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Dynamics of Organic Carbon and Nutrients in Litterfall of *Quercus mongolica* Forest in Mt. Songnisan National Park

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ABSTRACT: The amounts of organic carbon and several nutrients in litterfall on the forest floor of *Quercus mongolica* forest were assessed for two years from 1998 through 2000 in Mt. Songnisan National Park in Korea. The amounts of organic carbon (C) in litterfall were the highest in autumn with the values of 150.4 g/m^2 (62.6%) in 1998 and 219.2 g/m^2 (61.0%) in 1999. In winter, organic C was the lowest with the values of 16.3 g/m^2 (6.8%) in 1998 and 12.5 g/m^2 (6.7%) in 1999. It was estimated that the organic C added to forest floor via litterfall was 240.1 g · m^{-2} · yr^{-1} and 186.6 g · m^{-2} · yr^{-1} in 1998 and 1999, respectively. The amounts of nitrogen (N) in litterfall were the highest in autumn with the values of 5.9 g/m^2 (58.0%) in 1998 and 5.2 g/m^2 (62.3%) in 1999. The amount of phosphorus (P) in litterfall showed its peak in autumn with 0.19 g/m^2 (52.9%) in 1998 and 0.11 g/m^2 (52.6%) in 1999. The amount of P returned to forest floor via litterfall was 0.35 g · m^{-2} · yr^{-1} in 1998 and 0.22 g · m^{-2} · yr^{-1} in 1999. The amount of potassium (K) in litterfall showed its peak in autumn with 0.57 g/m^2 (53.8%) in 1998 and 0.42 g/m^2 (55.3%) in 1999. The amounts of K returned to forest floor via litterfall was 1.11 g · m^{-2} · yr^{-1} in 1998 and 0.81 g · m^{-2} · yr^{-1} in 1999.

Key words: Litter, Nutrient, Organic carbon, *Quercus mongolica* forest

INTRODUCTION

The annual return of organic material and nutrients to forest soil, via litterfall, is one of the most important renewal factors of a forest ecosystem. Litterfall is a particularly key process in nutrient cycling of forest ecosystem as it provides the main above-ground contribution of carbon and nutrients to forest floor through the formation of humus that is characteristic of each ecosystem (Gallardo *et al.* 1998, Roig *et al.* 2005) and represents a provisional accumulation of elements which are released gradually, thereby guaranteeing a permanent contribution of nutrients to the soil (Cuevas and Medina 1988, Hernandez *et al.* 1992, Palma *et al.* 1998, Kavvadias *et al.* 2001, Roig *et al.* 2005). Litter decomposition rates also determine soil organic matter accumulation rates on the forest floor. The balance between litter production and its decomposition controls the size of the carbon reservoir within the soil. And the litter accumulated to forest floor includes various inorganic components or minerals (Ovington and Heitkamp 1960).

Therefore, analysing the amount of several key nutrients contained in litterfall is one of the basic processes of understanding forest ecosystem. There are some studies on the amount of litterfall in each forest such as *Quercus mongolica*, *Q. acutissima*, *Pinus rigida* and *P. koraiensis* forests for the elucidation of nutrient cycles in Korea (Kwak and Kim 1992a, b, Mun and Kim 1992, Mun and Ju 1994, Kim *et al.* 1996, Kang and Han 2004, Osono and Takeda 2004, Son *et al.* 2004). The changes of chemical constituents and nutrients according to the process of litter decomposition were also carried out by Mun and Pyo (1994) and Kang and Han (2004).

The purpose of the present study is to estimate the amount of several important nutrients contained in litterfall to a *Quercus mongolica* forest for two years from 1998 to 2000 and to provide useful informations for characterizing the nutrient replenishment in Mt. Songnisan National Park located at the central part of Korea.

MATERIALS AND METHODS

Study Area

The *Quercus mongolica* forest is situated at so-called Yong-Ba-Wee-Gol (Dragon-Rock Valley, altitude 560-640 m) of Mt. Songnisan National Park, Chungbuk Province, Korea. The annual precipitation and average annual temperature were 1,700~2,000 mm and 11~12℃, respectively, by Boeun Meteorological Station.

Ten quadrats of 50 m × 50 m or 20 m × 20 m in size were established at the study area. The height of tree layer was 10~14 m, subtree layer 5~8 m, shrub layer 1.2~2.0 m and herb layer 0.7~0.8

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m. Coverage of tree layer was 90~95%, subtree layer 40~70%, shrub layer 20~70% and herb layer 40~95%.

The density of *Quercus mongolica* was 923 trees/ha, average DBH 11.7 cm and average tree height 11.6 m. *Quercus mongolica* was a dominant tree species but *Q. serrata*, *Q. acutissima* and *Pinus densiflora* were mixed. The subtree layer was consisted of *Acer pseudosieboldianum*, *Styrax obassia*, *Q. mongolica* and *Fraxinus sieboldiana* and others. The shrub layer consisted of *Rhododendron schlippenbachii*, *Lindera obtusiloba* and *A. pseudosieboldianum*, and herb layer consisted of *Sasa borealis* except *Carex humilis*, *Ainsliaea*, *Spodiopogon* and *Smilax riparia* var. *ussuriensis*.

Collection of Litter

Ten litter traps of 1 m^2 in size were placed randomly under a *Quercus mongolica* forest. Litter in the traps was collected every month for two years and was classified into species and plant organs such as leaves, barks, twigs, buds, reproductive organs and others. After the litter was oven dried at 80℃ for 48 hrs, the samples were grinded in mortar and were kept in plastic bottles for analysis.

Organic Carbon and Nutrients

Organic matter in litter analyzed by loss on ignition in 600℃ electric furnace for 6 hours. The loss on ignition was then divided by correction factor of 1.724 to get the amount of organic carbon in litter (Chapman 1976). Kjeldahl Protein/Nitrogen Analyzer (Kjeltec Auto 1035/1038 System, Tecator AB) was used to analyze nitrogen in litter. For phosphorus and potassium, litter samples were wet digested and the filtrate was analyzed by ICP (Inductively Coupled Plasma) Emission Spectrometer (ICPS-1000IV, Shimazu).

RESULTS AND DISCUSSION

Content of Organic Carbon (C)

The seasonal changes of organic C in litterfall from 1998 through 1999 are shown in Table 1. The amounts of organic C in litter were the highest in autumn of both 1998 and 1999 with 150.4 g/m^2 (62.6%) and 219.2 g/m^2 (61.0%), respectively. In winter, organic C was the lowest with the value of 16.3 g/m^2 (6.8%) in 1998 and 12.5 g/m^2 (6.7%) in 1999. It was evaluated that the organic C returned to forest floor via litterfall was 240.1 $g \cdot m^{-2} \cdot yr^{-1}$ in 1998 and 186.6 $g \cdot m^{-2} \cdot yr^{-1}$ in 1999.

The amounts of organic C of *Q. mongolica* were estimated as 1.67 ton $\cdot ha^{-1} \cdot yr^{-1}$ (69.7%) in 1998 and 1.32 ton $\cdot ha^{-1} \cdot yr^{-1}$ (68.3 %) in 1999. The litter of *Q. serrata* contained 0.16 C ton $\cdot ha^{-1} \cdot yr^{-1}$ (6.8%) in 1998 and 0.13 C ton $\cdot ha^{-1} \cdot yr^{-1}$ (7.0%) in 1999, *P. densiflora* 0.26 C ton $\cdot ha^{-1} \cdot yr^{-1}$ (10.7%) in 1998 and 0.21 C ton $\cdot ha^{-1} \cdot yr^{-1}$ (10.9%) in 1999 and the other tree species (e.g. *Q. acutissima*, *Prunus sargentii*, *A. pseudo-sieboldianum* etc.) 0.31 C ton $\cdot ha^{-1} \cdot yr^{-1}$ (12.8%) in 1998 and 0.27 C ton $\cdot ha^{-1} \cdot yr^{-1}$ (13.8%) in 1999.

Comparing the ratio of organic C content in fallen litter each season, the litterfall in April of spring was reached its highest peak with 53.4% in 1998 and 54.7% in 1999 and was occurred the lowest with the value of 44.0% in September and November of autumn during two years. In general, the ratio of organic C content in fallen litter was shown in similar values in ranging from 44.0% to 54.7% every season for both years. Consequently, the ratio of organic C content was reached its high concentration during spring from March through May and its low concentration during autumn from September through November for two years.

It is suggested that the high concentration of organic C in litterfall in spring rather than autumn was due to the abscission of vigorous photosynthetic leaves by wind or other factors before the translocation of carbohydrate to storage tissues. By the relation between

Table 1. Seasonal changes of dry weight (DW) and organic carbon (OC) in litter for each tree species accumulated on *Quercus mongolica* forest from March 1998 to February 2000 (unit : g/m^2)

Species	1998								1999							
	Spring		Summer		Autumn		Winter		Spring		Summer		Autumn		Winter	
	DW	OC	DW	OC	DW	OC	DW	OC	DW	OC	DW	OC	DW	OC	DW	OC
Q. mongolica	45.8	24.2	68.3	33.6	222.3	98.9	23.5	10.6	40.0	21.4	50.6	24.5	170.0	74.6	18.1	8.3
Q. serrata	0.4	0.2	0.8	0.4	31.8	15.0	1.4	0.7	0.3	0.2	0.7	0.3	26.2	11.6	1.2	0.5
P. densiflora	9.4	4.8	8.9	4.1	33.6	14.7	4.7	2.2	8.0	4.1	7.5	3.6	25.9	11.4	4.0	1.8
Other	3.3	1.7	9.3	4.4	46.1	21.8	6.0	2.8	2.0	1.0	7.6	3.6	40.1	17.8	4.4	1.9
Total	58.9	30.9	87.3	42.5	333.8	150.4	35.6	16.3	50.3	26.7	66.4	32.0	262.2	115.4	27.7	12.5
	240.1								186.6							

dry weight of plant and content of organic C in plant tissue, Satoo and Madgwick (1982) estimated the ratio of organic C content in plant tissues was in the range of 50% of plant dry weight. In addition, Song *et al.* (1997) measured that the ratio of organic C content in litter of *Q. mongolica* forest situated at Chungju was in the ranges from 48.8% to 49.9%. Considering these values above, it was suggested that the ratio of organic C obtained in the present study was a little low value which is 45.9% ~ 46.6% during two years.

Content of Nitrogen (N)

Seasonal changes of N content in litterfall to forest floor are shown in Table 2. The highest values of N content in fallen litter were occurred in autumn with 5.9 g/m^2 (58.0%) in 1998 and 5.2 g/m^2 (62.3%) in 1999, and the lowest values in winter of 1998 with 0.42 g/m^2 (4.2%) and in winter of 1999 with 0.43 g/m^2 (5.2%). It was estimated that annual N content in fallen litter in *Q. mongolica* forest studied was 10.1 $g \cdot m^{-2} \cdot yr^{-1}$ and 8.3 $g \cdot m^{-2} \cdot yr^{-1}$ in 1998 and 1999, respectively.

The N amounts in litter of *Q. mongolica* were 7.6 $g \cdot m^{-2} \cdot yr^{-1}$ (75.6%) in 1998 and 6.8 $g \cdot m^{-2} \cdot yr^{-1}$ (77.0%) in 1999, *Q. serrata* 0.7 $g \cdot m^{-2} \cdot yr^{-1}$ (7.2%) in 1998 and 0.6 $g \cdot m^{-2} \cdot yr^{-1}$ (6.9%) in 1999, *P. densiflora* 0.7 $g \cdot m^{-2} \cdot yr^{-1}$ (6.8%) in 1998 and 0.5 $g \cdot m^{-2} \cdot yr^{-1}$ (5.7%) in 1999, and the other trees 1.0 $g \cdot m^{-2} \cdot yr^{-1}$ (10.4%) in 1998 and 0.4 $g \cdot m^{-2} \cdot yr^{-1}$ (10.4%) in 1999.

Kimmins (1987) reviewed the amounts of N of aboveground litterfall over the world forests. By Kimmins (1987), N content of litterfall of *Quercus* forest in Belgium was 5.1 $g \cdot m^{-2} \cdot yr^{-1}$, Scot pine (*P. sylvestris*) forest of Finland 1.2 $g \cdot m^{-2} \cdot yr^{-1}$ and Jack pine (*P. banksiana*) forest of Ottawa in Canada 1.7 $g \cdot m^{-2} \cdot yr^{-1}$. By the comparison of these values to the present study, N content of litterfall in *Q. mongolica* forest was maintained relative high concentration. It means more time of nutrient retention by litter. Kang and Han (2004) estimated that the decomposition time of N in litter of *Q. mongolica* was 9.1±0.9 years for 95% decay and 15.18±1.47 years for 99% decomposition in the previous study on the same forest. Generally, the ratio of N content of litter was showed similar values from 0.9% to 3.6%. Son *et al.* (2004) reported that the ratio of foliage N in *Q. mongolica* of central Korea was 2.0% and thereby the result was within the ranges obtained from the present study.

The percentage of N amount in litter of *Q. mongolica* was 2.11% in 1998 and 2.43% in 1999, those of *Q. serrata* 2.12% in 1998 and 2.13% in 1999, those of *P. densiflora* 2.21% in 1998 and 1.11% in 1999 and those of the others 1.62% in 1998 and 1.70% in 1999. Comparing the ratio of N content of each tree species, N content of *Q. mongolica* was twice as high as the values of *P. densiflora*. The average ratio of N content obtained in the present study was 1.95% in 1998 and 2.17% in 1999. Lutz and Chandler (1946) presented the ratio of N content in several tree species as follows; 0.67% in Sugar maple (*A. saccharum*) and 0.58% in Jack pine (*P. banksiana*). The ratio of N content of litter obtained from the present study was relatively higher than these values.

Content of Phosphorus (P)

The seasonal changes of P in litterfall to the forest floor are shown in Table 3. The amount of P in litter was reached its peak in autumn with 0.19 g/m^2 (52.9%) in 1998 and 0.11 g/m^2 (52.6%) in 1999 and its lowest value in winter with 0.02 g/m^2 (4.9%) in 1998 and 0.01 g/m^2 (3.4%) in 1999. The annual amount of P in litter was 0.35 $g \cdot m^{-2} \cdot yr^{-1}$ in 1998 and 0.22 $g \cdot m^{-2} \cdot yr^{-1}$ in 1999.

The amount of P in litter for each tree species was 0.27 $g \cdot m^{-2}$

Table 2. Seasonal changes of dry weight (DW) and nitrogen (N) in litter for each tree species accumulated on *Quercus mongolica* forest from March 1998 to February 2000 (unit : g/m^2)

Species	1998								1999							
	Spring		Summer		Autumn		Winter		Spring		Summer		Autumn		Winter	
	DW	N	DW	N	DW	N	DW	N	DW	N	DW	N	DW	N	DW	N
Q. mongolica	45.8	1.42	68.3	1.85	222.3	4.07	23.5	0.28	40.0	1.08	50.6	1.32	170.0	4.05	18.1	0.33
Q. serrata	0.4	0.01	0.8	0.02	31.8	0.67	1.4	0.03	0.3	0.01	0.7	0.02	26.0	0.56	1.2	0.02
P. densiflora	9.4	0.12	8.9	0.13	33.6	0.39	4.7	0.04	8.0	0.08	7.5	0.10	25.9	0.30	4.0	0.03
Other	3.3	0.07	9.3	0.19	46.1	0.72	6.0	0.07	2.2	0.04	2.6	0.05	15.8	0.27	3.3	0.05
Total	58.9	1.62	87.3	2.19	333.8	5.85	35.6	0.42	50.5	1.21	61.4	1.49	237.7	5.18	26.6	0.43
	10.08								8.31							

$\cdot yr^{-1}$ (77.6%) in 1998 and 0.17 g $\cdot m^{-2} \cdot yr^{-1}$ (75.3%) in 1999 for *Q. mongolica*, 0.02 g $\cdot m^{-2} \cdot yr^{-1}$ (5.2%) in 1998 and 0.01 g $\cdot m^{-2} \cdot yr^{-1}$ (4.7%) in 1999 for *Q. serrata*, 0.03 g $\cdot m^{-2} \cdot yr^{-1}$ (7.7%) in 1998 and 0.02 g $\cdot m^{-2} \cdot yr^{-1}$ (10.8%) in 1999 for *P. densiflora*, and 0.03 g $\cdot m^{-2} \cdot yr^{-1}$ (9.5%) in 1998 and 0.02 g $\cdot m^{-2} \cdot yr^{-1}$ (9.2%) in 1999 for other trees. The amounts of P in litterfall to forest floor were 0.24 g $\cdot m^{-2} \cdot yr^{-1}$ in *Quercus* forest in Belgium and 0.10 g $\cdot m^{-2} \cdot yr^{-1}$ in Scots pine of Finland (Kimmins 1987). The amount of P in fallen litter obtained from the present study was similar values to these results.

The ratio of P in litter was 0.08% and 0.06% for *Q. mongolica*, 0.05% and 0.05% for *Q. serrata*, 0.04% and 0.05% for *P. densiflora* and 0.05% and 0.04% for other trees in 1998 and 1999, respectively. Therefore, it was known that the value of *Q. mongolica* was twice as high as those of other tree species.

The average of annual P content in the present study was 0.07% and 0.06% in 1998 and 1999, respectively. However, the ratio of P in litter of *Q. mongolica* described above was little higher than the value of 0.06% obtained from foliage of *Q. mongolica* reported by Son *et al.* (2004). Lutz and Chandler (1946) reported the content of P in several tree species as the followings: 0.11% for *A. saccharum* and 0.04% for *P. banksiana*.

Content of Potassium (K)

As shown in Table 4, the seasonal amount of K inflowing to forest floor reached its peak in autumn with 0.57 g/m^2 (53.8%) and 0.42 g/m^2 (55.3%), and its lowest values in winter with 0.04 g/m^2 (3.7%) and 0.03 g/m^2 (3.7%) in 1998 and 1999, respectively. The annual amounts of K in litter were 1.11 g $\cdot m^{-2} \cdot yr^{-1}$ in 1998 and 0.81 g $\cdot m^{-2} \cdot yr^{-1}$ in 1999. The amounts of K in litter for each tree species were 0.83 g $\cdot m^{-2} \cdot yr^{-1}$ (78.7%) and 0.61 g $\cdot m^{-2} \cdot yr^{-1}$ (76.0 %) for *Q. mongolica*, 0.05 g $\cdot m^{-2} \cdot yr^{-1}$ (5.0%) and 0.05 g $\cdot m^{-2} \cdot yr^{-1}$ (5.9%) for *Q. serrata*, 0.05 g $\cdot m^{-2} \cdot yr^{-1}$ (4.9 %) and 0.06 g $\cdot m^{-2} \cdot yr^{-1}$(7.4%) for *P. densiflora* and 0.12 g $\cdot m^{-2} \cdot yr^{-1}$ (11.4%) and 0.09 g $\cdot m^{-2} \cdot yr^{-1}$(10.7%) for the other trees in 1998 and 1999, respectively.

Table 3. Seasonal changes of dry weight (DW, g/m^2) and phosphorus (P, mg/m^2) in litter for each tree species accumulated on *Quercus mongolica* forest from March 1998 to February 2000

Species	1998								1999							
	Spring		Summer		Autumn		Winter		Spring		Summer		Autumn		Winter	
	DW	P	DW	P	DW	P	DW	P	DW	P	DW	P	DW	P	DW	P
Q. mongolica	45.8	55.3	68.3	70.0	222.3	135.9	23.5	12.7	40.0	36.3	50.6	39.4	170.0	88.9	18.1	5.3
Q. serrata	0.4	0.4	0.8	0.8	31.8	16.6	1.4	0.8	0.3	0.1	0.7	0.3	26.0	10.0	1.2	0.3
P. densiflora	9.4	5.6	8.9	6.5	33.6	13.4	4.7	1.5	8.0	5.0	7.5	6.0	25.9	12.0	4.0	1.2
Other	3.3	2.7	9.3	7.7	46.1	21.0	6.0	2.2	2.2	1.5	2.6	1.6	15.8	6.5	3.3	0.6
Total	58.9	64.0	87.3	85.0	333.8	186.9	35.6	17.2	0.5	42.9	61.4	47.3	237.7	117.4	26.6	7.4
	353.1								215.0							

Table 4. Seasonal changes of dry weight (DW, g/m^2) and potassium (K, mg/m^2) in litter for each tree species accumulated on *Quercus mongolica* forest from March 1998 to February 2000

Species	1998								1999							
	Spring		Summer		Autumn		Winter		Spring		Summer		Autumn		Winter	
	DW	K	DW	K	DW	K	DW	K	DW	K	DW	K	DW	K	DW	K
Q. mongolica	45.8	161.6	68.3	227.3	222.3	415.5	23.5	30.0	40.0	127.7	50.6	143.7	170.0	320.4	18.1	20.9
Q. serrata	0.4	0.8	0.8	2.1	31.8	49.0	1.4	1.6	0.3	0.7	0.7	1.8	26.0	43.2	1.2	1.4
P. densiflora	9.4	11.1	8.9	15.8	33.6	22.3	4.7	2.4	8.0	11.1	7.5	15.1	25.9	30.1	4.0	3.1
Other	3.3	7.6	9.3	24.2	46.1	83.8	6.0	5.6	2.2	5.1	2.6	6.2	15.8	27.1	3.3	3.1
Total	58.9	181.1	87.3	269.4	333.8	570.6	35.6	39.6	50.5	144.6	61.4	166.8	237.7	420.8	26.6	28.5
	1,060.7								760.7							

The ratio of K content in litter were 0.23% and 0.22% for *Q. mongolica*, 0.16% and 0.17% for *Q. serrata*, 0.09% and 0.13% for *P. densiflora*, and 0.19% and 0.16% for the other trees in 1998 and 1999, respectively. Son *et al.* (2004) reported that the ratio of K in foliage of *Q. mongolica* in central Korea was 0.97% and the value was higher than the result of the present study. Lutz and Chandler (1946) reported the ratio of K content in various trees. By their results, the ratio of K for *A. saccharum* was 0.75% and *P. banksiana* 0.16%. Comparing the results obtained from the present study with those results, the ratio of K content in litter of *Q. mongolica* forest in Mt. Songnisan National Park was lower than those results. It is suggested that such differences were dependent upon climate and regions (Osono and Takeda 2004).

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