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Decomposition of leaf litter of some evergreen broadleaf trees in Korea

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Abstract

Litter decomposition is an important process in terrestrial ecosystem. However, studies on decomposition are rare, especially in evergreen broadleaf trees. We collected the leaf litter of five evergreen broadleaf trees (*Daphniphyllum macropodum*, *Dendropanax morbifera*, *Castanopsis cuspidata* var. *thunbergii*, *Machilus thunbergii* and *Quercus acuta*), and carried out a decomposition experiment using the litterbag method in Ju-do, Wando-gun, Korea for 731 days from December 25, 2011 to December 25, 2013. Among the five experimental tree species, *C. cuspidata* var. *thunbergii* distribution was limited in Jeju Island, and *D. macropodum* was distributed at the highest latitude at Mt. Baekyang (N 35°40′). About 2% of the initial litter mass of *D. macropodum* and *D. morbifera* remained, while 20.9% remained for *C. cuspidata* var. *thunbergii*, 30.4% for *M. thunbergii*, and 31.6% for *Q. acuta*. *D. macropodum* litter decayed four times faster ($k = 2.02$ yr^{-1}) than the litter of *Q. acuta* ($k = 0.58$ yr^{-1}). The decomposition of litter was positively influenced by thermal climate such as accumulated mean daily air temperature (year day index) and precipitation, as well as by physical characteristics such as thickness (R^2=0.939, $P = 0.007$) and specific leaf area (SLA) ($R^2 = 0.964$, $P = 0.003$). The characteristics of chemical composition such as lignin ($R^2 = 0.939$, $P = 0.007$) and water-soluble materials ($R^2 = 0.898$, $P = 0.014$) showed significant correlations with litter decomposition. However, the nutrients in litter showed complicated species-specific trends. The litter of *D. macropodum* and *D. morbifera* had fast decomposition despite their low nitrogen concentration and high C/N ratio. This means that the litter decomposition was more strongly affected by physical characteristics than chemical composition and nutrient content. On the other hand, the litter of *Q. acuta* which had the slowest decay rate had a high amount of N and low C/N ratio. Thus, the decomposition of *Q. acuta* litter was more affected by the P content of the litter than the N content, although all litter had similar physical characteristics.

Key words: decomposition, decomposition constant, evergreen broadleaf, leaf litter, physico-chemical effects

INTRODUCTION

The structure and function of forest ecosystems are maintained by energy flows and nutrient cycling. The production of litter and its decomposition are the basic processes for maintaining ecosystem functioning because they move nutrients and energy from the forest canopy to the soil (Swift et al. 1979). The rate of decomposition and decaying processes of the litter differ in accordance with the chemical composition and physical characteristics of the litter species (Melillo et al. 1982, Moretto et al. 2001). Aspects of the chemical composition of litter, such as the nitrogen and lignin content, C/N ratio, and lignin/N ratio, are important factors controlling decomposition (Swift et

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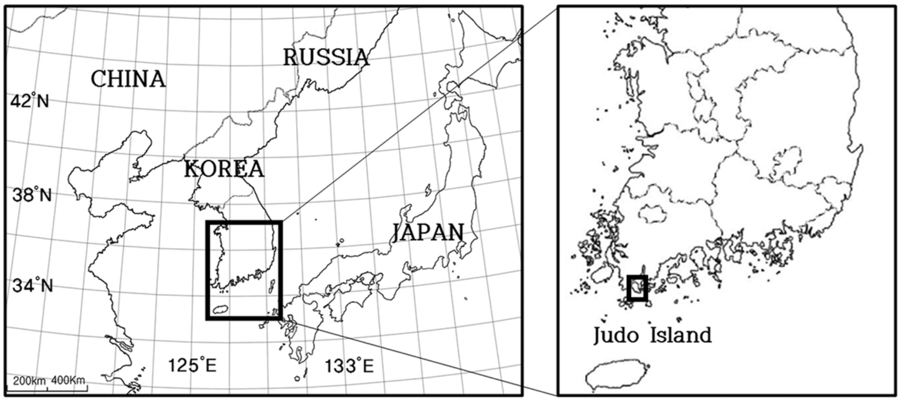

Fig. 1. Map showing the location of the study site.

al. 1979, Melillo et al. 1982).

Global warming has become a matter of primary concern in recent years, because it induces changes in plant distribution ranges and the migration of northern plants to higher latitudes and altitudes. While southern warm temperate evergreen broadleaf tree species in Korea could migrate, most evergreen broadleaf forests although disturbed, remain as scattered fragments in protected places, such as national conservation areas, or as temple forests and tutelary deity forests (Yim and Lee 1976). Further, the structure and function of the evergreen broadleaf forest on the southern coast of the Korean Peninsula, including Jeju Island, have not been actively studied.

Chang and Han (1985) predicted litter production and decomposition based on a model. Won et al. (2014) and the Long-Term Ecological Research Program of the Korean Ministry of Environment (Han 2014) surveyed and monitored the carbon distribution and dynamics in the evergreen broadleaf forest of Jeju Island. However, the activities of the Subtropical Institute established in Jeju Island have not yet progressed to the ecological function of the southern evergreen broadleaf forest. Instead, the surveys are mostly focused on biodiversity, genetic source conservation and exploitation, and development of management technology for subtropical forests.

In this study, we investigated the decomposition process and decomposition rates of the leaf litter of five main evergreen broadleaf trees in the field, as well as the effects of the physical and chemical characteristics of litters and climatic effects on litter decomposition in the south coast's typical evergreen broadleaf forests of Judo Island, 300 m away from Wando, Jollanamdo, Korea.

MATERIALS AND METHODS

Experiment design

The freshly fallen leaf litter of *Daphniphyllum macropodum* Miq., *Dendropanax morbifera* Lev., *Castanopsis cuspidata* var. *thunbergii* Nakai, *Machilus thunbergii* S. *et* Z., and *Quercus acuta* Thunb. collected in the evergreen forest of Wando Arboretum in December. The leaf litter was dried at 60°C for 2 weeks until the dry weight stopped changing, and the area, dry weight, thickness, and specific leaf area (SLA) of leaf litter were determined.

Litterbags were made of polyvinyl chloride (PVC)-coated fiberglass cloth with a 2-mm mesh. We put intact dried leaf litter into the bags along with aluminum tags with a unique record number, and the litterbags were closed with a nylon suture to prevent the loss of experiment materials. The size of the litterbags was 15 cm × 15 cm for the litter of *D. macropodum* and 10 cm × 10 cm for the others, and put on the forest floor with 4 replications. The litterbags were anchored with a wire pin to prevent movement, and were collected at six times at almost identical intervals from December 25, 2011 to December 25, 2013, a total of 731 days.

Experimental site

The experiment took place in the evergreen broadleaf forest of Judo Island, which is 300 m east of the port of Wando (E 126°46′, N 34°17′), in an area of 1.74 ha at 35 m above sea level (Fig. 1). Judo is covered with evergreen broadleaf forests and is a well-conserved natural evergreen plant community because it is traditionally a religious altar for a tutelary deity, and was designated as Nat-

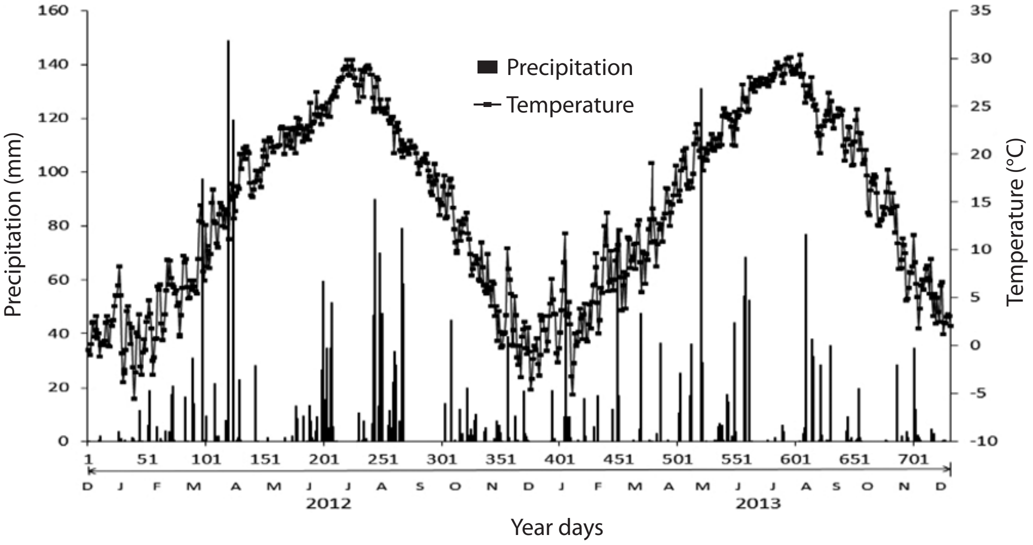

Fig. 2. Changes in daily mean air temperature and precipitation during the experimental period from December 25, 2011 to December 25, 2013. The data are from the Wan-do meteorological station, which is 500 m away from experimental site.

ural Monument No. 28 on December 3, 1962. The climate of Judo, according to the Wando meteorological station, shows an annual mean temperature of 13.4°C, annual precipitation of 1,532.6 mm, 105.1°C·month of warmth index (WI), and –2.5°C·month of coldness index (CI) for 30 years from 1981 to 2010 (Yim and Kira 1975, Yim and Lee 1976). Fig. 2 showed the changes in daily mean temperature and precipitation for the 731 day experimental period from December 2011 to December 2013. Most of the precipitation was in the summer months and the temperatures were scarcely below the freezing point in the winter season, with temperatures reaching 30°C in the summer.

The vegetation of Judo is dominated by *Castanopsis sieboldii*, with patches of *Lozoste lancifolia*, *Ilex integra*, and *M. thunbergii* communities. *Pinus densiflora*, *Celtis sinensis*, and *Albizia julibrissin* infrequently occur in the tree layer. The coverage of the tree layer was 85%, with a 12-m-high canopy, and trees with diameter at breast height (DBH) 30~70 cm. *I. integra* below a DBH of 10 cm frequently occurs with *Actinodaphne lancifolia* and *C. sinensis* in the sub-tree layer. *Trachelospermum asiaticum* var. *intermedium* is the dominant creeping vine species on the forest floor. *C. sieboldii* has a basal area of 70.97 m^2/ha and comprises 55.5% of the total basal area on Judo. *I. integra* and *L. lancifolia* respectively comprise 21.9% and 18.2% of the total basal area.

Analysis of plant materials

Determination of mass loss and decomposition constant

Plants roots and soil that penetrated the litterbag were removed from recovered litterbags, and the litter samples were moved to paper bags and dried at 60°C. The weight of the remaining leaf litter was determined and expressed as a percentage (%) against the initial dry weight when field incubation started.

The decomposition constant, *k*, was calculated by a non-linear regression model based on a single exponential decay model (Olson 1963, Fioretto et al. 2005, Garrett et al. 2012) of $X_t = X_o e^{-kt}$, where X_t is the mass at time t, X_o is the initial mass, and k is the exponential (base e) decay constant. Litter half-lives, i.e., the time necessary to reach 50% mass loss, were also calculated by $t_{1/2}$= -ln0.5/k = 0.693/k, and $t_{0.95}$= ln(1/0.05)/k = 3/k (Olson 1963, Yang et al. 2010).

The plant materials were ground using a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) to below 0.1 mm and used in the quantification of the carbon and nitrogen content and other chemical analysis.

Chemical analysis of plant materials

Amount of water- and alcohol-soluble substances

The amounts of water- and alcohol-soluble within the initial leaf litter were measured by comparing the weight before and after the immersion of the litter in distilled water or 95% ethanol for industrial use for three days, with the solvents exchanged six times.

Lignin and cellulose content determination

The cellulose and lignin contents of each litter sample were determined according to Rowland and Roberts (1994) and Lim et al. (2011). About 0.5 g of milled litter sample was weighed (W_1) and boiled for 1 h in 100 mL CTAB solution (1 g cetyltrimethyl ammonium bromide in 100 mL of 0.5 M H_2SO_4) under continuous stirring. The content was filtered through a pre-weighed sinter (W_2) and washed with hot distilled water and acetone, then dried for 2 h at 105°C and weighed (W_3). About 10 mL of cool 72% H_2SO_4 was added to the cooled sinter and the mixture was kept in 72% H_2SO_4 for 3 h. Thereafter, the acid was filtered off under vacuum, and the residue was washed with hot distilled water until it was acid-free. The sinter was dried at 105°C for 2 h, cooled, and weighed (W_4). The sinter was then heated at 500°C for 2 h, cooled, and weighed to determine the ash content of the residue (W_5). Lignin (%) and cellulose (%) were calculated as follows:

$$\% \text{ Lignin} = (W_4 - W_5) / W_1 \times 100$$
$$\% \text{ Cellulose} = (W_3 - W_4) / W_1 \times 100$$

Soluble carbohydrate content determination

The contents of soluble carbohydrate were determined by the anthrone method after hot water extraction (Allen et al. 1974). About 50 mg of milled litter sample was weighed and boiled for 1 h in 30 mL water. The solution was filtered through Whatman filter paper (No. 42). Then, 2 mL of extract solution was put into a boiling tube with 10 mL anthrone reagent and boil for 10 minutes. After cooling in the dark, the optical density at 625 nm was measured.

Total organic carbon and nitrogen content

Organic carbon content of plant samples was determined by 45% of loss of ignition at 400°C for 2 h (Lamlom and Savidge 2003, Chen et al. 2005). The total nitrogen contents were determined using FOSS digestion (FOSS, Hillerød, Frederiksborg, Denmark) and a distillation apparatus (FOSS). Then, 0.5 g of ground plant sample was put into 250 mL digestion tubes with two Kjeltab tablets (FOSS, 1527 0003) and 10 mL of sulfuric acid and digested in a digestion system at 400°C for 1 hour 20 min. After cooling for 15 min at room temperature, the solution was distilled and trapped with 4% boric acid (containing bromocresol green and methyl red), and the total nitrogen content was determined by titration with 0.05 N hydrochloric acid.

Nutrient content of plant samples

In accordance with Helrich (1990), the ground plant samples were digested using nitric acid (HNO_3) and 60% perchloric acid ($HClO_4$). Then, 10 mL of HCl (water:HCl=1:1, v/v) was added and adjusted for a total volume of solution of 50 ml. Then, the solution was filtered through Whatman filter paper (No. 42). The solution was used to determine the Ca, K, P, Na, and Mg content by inductively coupled plasma spectrometry JY-ULTIMA-2 (JobinYvon, Longjumeau, France).

Statistical analysis

Differences among samples in mass loss and chemical composition were analyzed statistically using a one-way ANOVA followed by a Tukey HSD test. For each value we provided linear correlation coefficients. All statistical work was performed with SPSS ver. 20.0 (SPSS Inc., Chicago, IL, U.S.A.). All significant results were reported at $P < 0.05$.

RESULTS

Physico-chemical characteristics of leaf litter species

The physico-chemical characteristics of each leaf litter species were shown in Table 1. The morphological features of the leaf litter were species-dependent. The litter of *D. macropodum* and *D. morbifera* had thin, large leaves and large SLAs of 82.1 and 87.7, respectively. On the other hand, *M. thunbergii* and *Q. acuta* had small, thick leaves and small SLAs of 59.8 and 60.2, respectively.

The species whose leaf litter contained large amounts of water-soluble material also contained large amounts of alcohol-soluble material, but *C. cuspidata* var. *thunbergii* contained the highest amount of alcohol-soluble material, 14.22%, while containing a low amount of water-soluble material of 2.30%. Soluble carbohydrate content showed a positive relationship with water-soluble content, but showed an inverse relationship with lignin and cellulose content. The contents of cellulose and lignin in the leaf litter were positively related. *D. morbifera* contained the lowest amounts of cellulose and lignin, 18.36% and 13.74%, respectively, and *M. thunbergii* and *Q. acuta* contained 24.39% and 30.10% cellulose and 33.60% and 33.95% lignin, respectively.

The carbon content of each species was 45.47% to 49.25% of dry weight, but the nitrogen content differed among species. The nitrogen contents of *C. cuspidata* var. *thunbergii* and *Q. acuta* were 0.81% and 0.96%, respectively, while *D. macropodum*, *D. morbifera*, and *M. thunbergii* had lower contents of 0.48%, 0.51%, and 0.57%, respectively. The content of phosphorous in the leaf litter was the highest value at *D. morbifera* and the lowest at *Q. acuta,* respectively at 308.08 μg/g and 101.06 μg/g. The phosphorous content in each species showed a negative relationship with nitrogen content (R^2 = 0.694, P = 0.182). The C/N ratio was lower in *C. cuspidata* var. *thunbergii* and *Q. acuta*, at 60.5 and 50.3, respectively, than in the other species, where it ranged from 86.9 to 94.6. The species with high C/N ratios had lower C/P ratios.

Litter mass loss

During the 731 experimental days, the leaf litter of *D. macropodum* and *D. morbifera* decayed by 98.2% and 98.0%, and *C. cuspidata* var. *thunbergii* decomposed by 79.1%. The litter of *M. thunbergii* and *Q. acuta* decomposed 69.6% and 68.4% of initial mass. The rate of mass loss was fast in the summer, which has high temperatures and precipitation (Fig. 3).

The decomposition constant was 2.02 and 1.95 yr^{-1} for *D. macropodum* and *D. morbifera*, and 0.78, 0.60, and 0.58 yr^{-1} for *C. cuspidata* var. *thunbergii*, *M. thunbergii*, and *Q. acuta*, respectively. The half-life of leaf litter decomposition was 0.34 and 0.36 yr for *D. macropodum* and *D. morbifera*, and 0.89 yr for *C. cuspidata* var. *thunbergii.* The litter of *C. cuspidata* var. *thunbergii* took twice as long to reach 50% decomposition than *D. macropodum* and *D. morbifera*. The half-life of the litter of *M. thunbergii* and *Q. acuta* was three times slower than that of *D. macropodum* and *D. morbifera* (Table 2).

Table 1. Physico-chemical characteristics of the leaf litter of experimental broadleaf evergreen tree species

	Leaf litter species				
	Daphniphyllum macropodum	***Dendropanax morbifera***	***Castanopsis cuspidata* var. *thunbergii***	***Machilus thunbergii***	***Quercus acuta***
Leaf area (cm^2)	86.42 ± 11.66	39.02 ± 11.46	17.69 ± 4.64	31.39 ± 9.41	35.51 ± 7.36
Leaf thickness (mm)	0.21 ± 0.03	0.15 ± 0.02	0.31 ± 0.04	0.36 ± 0.03	0.41 ± 0.03
Specific leaf area (cm^2/g)	82.1	87.7	71.1	59.8	60.2
Carbon (%)	45.47 ± 0.09	46.23 ± 0.08	48.67 ± 0.14	49.25 ± 0.19	48.42 ± 0.22
Total N (%)	0.48 ± 0.01	0.51 ± 0.01	0.81 ± 0.01	0.57 ± 0.01	0.96 ± 0.01
P (μg/g)	191.97 ± 3.43	308.08 ± 23.05	153.95 ± 4.02	220.58 ± 3.20	101.06 ± 0.84
C/N	94.6	90.4	60.5	86.9	50.3
C/P	2,368.5	1,500.5	3,161.6	2,232.8	4,790.6
Cellulose (%)	21.66 ± 1.10	18.36 ± 1.04	22.87 ± 1.93	24.39 ± 0.44	30.1 ± 1.22
Lignin (%)	19.46 ± 1.12	13.74 ± 0.48	26.38 ± 2.34	33.6 ± 0.90	33.95 ± 0.45
Lignin/N	40.5	26.9	32.8	59.3	35.3
Water solubles (%)	12.54 ± 0.30	16.16 ± 2.91	2.30 ± 1.20	2.23 ± 1.14	1.69 ± 0.09
Alcohol solubles (%)	11.97 ± 5.87	14.02 ± 2.32	14.22 ± 4.89	3.89 ± 1.53	5.26 ± 2.88
Soluble carbohydrate (%)	2.05 ± 0.13	1.53 ± 0.09	1.26 ± 0.04	1.12 ± 0.06	0.75 ± 0.05
K (μg/g)	1,900.73 ± 44.04	5,034.69 ± 133.79	2,048.58 ± 17.57	1637.6 ± 65.77	2,156.92 ± 36.66
Na (μg/g)	1,037.52 ± 52.09	1,323.93 ± 49.86	945.96 ± 46.2	1,011.52 ± 61.39	939.19 ± 61.11
Ca (μg/g)	3,222.37 ± 51.05	2,024.82 ± 16.11	2,739.88 ± 29.68	1,145.19 ± 33.15	1,404.69 ± 20.82
Mg (μg/g)	25,739.22 ± 293.84	26,780.15 ± 171.73	8,907.02 ± 214.33	15,422.64 ± 276.77	9,339.87 ± 181.58

Table 2. Decomposition coefficient (*k*) and decomposition period of 50%, 95%, and 99% decomposition of each type of leaf litter

Species	***k* (yr^{-1})**	**Period of decomposition (yr)**		
		50%	**95%**	**99%**
Daphniphyllum macropodum	2.02	0.34	1.48	2.47
Dendropanax morbifera	1.95	0.36	1.54	2.56
Castanopsis cuspidata var. *thunbergii*	0.78	0.89	3.84	6.40
Machilus thunbergii	0.60	1.16	5.03	8.39
Quercus acuta	0.58	1.20	5.21	8.68

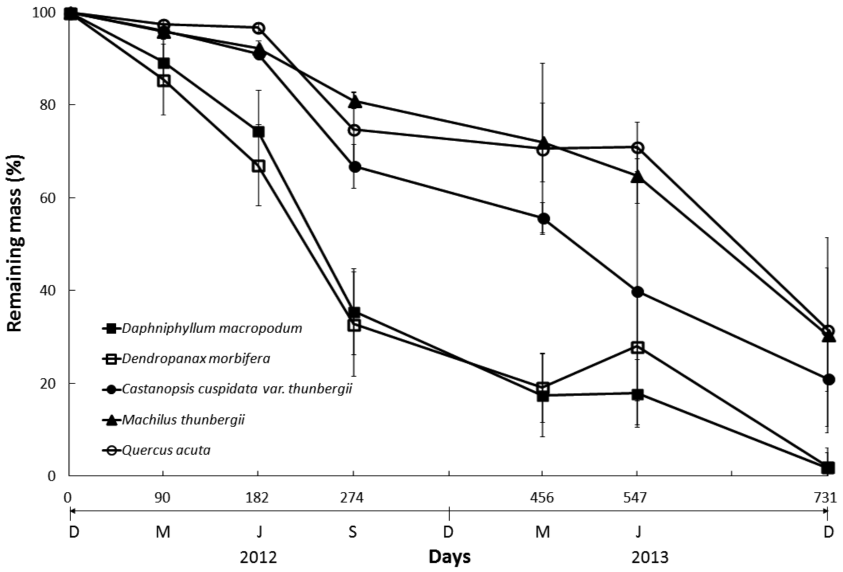

Fig. 3. Remaining dry weight (%) relative to the initial mass of each leaf litter for experimental 2 years in Judo. D, December; M, March; J, June; S, September.

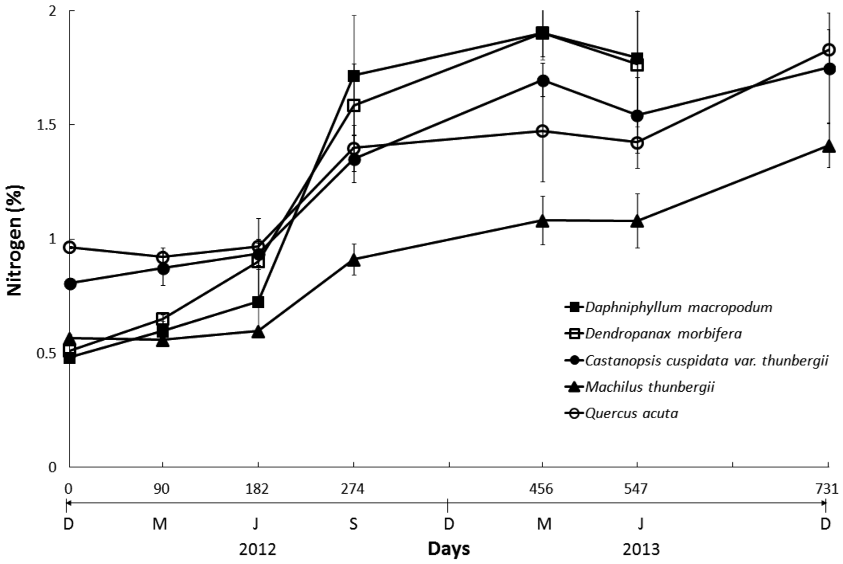

Fig. 4. Changes of remaining nitrogen concentration (%) of each decaying leaf litter for experimental 2 years field incubation in Judo. D, December; M, March; J, June; S, September.

Changes in nitrogen content in the decaying litter

The nitrogen concentration in decaying leaf litter increased, especially during the first summer. The nitrogen concentration in the litter of *D. macropodum* and *D. morbifera* was higher, at 1.90% of litter mass, than for the other species, and the litter of *M. thunbergii* showed the lowest concentration of 1.08% after 547 days of incubation (Fig. 4).

The total amount of nitrogen in decaying leaf litter relative to the initial amount showed two different patterns among the litter species. One was net mineralization in the early stage of decomposition and immobilization in the later stage (after 274 days of incubation), and the other was immobilization of nitrogen in the early stage and net mineralization in the later stage. *M. thunbergii* and *Q. acuta* belong to the former, and *D. macropodum*, *D. morbifera*, and *C. cuspidata* var. *thunbergii* to the latter (Fig. 5).

The litter of *D. macropodum*, *D. morbifera*, and *C. cus-*

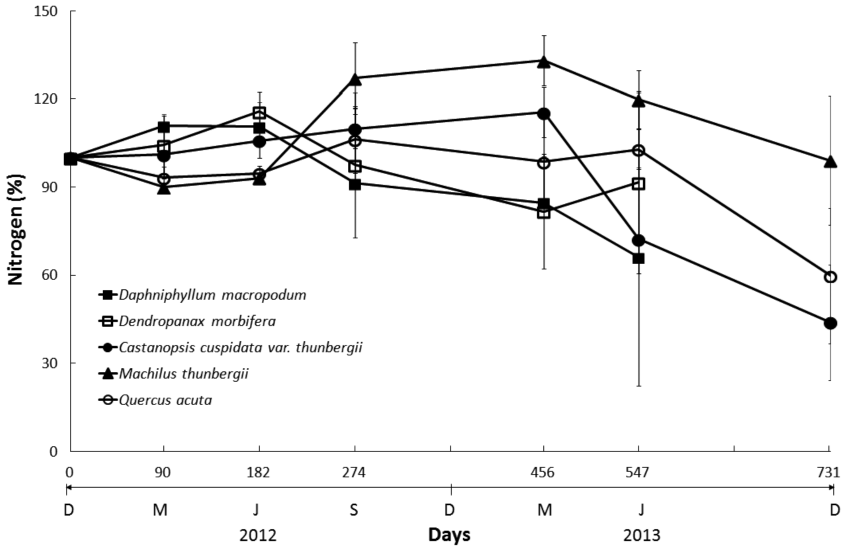

Fig. 5. Change in the remaining nitrogen (%) relative to the initial nitrogen content of each leaf litter species after 2 years of field incubation in Judo. D, December; M, March; J, June; S, September.

pidata var. *thunbergii* showed an increase in total nitrogen at in early stage of decomposition, although the litter mass decreased sharply. These three species showed 110–115% of the initial amount of nitrogen during the net immobilization period. However *M. thunbergii* and *Q. acuta* litter showed a net mineralization of nitrogen at 182 days of incubation, in September of the first year, and then showed net immobilization to the beginning of the autumn of the second year. The litter of *M. thunbergii* and *Q. acuta* immobilized to 133%, and 106%, respectively, of the initial amount of nitrogen during the net immobilization period.

Factors affecting the decomposition of leaf litters

Litter decomposition showed strong, significantly positive correlations with the precipitation, and year day index (Table 3). The year day index is thermal effect calculated by the accumulation of daily mean temperatures above 5°C for all leaf litter species. *D. macropodum* and *D. morbifera* showed steeper slopes and higher y-intercepts than the other species, meaning that their litter decays were more readily affected by precipitation and year day index.

The thickness and SLA of the leaf litter were important factors limiting the decomposition rate of litter species, and these physical characteristics positively affected litter decomposition (Fig. 6). Thick litter species with low SLAs, such as *M. thunbergii* and *Q. acuta*, decayed more slowly than thin leaf litter species, such as *D. macropodum* and *D. morbifera*. The litter of species with large amounts of cellulose and lignin, such as *Q. acuta* and *M. thunber-*

Table 3. Equations and correlation coefficients between litter mass loss and accumulated daily mean temperatures above 5°C (year day index) and precipitation

	Litter species	Slope	y - intercept	R^2	*P*-value
Year day index	*Daphniphyllum macropodum*	0.0126	18.447	0.888	0.001
	Dendropanax morbifera	0.0113	23.168	0.889	0.001
	Castanopsis cuspidata var. *thunbergii*	0.0110	1.3197	0.978	0.000
	Machilus thunbergii	0.0089	-2.5465	0.952	0.000
	Quercus acuta	0.0089	-3.5261	0.936	0.000
Precipitation	*Daphniphyllum macropodum*	0.0322	8.7203	0.959	0.000
	Dendropanax morbifera	0.0283	15.262	0.927	0.000
	Castanopsis cuspidata var. *thunbergii*	0.0272	-5.6035	0.983	0.000
	Machilus thunbergii	0.0208	-6.2341	0.857	0.002
	Quercus acuta	0.0207	-7.1233	0.838	0.003

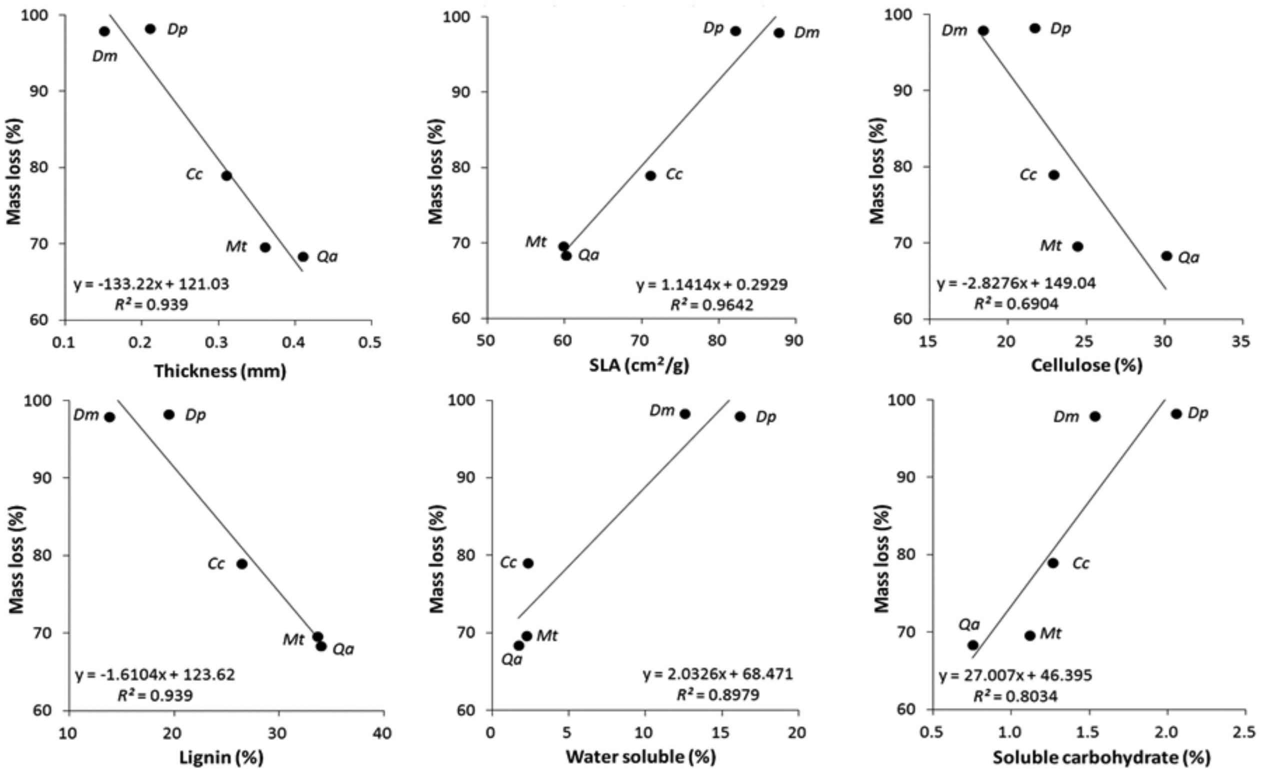

Fig. 6. The relationships between mass loss and physical characteristics and macro organic componenets in freshly fallen leaf litter of each species. Dp, *Daphniphyllum macropodum*; Dm, *Dendropanax morbifera*; Cc, *Castanopsis cuspidata* var. *thunbergii*; Qa, *Quercus acuta*; Mt, *Machilus thunbergii*.

gii, had slow decomposition. The mass loss of each litter species was negatively correlated with the cellulose (R^2 = 0.690, P = 0.081) and lignin (R^2 = 0.939, P = 0.007) content. The mass loss rate of each litter species was positively related to the water-soluble contents (R^2 = 0.898, P = 0.014), alcohol-soluble contents (R^2 = 0.597, P = 0.126), and soluble carbohydrates (R^2 = 0.803, P = 0.039). *D. morbifera* and *D. macropodum*, which contained large amounts of soluble materials, had fast decomposition rates, while *C. cuspidata* var. *thunbergii* and *Q. acuta*, which contained small amounts of soluble materials, had slow decomposition rates.

Litter decomposition was faster in the litter species containing high contents of the nutrients P, K, Na, Mg, and Ca. However, the total nitrogen content in litters showed a different pattern from the above-mentioned nutrients. The litter of *D. macropodum* and *D. morbifera*, which have low nitrogen content, decayed faster than *C. cuspidata* var. *thunbergii* and *Q. acuta* litter, which have a higher concentration of nitrogen. These results are contrary to the general tendency that higher nitrogen content in litter accelerates decomposition (Fig. 7). However, the litter of *M. thunbergii*, which has a low concentration of nitrogen, decayed slowly, consistent with general trends. For this reason, the nitrogen content negatively affected litter decomposition, and the C/N ratio of each litter species was also positively correlated with the mass loss rate, although *M. thunbergii*, which had a high C/N ratio, decayed slowly. On the other hand, the lignin/N ratio of each litter species, which is a general prediction index of litter decomposition, did not show a significant relationship with mass loss in any litter species. The phosphorus content was the opposite of that of nitrogen. The litter species contain high C/P ratios decayed slower than low C/P ratio species, with the exception of *M. thunbergii*, which had a small C/P ratio and slow decomposition.

DISCUSSION

Litter decomposition is the main process in ecosystems to circulate nutrients (van Vuuren et al. 1993, Vitousek et al. 1994, Aerts and Chapin 2000, Wang et al. 2008, Klotzbücher et al. 2011), supply organic and inorganic elements (Wang et al. 2008), sustain soil fertility (Koukoura et al. 2003), release carbon dioxide to the atmosphere

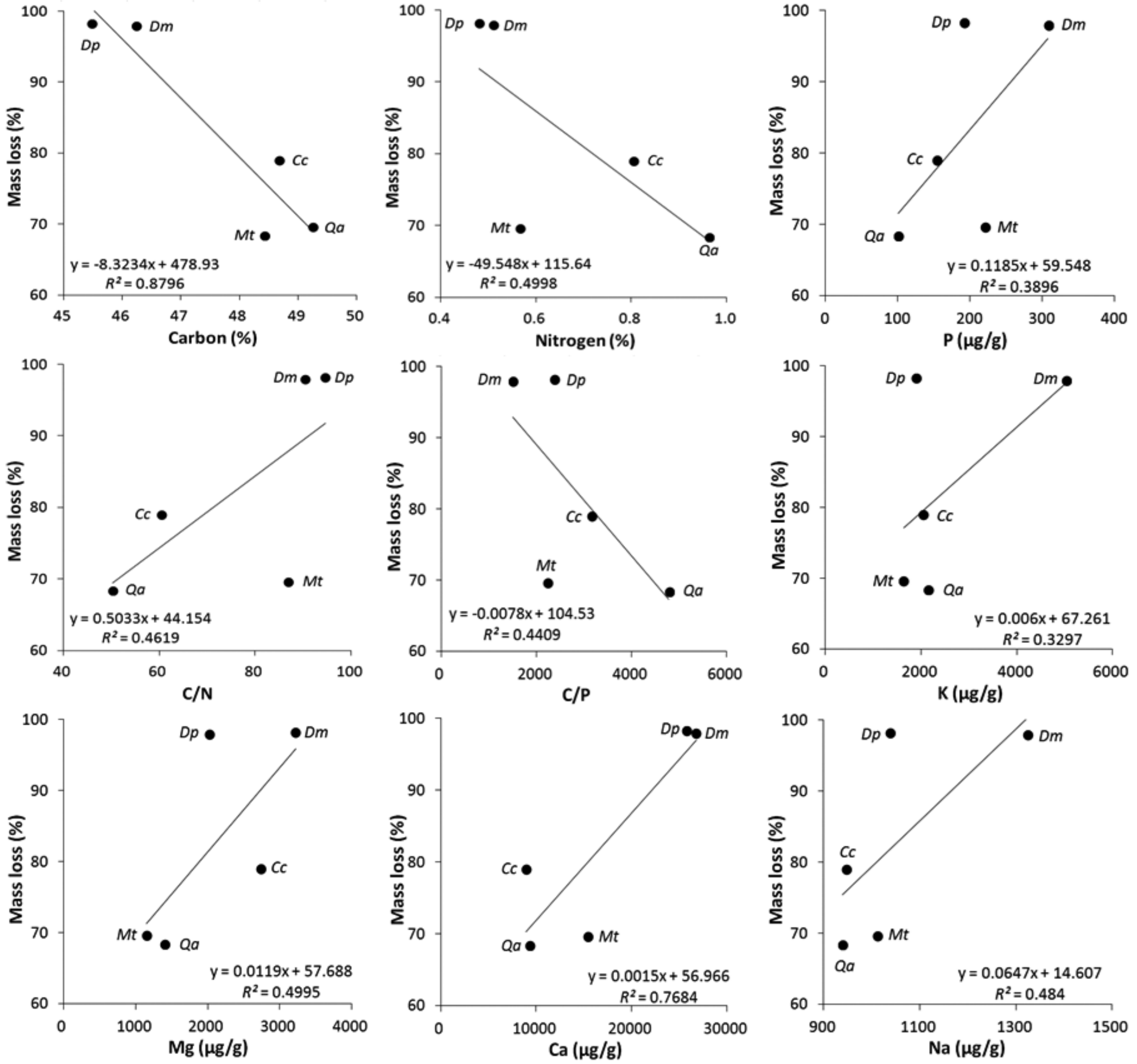

Fig. 7. The relationships between mass loss and nutrient content, C/N and C/P ratio in freshly fallen leaf litter of each species. Dp, *Daphniphyllum macropodum*; Dm, *Dendropanax morbifera*; Cc, *Castanopsis cuspidata* var. *thunbergii*; Qa, *Quercus acuta*; Mt, *Machilus thunbergii*.

(Coûteaux et al. 1995, Silver and Miya 2001, Austin and Vivanco 2006), and control the carbon cycle and climate change (Saura-Mas et al. 2012).

The original evergreen broadleaf forest was severely disturbed by cutting for firewood or farmland, and so, it is difficult to find the original community or forest in the Korean Peninsula, except in rare cases such as small conservation areas for religious purposes or in very steep areas. The evergreen broadleaf trees and their community are expected to have a northward expansion of their distribution range with global warming. The southern edge of deciduous forest will be displaced by evergreen forest in the near future unless warming is slowed. However, surveys and studies on the evergreen forest in Korea have focused on the flora and distribution, and studies on the structures and functions of the evergreen forest were scarce until the Long Term Ecological Research of the Ministry of Environment. We surveyed the decomposition of leaf litter of five main evergreen broadleaf tree species distributed in the southern coastal area, including Jeju Island.

The experimental five litter species have different physicochemical characteristics and different decomposition rates. The litters decomposed faster in the summer with high temperatures and precipitation. Millar (1974) and Swift et al. (1979) suggested that the litter was actively decomposed in the summer because the concentration of precipitation facilitates the leaching of water-soluble materials and high temperature facilitate the activity of decomposers. The water-soluble materials are used as energy sources for microorganisms in the early stage of decomposition (Swift et al. 1979, Hobbie 1996), and the litter contains large amounts of water-soluble materials that are affected by decomposers more readily in the early stage of litter decomposition. Therefore, the litter of *D. morbifera* and *D. macropodum*, which contain higher concentrations of water soluble materials than that of other species, lost litter mass faster than the other species in the summer. The water-soluble substances and soluble carbohydrates, about 80% of the soluble materials, easily leached within a few days after incubation in the early decaying stage (Swift et al. 1979, Gessner 1991, Cunha-Santino et al. 2003).The leaching of soluble materials was influenced by physical characteristics such as the toughness and thickness of litter. Thin litter species such as *D. morbifera* and *D. macropodum*, which have a higher SLA, contain more water-soluble materials than thicker leaf litter. In this experiment, the decomposition of each litter species showed a significantly linear correlation with thickness (mass loss, percent = -133.22 thickness + 121.03, $R^2 = 0.939$, $P = 0.007$) and SLA (mass loss, percent = 1.1414 SLA + 0.2929, $R^2 = 0.964$, $P = 0.003$).

The decomposition constant differed among the five experimental species. *D. macropodum* and *D. morbifera* had rates of 2.02 yr^{-1} and 1.95 yr^{-1}, respectively, while *M. thunbergii* and *Q. acuta* had slower decomposition constant of 0.60 yr^{-1} and 0.58 yr^{-1}, respectively. *C. cuspidata* var. *thunbergii* had a decomposition rate of 0.78 yr^{-1}. These rates are comparable to other studies. Chang and Han (1985) separately collected litter and accumulation layers in an evergreen broadleaf forest regarded as in a steady state of equilibrium between production and decomposition of litter, measured the carbon content, and fitted Olson's model (1963). They obtained a decomposition coefficient of 0.287 ± 0.0223 yr^{-1} for *Q. acuta*. This result is a significantly lower decomposition rate. Won et al. (2014) observed a decomposition constant of 0.49 yr^{-1} for *Q. mysinifolia* in *Q. acutissima* forest in Gongju (N 36°25′21″), and Han (2014) observed a decomposition constant of 0.57 yr^{-1} for *Q. glauca* in a 24-month experiment and 0.39 yr^{-1} for *C. cuspidata* var. *thunbergii* in a 23-month in Gotzawal on Jeju Island, respectively, by using the litterbag method.

In addition, litter decomposition is affected not only by the physical characteristics of litter but also by its chemical composition (Swift et al. 1979, Heal et al. 1997, Zimmer 2002, Sariyildiz and Anderson 2003, Polyakova and Billor 2007). Climatic conditions are a general limiting factor to litter decaying at a large scale, and the physico-chemical characteristics determine the decomposition rate at a small scale (Berg et al. 1993, Heal et al. 1997). The decomposition rates of each litter species showed a dispersed distribution on each nutrient content gradient, and differed from those for water-soluble materials and soluble carbohydrate contents.

The chemical composition, such as the lignin and nitrogen contents, determine litter substrate quality (Melillo et al. 1982, Berg et al. 1993, Aerts and De Caluwe 1997, Austin and Vitousek 1998, Cotrufo et al. 1998,), and the litter quality affects the rate of decomposition (Singh et al. 1999, Sundarapandian and Swamy 1999, Ribeiro et al. 2002, Tateno et al. 2007). Our results also showed a significant positive relationship between litter mass loss and lignin, thickness, and SLA. However, the nitrogen content was not a critical factor for our litter species. For example, *D. macropodum* and *D. morbifera*, which have low nitrogen, had a high decomposition rate, while the litter of *Q. acuta* contained high nitrogen content, but had a low mass loss rate. In addition, the litter mass loss of each litter species distributed on the C/N ratio gradient showed no linear relations. These results suggest that other factors acted as critical limiting factors in litter decomposition. *D. macropodum* and *D. morbifera* litter contain low lignin content and high SLA, and thin leaf litter leads to fast decomposition, although these litters contain low N and a high C/N ratio. *Q. acuta* leaf litter has a high concentration of N but a slow decomposition rate because of its thick leaf litter with a small SLA and low content of phosphorus. Wieder et al. (2009) noted the importance of phosphorus in litter decomposition. The physical characteristics of litter, such as thickness and SLA, were greater factors in leaf litter decomposition than nutrient content characteristics, such as N and the C/N ratio (Gallardo and Merino 1992, Yang 1995).

Swift et al. (1979), Melillo et al. (1982), Berg and Lundmark (1987), and Wang et al. (2008) have commented on the effects of lignin and nitrogen content on litter decomposition; our results showed that lignin was more critical for litter decomposition than N content. This result agrees with Bollen (1953) and Fogel and Cromack (1977), who suggested that lignin is more important than N in the relationship between chemical constituents and the decomposition rate. The lignin content seems to be a limiting factor for litter decomposition at a later stage, after the soluble materials are leached out (Fogel and Cromack 1977, Meentemeyer 1978, Swift et al. 1979, Melillo et al. 1982, Hobbie 1996, Klotzbücher et al. 2011).

The nitrogen content in decaying litter showed two patterns in our experiment. One was net mineralization in the early stage of decomposition and immobilization in the later stage (after 274 days of incubation), and the other is immobilization of nitrogen in the early stage and net mineralization in the later stage. We estimated that the litter of *M. thunbergii* and *Q. acuta*, which belong to the former group, contained low nitrogen and was tough, inhibiting microbial colonization and leading to net mineralization in the early decomposition stage. On the other hand, *D. macropodum*, *D. morbifera*, and *C. cuspidata* var. *thunbergii* belong to the latter group containing a large amount of nitrogen that supports increasing microbes on decaying litter in the early decomposition stage.

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