rate of *Quercus glauca* leaves for longer than 30 days and to compare overall leaching characteristics of the substances originating from rock weathering, soil and leaf litter of the evergreen species that are dominant in the riparian zone.

2. Methods

2-1. Site description

Experiments were conducted in the Takeo River of Saito City in Miyazaki Prefecture. The Takeo River, a tributary of the Hitotsuse River, ranges in elevation from 100 m to 600 m and originates in the Southern Kyushu Mountains. The Takeo River Basin overlays the Miyazaki Formation, which was formed during the Cretaceous to middle Paleocene periods. The formation consists of black slate, sandstone and shale. The geologic structure of the basin, therefore, is characterized by the prevalence of weak and extensively folded rock strata with numerous faults that are susceptible to weathering. These geologic conditions have formed steep and unstable basin slopes where several mid-sized landslides have occurred in the last fifty years. To prevent sediment disasters caused by landslides resulting from the weakness of this basin, seven 3–5 m high sabo dams have been constructed in the stream since 1965[8]. The study site consists of an approximately 1 km river reach between sabo dams No. 5 and No. 6 (Fig. 1). The stream is a first-order stream with a mean width of 10 m, mean depth (at modal flow) of 0.3 m, mean slope of 1/40, and mean current velocity ranging from 20 to 30 cm/sec. The stream bottom is composed primarily of gravel, pebbles and cobble substrates.

The riparian vegetation consists of evergreen broad-leaved trees, such as *Quercus glauca*, *Symplocos theophrastifolia* Sieb. et Zucc., *Machilus japonica* Sieb. et Zucc., *Meliosma rigida* Sieb. et Zucc., and *Litsea acuminata* Kurata. Since the slope of the stream basin is steep, tree leaves supplied to the forest floor of the slope tend to be removed to the stream bed.

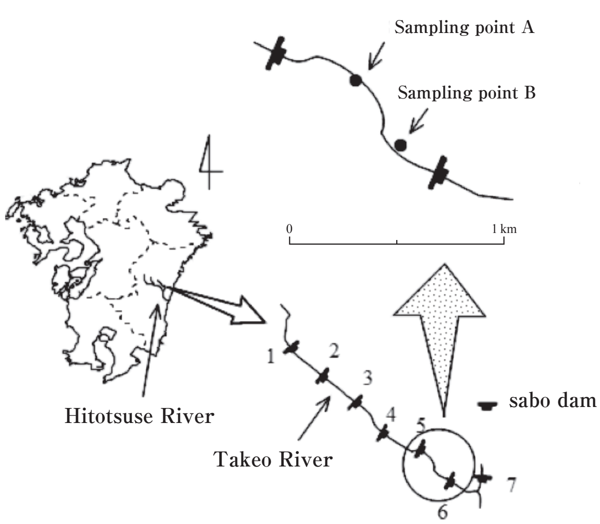

Fig. 1. Investigated rivers and sampling points

2-2. Materials

Two sampling points were selected along the investigated reach, sampling points A and B. Sampling point B is about 350 m downstream from sampling point A (refer to Fig. 1). The materials used in the study included leaves, soil and fragments of bedrock. All of the specimens were obtained from these sampling points. All materials were collected on March 20, 2016. Stream water (100 L) was collected from the same stream for leaching experiments.

2-2-1. Leaves

The leaves of *Quercus glauca*, which is common in the riparian zone of the investigated stream basin and makes a substantial contribution toward annual litter fall, was used in the leaching tests from leaf litter. Leaves were collected from one *Quercus glauca* tree at each sampling point that had been growing on the sunny and unfertilized alluvial plain of the stream at sampling points A and B (*Quercus glauca* A and *Quercus glauca* B). From both trees, 100 leaves were collected from the branches at a height 2–4 m above the ground surface. All leaves were sun leaves. Leaves picked from the old branches of the tree were considered to be old leaves and were collected just prior to abscission. These leaves were intact and retained their original shape without any skeletonization.

2-2-2. Soil

Soil (100g) was collected as samples at 20–30cm depth from the surface adjacent to the roots of *Quercus glauca* trees. At each sampling point, 5 soil samples were collected at random.

2-2-3. Bedrock

In a preliminary experiment, we observed that black slate leached many more cations than sandstone or shale. Therefore, 5 fragments of bedrock were collected at an outcrop of bedrock of black slate and ground into pieces with a rock hammer at each sampling point for leaching tests.

2-3. Leaching experiments

2-3-1. Leaf samples

Collected leaves were washed with distilled water to remove aerosol dust and atmospheric gases, air-dried for 1 week and then oven-dried at 80°C for 12 hr. Two sets of beakers for each *Quercus glauca* tree were prepared, each with five replicates (subsamples). Each beaker was filled with 1000 ml of distilled water or stream water. Three randomly selected leaves were then weighed and placed into each beaker. In this way, 20 beakers were prepared; leaves of *Quercus glauca* A in distilled water (LAd1–LAd5), leaves of *Quercus glauca* A in stream water (LAs1–LAs5), leaves of *Quercus glauca* B in distilled water (LBd1–LBd5) and leaves of *Quercus glauca* B in stream water (LBs1–LBs5). Then, each sample was allowed to stand at ambient temperature between 15 and 25°C in April to June.

30 days (about a month) after submersion, the concentrations of TC (including total organic carbon (TOC) and inorganic carbon (IC)) and TN were measured with a TOC-TN measuring instrument (TNC-6000, Toray Engineering K.K.). SiO_2 was measured with probe DR-900 (Hach Inc., USA). The concentrations of cations (Li^+, Na^+, NH_4^+, K^+, Ca^{2+} and Mg^{2+}) were measured using ion chromatography (DX-120, Nippon Dionex K.K.).

After 90 days (about 3 months) of incubation, all of the remaining materials were removed from each beaker. The processed leaves and leaf fragments larger than 1 mm in diameter were selected as coarse particulate organic matter (CPOM), and leaf fragments and particles smaller than 1 mm in diameter were selected as fine particulate organic matter (FPOM) using a sieve. The CPOM and FPOM fractions from each chamber were air-dried for 1 week, oven-dried at 80°C for 12 h, and weighed.

2-3-2. Soil samples

Soil particles smaller than 2 mm in diameter were selected for subsamples in each soil sample using a sieve. Two sets of beakers were prepared. Each beaker was filled with 1000 ml of stream water or distilled water. 2 g of each sub-sample was placed into each beaker (SAd1–SAd5, SAs1–SAs5, SBd1–SBd5 and SBs1–SBs5) and was allowed to stand at ambient temperature, which ranged from 15 to 25°C in April to June. The concentrations of TC, IC, TN, SiO_2 and cations in each beaker were determined by the same methods described above 30 and 90 days after submersion.

2-3-3. Bedrock samples

Fragments of rock obtained at each sampling point were ground into fine particles using a crusher. Particles smaller than 2 mm in diameter were selected for subsamples using a sieve. Two sets of beakers were prepared. Each beaker was filled with 1000 ml of stream water or distilled water. A portion of each subsample (2g) was placed into each beaker (RAd1–RAd5, RAs1–RAs5, RBd1–RBd5 and RBs1–RBs5) and was allowed to stand at ambient temperature, which ranged from 15 to 25°C in April to June. The concentrations of TC, IC, TN, SiO_2 and cations in each beaker were determined by the same methods described above 30 and 90 days after submersion.

2-4. Calculation of release rates per day

The concentrations of each substance in each treatment obtained by the methods described above cannot be compared among treatments, because the initial concentrations of each substance in distilled water and stream water and in the experimental periods were not equal. The release rate per day of each substance for each treatment was calculated and compared among treatments. The release rates per day were defined as follows using mean concentrations from each treatment.

- first 30 days after submersion:
  ((concentration after 30 days) – (initial concentration))/ experimental period (30 days)
- for 30th day to 90th day:
  ((concentration after 90 days) – (concentration after 30 days))/experimental period (60 days)

2-5. Statistical analysis

The differences in the weight loss of leaves by decomposition in each treatment solution (stream water and diluted leachate) were analyzed by one-way analysis of variance (ANOVA). The differences in TC, TN, SiO_2 and cation concentrations leached from each submerged substance in each treatment corresponding to the experimental period were also analyzed by one-way ANOVA.

Furthermore, the effects of materials (leaf litter, soil and bedrock) and treatment solution on the release rate of each substance leached (TC, TN, SiO_2 and cations) corresponding to the experimental period were analyzed by two-way ANOVA. In this analysis, materials from which substances were leached and treatment solutions in each beaker were regarded as independent variables and the release rate of each substance was considered the dependent variables.

3. Results

3-1. Leaf weight loss after incubation

Table 1 shows the weight loss rates of leaves submerged in distilled water and stream water during the experimental period. Weight loss was calculated by subtracting the weight of the leaves 90 days after submergence from the weight before submergence. No fragmentation of leaves occurred because microbial and invertebrate activity was removed in the tests.

The ranges of weight loss were 0.60–0.76, 0.40–0.58, 0.51–0.61 and 0.45–0.56 g respectively in distilled water of sampling point A (LAd), stream water of sampling point A (LAs), distilled water of sampling point B (LBd) and stream water of sampling point B (LBs). The corresponding ranges of rate of weight loss were 48.68–54.94, 46.51–59.57, 55.45–61.41 and 55.14–58.95% , in LAd, LAs, LBd and LBs, respectively.

A significant difference was observed for the weight loss in distilled water versus stream water ($P<0.05$; Table 2). The mean $\pm$ standard error of weight loss of leaves in each treatment beaker were 0.68 ± 0.03, 0.53 ± 0.03, 0.55 ± 0.02 and 0.48 ± 0.02 g, in LAd, LAs, LBd and LBs, respectively, indicating that the most weight loss occurred in the beaker with distilled water and leaves from sampling point A (LAd). The mean weight loss of leaves was greater in distilled water than in stream water for both samples.

3-2. TC, TN, SiO_2 and cation concentrations leached from each submerged substance

TC, TN, SiO_2 and cations appeared to leach from the submerged substances immediately after submersion, as in our previous experiments[10,11,12].

In the present study, measurement results of concentrations were illustrated in three Tables due to limitations of space. Table 3a and Table 3b show the concentrations of TC, TN, SiO_2 and cations that had leached from all samples of *Quercus glauca* leaves, soil and bedrock submerged in distilled water or stream water for 30 days or 90 days. In Table 3a and Table 3b, the concentrations per 1 g of leaves are indicated. Table 4 shows the mean $\pm$ standard error of each concentration corresponding to the materials and treatment solutions based on Table 3. Furthermore, Fig. 2 illustrates the mean concentrations of each substance leached corresponding to materials and treatment solutions with results combined for samples A and B for further understanding. In Fig.2, Ld, Ls, Sd, Ss,

Table 1. Comparison of weight loss of *Quercus glauca* leaves by decomposition for each treatment

beaker		treatment solution	initial (g) ①	final (g) ②	weight loss (g) ①−②	mean±standard error (g)	percentage (%) (①−②)*100/①	mean±standard error (%)
LAd-1	*Quercus glauca* A	distilled water	1.19	0.55	0.64	0.68 ± 0.03	53.78	52.27 ± 1.18
LAd-2	〃	distilled water	1.12	0.52	0.60		53.57	
LAd-3	〃	distilled water	1.51	0.75	0.76		50.33	
LAd-4	〃	distilled water	1.33	0.68	0.65		48.68	
LAd-5	〃	distilled water	1.39	0.63	0.76		54.96	
LAs-1	*Quercus glauca*A	stream water	1.13	0.58	0.55	0.53 ± 0.03	48.67	52.88 ± 2.35
LAs-2	〃	stream water	0.86	0.46	0.40		46.51	
LAs-3	〃	stream water	0.94	0.38	0.56		59.57	
LAs-4	〃	stream water	1.07	0.49	0.58		54.43	
LAs-5	〃	stream water	1.03	0.46	0.57		55.21	
LBd-1	*Quercus glauca* B	distilled water	0.89	0.38	0.51	0.55 ± 0.02	57.30	57.73 ± 1.00
LBd-2	〃	distilled water	0.90	0.39	0.51		56.67	
LBd-3	〃	distilled water	1.01	0.45	0.56		55.45	
LBd-4	〃	distilled water	1.00	0.38	0.61		61.41	
LBd-5	〃	distilled water	1.00	0.42	0.58		57.82	
LBs-1	*Quercus glauca* B	stream water	0.85	0.38	0.47	0.48 ± 0.02	55.29	56.47 ± 0.70
LBs-2	〃	stream water	0.79	0.34	0.45		56.96	
LBs-3	〃	stream water	0.95	0.39	0.56		58.95	
LBs-4	〃	stream water	0.83	0.37	0.47		56.01	
LBs-5	〃	stream water	0.83	0.37	0.46		55.14	

Table 2. Results of one-way ANOVA between stream water and distilled water, and between sampling points A and B

dependent variable	n	mean square	*F*	*P*
weight loss (g)				
sampling point A	1	0.056	9.919	<0.05
sampling point B	1	0.013	6.758	<0.05
weight loss rates (%)				
sampling point A	1	0.941	0.054	n.s.
sampling point B	1	3.951	1.060	n.s
weight loss (g)				
distilled water	1	0.041	10.830	<0.05
stream water	1	0.007	1.752	n.s.
weight loss rates (%)				
distilled water	1	74.589	12.445	<0.05
stream water	1	32.247	2.138	n.s.

Rd and Rs indicate the abbreviations of treatment type based on materials (leaves, soil and bedrock) and treatment solutions (distilled water and stream water) used. For example, treatments using leaves and distilled water and leaves and stream water are illustrated as Ld and Ls, respectively.

3-2-1. TC, TN and SiO_2

The measured TC concentration was equal to the TOC concentration, because no IC was detected in any samples.

In the first 30 days, the mean concentrations of TC were in the range of 30.73–37.38, 4.50–5.51 and 2.05–15.34 mg/l in solutions of submerged samples of leaf, soil and bedrock, respectively (Table 4). The solution with the highest concentration of TC contained *Quercus glauca* leaves, and was one order of magnitude higher than the concentrations of the others. As with TC concentrations, TN and SiO_2 concentration were the highest in the solution with submerged leaves for the first 30 days. However, the concentrations of TC, TN and SiO_2 in each treatment for the first 30 days were one order of magnitude lower than those of TC. There were no marked differences in the concentrations of TC, TN and SiO_2 between 30 days or 90 days after submergence. In rock samples, the difference in TC concentration between samples with stream water and samples with distilled water was drastic (Table 4).

3-2-2. Cation concentrations leached from submerged leaves, soil and bedrock

The cations detected in all samples during the experimental period were Na^+, NH_4^+, K^+, Mg^{2+} and Ca^{2+}. The cation concentrations in leachate after 30 days were generally higher in NH_4^+ and K^+ in solutions with *Quercus glauca* leaves than in those with bedrock. Ca^{2+} was the most abundantly leached cation in distilled water with bedrock. In rock samples, however, the difference in Ca^{2+} concentrations between samples with stream water and samples with distilled water was remarkable. The concentrations of cations in solutions with soil were the lowest among treatments with the exception of K^+. The concentrations in each treatment after 90 days seemed to be generally equal to or slightly lower than the concentrations after 30 days, except for Na^+, NH_4^+ and Ca^{2+}. In rock samples, however, the differences in these concentrations between samples with stream water and samples with distilled water were remarkable, as described for TC.

Fig. 2 indicates that K^+ was mostly released from *Quercus glauca* leaves after 30 days and 90 days and that Na^+ and Ca^{2+} were released from bedrock in the period 30–90 days. Fig. 2 also indicates that cations release from each material was promoted more in stream water than in distilled water. However, it must be considered that the initial concentrations of each substance in distilled water

Table 3a. Concentrations (mg/l) of substances in leaching experiments corresponding to the experimental period in each treatment

beaker	material	treatment solution	measurement values: after 30 days TC	TN	SiO_2	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	after 90 days TC	TN	SiO_2	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
LAd-1			28.76	2.87	4.96	0.537	1.719	2.472	0.057	1.232	25.04	2.00	9.47	0.000	2.314	2.315	0.000	2.488
LAd-2			41.28	3.27	5.47	4.866	2.288	4.414	0.489	2.044	35.47	3.72	9.30	0.000	2.938	3.615	0.000	4.754
LAd-3	*Quercus glauca* leaves A	distilled water	38.83	3.28	3.30	1.251	3.116	3.542	0.082	1.335	33.62	3.04	9.57	0.000	2.899	3.442	0.000	5.449
LAd-4			29.08	3.21	5.02	4.532	2.540	3.808	0.229	1.536	32.30	2.91	9.55	0.000	2.412	2.846	0.000	3.856
LAd-5			36.22	3.18	4.39	4.443	3.112	4.158	0.340	1.948	32.01	3.39	9.53	0.000	2.331	3.181	0.000	5.388
LAs-1			37.73	1.32	16.05	2.860	1.570	4.201	0.889	4.650	43.61	3.79	13.45	2.958	0.356	4.415	0.933	7.620
LAs-2			37.86	1.80	19.91	5.561	1.184	5.337	1.803	8.325	36.43	3.16	15.00	5.385	0.000	5.019	1.492	10.789
LAs-3	*Quercus glauca* leaves A	stream water	27.75	1.86	14.90	4.404	0.826	4.479	1.355	5.597	27.75	0.37	16.62	4.056	0.000	4.277	1.100	7.161
LAs-4			30.43	1.72	19.81	3.778	1.276	5.218	1.135	7.963	32.09	3.64	16.34	3.294	0.101	4.782	1.430	9.848
LAs-5			37.65	1.55	15.82	4.608	1.310	4.907	0.978	7.143	43.59	2.00	15.21	4.157	0.215	5.017	1.342	7.255
LBd-1			35.41	3.78	8.35	0.779	4.165	3.669	0.101	2.008	31.76	0.00	8.59	0.000	3.050	3.465	0.151	3.431
LBd-2			38.99	4.14	5.06	0.573	4.818	3.944	0.237	3.309	33.04	2.20	10.76	0.000	3.432	3.699	0.184	5.884
LBd-3	*Quercus glauca* leaves B	distilled water	38.74	3.71	5.89	0.189	5.923	2.954	0.057	1.069	29.26	2.14	8.42	0.000	3.235	4.164	0.191	4.323
LBd-4			37.69	3.85	7.36	0.522	4.760	3.598	0.158	1.167	31.55	1.12	8.69	0.000	3.077	4.132	0.175	4.592
LBd-5			36.09	3.71	5.14	0.723	4.478	3.464	0.107	3.246	31.38	0.49	9.99	0.000	3.125	4.017	0.169	4.607
LBs-1			31.69	3.21	10.45	6.911	1.757	6.669	2.342	9.503	31.69	4.88	15.62	6.799	0.000	5.908	1.809	12.520
LBs-2			31.44	4.17	16.56	6.782	1.773	5.424	2.745	9.787	31.00	3.46	18.89	6.725	0.000	5.188	2.222	13.221
LBs-3	*Quercus glauca* leaves B	stream water	29.90	1.77	17.33	6.183	1.424	5.107	2.474	7.759	24.75	4.63	13.86	6.158	0.000	5.211	2.103	11.397
LBs-4			29.97	4.12	13.57	6.776	1.744	6.359	2.382	9.008	29.60	3.46	15.29	6.754	0.000	5.334	2.068	12.239
LBs-5			30.64	1.82	11.85	6.813	1.479	6.644	2.677	8.723	29.02	4.72	14.68	6.317	0.000	5.514	2.194	11.686
SAs-1			5.50	0.91	4.45	1.763	0.446	0.294	0.291	1.481	5.70	1.55	3.55	1.590	0.049	0.250	0.321	1.817
SAs-2			5.35	0.93	4.00	2.584	0.372	0.306	0.521	2.239	5.05	1.22	3.25	2.355	0.040	0.284	0.518	2.305
SAs-3	soil A	stream water	5.00	0.82	3.75	2.672	0.391	0.299	0.538	2.362	5.30	1.09	3.00	2.363	0.033	0.252	0.517	2.266
SAs-4			5.26	0.87	3.76	2.072	0.431	0.299	0.304	1.831	5.40	1.16	3.54	1.718	0.041	0.253	0.357	2.113
SAs-5			5.43	0.86	4.19	2.539	0.398	0.297	0.416	1.739	5.24	1.50	3.48	2.217	0.048	0.252	0.387	2.172
SAd-1			4.95	0.75	0.80	1.190	0.441	1.297	0.194	0.810	4.65	0.92	0.35	0.140	0.289	0.187	0.000	1.114
SAd-2			5.70	0.55	0.50	0.142	0.740	0.675	0.000	0.654	5.30	0.94	0.25	0.000	0.171	0.000	0.000	0.000
SAd-3	soil A	distilled water	4.80	0.72	0.30	0.117	0.602	0.173	0.000	0.000	4.65	1.06	0.00	0.000	0.749	0.126	0.000	0.000
SAd-4			4.96	0.67	0.35	0.293	0.650	1.118	0.006	0.330	4.91	0.97	0.16	0.095	0.343	0.024	0.000	1.058
SAd-5			4.86	0.73	0.56	0.233	0.513	1.289	0.078	0.486	5.20	1.04	0.17	0.029	0.296	0.156	0.000	0.732
SBd-1			4.45	1.11	0.45	0.150	0.628	0.179	0.000	0.292	4.30	1.52	0.00	0.000	0.452	0.168	0.000	1.792
SBd-2			4.55	1.06	0.00	0.130	0.621	0.160	0.000	0.379	3.26	1.11	0.00	0.000	0.181	0.131	0.000	2.051
SBd-3	soil B	distilled water	4.50	1.33	0.25	0.161	0.628	0.169	0.000	0.409	3.30	1.37	0.00	0.000	0.203	0.120	0.000	0.930
SBd-4			4.50	1.31	0.10	0.131	0.626	0.168	0.000	0.402	3.48	1.21	0.00	0.000	0.221	0.120	0.000	0.958
SBd-5			4.52	1.07	0.28	0.156	0.626	0.170	0.000	0.353	3.95	1.32	0.00	0.000	0.249	0.149	0.000	1.844
SBs-1			5.40	1.06	2.95	3.019	0.284	0.339	0.692	2.791	5.50	1.20	3.00	2.348	0.042	0.298	0.604	2.734
SBs-2			5.60	1.06	2.80	2.929	0.357	0.305	0.746	2.925	5.30	1.10	3.00	2.448	0.035	0.289	0.634	2.954
SBs-3	soil B	stream water	5.65	1.20	3.80	2.814	0.400	0.282	0.725	2.910	5.45	1.27	0.35	2.357	0.000	0.254	0.606	2.862
SBs-4			5.46	1.12	3.48	2.964	0.301	0.307	0.735	2.833	5.41	1.25	1.56	2.411	0.010	0.269	0.615	2.885
SBs-5			5.44	1.15	2.84	2.880	0.355	0.292	0.720	2.896	5.46	1.19	1.23	2.377	0.002	0.261	0.606	2.780

differed from those in stream water.

3-3. Comparison of release rate among treatments

The results of calculations of release rate for each substance leached are shown in Fig. 3a and b. The initial concentrations of each substance in stream water was 5.32, 0.72, 3.25, 5.073, 0.252, 0.416, 1.686 and 8.022 mg/l in TC, TN, SiO_2, Na^+, NH_4^+, K^+, Mg^{2+} and Ca^{2+}, respectively. The values in distilled water were regarded as 0.

For the first 30 days, all examined substances had already been released from *Quercus glauca* leaves, especially TC, SiO_2 and K^+ in both solutions. SiO_2, Na^+ and Ca^{2+} indicated negative values in stream water. For the 30th to the 90th day of the experiments, the release rate decreased one order of magnitude for all substances and the number of substances showing decreased values increased. In this period, the main substances released were SiO_2 and Ca^{2+} from leaves and Ca^{2+} from all materials in distilled water. In stream water in this period, the release of TN from all materials, Na^+, NH_4^+ and Ca^{2+} from rock, and Ca^{2+} from leaves were observed.

3-4. Statistical analysis

Table 5 shows the results of one-way ANOVA between

Table 3b. Concentrations (mg/l) in leaching experiments corresponding to the experimental period in each treatment

beaker	material	treatment solution	measurement values															
			after 30 days								after 90 days							
			TC	TN	SiO_2	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	TC	TN	SiO_2	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
RAd-1	bedrock A	distilled water	1.58	0.40	0.55	1.081	0.462	0.147	0.181	0.812	2.28	0.86	0.00	0.748	0.071	0.168	0.217	0.988
RAd-2			2.33	0.83	0.45	0.246	0.635	0.132	0.261	0.085	0.10	0.00	0.50	0.101	0.148	0.110	0.063	0.912
RAd-3			2.50	0.61	0.50	0.249	0.661	0.151	0.092	0.091	4.05	1.24	0.00	0.033	0.081	0.097	0.000	1.532
RAd-4			1.85	0.66	0.46	1.057	0.642	0.136	0.094	0.088	0.21	1.20	0.22	0.170	0.139	0.151	0.118	1.410
RAd-5			2.13	0.73	0.46	0.586	0.648	0.148	0.104	0.471	0.78	0.41	0.33	0.185	0.092	0.098	0.066	1.491
RBs-1	bedrock A	stream water	15.70	0.25	0.00	2.892	1.771	0.246	1.432	8.477	16.16	0.54	0.00	7.727	5.078	0.381	1.171	13.415
RBs-2			16.10	0.24	0.10	5.653	0.356	0.412	2.680	14.860	16.57	0.52	0.32	15.104	1.020	0.640	2.192	23.518
RBs-3			13.40	0.28	0.13	5.709	0.441	0.368	2.309	12.874	13.79	0.61	0.41	15.254	1.265	0.571	1.888	20.374
RBs-4			14.86	0.27	0.03	3.879	0.917	0.251	2.663	14.379	14.77	0.60	0.26	7.890	4.768	0.468	1.836	21.088
RBs-5			14.95	0.25	0.02	4.093	1.071	0.370	2.150	10.065	14.49	0.57	0.01	14.087	2.255	0.523	1.540	20.565
RAd-1	bedrock B	distilled water	1.91	0.64	0.54	1.010	0.568	0.144	0.206	0.547	1.29	0.33	0.08	0.643	0.131	0.163	0.046	5.938
RAd-2			1.68	0.75	0.54	0.510	0.618	0.148	0.153	0.767	1.79	0.77	0.46	0.148	0.100	0.114	0.083	12.340
RAd-3			2.46	0.65	0.52	0.888	0.522	0.147	0.188	0.355	1.62	1.08	0.19	0.232	0.066	0.101	0.189	1.923
RAd-4			1.75	0.59	0.51	0.623	0.471	0.149	0.255	0.253	0.42	0.45	0.22	0.282	0.063	0.138	0.053	4.209
RAd-5			2.46	0.48	0.50	1.065	0.603	0.149	0.208	0.659	1.71	0.05	0.15	0.469	0.119	0.115	0.151	5.461
RBs-1	bedrock B	stream water	14.83	0.25	0.10	4.600	0.771	0.321	1.477	11.048	14.74	0.54	0.41	13.161	2.597	0.584	1.037	22.328
RBs-2			14.44	0.26	0.03	5.704	1.759	0.395	1.803	14.017	14.47	0.56	0.10	16.245	4.818	0.653	1.464	23.773
RBs-3			15.42	0.26	0.03	5.335	0.518	0.334	2.237	12.037	15.50	0.57	0.12	13.844	1.365	0.559	1.662	18.742
RBs-4			16.09	0.25	0.13	4.666	1.231	0.261	1.622	12.656	15.73	0.55	0.88	14.754	5.969	0.405	1.202	21.718
RBs-5			15.93	0.28	0.13	5.452	1.118	0.286	2.290	8.933	16.28	0.62	0.97	14.971	3.819	0.444	1.784	17.384

Table 4. Overall comparison of mean concentrations of TC, TN, SiO_2 and cations in water corresponding to the days of experimental treatment

beaker	material	treatment solution	mean±standard error (mg/l)							
			TC	TN	SiO_2	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
	＜ after 30 days ＞									
LAd	*Quercus glauca* leaves A	distilled water	34.83 ± 2.54	3.16 ± 0.08	4.62 ± 0.37	3.126 ± 0.921	2.555 ± 0.264	3.679 ± 0.336	0.239 ± 0.081	1.619 ± 0.162
LAs	*Quercus glauca* leaves A	stream water	34.28 ± 2.16	1.65 ± 0.10	17.30 ± 1.06	4.242 ± 0.448	1.233 ± 0.120	4.828 ± 0.216	1.232 ± 0.163	6.735 ± 0.702
LBd	*Quercus glauca* leaves B	distilled water	37.38 ± 0.71	3.84 ± 0.08	6.36 ± 0.65	0.557 ± 0.103	4.829 ± 0.297	3.526 ± 0.163	0.132 ± 0.031	2.160 ± 0.485
LBs	*Quercus glauca* leaves B	stream water	30.73 ± 0.37	3.02 ± 0.53	13.95 ± 1.32	6.693 ± 0.130	1.635 ± 0.076	6.041 ± 0.325	2.524 ± 0.080	8.956 ± 0.352
SAd	soil A	distilled water	5.06 ± 0.16	0.68 ± 0.04	0.50 ± 0.09	0.395 ± 0.201	0.589 ± 0.052	0.910 ± 0.216	0.056 ± 0.038	0.456 ± 0.139
SAs	soil A	stream water	5.31 ± 0.09	0.88 ± 0.02	4.03 ± 0.13	2.326 ± 0.175	0.408 ± 0.013	0.299 ± 0.002	0.414 ± 0.052	1.930 ± 0.163
SBd	soil B	distilled water	4.50 ± 0.02	1.17 ± 0.06	0.22 ± 0.08	0.146 ± 0.006	0.626 ± 0.001	0.169 ± 0.003	0.000 ± 0.000	0.367 ± 0.021
SBs	soil B	stream water	5.51 ± 0.05	1.12 ± 0.03	3.17 ± 0.20	2.921 ± 0.035	0.339 ± 0.021	0.305 ± 0.010	0.724 ± 0.009	2.871 ± 0.025
RAd	bedrock A	distilled water	2.08 ± 0.17	0.64 ± 0.07	0.48 ± 0.02	0.644 ± 0.184	0.610 ± 0.037	0.143 ± 0.004	0.147 ± 0.033	0.274 ± 0.160
RAs	bedrock A	stream water	15.00 ± 0.46	0.26 ± 0.01	0.06 ± 0.03	4.445 ± 0.544	0.911 ± 0.254	0.329 ± 0.034	2.247 ± 0.228	12.131 ± 1.239
RBd	bedrock B	distilled water	2.05 ± 0.17	0.62 ± 0.04	0.52 ± 0.01	0.819 ± 0.109	0.556 ± 0.027	0.147 ± 0.001	0.202 ± 0.017	0.516 ± 0.095
RBs	bedrock B	stream water	15.34 ± 0.31	0.26 ± 0.01	0.08 ± 0.02	5.151 ± 0.220	1.079 ± 0.212	0.319 ± 0.023	1.886 ± 0.163	11.738 ± 0.851
	＜ after 90 days ＞									
LAd	*Quercus glauca* leaves A	distilled water	31.69 ± 1.77	3.01 ± 0.29	9.49 ± 0.05	0.000 ± 0.000	2.579 ± 0.140	3.080 ± 0.231	0.000 ± 0.000	4.387 ± 0.555
LAs	*Quercus glauca* leaves A	stream water	36.70 ± 3.14	2.59 ± 0.64	15.32 ± 0.56	3.970 ± 0.420	0.134 ± 0.068	4.702 ± 0.153	1.259 ± 0.105	8.535 ± 0.747
LBd	*Quercus glauca* leaves B	distilled water	31.40 ± 0.61	1.19 ± 0.44	9.29 ± 0.46	0.000 ± 0.000	3.184 ± 0.070	3.895 ± 0.135	0.174 ± 0.007	4.568 ± 0.393
LBs	*Quercus glauca* leaves B	stream water	29.21 ± 1.21	4.23 ± 0.32	15.67 ± 0.86	6.550 ± 0.131	0.000 ± 0.000	5.431 ± 0.133	2.079 ± 0.073	12.213 ± 0.321
SAd	soil A	distilled water	4.94 ± 0.14	0.98 ± 0.03	0.18 ± 0.06	0.053 ± 0.028	0.370 ± 0.099	0.099 ± 0.037	0.000 ± 0.000	0.581 ± 0.246
SAs	soil A	stream water	5.34 ± 0.11	1.30 ± 0.09	3.36 ± 0.11	2.049 ± 0.164	0.042 ± 0.003	0.258 ± 0.007	0.420 ± 0.041	2.135 ± 0.086
SBd	soil B	distilled water	3.66 ± 0.20	1.30 ± 0.07	0.00 ± 0.00	0.000 ± 0.000	0.261 ± 0.049	0.137 ± 0.009	0.000 ± 0.000	1.515 ± 0.237
SBs	soil B	stream water	5.42 ± 0.03	1.20 ± 0.03	1.83 ± 0.52	2.388 ± 0.019	0.018 ± 0.009	0.274 ± 0.008	0.613 ± 0.006	2.843 ± 0.039
RAd	bedrock A	distilled water	1.48 ± 0.75	0.74 ± 0.24	0.21 ± 0.10	0.248 ± 0.128	0.106 ± 0.016	0.125 ± 0.015	0.093 ± 0.036	1.267 ± 0.131
RAs	bedrock A	stream water	15.16 ± 0.52	0.57 ± 0.02	0.20 ± 0.08	12.012 ± 1.728	2.877 ± 0.862	0.517 ± 0.044	1.725 ± 0.173	19.792 ± 1.691
RBd	bedrock B	distilled water	1.37 ± 0.25	0.54 ± 0.18	0.22 ± 0.06	0.355 ± 0.089	0.096 ± 0.014	0.126 ± 0.011	0.104 ± 0.028	5.974 ± 1.737
RBs	bedrock B	stream water	15.34 ± 0.33	0.57 ± 0.01	0.50 ± 0.18	14.595 ± 0.525	3.714 ± 0.809	0.529 ± 0.046	1.430 ± 0.139	20.789 ± 1.182

treatments with distilled water and stream water of all substances that had leached from each material on the 30th day and 90th day after submergence. Significant differences were observed between distilled water and stream water except for TC in samples LA and SA, TN in samples LB and SB, and NH_4^+ in sample RA on the 30th day after submergence, and TC in samples LA, LB and SA and TN in samples SB, RA and RB on the 90th day after submergence. Table 6 shows the differences in each concentration between sample A and sample B based on one-way ANOVA. There were no significant differences in TC concentration in any material or measurement day except for soil with distilled water. Furthermore, no significant differences were observed in treatments with rock except for Ca^{2+} on 90 days after submergence.

Table 7 shows the results of two-way ANOVA for each

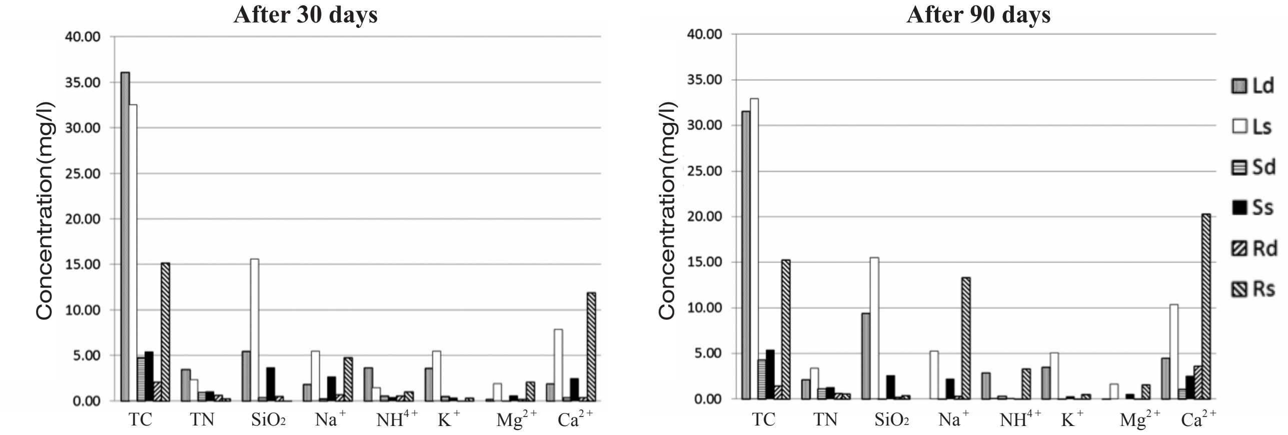

Fig. 2. Mean concentration of substances in each treatment solution on the 30th day and 90th day after submergence

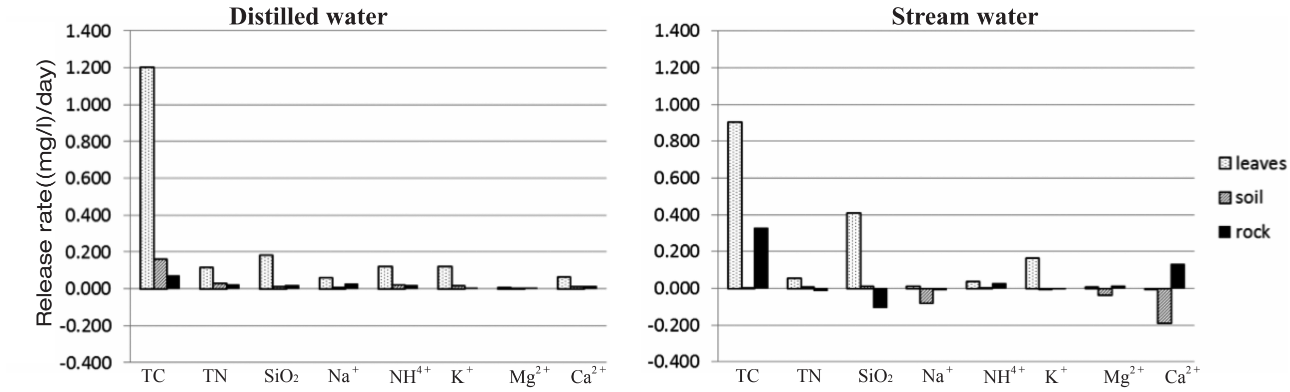

Fig. 3a. Release rate of each substance leached based on treatment water and material for 30 days after submergence

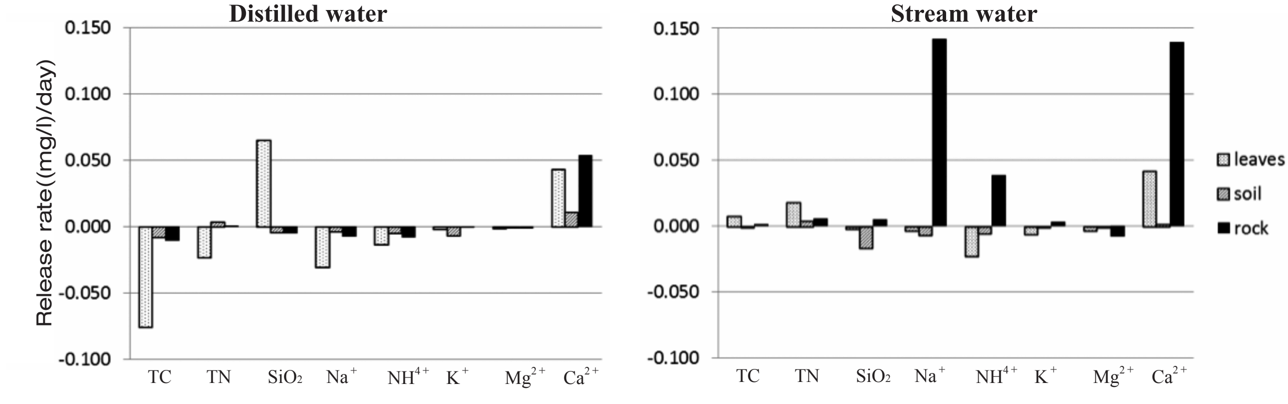

Fig. 3b. Release rate of each substance leached based on treatment water and material for the 60 days between the 30th day and the 90th day

experimental period. Significant differences among treatments and release rates were observed for all substances in both experimental periods, except for K^+ in the type of treatment water used for both the first 30 days and for the 30th to 90th day.

4. Discussion

4-1. Weight loss from evergreen *Quercus glauca* leaves after 90 days

When leaves fall into streams, soluble organic and inorganic chemicals begin to leach immediately. The second stage of leaf decomposition is microbial colonization and growth (conditioning), which in turn promote leaf fragmentation by invertebrate activity. The initial leaching from leaves is part of leaf decomposition.

In deciduous leaves, most leaching occurs within a few days of submergence. For example, autumn-shade leaves in water can lose up to 40% of their dry weight in a few days[7] ; the ash-free dry weight of sugar maple, yellow birch, and beech was only 85.4% of the initial weight after 2 days submerged in the laboratory.[17] Up to 25% of the initial dry weight of some riparian deciduous tree leaves (e.g., *Alnus* sp., *Salix* sp.) is lost by leaching in the first 24 h of submergence[20].

In contrast to these results from deciduous species, evergreen leaves of *Quercus glauca* submerged in stream water in our previous study lost 20–25% of their initial weight after 30 days[12], indicating that overall weight loss from evergreen leaves is less than a quarter of that from deciduous leaves. This may be due to differences in the outer surfaces of the leaves. The tough outer surfaces of evergreen leaves (e.g., the cuticle) may delay leaching and subsequent weight loss until the outer layer of the epidermis, which consists of cutin, breaks down in water.

If it is assumed that the weight loss proceeded at the same rate as before, 20–25%, for the first 30 days, the weight loss rate for 90 days is estimated to be 60–75%. The mean weight loss rate for 90 days in the present study, however, was 52.77–57.73 in distilled water and 52.88–56.47% in stream water, values that were lower than estimated. As described below, since TC was released faster in the first 30 days than in the 30th to 90th days from *Quercus glauca* leaves in the present experiment, leaching from these evergreen leaves was almost complete 30 days after submergence, so weight loss after 30 days may be due to leachates other than cutin.

Table 5. One-way ANOVA between treatment with distilled water and stream water of all substances leached from each materials on 30th day and 90th days after submergence

<after 30 days>

beaker	materials	TC n	TC the mean square	TC *F*	TC *P*	TN n	TN the mean square	TN *F*	TN *P*	SiO_2 n	SiO_2 the mean square	SiO_2 *F*	SiO_2 *P*	Na^+ n	Na^+ the mean square	Na^+ *F*	Na^+ *P*
LA	*Quercus glauca* leaves A	1	0.761	0.027	n.s.	1	5.698	149.280	<0.001	1	401.551	126.310	<0.001	1	3.115	1.188	n.s.
LB	*Quercus glauca* leaves B	1	110.750	69.418	<0.001	1	1.672	2.345	n.s.	1	143.935	26.572	<0.001	1	94.116	1368.062	<0.001
SA	soil A	1	0.159	1.850	n.s.	1	0.096	24.037	<0.01	1	31.159	486.944	<0.001	1	9.322	52.397	<0.001
SB	soil B	1	2.530	382.403	<0.001	1	0.009	0.804	n.s.	1	21.886	192.238	<0.001	1	19.263	6038.200	<0.001
RA	bedrock A	1	417.549	691.707	<0.001	1	0.371	29.247	<0.001	1	0.458	182.567	<0.001	1	36.123	43.841	<0.001
RB	bedrock B	1	441.494	1381.105	<0.001	1	0.333	69.230	<0.001	1	0.484	318.589	<0.001	1	46.920	311.567	<0.001

beaker	materials	NH_4^+ n	NH_4^+ the mean square	NH_4^+ *F*	NH_4^+ *P*	K^+ n	K^+ the mean square	K^+ *F*	K^+ *P*	Mg^{2+} n	Mg^{2+} the mean square	Mg^{2+} *F*	Mg^{2+} *P*	Ca^{2+} n	Ca^{2+} the mean square	Ca^{2+} *F*	Ca^{2+} *P*
LA	*Quercus glauca* leaves A	1	4.369	20.739	<0.01	1	3.303	8.272	<0.05	1	2.462	29.672	<0.001	1	65.445	50.482	<0.001
LB	*Quercus glauca* leaves B	1	25.499	108.442	<0.001	1	15.808	47.841	<0.001	1	14.306	778.105	<0.001	1	115.468	128.672	<0.001
SA	soil A	1	0.082	11.329	<0.01	1	0.934	7.988	<0.05	1	0.321	31.133	<0.001	1	5.435	47.314	<0.001
SB	soil B	1	0.205	187.107	<0.001	1	0.046	180.666	<0.001	1	1.309	6362.780	<0.001	1	15.678	5741.535	<0.001
RA	bedrock A	1	0.227	1.375	n.s.	1	0.087	29.698	<0.001	1	11.027	83.237	<0.001	1	349.375	89.862	<0.001
RB	bedrock B	1	0.684	6.004	<0.05	1	0.074	56.488	<0.001	1	7.088	105.842	<0.001	1	314.833	171.927	<0.001

<after 90 days>

beaker	materials	TC n	TC the mean square	TC *F*	TC *P*	TN n	TN the mean square	TN *F*	TN *P*	SiO_2 n	SiO_2 the mean square	SiO_2 *F*	SiO_2 *P*	Na^+ n	Na^+ the mean square	Na^+ *F*	Na^+ *P*
LA	*Quercus glauca* leaves A	1	62.670	1.933	n.s.	1	0.446	0.364	n.s.	1	85.183	106.345	<0.001	1	39.406	89.415	<0.001
LB	*Quercus glauca* leaves B	1	11.960	2.600	n.s.	1	23.093	31.543	<0.001	1	101.643	42.740	<0.001	1	107.271	2508.714	<0.001
SA	soil A	1	0.394	5.296	n.s.	1	0.255	10.929	<0.05	1	25.265	695.107	<0.001	1	9.959	143.234	<0.001
SB	soil B	1	7.818	73.779	<0.001	1	0.027	1.895	n.s.	1	8.348	12.450	<0.01	1	14.260	16656.022	<0.001
RA	bedrock A	1	467.361	223.549	<0.001	1	0.076	0.535	n.s.	1	0.000	0.005	n.s.	1	346.026	46.098	<0.001
RB	bedrock B	1	488.308	1140.721	<0.001	1	0.003	0.032	n.s.	1	0.194	2.047	n.s.	1	506.962	715.344	<0.001

beaker	materials	NH_4^+ n	NH_4^+ the mean square	NH_4^+ *F*	NH_4^+ *P*	K^+ n	K^+ the mean square	K^+ *F*	K^+ *P*	Mg^{2+} n	Mg^{2+} the mean square	Mg^{2+} *F*	Mg^{2+} *P*	Ca^{2+} n	Ca^{2+} the mean square	Ca^{2+} *F*	Ca^{2+} *P*
LA	*Quercus glauca* leaves A	1	14.937	247.197	<0.001	1	6.578	34.245	<0.001	1	3.966	143.136	<0.001	1	43.002	19.864	<0.01
LB	*Quercus glauca* leaves B	1	25.343	2084.026	<0.001	1	5.896	65.665	<0.001	1	9.077	670.101	<0.001	1	146.118	227.285	<0.001
SA	soil A	1	0.268	10.903	<0.05	1	0.064	18.166	<0.01	1	0.441	104.327	<0.001	1	6.037	35.559	<0.001
SB	soil B	1	0.148	23.951	<0.01	1	0.047	119.444	<0.001	1	0.940	12031.780	<0.001	1	4.408	30.532	<0.001
RA	bed rock A	1	19.194	10.335	<0.05	1	0.383	71.061	<0.001	1	6.663	85.423	<0.001	1	857.978	119.352	<0.001
RB	bed rock B	1	32.720	20.004	<0.05	1	0.406	73.354	<0.001	1	4.392	87.272	<0.001	1	548.673	49.742	<0.001

As leaf decomposition proceeds, a certain amount of FPOM is generated from maceration by aquatic hyphomycetous fungi, and by consumption and egestion by shredders[21) ; however, FPOM was hardly generated in the present experiment because no shredders were submerged in the beakers used in the experiment.

4-2. Release of TC, TN, SiO_2 from leaves, soil and rock

TC, TN and SiO_2 contained in *Quercus glauca* leaves, soil and rock were released immediately after submergence and the release rate of each substance seemed to be at a maximum within 30 days after submergence.

Table 6. Comparison of significance of the concentrations of leachate between sample A and B

material	treatment solution	leachate	after 30 days	after 90 days
Quercus glauca leaves	stream water	TC	n.s.	n.s.
		TN	$P < 0.05$	n.s.
		SiO_2	n.s.	n.s.
		Na^+	$P < 0.001$	$P < 0.01$
		NH_4^+	n.s.	n.s.
		K^+	$P < 0.05$	$P < 0.01$
		Mg^{2+}	$P < 0.001$	$P < 0.01$
		Ca^{2+}	$P < 0.05$	$P < 0.01$
	distilled water	TC	n.s.	n.s.
		TN	$P < 0.001$	$P < 0.01$
		SiO_2	$P < 0.05$	n.s.
		Na^+	$P < 0.05$	—
		NH_4^+	$P < 0.01$	$P < 0.001$
		K^+	$P < 0.05$	$P < 0.05$
		Mg^{2+}	n.s.	$P < 0.0001$
		Ca^{2+}	n.s.	n.s.
soil	stream water	TC	n.s.	n.s.
		TN	$P < 0.001$	n.s.
		SiO_2	$P < 0.001$	$P < 0.05$
		Na^+	$P < 0.05$	n.s.
		NH_4^+	$P < 0.05$	$P < 0.05$
		K^+	n.s.	n.s.
		Mg^{2+}	$P < 0.001$	$P < 0.05$
		Ca^{2+}	$P < 0.001$	$P < 0.0001$
	distilled water	TC	$P < 0.05$	$P < 0.001$
		TN	$P < 0.001$	$P < 0.001$
		SiO_2	$P < 0.05$	$P < 0.05$
		Na^+	n.s.	n.s.
		NH_4^+	n.s.	n.s.
		K^+	$P < 0.001$	n.s.
		Mg^{2+}	n.s.	—
		Ca^{2+}	n.s.	$P < 0.05$
bedrock	stream water	TC	n.s.	n.s.
		TN	n.s.	n.s.
		SiO_2	n.s.	n.s.
		Na^+	n.s.	n.s.
		NH_4^+	n.s.	n.s.
		K^+	n.s.	n.s.
		Mg^{2+}	n.s.	n.s.
		Ca^{2+}	n.s.	n.s.
	distilled water	TC	n.s.	n.s.
		TN	n.s.	n.s.
		SiO_2	n.s.	n.s.
		Na^+	n.s.	n.s.
		NH_4^+	n.s.	n.s.
		K^+	n.s.	n.s.
		Mg^{2+}	n.s.	n.s.
		Ca^{2+}	n.s.	$P < 0.05$

The amount of TC leached may vary among leaves, soil and rock. The release rates of TC from leaves for the first 30 days were extremely high. TC is derived from soluble carbohydrates, organic acids, hemicellulose and other organic material. Soluble carbohydrates are lost through the cuticle on the surface of *Quercus glauca* leaves, but the thick cuticle reduces the rate of decomposition. The rate of decomposition of leaf litter in the water may be increased by abrasion of leaf surfaces. For example, one major constituent of the leaf cuticle is lipid, which is lost more rapidly than total mass[1). Broadleaf evergreens such as *Quercus glauca*, however, break down slowly. The tough outer surfaces of evergreen leaves may delay leaching and subsequent weight loss in leaves until the outer layer of the epidermis, which consists of cutin, breaks down in water. Judging from the comparison of release rates between the first 30 days and the subsequent 60 days, TC leaching from evergreen leaves was almost complete 30 days after submergence. Thus, TC released from the 30th to the 90th day may comprise leachates other than cuticle.

No significant relations were observed in TC release rates between stream water and distilled water. The reason for this, in part, may be due to conditioning in distilled water by the saprophytic fungi and bacteria colonizing the leaves.

TN showed the same release trend as TC. As leaf decomposition proceeds, nitrogen concentration in the leaves increases[19), presumably because TC falls and higher leaf decomposition rates occur in nutrient-rich conditions[7) due to the greater availability of nitrogen. There was a direct relationship between nitrogen content and leaf weight loss. The observed increases in TN in both types of water used for treatment were due in part to leaching of N from leaves during decomposition, which was accelerated by aeration. This is partly because some fungi can increase the protein content of the leaves and partly because the addition of N to the water accelerates fungal growth[21).

It has been said that of all mineral groups, silicates have received the most attention in weathering studies because they make up the most abundant type of rock[4). In the present experiments, however, SiO_2 was released at a much greater rate from leaves than rock during the entire experimental period. This may be because the formations in the investigated basin consist of black slate, sandstone and shale, which contain hardly any quartz.

4-3. cations

Cations in *Quercus glauca* leaves, soil and rock were also released immediately after submergence. The concentrations of cations 30 days after submergence were similar to those of our previous studies[10,11,12).

In the present study, most cation release in distilled water for the first 30 days occurred mainly from leaves. This is attributable to the leaching of some components from the leaves. The dominant cation in the water samples was K^+. In contrast to the high K^+ concentrations in the water of the leaching experiments, the initial K^+ concentration in the stream water was lower than that of the other cations, reflecting the lowest abundance and least variability of K^+ in river water among the major cations[1). The lower concentration of K^+ in the stream water would suggest that there is a differential utilization of K^+ by the biota. K^+ appears to be completely water soluble in plants but may combine with organic compounds[18], and stream sediment acts as an important agent for removal of leachate from water[16]. Therefore, the clay component of the sediment may serve as a reservoir of chemically bound K^+. Biota may also provide a reservoir for K^+ if there is some net increase in biomass.

Ca^{2+} is known not to leach as readily as K^+ [17]. However, Ca^{2+} had been released from leaves and rock at nearly the same rates at 90 days after submergence, as had K^+. Previous experimental results[10] indicated that the release of Ca^{2+} is accelerated markedly at higher temperatures and that lower pH increases Ca^{2+} release further. Ca^{2+} release from leaves is thought to be promoted through a combination of these factors: Ca^{2+} content increases in the leaves throughout the growing season and it is retained until major structural breakdown of the leaf occurs[16]. Also, because Ca^{2+} occurs in an exchangeable form that is highly mobile and readily replaced by H^+, Ca^{2+} can readily be leached from the surface organic layers[22]. The significant differences in Ca^{2+} concentration between stream water and distilled water might be induced by differences in their pH, which was 6.5 in the investigated stream[10] and 7.0–7.5 in distilled water[11]. The reason for that the effect of pH on concentrations of substances leached except for TN and SiO_2 were extreme in bedrock is not cleared in this study.

The increases in NH_4^+ concentration in *Quercus glauca* leaves 30 days after submergence may be attributable to the same explanation about TN mentioned above; however, the reason for acceleration of NH_4^+ release in water with rock for the 30th–60th days was not clear.

Na^+ is generally found in association with Cl^- [10,11], indicating their common origin. Most Na^+ found in stream water is derived from rock weathering, but some Na^+ may be supplied through rain water and Na^+-rich dust attached to the surface of leaves. Closer to the coast, rain water may contribute significantly to ion supply[1], as in the investigated basin. Na^+ release from rock was accelerated for the 30th to 60th days after submersion, indicating that the rate of Na^+ release from rock is slower than that from leaves.

Insufficient Mg^{2+} was detected to adequately understand its release characteristics in the present study.

5. Conclusion

The cuticle of *Quercus glauca* leaves may be a physical obstacle to leaching of several substances, and it gradually disappears as a result of conditioning by the saprophytic fungi and bacteria in stream water as well as

Table 7. Results of two-way analysis of variance corresponding to experiment period

		for first 30 days				for 30th to 90th day			
	independent variables	n	mean square	*F*	*P*	n	mean square	*F*	*P*
TC	treatment water	1	0.063	10.441	< 0.001	1	0.018	16.337	< 0.001
	materials	2	5.650	937.821	< 0.0001	2	0.006	5.475	< 0.001
	interaction	2	0.419	69.589	< 0.0001	2	0.009	8.394	< 0.001
	residual error	54	0.006			54	0.001		
TC	treatment water	1	0.024	92.320	< 0.0001	1	0.004	15.628	< 0.001
	materials	2	0.038	142.785	< 0.0001	2	0.000	1.045	n.s.
	interaction	2	0.002	8.186	< 0.0001	2	0.002	10.538	< 0.001
	residual error	54	0.000			54	0.000		
SiO_2	treatment water	1	0.019	8.501	< 0.01	1	0.008	10.771	< 0.01
	materials	2	0.674	303.817	< 0.0001	2	0.010	12.602	< 0.0001
	interaction	2	0.160	72.012	< 0.0001	2	0.008	10.269	< 0.0001
	residual error	54	0.002			54	0.001		
Na^+	treatment water	1	0.050	37.251	< 0.0001	1	0.050	120.351	< 0.0001
	materials	2	0.027	20.610	< 0.0001	2	0.042	100.290	< 0.0001
	interaction	2	0.004	3.306	< 0.05	2	0.032	77.366	< 0.0001
	residual error	54	0.001			54	0.000		
NH_4^+	treatment water	1	0.015	37.511	< 0.0001	1	0.002	14.263	< 0.001
	materials	2	0.028	70.282	< 0.0001	2	0.006	36.756	< 0.0001
	interaction	2	0.011	27.161	< 0.0001	2	0.004	29.310	< 0.0001
	residual error	54	0.000			54	0.000		
K^+	treatment water	1	0.001	2.085	n.s.	1	0.000	1.229	n.s.
	materials	2	0.130	531.349	< 0.0001	2	0.000	4.212	< 0.05
	interaction	2	0.007	27.154	< 0.0001	2	0.000	3.287	< 0.05
	residual error	54	0.000			54	0.000		
Mg^{2+}	treatment water	1	0.002	10.766	< 0.001	1	0.000	15.951	< 0.001
	materials	2	0.005	30.227	< 0.0001	2	0.000	9.381	< 0.001
	interaction	2	0.003	19.739	< 0.0001	2	0.000	6.664	< 0.01
	residual error	54	0.000			54	0.000		
Ca^{2+}	treatment water	1	0.039	23.776	< 0.0001	1	0.010	11.245	< 0.01
	materials	2	0.135	81.911	< 0.0001	2	0.041	48.655	< 0.0001
	interaction	2	0.127	77.363	< 0.0001	2	0.014	16.319	< 0.0001
	residual error	54	0.002			54	0.001		

those that colonize the leaves. The 30-day incubation of leaves for leachate preparation seemed to be sufficient to achieve full leaching of the cuticle from the leaves used in these experiments[10,12]. Since the amount of TC that is leached depends on the extent of leaf conditioning, which in turn is affected by the extent of leaching that occurs in the terrestrial environment prior to immersion in water[3], the conditioning rates presumably differ among leaves, and the rates of leaching of substances in the present experiments were not comparable among leaves.

The order of materials from which substances are released, from the most rapid to the slowest, was leaves > soil > rock in distilled water for the first 30 days. This order was not observed for the other treatments in each experimental period. It is possible that the substances are released faster from *Quercus glauca* leaves than from rock. It is also possible that lower cation release rates in stream water than in distilled water for the first 30 days and net negative values of cation release for the 30th to 90th days were induced by microbial consumption in stream water.

It has been said that minerals, such as Mg^{2+} and Ca^{2+}, in streams originate almost entirely from the weathering of sedimentary carbonate rocks, and approximately 90% of K^+ originates from the weathering of silicate materials, especially potassium feldspar and mica[1]. However, based on the observed results, changes in water composition are predicted from the natural input and subsequent leaching of leaf litter. This hypothesis is supported by the field measurements in our previous studies[10,11,12].

Soil can be defined as a complex system of air, water, decomposing organic matter, living plants and animals, and the residues of rock weathering[14]. Soil solutions carry nutrients, derived from minerals, rain water, and organic matter, directly to plant roots. Therefore, high concentrations of TC, TN and cations in treatments containing soil were expected. In the investigated basin, because the soil samples analyzed were obtained from an unstable alluvial plain of the river, which lacks a humus layer, the concentrations of substances leached from soil might have been low.

In the present study, by enclosing the experimental system within beaker, the potential effects of interactions among leaf litter, soil and bedrock due to current variation on stream water and ground water were neglected. Further field experiments on different vegetation and geologic structures are necessary.

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要　旨

南九州の山地渓流域におけるリーフリター（アラカシ；*Quercus glauca*），森林土壌、基岩の溶出特性

北村泰一
南九州大学環境園芸学部環境園芸学科
緑地保全学研究室

渓流水質組成を規定する第一の要因は，流域を構成する基岩の岩種や地質構造等の地質的要因であるといわれてきたが，筆者は河畔域から渓流に供給されるリーフリターは膨大な量にのぼると推測されることから，その溶出成分も渓流水質の形成に重要な役割を果たすものであることを明らかにしてきた．しかしながら，落葉広葉樹リーフリターの分解に伴う重量損失と構成成分の変化については知られているが，常緑樹リーフリターの溶出特性については依然として既往実験が少ない．さらに，流域を構成する基岩・土壌の成分溶出特性についても不明な点が多い．このような観点から本研究は，古第三紀層より構成され，常緑広葉樹のアラカシ（*Quercus glauca*）が優占する南九州山地渓流を対象地として，常緑広葉樹のアラカシリーフリター，流域を構成する基岩，土壌の溶出特性を比較検討することを目的とした．

2016年3月，一ツ瀬川支流竹尾川下流（宮崎県西都市）の河畔域の2地点に生育するアラカシリーフリター（2年葉），根茎付近の土壌サンプル，基岩サンプル（粒径2mm 以下）を採取した．リーフリターは十分な洗浄・乾燥と重量測定の後3枚，土壌サンプル，基岩サンプルは1mg ずつ，それぞれ1,000（ml）の現地渓流および蒸留水を満たしたビーカーに投入し常温の実験室内に置いた．各サンプルにはそれぞれ５回の繰り返し（サブサンプル）を設けた．30日後，90日後の各溶液中の TC（全炭素），TN（全窒素），SiO_2，陽イオン（NH_4^+，Na^+，K^+，Mg^{2+}，Ca^{2+}）濃度を測定した．また，90日間での分解によるアラカシリーフリターの損失重量も測定した．

アラカシリーフリター表面のクチンは成分溶出の妨げとなるが，損失重量とTC放出量を目安とすればクチンの溶出には概ね30日を要し，成分放出量は概ねリター＞土壌＞基岩という傾向を示した（$P<0.05$）．リーフリターでは実験開始直後からK^+，Ca^{2+} の放出が進むのに対し，基岩では実験開始から30日以降でのNH_4^+，K^+，Ca^{2+} の放出が進んだ（$P<0.0001$）．なお，本実験では腐植土の形成が不十分な不安定な河畔から土壌サンプルを採取したため，十分な成分放出は確認できなかった．以上の結果から，渓流に供給されるリターも渓流水質の化学的組成に寄与している可能性のあることが明らかになった．